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Dredge survey of scallops in Marlborough Sounds, January 2018

New Zealand Fisheries Assessment Report 2018/19

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A dredge survey of scallops (*Pecten novaezelandiae*) in Marlborough Sounds (within SCA 7) was conducted from 21 to 26 January 2018. The highly valued SCA 7 scallop fishery is currently closed due to sustainability concerns. The aim of the January 2018 survey was to evaluate the status of the scallop stocks in Marlborough Sounds, to inform fisheries management decisions for in 2018. This work included: providing estimates of the current population distribution, size structure, abundance, and biomass; estimating the biomass of scallops using a range of commercial density thresholds from 0 to 0.2 recruited scallops per square metre; and comparing the estimates with other relevant data from previous surveys. Additional research on dredge efficiency and fine scale analysis is currently underway and will be reported separately.

The January 2018 dredge survey used a stratified random sampling allocation design, with sampling conducted using a chartered commercial fishing vessel and ring-bag scallop dredge. The sample extent was directly comparable with that in the January 2017 survey, but also included an additional small stratum at Dieffenbach Point. A total of 123 valid stations (dredge tows) were sampled within the 28 strata. As expected, the highest catches of recruited scallops (90 mm or larger) were from tows within key strata which represent the banks and bays that support the main scallop beds. Catches were very low in other strata.

Given that a January survey timing is quite different to that of the annual May–June pre-season surveys from 1994–2015, additional analysis was needed to ensure comparability of the survey results with surveys since 2015. This involved conducting population projections to predict what the population biomass would be in May 2018 (for comparison with the annual pre-season surveys) and September 2018 (for comparison with previous start of season projected biomass estimates). The projection methods used were the same as those used in the 2017 survey analysis. Addressing spatial differences (in survey extent) among earlier surveys requires additional reanalysis of the SCA 7 survey time series data. This work is currently underway.

The key findings from the 2018 dredge survey are that there has been an increasing trend in the Marlborough Sounds recruited scallop biomass since the November 2015 survey, and most of that biomass is held in a limited number of scallop beds, mostly in the outer Sounds. In the areas surveyed, population projections predicted the Marlborough Sounds recruited biomass in September 2018 was 147 t meat weight (95% CI = 92 to 237 t). Of the Marlborough Sounds recruited biomass available at potentially fishable densities (higher than 0.04 m^{-2}, or 1 scallop per 25 m^2), 99% was held within 10 strata which collectively represent seven different scallop beds: Chetwodes, Ketu, Wynens, Guards (2 strata), Ship/Motuara (2 strata), Bay of Many Coves (2 strata) and Dieffenbach.

1. INTRODUCTION

1.1 Overview

Scallops (*Pecten novaezelandiae*) support regionally important commercial and non-commercial (recreational and customary) fisheries in the Southern scallop stock 'SCA 7' at the north of New Zealand's South Island, which comprises the regions (substocks) of Golden Bay, Tasman Bay, and Marlborough Sounds (Figure 1). Due to sustainability concerns (Ministry for Primary Industries 2016), MPI implemented a temporary partial area closure for the taking and possession of scallops in Marlborough Sounds and part of Tasman Bay (sector 7HH) for the 2016–17 scallop season (15 July 2016 to 14 February 2017). The temporary closure was extended for the 2017–18 scallop season and expanded to cover all areas within SCA 7 and Port Underwood (Ministry for Primary Industries 2017).

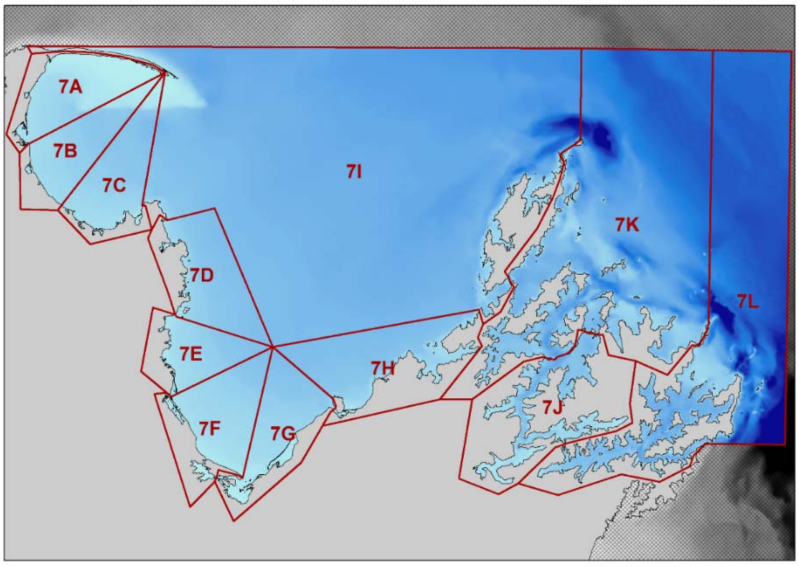


Figure 1: SCA 7 stock. SCA 7 is subdivided into its constituent Statistical Reporting Areas (sectors) 7A–7C (Golden Bay), 7D–7H (Tasman Bay), 7I (outer Golden/Tasman Bays), and 7J–7L (Marlborough Sounds).

Dredge surveys are used to monitor the SCA 7 stock status. The surveys collect data for estimating scallop population distribution, size structure, abundance, biomass and yield (Williams et al. 2014b). Dredges are not 100% efficient because they catch only a proportion of scallops within the area of seabed swept by the dredge, but with information on dredge efficiency (i.e. efficiency and size selectivity of the dredge) relative estimates can be converted to absolute estimates. Survey estimates form the basis of science advice to fisheries management.

From 1994–2015, dredge surveys were conducted annually in SCA 7 in May–June (Williams et al. 2014a, Williams et al. 2014b, Williams et al. 2015a), before the start of the scallop fishing season (15 July to 14 February, noting that since 1997 commercial scallop fishing has not started until September–October). Later in 2015, additional surveys were conducted during the commercial fishing season in October (Williams et al. 2015b) and post-season in November (Williams et al. 2015b). In 2016 no survey was conducted. The most recent survey was conducted in January 2017 (Williams et al. 2017), in time to inform fisheries management decisions for the 1 April 2017 Sustainability Round.

The surveys show that scallop biomass in Golden and Tasman Bays declined substantially in the 2000s and has since remained at negligible levels, and biomass in Marlborough Sounds followed a declining trend from 2009 to 2015 which appeared to have discontinued by January 2017; the January 2017 survey showed that over 90% of the Marlborough Sounds biomass at potentially fishable densities was held in only five scallop beds (Williams et al. 2017).

1.2 Objectives

The overall research objective for this project, SCA201702, was to evaluate the status of the scallop stocks in the Marlborough Sounds area of SCA 7. The specific research objectives for this project were:

Objective 1 – Survey

- To conduct a biomass survey that will provide, estimates of current relative and absolute abundance (numbers and biomass in tonnes greenweight and meatweight), length frequency profile, density and distribution of recruited and pre-recruit scallops in the Marlborough Sounds;
- To estimate the biomass of scallops using a range of commercial density thresholds from 0.00 to 0.2 recruited scallops per square metre;
- To compare the estimates from Objective 1 with other relevant data from previous surveys.

Objective 2 – Dredge efficiency

- To determine dredge efficiency of the survey dredge on hard floor environments in the Marlborough Sounds.

Objective 3 – Fine scale analysis

- To conduct fine scale population and catch analysis.

This report documents the findings of a January 2018 dredge survey of scallops in Marlborough Sounds (Objective 1). Scallop population estimates from the survey will inform management decisions for the 2018–19 scallop fishing year commencing 1 April 2018.

Results of the new research on dredge efficiency (Objective 2) and fine scale population/catch dynamics (Objective 3) will be reported separately.

2. METHODS

2.1 Survey design

A dredge survey of scallops in Marlborough Sounds was conducted in January 2018 using a stratified random sampling allocation design. Sampling was single phase only due to logistics. To allow comparisons with previous surveys, the sample extent (survey coverage) and stratification (Figure 2) was identical to that used in the January 2017 survey (Williams et al. 2017) except for the splitting of the 2017 Bay of Many Coves stratum 39 into two strata (39a and 39b, to better partition areas of high and low scallop densities), and the addition of stratum 42 (Dieffenbach West, a small area immediately adjacent to stratum 41 that was not sampled in 2017, but was expected to contain scallop densities similar to those in stratum 41) (Figure 3). A total of 121 stations were initially allocated to the 28 strata for the January 2018 dredge survey. The total area of the survey extent was 186 km^2 (areas calculated using ArcGIS®) (Table 1).

Table 1: Stratum details for the Marlborough Sounds dredge survey, January 2018. At seven strata (highlighted in bold), diving (trip code GAL1801) was conducted prior to the dredge survey (trip code RON1801), to collect data for estimating dredge efficiency. All stations sampled by diving were sampled subsequently by dredging using the survey ring-bag dredge, by towing adjacent to the diver transect. At a subset (n = 21) of these 'dredge efficiency' stations (i.e. at the first 3 stations in each stratum sampled by divers), two dredges were towed simultaneously (survey ring-bag vs survey ring-bag with small-mesh liner), to collect data for estimating dredge selectivity. Dredging at all other stations involved towing the single survey ring-bag dredge only.

Sector	Biotoxin	Stratum	Area (km^2)	Stratum name	Tow length (n.miles)	Tows allocated	Tows sampled	Dive transects sampled
7K	G100	20a	9.8	Admirality/Penguin Bays High	0.4	3	3	–
		20b	7.0	Admirality/Penguin Bays Low	0.4	3	3	–
		21	**5.5**	**Chetwode Is**	**0.2**	**8**	**8**	**4**
	G43	22	3.4	Waitata Bay	0.2	3	3	–
		23	1.5	Waitata Bank	0.2	3	3	–
		24	2.7	Clara Island	0.2	3	3	–
		25	14.4	Waitata Reach	0.4	3	3	–
	G42	26a	1.0	Horseshoe Bay	0.2	3	3	–
		26b	3.6	Tawhitinui High	0.2	3	3	–
		27	22.1	Tawhitinui Low	0.4	3	3	–
	G43	28	3.6	Richmond Bay	0.2	3	3	–
		29	**2.4**	**Ketu Bay**	**0.2**	**12**	**12**	**6**
	G45	**30**	**2.3**	**Wynens Bank**	**0.2**	**8**	**8**	**7**
		31	10.9	Forsyth Bay Low	0.4	3	3	–
	G46	32	5.9	Guards Bank Outer	0.2	6	6	–
		321	**6.4**	**Guards Bank Fishing Area**	**0.2**	**6**	**6**	**6**
		33	10.8	Guards Bay Low	0.4	3	3	–
		34	1.2	Guards Anakoha Bank	0.4	3	3	–
	G90	35	37.6	Waitui/Port Gore Low	0.4	3	3	–
		36	6.0	Port Gore Bank	0.4	3	3	–
7L	G29	**37a**	**6.1**	**Motuara Is Medium**	**0.2**	**8**	**8**	**6**
		37b	9.9	Motuara Is Low	0.4	3	3	–
		38	**4.6**	**Ship Cove**	**0.2**	**6**	**8**	**7**
		39a	1.3	Bay of Many Coves Bank	0.2	3	3	–
		39b	3.1	Bay of Many Coves Main Bay	0.4	3	3	–
		40	1.1	Dieffenbach Low	0.4	3	3	–
		41	**1.5**	**Dieffenbach High**	**0.2**	**7**	**7**	**3**
		42	0.3	Dieffenbach West	0.2	3	3	–
Totals:		**28**	**186.0**			***n* = 121**	***n* = 123**	***n* = 39**

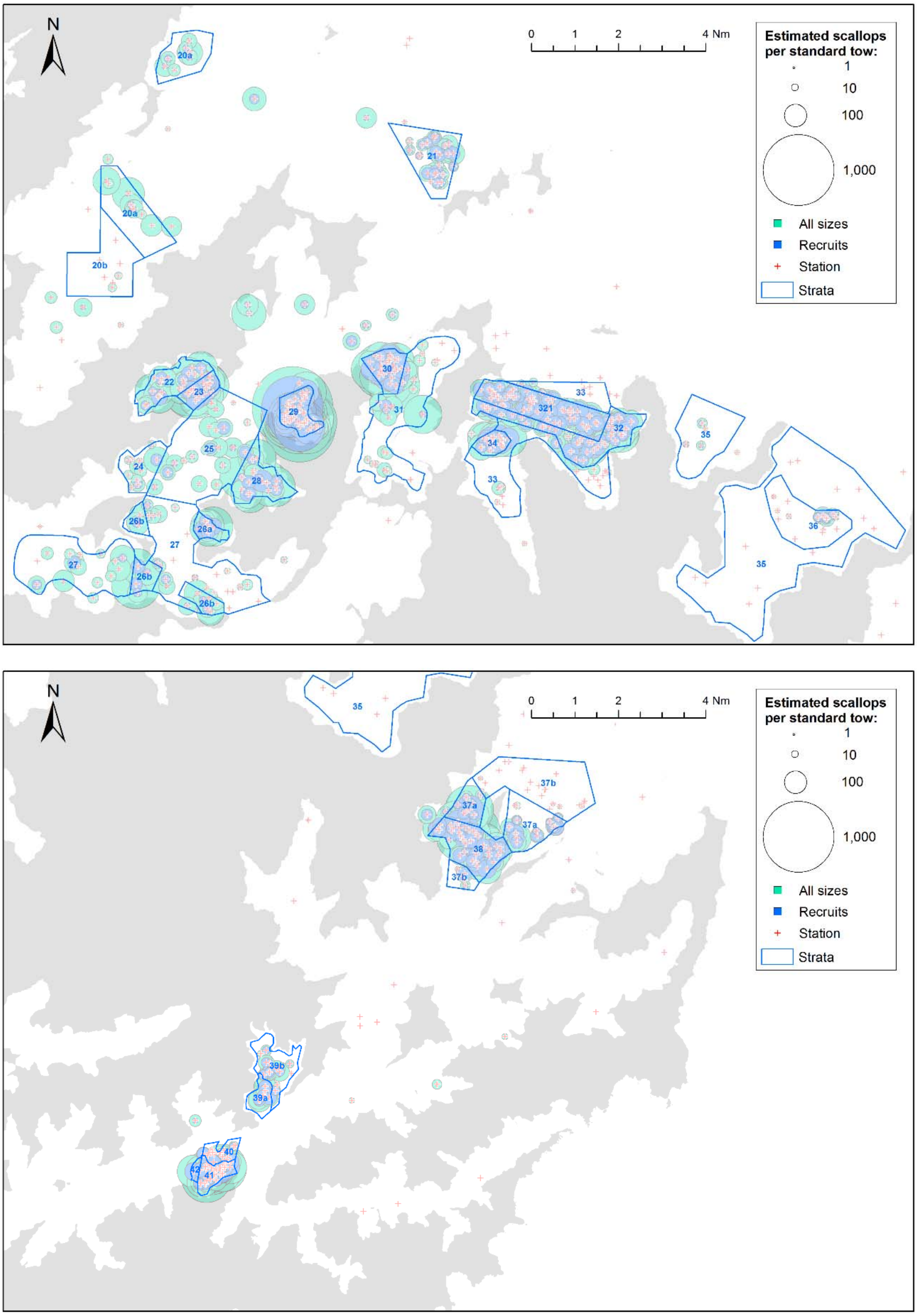


Figure 2: Stratification for the SCA 7 survey, January 2018: Marlborough Sounds sectors 7K Pelorus Sound (top) and 7L Queen Charlotte Sound (bottom). Strata 20, 26, 27, 33, 35, 37a and 37b are multi-part strata (each stratum is made up of geographically separate areas that in combination are treated as a single stratum). Circles show the abundance of recruited scallops (90 mm or larger shell length; dark shaded circles) and scallops of any size (light shaded circles) caught in the five years of SCA 7 surveys from 2012 to 2017, crosses denote tow positions. Circle area is proportional to the number of scallops per standard tow (0.4 n.mile in length), uncorrected for dredge efficiency.

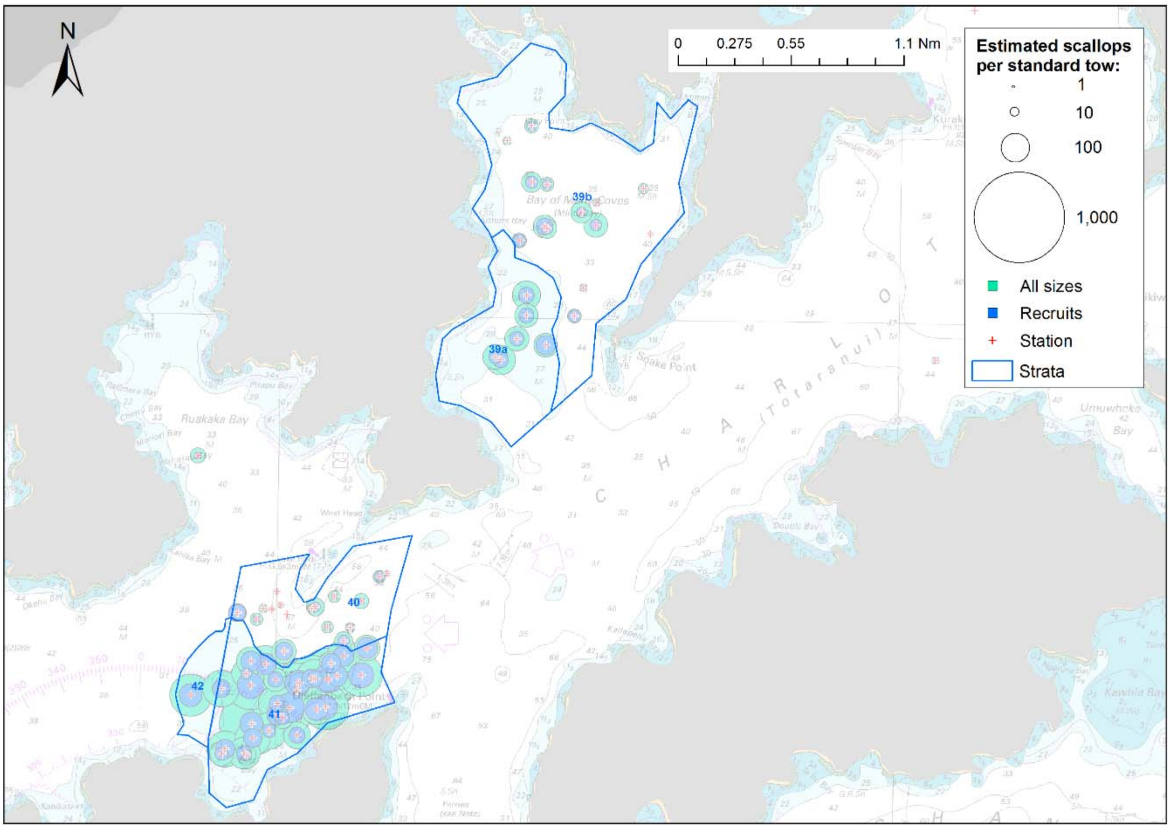


Figure 3: Stratification for the SCA 7 dredge survey, January 2018: revisions to Bay of Many Coves (top) and Dieffenbach Point (bottom) stratum boundaries in Queen Charlotte Sound. Circles show the abundance of recruited scallops (90 mm or larger shell length; dark shaded circles) and scallops of any size (light shaded circles) caught in the five years of SCA 7 surveys from 2012 to 2017, crosses denote tow positions. Circle area is proportional to the number of scallops per standard tow (0.4 n.mile in length), uncorrected for dredge efficiency.

2.2 Station allocation

Station allocation was examined using the R function *allocate* (Francis 2006), which allocates stations to strata so as to achieve a specified coefficient of variation (CV), or to minimise the CV with a fixed number of stations. For the SCA 7 surveys, station allocation is usually to minimise the CV with a fixed number of stations (i.e. which can realistically be sampled within a fixed survey duration). The CV is calculated from historical survey catch data and the estimated areas of the strata. The strata for the January 2018 survey were intersected with station data from the 2012–17 SCA 7 surveys (five years of survey data – there was no survey in 2016) to assign catch densities (number of recruited scallops 90 mm or larger per standard tow of 0.4 nm in length, uncorrected for dredge efficiency) to the specified survey strata. Boxplots of scallop density by stratum are shown in Appendix A.

In the proposed design, we estimated that a fixed survey duration of five to six days was required, during which we expected to complete up to 120 stations, with the aim of meeting a CV target of 20% for each of the scallop beds (stratum or groups of strata) that comprise the core areas in the Marlborough sounds substock.

First, a minimum allocation of six stations was specified in each of the eight strata where diving for dredge efficiency was potentially required, with a minimum of three stations per stratum specified for all other strata. With 28 strata, this meant that a minimum of 108 stations were required, producing a predicted substock CV of 7.42%.

Second, specifying that a minimum CV of 18% needed to be met for each of the 7 main scallop beds (locations), and allowing only 3 stations per stratum in all other strata, required an allocation of 121 stations (118 plus 3 in Dieffenbach stratum 42), producing an overall CV of 6.81%. This was the initial proposed allocation.

Third, after the dive survey (for estimating dredge efficiency) had been completed in early January 2018, an additional 2 stations were allocated to the Ship Cove stratum 38 to match up dredge tows with two additional positions dived. This brought the total number of stations allocated to the dredge survey to 123 stations, which required 6 days of dredge sampling.

Station positions within strata were randomised using GIS software, constrained to keep stations a minimum distance apart; this software was also used to estimate the area of each stratum.

2.3 Dredging procedures

Dredging was undertaken from a chartered fishing vessel (FV *Rongatea II*) using the same commercial ring-bag dredge (2.4 m in width) as used in SCA 7 surveys since 1998, and the same vessel master as used since 2011. The FV *Rongatea II* was used previously in the May 2015 and January 2017 surveys of SCA 7 (see Table 7, Appendix B).

A standard protocol for scallop dredge sampling was followed. In this protocol, the vessel is positioned at each random station position allocated with non-differential GPS. A single dredge is deployed (Figure 4) and towed for a standard tow length of 0.4 n.miles, but the tow length is 0.2 n.miles in some strata (see Table 1) selected *a priori* because of their small size and expected high catches. The actual tow length (distance towed) is calculated from the vessel GPS positions logged from the start of the tow (when the winch brakes are set) to the end of the tow (when hauling with the winch commences). The skipper is instructed to fish the gear (tow towards the next station, maintain constant target speed of 2.8 knots, and maintain consistent warp to depth ratio) so as to maximise the total catch at that station while avoiding crossing stratum boundaries, depth contours, foul ground, and obstructions. At the end of the tow, the dredge is retrieved and the dredge contents are emptied onto a sorting tray at the stern of the vessel.

Figure 4: Stern of FV *Okarito* showing deployment of ring-bag dredge in Marlborough Sounds. Photo credit: J. Williams.

2.4 Catch sampling

A standard dredge catch sampling procedure was followed. In this procedure, the total volume of the unsorted catch is visually estimated and recorded to the nearest 0.1 of a standard size fish case (bin). All live scallops (*Pecten novaezelandiae*) and dead scallops termed 'cluckers' (articulated scallop shells, shell hinge still intact) are sorted from the entire catch (Figure 5) and placed into bins by scallop life status category (live or dead). Similarly, all live and dead clucker oysters (*Ostrea chilensis*), and all live green-lipped mussels (*Perna canaliculus*), starfish (*Coscinasterias calamaria*), sea cucumbers (*Australostichopus mollis*) and other taxa that are easily counted (e.g. fish) are sorted from the catch and placed into bins by category. All individuals in each category are counted, and the volume of each category is visually estimated to the nearest 0.1 bin. The remaining unsorted catch is characterised by estimating its total volume (number of bins) and the percentage composition in different taxonomic categories (e.g. algae, sponges, ascidians, bryozoans, echinoderms, crustaceans, bivalves, gastropods, cephalopods, shells).

Size data were also collected for scallops and oysters using the following method. All live and dead clucker scallops are measured for shell length (along the anterior–posterior axis, using digital measuring boards), except for those from large catches (more than 200 live scallops) where a random subsample (of at least 20% of the total catch) may be taken and measured (all unmeasured scallops are counted). For any catches subsampled for scallop length, the random subsample of scallops is taken by progressively halving and mixing the fish cases of scallops sorted from the catch. All live oysters and dead clucker oysters are measured using standard oyster measuring rings (58 mm internal diameter), and the number in each size category (recruits and pre-recruits) is recorded. Recruit size oysters are those that cannot be passed through the measuring ring.

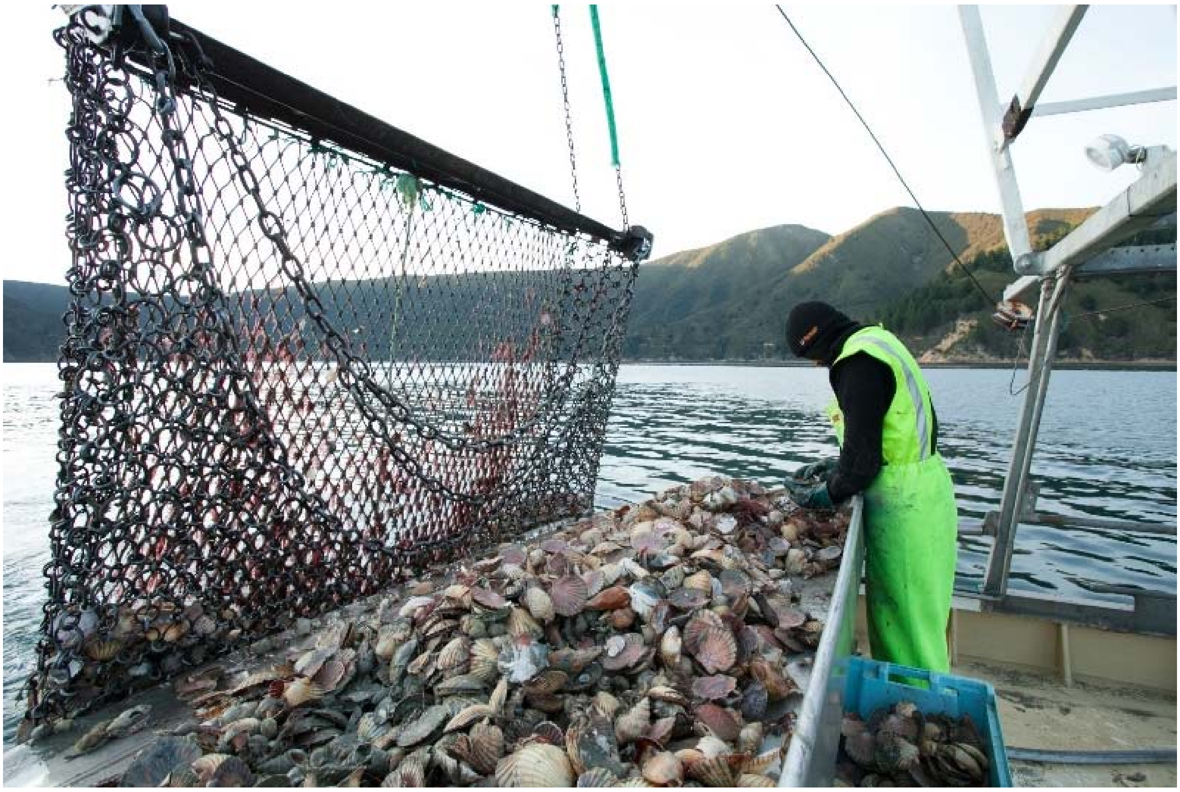


Figure 5: Ring-bag dredge survey catch being sorted at the stern of the vessel. Photo credit: J. Williams.

The station data (date, station number, recorder, tow start and finish times and positions, wind force, water depth, dredge fullness, bottom type) and catch data (species counts, oyster size, catch volumes and percentage compositions by category) were recorded on pre-printed waterproof forms, and the scallop length data were captured electronically. All data were checked and verified, ready for loading to the MPI '*scallop*' database. Raw data forms were scanned.

2.5 Population estimation

The population estimation approach was originally described by Cryer & Parkinson (2006); an updated, and more detailed, description of the method can be found in Williams et al. (2013). The current SCA 7 survey analytical approach has been used since 2008 (Tuck & Brown 2008). Parameters specific to the SCA 7 survey analysis were summarised in Williams et al. (2014b), and also detailed in section 2.6 of the May 2015 survey report (Williams et al. 2015a).

The application of the approach for the 2018 survey was the same as that used in 2017, deriving survey estimates of scallop density (number per unit area swept), abundance (total numbers of scallops) and biomass (in green and meat weight) for each stratum; combining these to produce the population estimates at different spatial scales of interest; and projecting these time of survey estimates to May and to September, accounting for growth and natural mortality. The method uses a non-parametric resampling with replacement (bootstrapping) approach in the derivation of summary statistics (mean, CV, median and 95% confidence intervals). For the projections, we used the same two projection approaches as those used in the 2017 survey analysis (Williams et al. 2017), which are based on two different sets of growth estimates 1) new estimates of growth derived from length frequency analysis in the present study; 2) existing estimates of growth from logarithmic modelling of tagging data.

Stratum length frequency distributions are calculated at the time of the survey as the mean tow length frequency distribution for that stratum scaled by the stratum area. Substock length frequency distributions are calculated as the sum of the stratum length frequency distributions for the strata within each substock. The stratum areas, used to scale the tow sampling data, are considered to be known without error.

2.6 Comparative analysis

The Marlborough Sounds scallop population estimates generated from the January 2018 survey were compared with estimates from previous surveys, addressing spatial and temporal differences among the surveys as required.

The spatial extent of the 2018 survey (excluding stratum 42) was the same as that surveyed in 2017, enabling direct comparison of the January 2018 estimates with those produced by Williams et al. (2017) for the January 2017, November 2015 and May 2015 surveys. Population projections to May and September 2018 were also conducted to address the January survey timing (see section 2.5 Population estimation).

Comparisons with the estimates from earlier surveys are confounded somewhat by changes to survey coverage. In particular, surveys before 2009 covered a greater spatial extent. To address these spatial differences requires reanalysis of the SCA 7 survey series data, which is currently underway. For each relevant previous survey, station data that intersect with the 2018 survey strata will be reanalysed using the population estimation method detailed above. This will generate a new set of 'time of survey' population estimates from the same spatial extent, and allow examination of population trends in different geographical areas within Marlborough Sounds, particularly in relation to fishery harvests and environmental conditions.

The new survey time series generated will be examined to establish if changes have occurred in the scallop populations. The examination will be based on readily available outputs from the analysis, comprising population length frequency plots and estimates of abundance (numbers and biomass) by strata groups of interest (e.g. at the level of individual strata, scallop beds, and in total). These outputs will be used to describe and interpret the status of the scallop population over time.

3. RESULTS

3.1 Sampling conducted

The dredge survey was carried out during six days at sea from 21 to 26 January 2018. A total of 123 valid stations (dredge tows) were sampled within the 28 strata (the 121 stations initially allocated were sampled, plus 2 additional stations which had been extra stations dived for estimating dredge efficiency) (Figure 6). Overall, a total of 39 935 live scallops were caught on the dredge survey, of which 29 185 (73%) were measured and the rest were counted; a total of 2 527 dead scallops ('cluckers') were caught, of which 2 471 (98%) were measured and the rest counted.

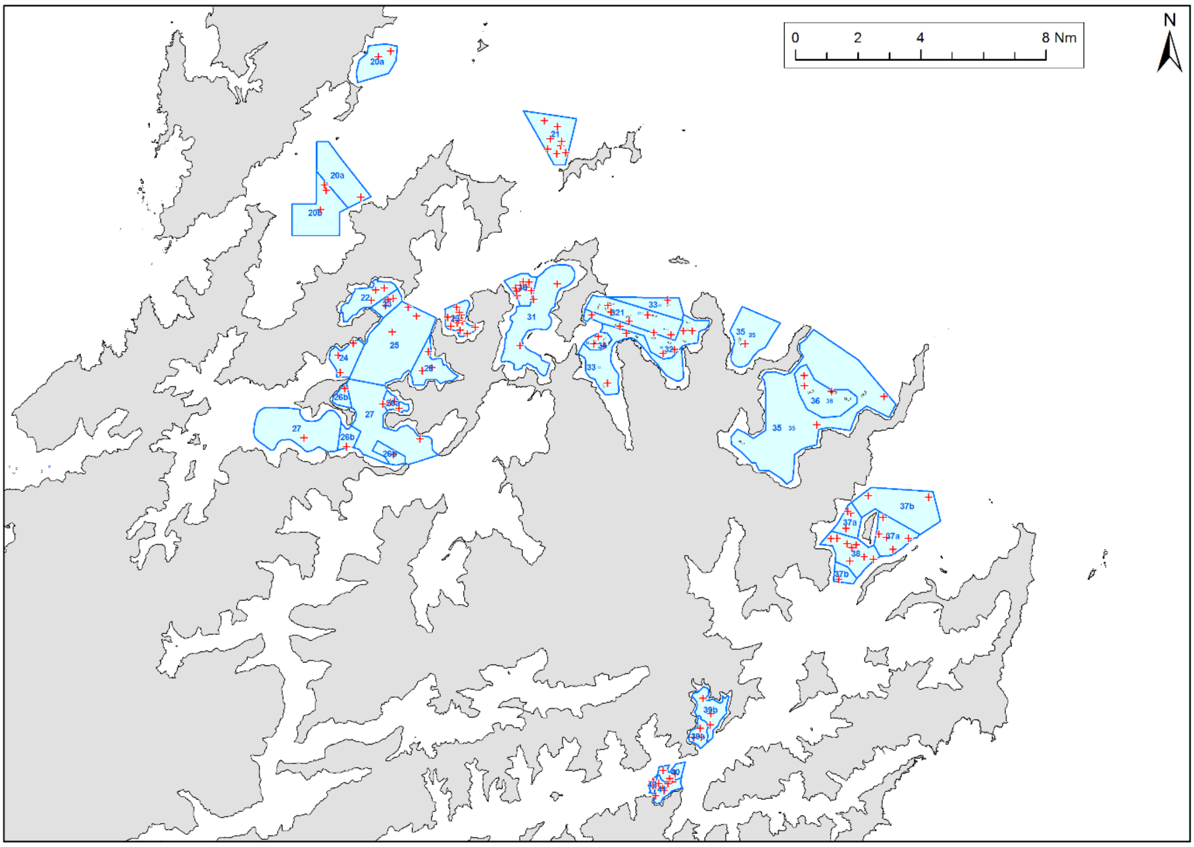


Figure 6: Station positions sampled, Marlborough Sounds dredge survey, January 2018.

Additional to recording the vessel GPS coordinates logged from the start to the end of each dredge tow (determined using SeaPlot software), the path of the vessel during the tow was also logged using independent GPS tracking technology (Voyage Tracker software, Lennard Electronics, Wellington) and data logger technology (Deck Unit and Wet-Tag, Zebra-Tech Ltd., Nelson). These two additional sources of tracks logged were useful for error checking and assessing the position of tows in relation to the station positions allocated and dive transects completed (see example for Ship Cove in Figure 7).

Video (GoPro) footage of the dredge in operation was also recorded on a subset of dredge tows.

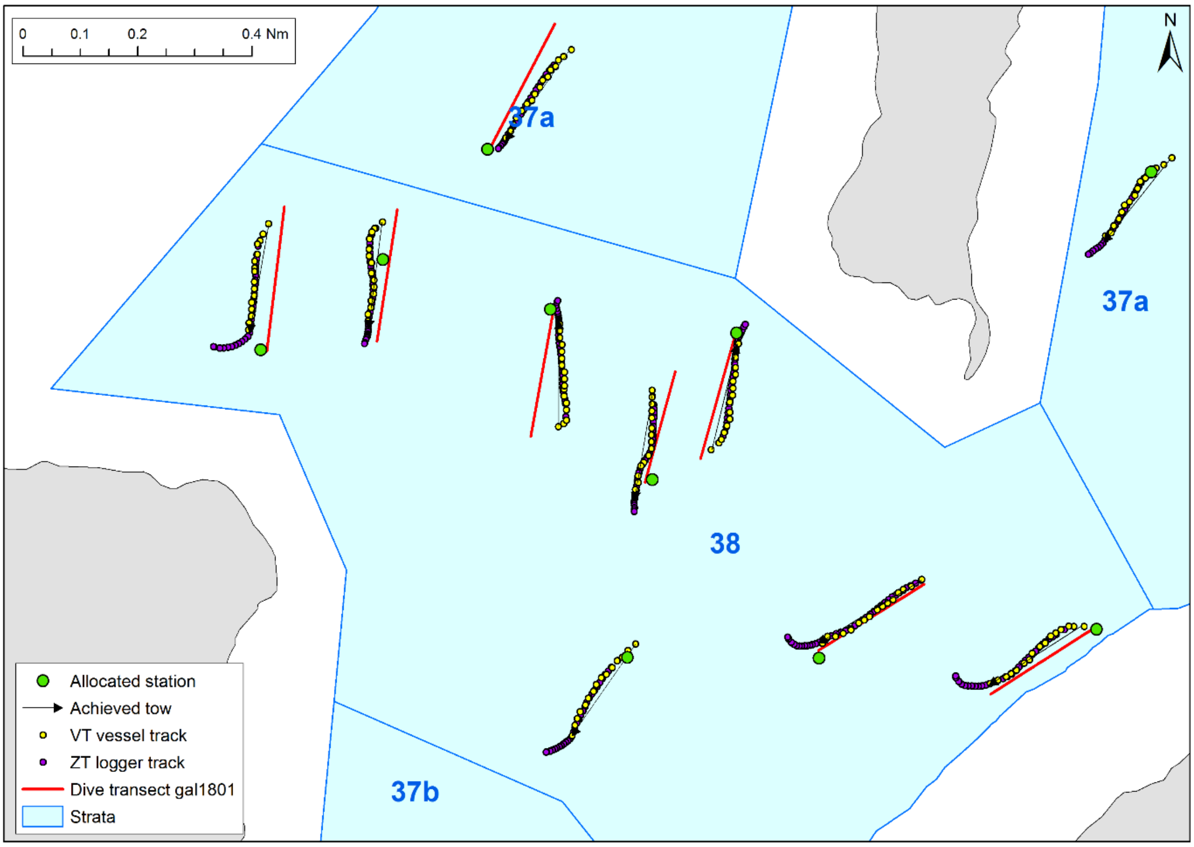


Figure 7: Dredge tow positions conducted compared with station positions allocated, Ship Cove stratum 38, Marlborough Sounds, January 2018. Green circles denote station positions initially allocated that were subsequently sampled. Black arrows denote the approximate position and direction of the dredge tows sampled, calculated from the vessel plotter data. Yellow circles show the Voyage Tracker vessel track for each tow, purple circles show the positions logged by the Zebra-Tech logger gear during each tow. Polygons denote survey strata. Red lines denote positions of dive transects searched during the dive survey GAL1801 conducted before the RON1801 dredge survey.

3.2 Achievement of survey CVs

Relative density estimates (i.e. uncorrected for dredge efficiency) and their CVs were calculated from the survey data, enabling comparison of the CVs achieved by the survey with those predicted by *allocate* in the survey design (Table 2). Recruited estimates with high precision (CVs of 20% or lower) were achieved at the substock and sector levels, and at three of the beds (Wynens, Guards and Ship) targeted in the design; CVs for the other four beds targeted in the design were higher than the 20% CV target, at Dieffenbach (21.8%), Chetwodes (23.7%), Ketu Bay (CV = 27.8%) and the Bay of Many Coves (37.8%), where catches were more variable within strata.

Table 2: Comparison of the coefficient of variation (CV) values predicted in the design ('allocate') with those achieved by the survey ('survey'), SCA 7 survey, January 2018. CVs are on the estimated relative mean density of recruited scallops (uncorrected for dredge efficiency). Relative mean density values are also shown expressed as scallops per metre of seabed swept, or scallops per standard 0.4 n.mile tow.

Level	Code	Tows		CV		Scallops	
		allocate	survey	allocate	survey	m^{-2}	tow^{-2}
Substock	MS	121	123	6.8	8.6	0.031	55
Sector	7K	85	85	–	11.5	0.023	41
	7L	36	38	–	12.5	0.073	130
Bed	Wynens Bank (30)	8	8	17.8	19.3	0.299	532
	Dieffenbach Point (40, 41, 42)	13	13	17.5	21.8	0.209	372
	Chetwodes (21)	8	8	17.6	23.7	0.181	321
	Ketu Bay (29)	12	12	17.5	27.8	0.071	126
	Bay of Many Coves (39a, 39b)	6	6	16.7	37.8	0.059	105
	Guards Bay (32, 321, 33, 34)	18	18	11.9	18.4	0.058	103
	Ship Cove (37a, 37b, 38)	17	19	17.7	16.7	0.057	102

3.3 Spatial distribution

The distribution of relative spatial density (expressed as the survey catch of scallops per standard 0.4 n.mile tow, uncorrected for dredge efficiency) for the areas surveyed is shown in Figure 8. As expected, the highest catches of recruited scallops (90 mm or larger) were from tows within key strata which represent the banks and bays that support the main scallop beds. Catches were very low in other strata.

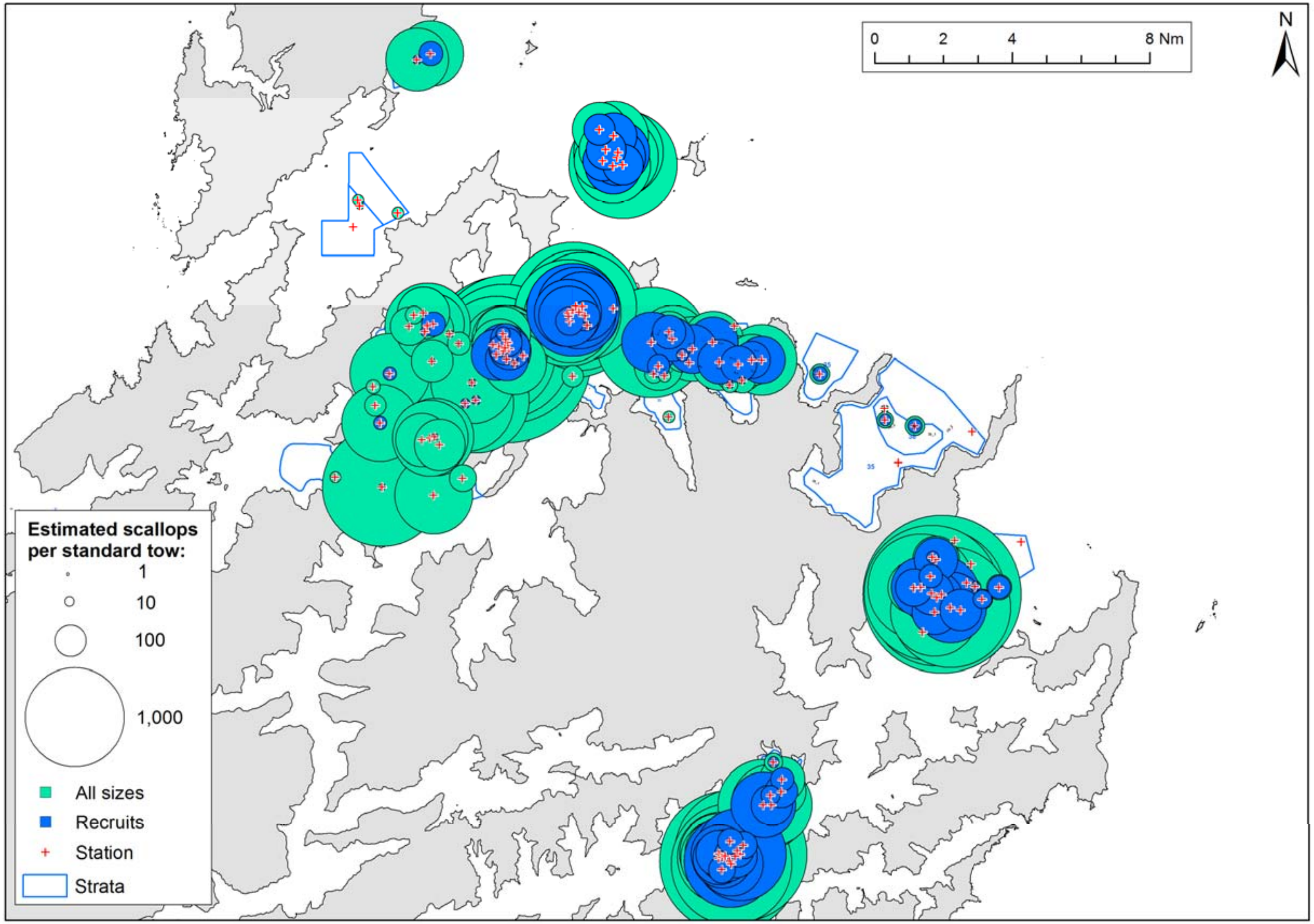


Figure 8: Catch per standard tow, Marlborough Sounds survey, January 2018. Circle area is proportional to the number of scallops caught per standard distance towed (0.4 n.miles). Dark blue shaded circles denote scallops of commercial recruited size (90 mm or larger), green shaded circles denote scallops of any size. Values are uncorrected for dredge efficiency. Polygons denote survey strata boundaries.

3.4 Population estimates

Our estimation approach used non-parametric re-sampling with replacement (1000 bootstraps) to produce a sample of 1000 estimates of scallop biomass (or other metric of interest). A frequency distribution plot of those estimates provides the most complete description of the nature of the variation in our sample and can be viewed as an approximation of the uncertainty in our knowledge of the biomass. The CV (standard deviation divided by the mean) is a good measure of the dispersion of that sample. The median (as opposed to the mean) is the best measure of central tendency for our sample, and the 95% confidence interval (CI) is used to express the uncertainty in our estimate.

Analysis of the 2018 dredge survey data used the standard estimation approach, correcting for dredge efficiency using existing estimates, as in the 2017 analysis (Williams et al. 2017). Excluding stratum 42, the Marlborough Sounds recruited biomass (t green-weight, median value) in January 2018 was 803 t (median value, 95% CI = 569–1219 t; mean = 821, CV = 0.20; Figure 9). Within the same area of the Marlborough Sounds as that surveyed in May 2015, recruited biomass has increased since November 2015 (Table 3).

A separate run estimated that stratum 42 held 6 t of recruited green weight biomass (95% CI = 4–9 t; mean = 6 t, CV = 0.19). Population estimates for the full survey extent (including stratum 42) are tabulated in Appendix C (see Table 8).

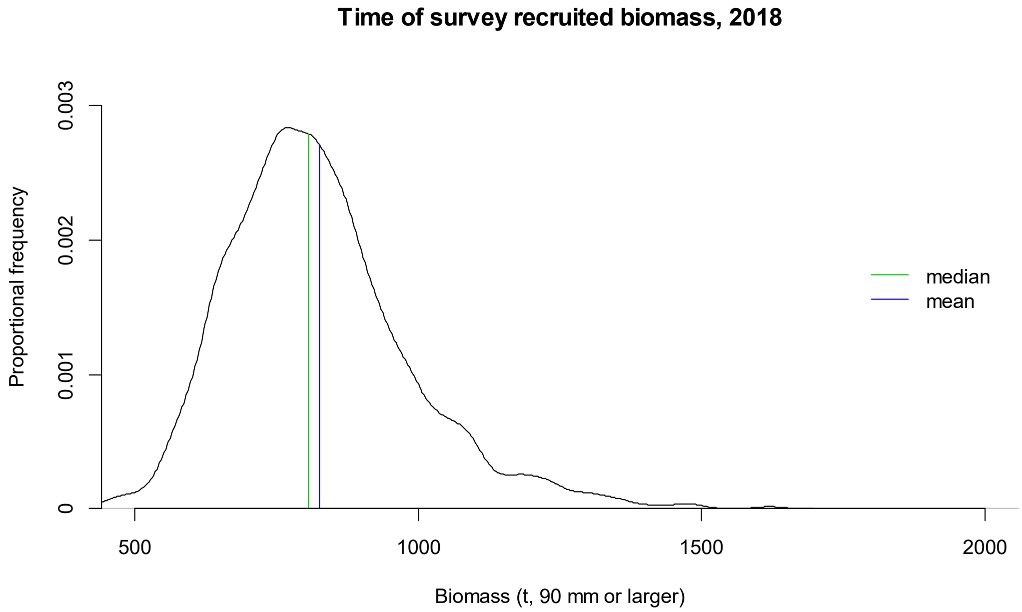


Figure 9: Proportional frequency distribution of the biomass (t green weight) of recruited scallops (90 mm or larger) in Marlborough Sounds at the time of the survey, January 2018. The distribution was derived using a non-parametric resampling with replacement approach to estimating biomass (1000 bootstraps).

Table 3: Population estimates of recruited green weight biomass (scallops 90 mm or larger) at the time of the surveys in May and November 2015, January 2017 and January 2018, produced using the May 2015 survey extent, assuming historical average dredge efficiency and predicting weight from length. The analysis used a non-parametric resampling with replacement approach to estimation (1000 bootstraps).

Year	Survey	Location	Area (km^2)	*n* tows	Mean	CV	Median	2.5%	97.5%
2015	May	MS	186	89	723	0.19	703	512	1046
	Nov	MS	186	81	534	0.20	522	368	787
2017	Jan	MS	186	110	658	0.19	638	470	966
2018	Jan	MS	186	123	821	0.20	803	569	1219

3.5 Length frequency

To assist in assessing recent changes in population size structure, time series of scallop length frequency distributions from surveys between 2014 and 2018 were plotted by sector (Figure 10) and for key scallop beds: Wynens Bank, Guards Bank and Ship Cove (Figure 12); Waitata Bank, Ketu Bay, Dieffenbach (Figure 11); and Chetwode Islands (Figure 13).

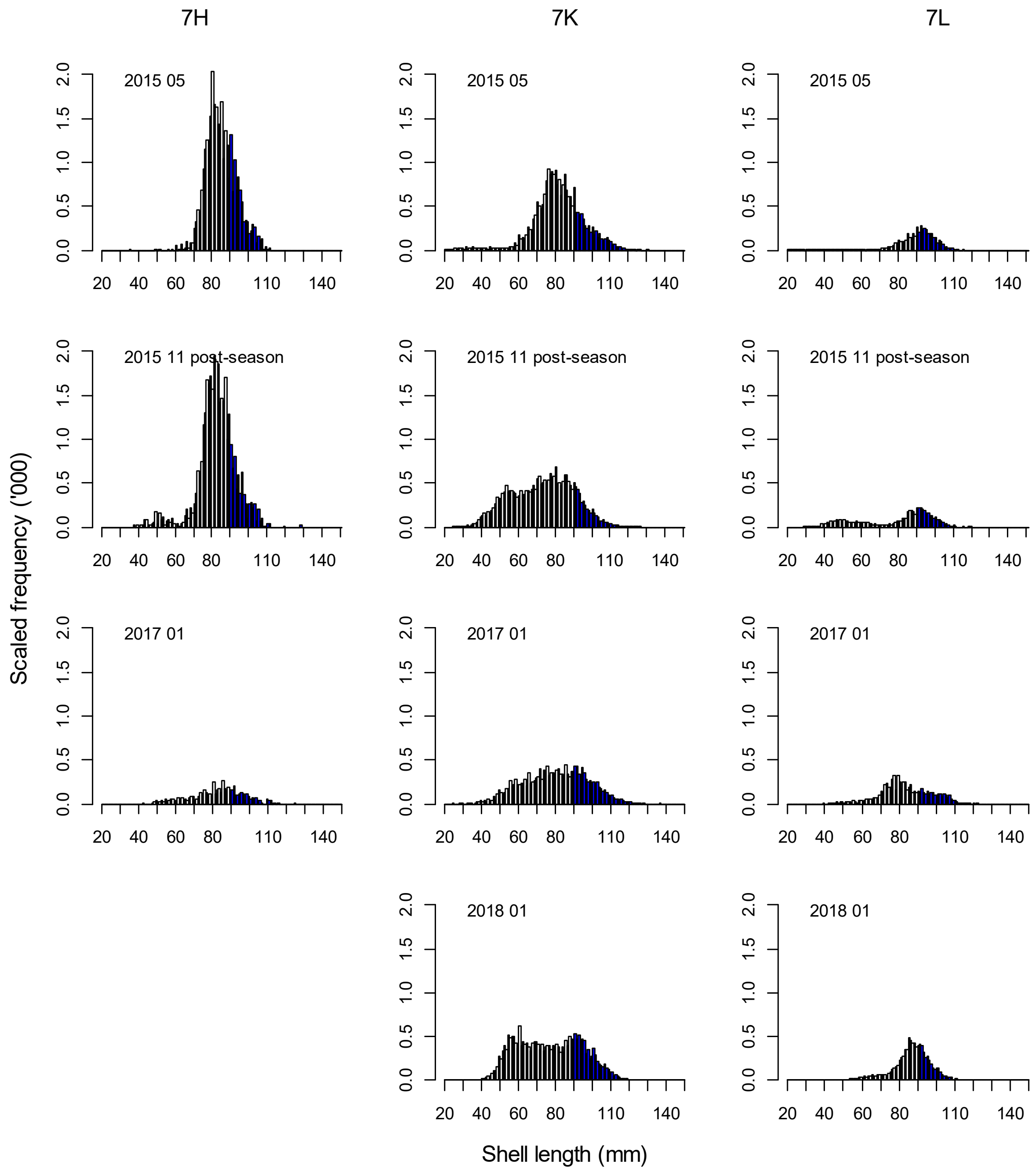


Figure 10: Length frequency distributions for scallops in Marlborough Sounds sectors 7K (Pelorus Sound) and 7L (Queen Charlotte Sound), May 2015 to January 2018. Data corrected for historical average dredge efficiency. Dark shaded bars show recruited scallops (90 mm shell length or larger).

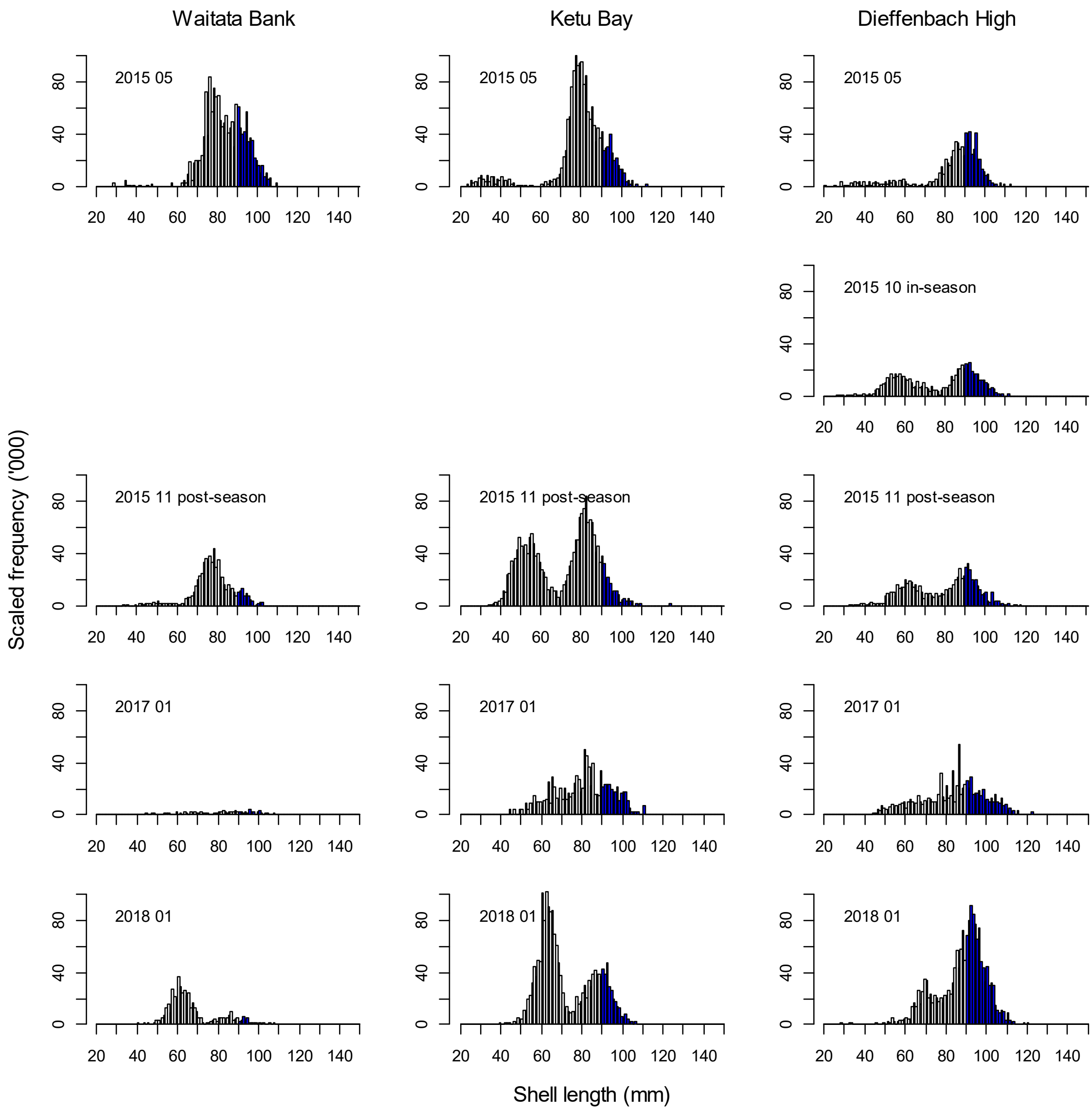


Figure 11: Length frequency distributions for scallops in key beds in Marlborough Sounds, May 2015 to January 2018: stratum 23, Waitata Bank (left); stratum 29, Ketu Bay (centre); stratum 41, Dieffenbach High (right). Data corrected for historical average dredge efficiency. Dark shaded bars show recruited scallops (90 mm shell length or larger).

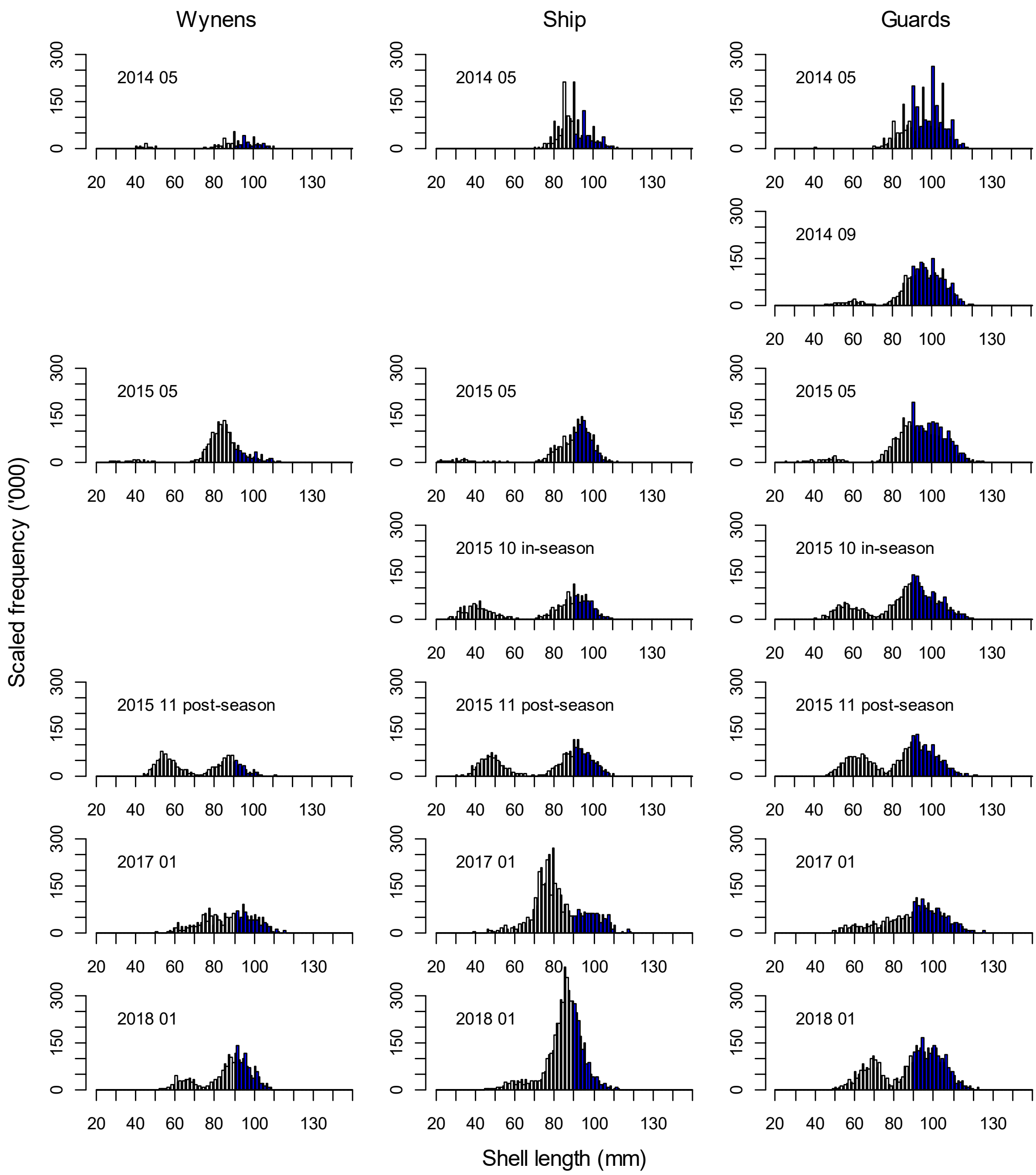


Figure 12: Length frequency distributions for scallops in key beds in Marlborough Sounds, May 2014 to January 2018: stratum 30, Wynens Bank (left); stratum 38, Ship Cove (centre); strata 32 and 321 combined, Guards Bank (right). Data corrected for historical average dredge efficiency. Dark shaded bars show recruited scallops (90 mm shell length or larger).

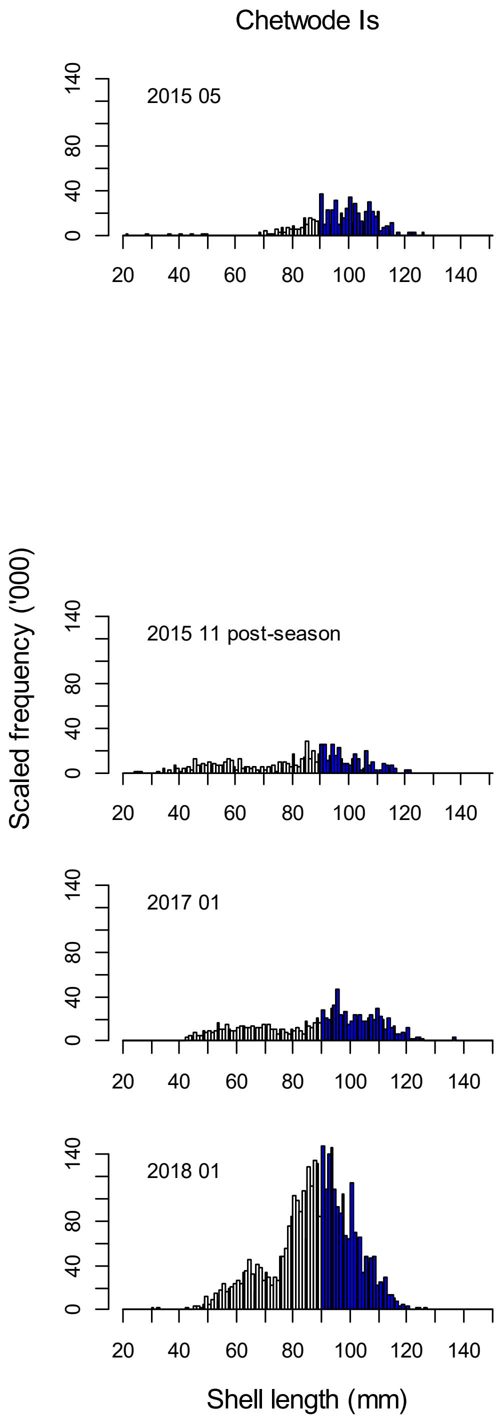


Figure 13: Length frequency distributions for scallops in a key bed in Marlborough Sounds, May 2015 to January 2018: stratum 21, Chetwode Islands. Data corrected for historical average dredge efficiency. Dark shaded bars show recruited scallops (90 mm shell length or larger).

3.6 May projected biomass

Estimates of absolute green weight biomass in 2015, 2017 and 2018 in Marlborough Sounds at the time of the surveys and from population projections were tabulated for comparison (Table 4). Plotting the projected May 2017 estimates of recruited green weight biomass together with the time series of May survey estimates (Figure 14) suggests that there has been an increasing trend in the Marlborough Sounds biomass since November 2015. The trends in green weight biomass for Marlborough Sounds are also plotted alongside those for Golden and Tasman Bays, and for the overall SCA 7 stock, in Figure 19 (Appendix D).

Table 4: Summary of absolute green weight recruited biomass estimates (t) in 2015, 2017 and 2018. Time of survey estimates are shown, together with estimates projected from the surveys. Two different projection approaches were used 1) using growth estimated from tag-return data ('Projected tagging'); 2) using growth estimated from multiple length frequency analysis ('Projected Multifan').

2015	Month	Location	Bgr_mean	Bgr_cv	Bgr_median	2.5%	97.5%
Time of survey	May	MS	723	0.19	703	512	1046
Time of survey	Nov	MS	534	0.20	522	368	787
2017	Month	Location	Bgr_mean	Bgr_cv	Bgr_median	2.5%	97.5%
Time of survey	Jan	MS	658	0.19	638	470	966
Projected tagging	May	MS	769	0.18	749	559	1084
Projected Multifan	May	MS	914	0.26	883	547	1464
2018	Month	Location	Bgr_mean	Bgr_cv	Bgr_median	2.5%	97.5%
Time of survey	Jan	MS	821	0.20	803	569	1219
Projected tagging	May	MS	1020	0.18	1009	718	1422
Projected Multifan	May	MS	1188	0.22	1162	745	1770

Time of survey green weight

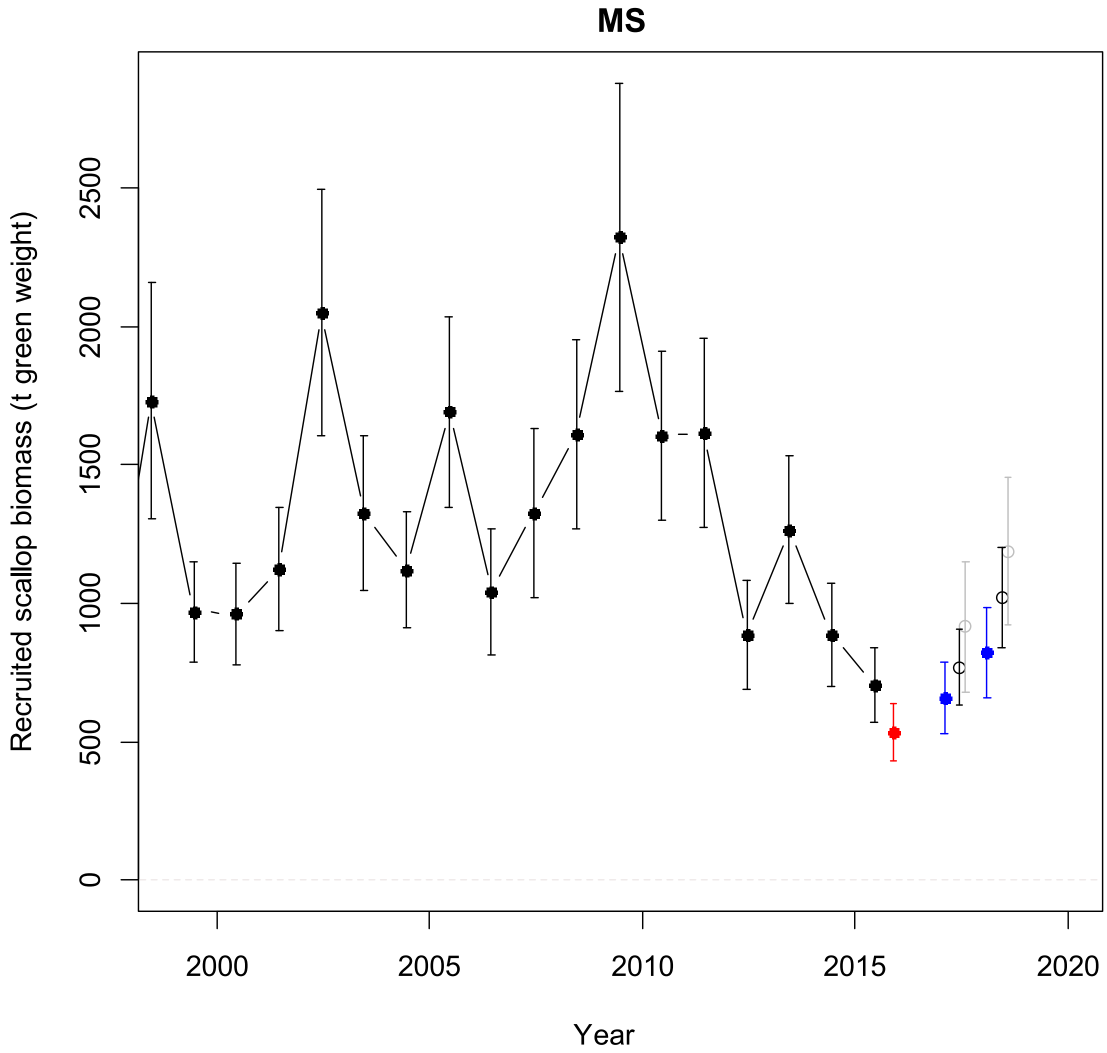


Figure 14: Trends in <u>time of survey</u> (nominally May, black symbols) biomass (t <u>green weight</u>) of recruited scallops (90 mm or larger) for Marlborough Sounds, 1998–2018. Estimates from the November 2015 post-season survey (red symbol) and the January 2017 and 2018 surveys (blue symbols) are also shown. Two projected estimates for 2017 and 2018 are shown, derived from two different January to May projection approaches: 1) using growth estimated from tag-return data (hollow black symbols); 2) using growth estimated from Multifan analysis of multiple length frequencies (hollow grey symbols, slightly offset for clarity). Values are the estimated mean and CV of the recruited biomass. The stock was not surveyed in 2016.

3.7 September projected biomass

Projected estimates of absolute meat weight biomass in September 2015, 2017 and 2018 in Marlborough Sounds were also tabulated (Table 5). The two different approaches to estimating growth resulted in very similar estimates of projected biomass in September 2018 (tagging approach = 153 t meat weight; Multifan approach = 147 t meat weight), with higher uncertainty in the estimate from the Multifan approach (CV = 24%) than the tagging approach (CV = 18%).

Table 5: Summary of absolute recruited meat weight biomass estimates (t) in September 2015, 2017 and 2018. Two different projection approaches were used 1) using growth estimated from tag-return data ('Projected tagging'); 2) using growth estimated from multiple length frequency analysis ('Projected Multifan').

2015	Month	Location	Bmt_mean	Bmt_cv	Bmt_median	2.5%	97.5%
Projected tagging	Sep	MS	104	0.19	102	73	148
2017	Month	Location	Bmt_mean	Bmt_cv	Bmt_median	2.5%	97.5%
Projected tagging		MS	123	0.19	120	86	174
Projected Multifan		MS	119	0.28	115	68	194
2018	Month	Location	Bmt_mean	Bmt_cv	Bmt_median	2.5%	97.5%
Projected tagging		MS	155	0.18	153	106	213
Projected Multifan		MS	152	0.24	147	92	237

Projected estimates of September recruited biomass were also plotted to assess longer term trends (Figure 15). The trends in meat weight biomass for Marlborough Sounds are also plotted alongside those for Golden and Tasman Bays, and for the overall SCA 7 stock, in Figure 20 (Appendix E).

Projected September meat weight

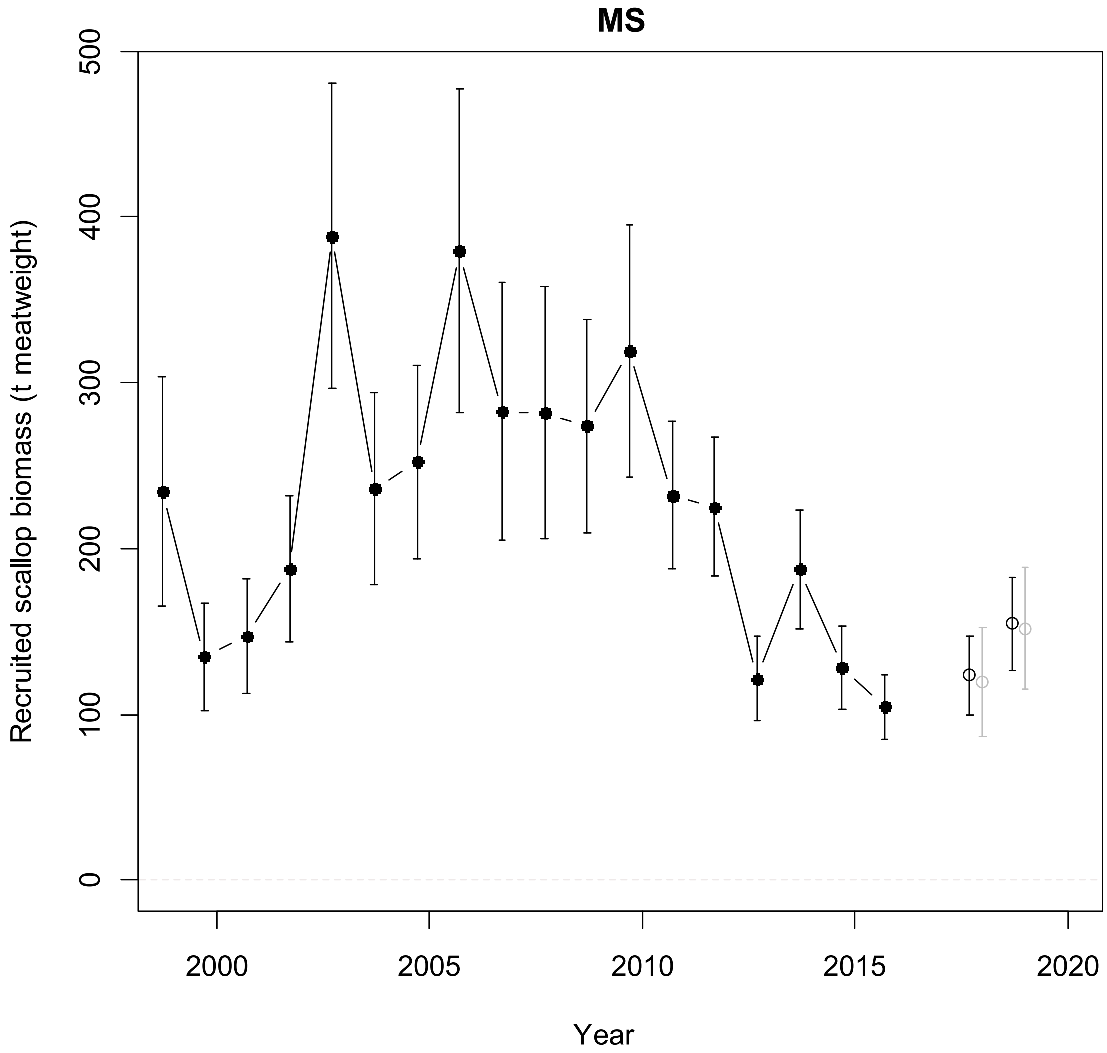


Figure 15: Trends in projected start of season (1 September, black symbols) biomass (t meat weight) of recruited scallops (90 mm or larger) for Marlborough Sounds, 1998–2018. Two projected estimates for 2017 and 2018 are shown slightly offset, derived from two different projections: 1) using growth estimated from tag-return data (hollow black symbols); 2) using growth estimated from Multifan analysis of multiple length frequencies (hollow grey symbols, offset for clarity). Values are the estimated mean and CV of the recruited biomass. The stock was not surveyed in 2016.

3.8 Biomass sensitivity to density

Biomass is held at various densities (scallops per unit area) throughout the stock, typically with smaller areas of high density aggregations commonly known as ‘beds’ distributed among larger areas of low densities or no scallops. High density scallop beds are important both for sustainability (i.e. larval production) and for fisheries utilisation.

Estimates of biomass are sensitive to the exclusion of areas of low scallop density, and in the past it has generally been assumed that 0.04 m^{-2} (one recruited scallop for each 25 m^{-2} of seabed) is a reasonable working definition for the lowest limit of economic fishing, although this will vary with market price and costs. A recruited scallop density of 0.04 m^{-2} on the seabed (corrected for historical average dredge efficiency) equates to a catch of about 40 scallops per standard 0.4 n.mile survey tow using a single dredge (Table 6). In the commercial scallop fishery in SCA 7, vessels typically fish two dredges simultaneously for 20–25 mins per tow (a distance of about 1 n.mile). Assuming the same dredge width and efficiency as in the survey, a recruited scallop density of 0.04 m^{-2} on the seabed equates to a catch of about 200 scallops per commercial fishery tow using 2 dredges.

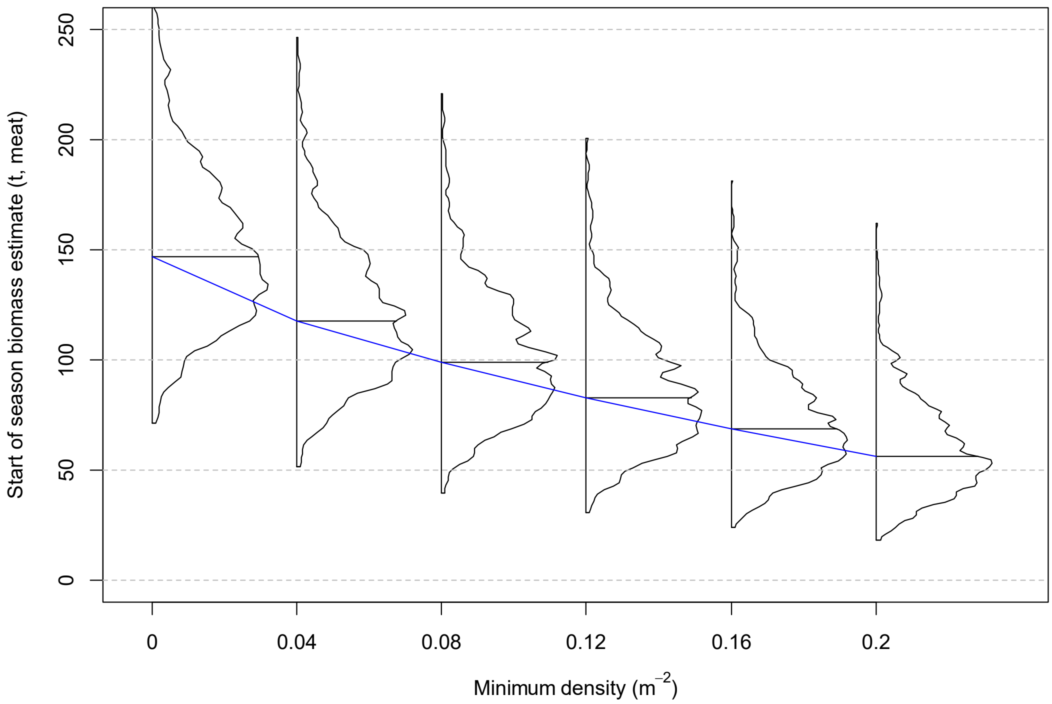
Table 6: Approximation of the relationship between density (scallops.m^{-2} of seabed) and survey catch rate (scallops per standard 0.4 n.mile survey tow using 1 dredge of 2.4 m in width), assuming a dredge efficiency of 0.56.

Density (scallops.m^{-2})	Survey catch rate (scallops.tow)
0.01	10
0.04	40
0.08	80
0.10	100
0.12	119
0.16	159
0.20	199

To assess the amount of biomass held at potentially fishable densities, the survey data were reanalysed assuming that all stations where scallops were scarcer than 0.04 m^{-2} had zero density, and stations where scallops were denser than 0.04 m^{-2} had a density of the actual density minus 0.04 m^{-2}. This was conducted for critical densities in the range 0 to 0.20 scallops m^{-2}. For each critical density level, projected recruited biomass in September was calculated using the Multifan projection approach.

Estimates of September 2018 projected biomass gradually decreased with increasing critical threshold density (Figure 16, and Table 10 in Appendix F). Of the Marlborough Sounds absolute biomass (147 t), 80% (118 t) was held in areas with a critical density of 0.04 m^{-2} or higher, and this reduced to 67% (99 t) at 0.08 m^{-2}, through to 38% (56 t) at 0.20 m^{-2}. These are median point estimates, which have increasingly large uncertainty as the critical density threshold increases (Table 10 in Appendix F).

Of the Marlborough Sounds recruited biomass available at the 0.04 m^{-2} density level, 99% was held within 10 strata (Table 10 in Appendix F), which collectively represent seven different scallop beds: Chetwodes, Ketu, Wynens, Guards (2 strata), Ship/Motuara (2 strata), Bay of Many Coves (2 strata) and Dieffenbach.



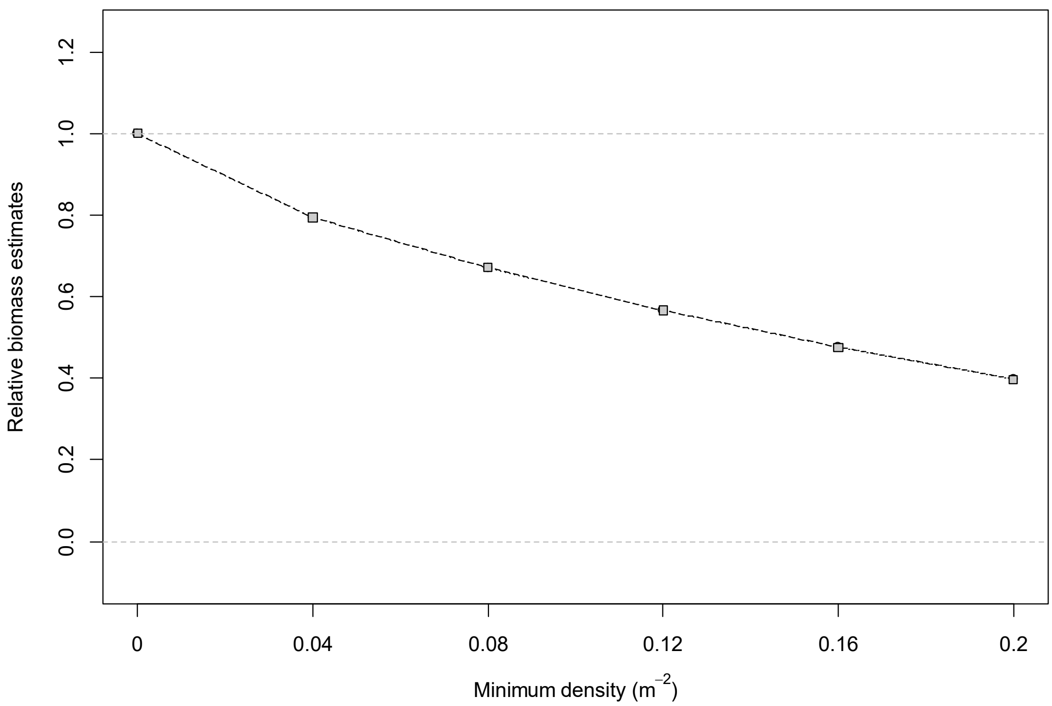


Figure 16: Effect of excluding areas of low scallop density on projected estimates of recruited biomass, Marlborough Sounds, September 2018. Estimates were produced using the tag-return projection approach. Critical density corrections were applied after correcting for dredge efficiency. Top plot: for each minimum ('critical') density, the distribution and median (horizontal line) of the recruited biomass are shown. Bottom plot: Trend in the proportion of the total recruited biomass with increasing critical density.

4. DISCUSSION

The results of the January 2018 dredge survey (RON1801) provide the most recent available information to assess the status of the Marlborough Sounds scallop population. The results of the survey show that there has been an increasing trend in the Marlborough Sounds recruited scallop biomass since the November 2015 survey, and that most of the biomass is held in a limited number of scallop beds, mostly in the outer Sounds. In the areas surveyed, population projections (using the Multifan approach to estimating growth) predicted that the Marlborough Sounds recruited biomass in September 2018 was 147 t meat weight, compared with 115 t in 2017 (Williams et al. 2017), and 102 t in 2015 (Williams et al. 2015b). Of the recruited biomass available at potentially fishable densities (higher than 0.04 m^{-2}, or 1 scallop per 25 m^2), 99% was held within 10 strata which collectively represent seven different scallop beds: Chetwodes, Ketu, Wynens, Guards (2 strata), Ship/Motuara (2 strata), Bay of Many Coves (2 strata) and Dieffenbach.

Length frequency data from the January 2018 dredge survey show evidence of a cohort of juvenile scallops of about 60–70 mm modal length, most likely the product of successful spat settlement and survival in the summer of 2015–16. This cohort was also detected in the January 2018 dive survey, together with a much smaller cohort of modal size 10 mm shell length, which probably arose from spawning and larval development in late 2017.

Dredge efficiency is defined as the proportion of the scallops in the path of the gear that are caught (Orensanz et al. 2016), and is a key parameter in calculating absolute biomass. Dredge efficiency varies with scallop size (efficiency is typically low for the smallest individuals, and increases with size), and may also vary with other factors including depth, distance towed, and habitat type. Dredge efficiency is expected to be lower on hard substrates (e.g. sand/shell) than on soft substrates (e.g. silt). These factors are being investigated in the remainder of the current project, and will be reported separately. Note that the estimates of recruited biomass presented in this report were calculated using existing estimates of ring-bag dredge efficiency, derived by Tuck & Brown (2008) using the best available data from historical diver and dredge sampling in SCA 7 (Cranfield et al. 1996, Handley et al. 2004). Revised estimates of biomass will be calculated using new estimates of dredge efficiency as soon as they are finalised. Differences in the estimated dredge efficiency parameter will change the estimates of absolute biomass, but not the biomass trends observed.

5. ACKNOWLEDGEMENTS

This work was funded by the Ministry for Primary Industries (MPI) through project SCA201702. Special thanks to vessel skipper Cris West and crew for their expertise in conducting the dredge survey aboard FV *Rongatea II*, and to Grant Roberts (Rongo Marie Ltd) for coordinating the charter arrangements. We are grateful to members of the Shellfish Fisheries Working Group for their appraisal of the survey methods and draft results. Thanks to Ian Tuck for reviewing an earlier version of this draft report.

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7. APPENDIX A: Boxplots of historical scallop density by stratum

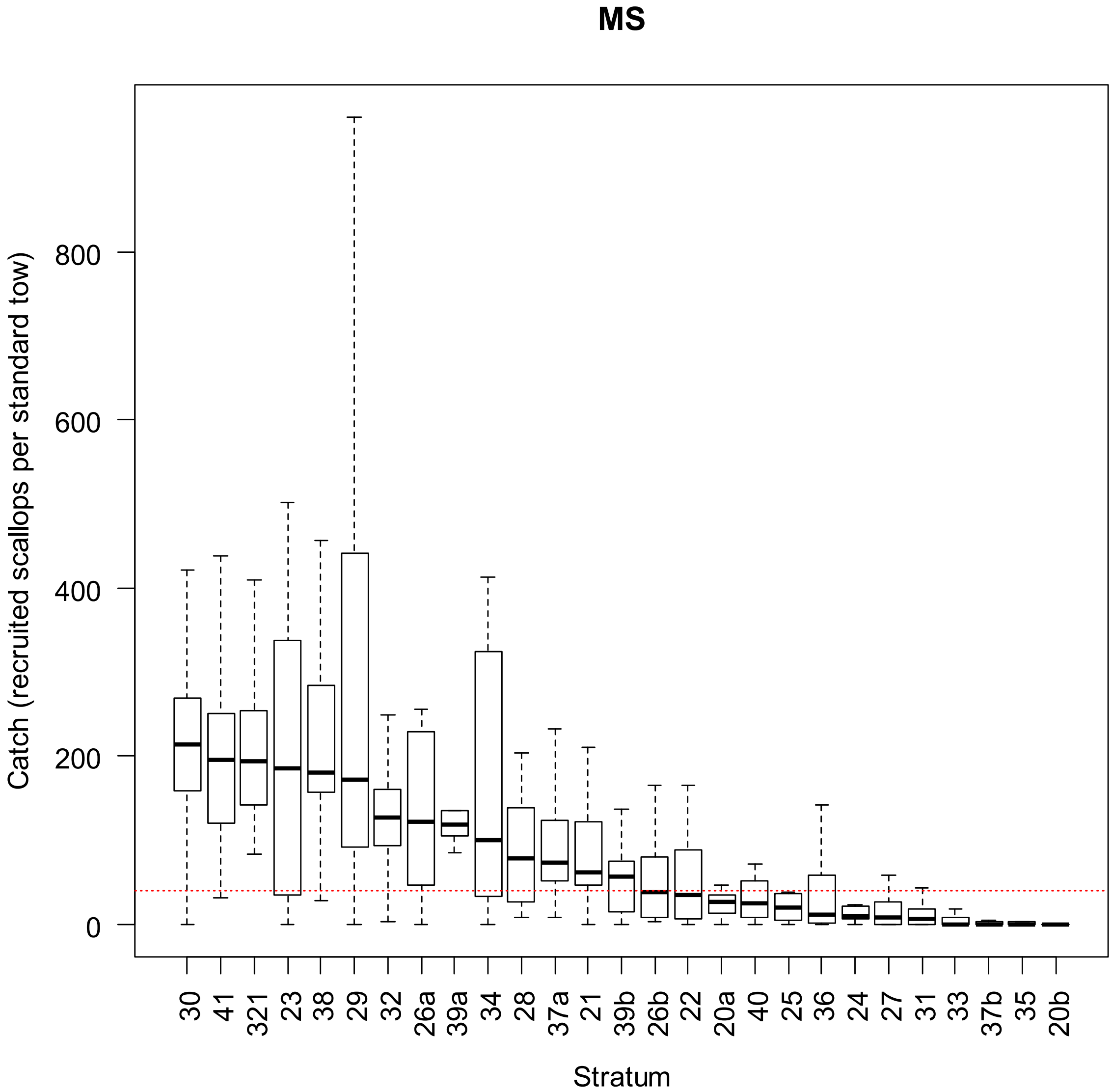

Figure 17: Boxplot of historical scallop density (recruited scallops per standard 0.4 n.mile tow, 2015–17 surveys) by stratum (2018 stratification) in decreasing order of median density (x-axis left to right). Outliers have been excluded. Horizontal dashed line denotes a median density of 40 recruited scallops per standard tow.

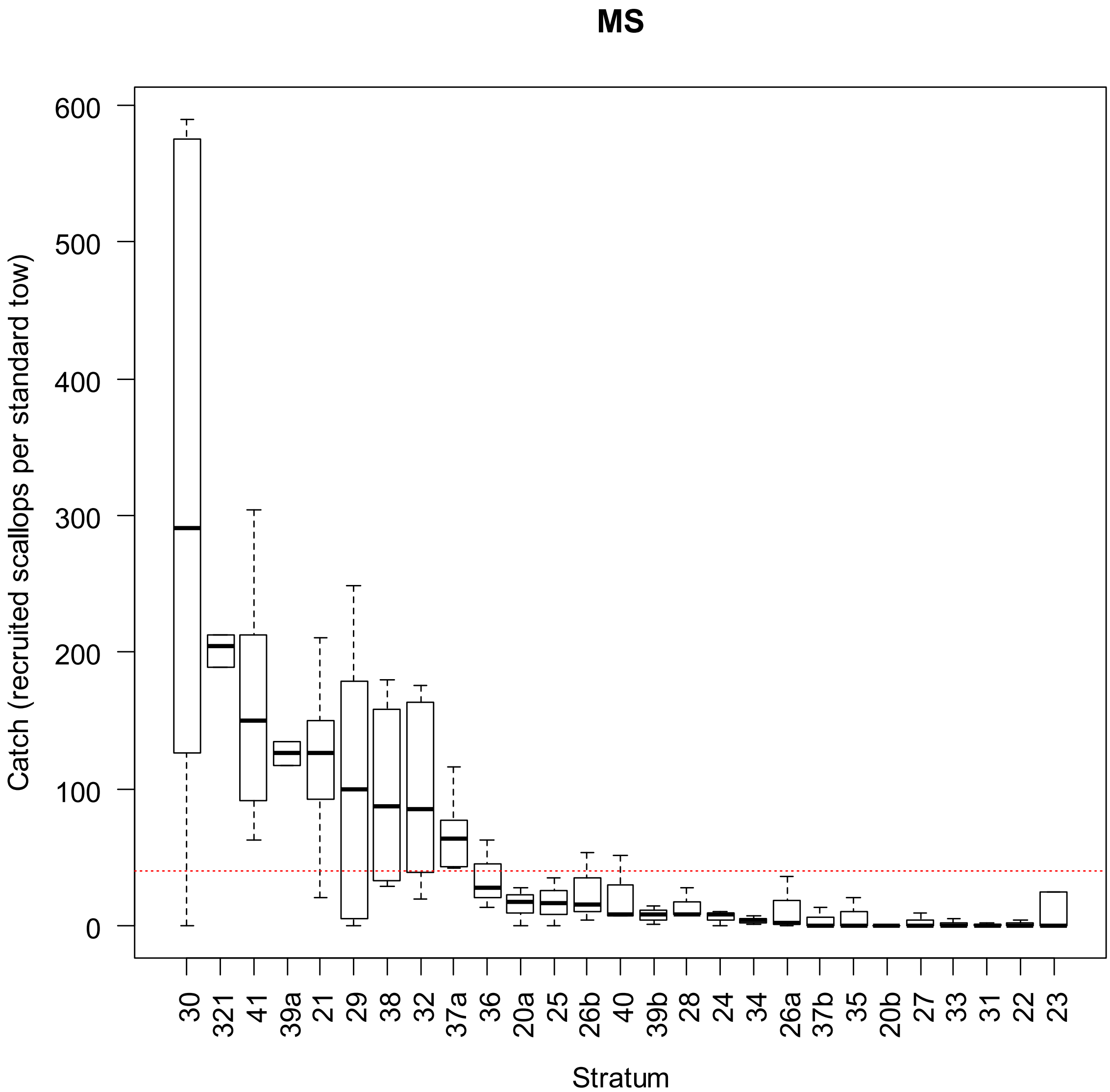

Figure 18: Boxplot of historical scallop density (recruited scallops per standard 0.4 n.mile tow, 2017 survey only) by stratum (2018 stratification) in decreasing order of median density (x-axis left to right). Outliers have been excluded. Horizontal dashed line denotes a median density of 40 recruited scallops per standard tow.

8. APPENDIX B: SCA 7 survey vessels

Table 7: Vessels, masters, and dredge details for SCA 7 surveys since 1994. –, unknown at time of writing. FV *Rongatea II* is 42 ft (12.8 m) in length and has a 110 horsepower (hp) Gardner engine, and FV *Okarito* is 47 ft (14.37 m) in length and has a 180 hp GM engine; both vessels have similar dredging capability for conducting the survey (and both have been core vessels used in the commercial SCA 7 fishery).

Trip code	Year	Survey type	Vessel	Master	Dredge type and width
HIN9401	1994	Pre-season	*Hinewai*	–	MAF ring-bag, 2.45 m
TAS9501	1995	Pre-season	*Tasman Challenger*	Paul Botica	MAF ring-bag, 2.45 m
TAS 9601	1996	Pre-season	*Tasman Challenger*	–	MAF ring-bag, 2.45 m
TAS 9701	1997	Pre-season	*Tasman Challenger*	–	CSEC ring-bag, 2.40 m
TAS 9801	1998	Pre-season	*Tasman Challenger*	Paul Botica	CSEC ring-bag, 2.40 m
TAS 9901	1999	Pre-season	*Tasman Challenger*	–	CSEC ring-bag, 2.40 m
TAS 0001	2000	Pre-season	*Tasman Challenger*	–	CSEC ring-bag, 2.40 m
TAS 0101	2001	Pre-season	*Tasman Challenger*	–	CSEC ring-bag, 2.40 m
TAS 0201	2002	Pre-season	*Tasman Challenger*	Paul Botica	CSEC ring-bag, 2.40 m
TAS 0301	2003	Pre-season	*Tasman Challenger*	Paul Botica	CSEC ring-bag, 2.40 m
TAS 0401	2004	Pre-season	*Tasman Challenger*	Paul Botica	CSEC ring-bag, 2.40 m
TAS 0501	2005	Pre-season	*Tasman Challenger*	Paul Botica	CSEC ring-bag, 2.40 m
TAS 0601	2006	Pre-season	*Tasman Challenger*	Paul Botica	CSEC ring-bag, 2.40 m
FAL0701	2007	Pre-season	*Falcon III*	–	CSEC ring-bag, 2.40 m
CAL0801	2008	Pre-season	*Calypso*	Phillip Trewavas	CSEC ring-bag, 2.40 m
OKA0901	2009	Pre-season	*Okarito*	Grant Roberts	CSEC ring-bag, 2.40 m
OKA1001	2010	Pre-season	*Okarito*	Grant Roberts	CSEC ring-bag, 2.40 m
OKA1101	2011	Pre-season	*Okarito*	Cris West	CSEC ring-bag, 2.40 m
OKA1201	2012	Pre-season	*Okarito*	Cris West	CSEC ring-bag, 2.40 m
OKA1301	2013	Pre-season	*Okarito*	Cris West	CSEC ring-bag, 2.40 m
OKA1302	2013	In-season (Ketu)	*Okarito*	Cris West	CSEC ring-bag, 2.40 m
OKA1401	2014	Pre-season	*Okarito*	Cris West	CSEC ring-bag, 2.40 m
OKA1402	2014	In-season (Guards)	*Okarito*	Cris West	CSEC ring-bag, 2.40 m
OKA1501	2015	Pre-season (MS, TB)	*Okarito*	Cris West	CSEC ring-bag, 2.40 m
RON1501	2015	Pre-season (GB, 7H)	*Rongatea II*	Cris West	CSEC ring-bag, 2.40 m
OKA1502	2015	In-season (MS areas)	*Okarito*	Cris West	CSEC ring-bag, 2.40 m
OKA1503	2015	Post-season	*Okarito*	Cris West	CSEC ring-bag, 2.40 m
RON1701	2017	January	*Rongatea II*	Cris West	CSEC ring-bag, 2.40 m
RON1801	2018	January	*Rongatea II*	Cris West	CSEC ring-bag, 2.40 m

9. APPENDIX C: Tabulated population estimates, January 2018

Table 8: Population estimates of scallops in Marlborough Sounds, January 2018 (full survey extent, including stratum 42) at different spatial scales (bed, sector, substock). Estimates were produced for recruited scallops (90 mm or larger), assuming historical average dredge efficiency, predicting green weight from length, and predicting meat weight from data on the recovery of meat weight from green weight observed in the 1996–2008 commercial fishing seasons. The analysis used a non-parametric resampling with replacement approach to estimation (1000 bootstraps). Bed estimates are shown in decreasing order of estimated mean density (scallops.m^{-2}).

Grouping	Location	Area	Tows	Density (scallops.m^{-2})				Abundance (millions)				Scallop weight (g)		Biomass (t green)				Biomass (t meat)			
		(km^2)	*n*	Mean	CV	Median	95%CI	Mean	CV	Median	95%CI	Mean	Median	Mean	CV	Median	95%CI	Mean	CV	Median	95%CI
RECRUITED																					
Bed	Wynens Bank	2	8	0.517	0.25	0.509	0.292–0.804	1.185	0.25	1.165	0.669–1.841	79.2	79.1	93.8	0.26	92.2	53.1–146.2	12.4	0.26	12.1	6.9–19.6
	Dieffenbach	3	13	0.362	0.26	0.353	0.199–0.567	1.056	0.26	1.031	0.582–1.657	80.9	80.6	85.4	0.26	83.1	47.6–133.1	11.3	0.27	11.0	6.3–18.3
	Chetwodes	6	8	0.318	0.28	0.307	0.178–0.532	1.752	0.28	1.694	0.980–2.933	85.7	85.5	150.1	0.28	144.9	83.8–253.3	19.8	0.29	19.4	10.9–33.4
	Ketu Bay	2	12	0.120	0.31	0.117	0.059–0.207	0.285	0.31	0.278	0.139–0.492	75	74.9	21.4	0.31	20.8	10.5–36.3	2.8	0.32	2.7	1.3–4.8
	Guards	24	18	0.103	0.24	0.100	0.065–0.162	2.505	0.24	2.426	1.573–3.937	88.7	88.5	222.1	0.25	214.6	137.8–351.8	29.3	0.26	28.0	17.9–46.7
	BayofManyCoves	4	6	0.100	0.36	0.097	0.041–0.177	0.438	0.36	0.429	0.181–0.777	78.3	77.7	34.3	0.36	33.3	14.2–61.1	4.5	0.36	4.4	1.9–8.1
	Ship	21	19	0.098	0.23	0.096	0.06–0.149	2.017	0.23	1.980	1.229–3.065	78.1	78.4	157.6	0.23	155.2	96.6–235.9	20.9	0.24	20.5	12.5–31.9
	AdmiralityPenguin	17	6	0.012	0.69	0.012	0–0.030	0.198	0.69	0.198	0–0.502	76.7	76.4	15.2	0.7	15.1	0–38.7	2.0	0.7	2.0	0–5.1
	WaituiPortGore	44	6	0.009	0.62	0.008	0.001–0.020	0.374	0.62	0.360	0.046–0.872	86.2	86	32.2	0.61	31.0	4.2–74.7	4.3	0.62	4.1	0.6–9.8
	Richmond Bay	4	3	0.008	0.21	0.007	0.005–0.011	0.027	0.21	0.026	0.017–0.039	75.2	75.2	2.0	0.21	2.0	1.3–2.9	0.3	0.22	0.3	0.2–0.4
	Waitata	5	6	0.007	0.6	0.007	0.001–0.017	0.036	0.6	0.034	0.005–0.083	76.4	76.6	2.7	0.6	2.6	0.4–6.4	0.4	0.61	0.3	0–0.8
	Tawhitinui High	4	3	0.007	0.68	0.007	0–0.018	0.025	0.68	0.024	0–0.064	77	77.4	2.0	0.68	1.9	0–4.9	0.3	0.69	0.2	0–0.7
	Clara Island	3	3	0.006	0.76	0.006	0–0.018	0.018	0.76	0.017	0–0.049	70.2	70.1	1.2	0.76	1.2	0–3.4	0.2	0.76	0.2	0–0.4
	Waitata Reach	14	3	0.002	0.42	0.002	0–0.003	0.028	0.42	0.027	0–0.049	70.4	70.3	1.9	0.42	1.9	0–3.4	0.3	0.43	0.3	0–0.5
	Horseshoe Bay	1	3	0.002	0.52	0.002	0–0.004	0.002	0.52	0.002	0–0.004	72.7	72.7	0.1	0.52	0.1	0–0.3	<0.02	0.52	<0.02	0–<0.04
	Forsyth Bay Low	11	3	0.001	0.81	0.001	0–0.004	0.015	0.81	0.014	0–0.041	80.4	80.4	1.2	0.81	1.1	0–3.3	0.2	0.81	0.1	0–0.4
	Tawhitinui Low	22	3	0	0.87	0	0–0.001	0.007	0.87	0.007	0–0.019	66.6	66.6	0.4	0.87	0.4	0–1.3	0.1	0.87	0.1	0–0.2
Sector	7K	158	85	0.041	0.20	0.040	0.028–0.06	6.471	0.20	6.302	4.46–9.519	84.6	84.2	547.8	0.20	530.5	376.3–805.8	72.1	0.20	69.9	49.5–106.5
	7L	28	38	0.126	0.20	0.124	0.083–0.185	3.525	0.20	3.468	2.31–5.18	79.0	79.0	278.4	0.20	274.1	183.4–411.5	36.7	0.21	35.9	23.9–54.1
Substock	MS	186	123	0.054	0.18	0.052	0.038–0.078	9.996	0.18	9.736	7.041–14.472	82.7	82.4	826.2	0.19	801.8	582.5–1210.6	108.7	0.19	105.7	76.2–159

Table 9: Population estimates of scallops in Marlborough Sounds, January 2018 (full survey extent, including stratum 42) by stratum. Estimates were produced for recruited scallops (90 mm or larger), assuming historical average dredge efficiency, predicting green weight from length, and predicting meat weight from data on the recovery of meat weight from green weight observed in the 1996–2008 commercial fishing seasons. The analysis used a non-parametric resampling with replacement approach to estimation (1000 bootstraps). Bed estimates are shown in decreasing order of estimated mean density (scallops.m^{-2}).

Grouping	Location	Area	Tows	Density (scallops.m^{-2})				Abundance (millions)				Scallop weight (g)		Biomass (t green)				Biomass (t meat)			
		(km^2)	*n*	Mean	CV	Median	95%CI	Mean	CV	Median	95%CI	Mean	Median	Mean	CV	Median	95%CI	Mean	CV	Median	95%CI
RECRUITED																					
Stratum	20a	10	3	0.020	0.69	0.020	0–0.051	0.198	0.69	0.198	0–0.502	76.7	76.5	15.2	0.70	15.1	0–38.6	2.0	0.70	2.0	0–5.1
	20b	7	3	0	NA	0	0–0	0	NA	0	0–0	NA	NA	0	NA	0	0–0	0	NA	0	0–0
	21	6	8	0.318	0.28	0.307	0.178–0.532	1.752	0.28	1.694	0.98–2.933	85.7	85.6	150.1	0.28	145.0	83.8–254.1	19.8	0.29	19.4	10.9–33.4
	22	3	3	0.001	0.84	0.001	0–0.002	0.002	0.84	0.002	0–0.006	74.9	75.0	0.2	0.84	0.2	0–0.4	0.0	0.84	0.0	0–0.1
	23	1	3	0.023	0.63	0.022	0.002–0.056	0.034	0.63	0.032	0.003–0.081	76.5	76.4	2.6	0.64	2.4	0.2–6.3	0.3	0.64	0.3	0–0.8
	24	3	3	0.006	0.76	0.006	0–0.018	0.018	0.76	0.017	0–0.049	70.2	70.1	1.2	0.76	1.2	0–3.4	0.2	0.76	0.2	0–0.4
	25	14	3	0.002	0.42	0.002	0–0.003	0.028	0.42	0.027	0–0.049	70.4	70.3	1.9	0.42	1.9	0–3.5	0.3	0.43	0.3	0–0.5
	26a	1	3	0.002	0.52	0.002	0–0.004	0.002	0.52	0.002	0–0.004	72.7	72.7	0.1	0.52	0.1	0–0.3	0.0	0.52	0.0	0–0
	26b	4	3	0.007	0.68	0.007	0–0.018	0.025	0.68	0.024	0–0.064	77.0	77.4	2.0	0.68	1.9	0–4.9	0.3	0.69	0.2	0–0.7
	27	22	3	0.000	0.87	0.000	0–0.001	0.007	0.87	0.007	0–0.019	66.6	66.6	0.4	0.87	0.4	0–1.3	0.1	0.87	0.1	0–0.2
	28	4	3	0.008	0.21	0.007	0.005–0.011	0.027	0.21	0.026	0.017–0.039	75.2	75.2	2.0	0.21	2.0	1.3–2.9	0.3	0.22	0.3	0.2–0.4
	29	2	12	0.120	0.31	0.117	0.059–0.207	0.285	0.31	0.278	0.139–0.492	75.0	75.0	21.4	0.31	20.8	10.5–36.5	2.8	0.32	2.7	1.3–4.8
	30	2	8	0.519	0.25	0.511	0.293–0.807	1.190	0.25	1.170	0.672–1.849	79.2	79.0	94.2	0.25	92.4	53.5–146.3	12.4	0.26	12.1	6.9–19.6
	31	11	3	0.001	0.81	0.001	0–0.004	0.015	0.81	0.014	0–0.041	80.4	80.5	1.2	0.81	1.1	0–3.3	0.2	0.81	0.1	0–0.4
	32	6	6	0.121	0.48	0.115	0.028–0.261	0.716	0.48	0.680	0.164–1.540	82.8	82.9	59.3	0.48	56.3	13.5–127.4	7.8	0.49	7.3	1.7–16.4
	321	6	6	0.275	0.24	0.266	0.171–0.43	1.764	0.24	1.704	1.095–2.762	91.3	90.6	161.0	0.25	154.5	98.6–255.6	21.2	0.26	20.2	12.5–34.6
	33	11	3	0.001	0.26	0.001	0.001–0.002	0.014	0.26	0.014	0.008–0.022	78.9	79.0	1.1	0.24	1.1	0.7–1.7	0.1	0.25	0.1	0.1–0.2
	34	1	3	0.017	0.81	0.017	0–0.046	0.020	0.81	0.020	0–0.055	74.7	74.7	1.5	0.80	1.5	0–4.1	0.2	0.80	0.2	0–0.5
	35	38	3	0.008	0.77	0.008	0–0.021	0.301	0.77	0.288	0–0.801	83.5	83.4	25.1	0.78	24.0	0–67.1	3.3	0.78	3.2	0–8.8
	36	6	3	0.013	0.44	0.012	0.001–0.024	0.075	0.44	0.073	0.006–0.141	97.0	96.9	7.3	0.45	7.1	0.4–13.9	1.0	0.46	0.9	0.1–1.8
	37a	6	8	0.055	0.45	0.052	0.014–0.111	0.334	0.45	0.315	0.083–0.675	88.7	88.9	29.6	0.44	28.0	7.3–59.1	3.9	0.45	3.7	1–7.9
	37b	10	3	0	NA	0	0–0	0	NA	0	0–0	NA	NA	0	NA	0	0–0	0	NA	0	0–0
	38	5	8	0.364	0.24	0.354	0.209–0.554	1.691	0.24	1.645	0.971–2.573	76.1	76.0	128.6	0.24	124.9	74.6–196.5	17.0	0.25	16.5	9.7–26.4
	39a	1	3	0.208	0.48	0.198	0.036–0.423	0.268	0.48	0.255	0.047–0.544	77.8	77.6	20.8	0.48	19.8	3.8–42.7	2.7	0.49	2.6	0.5–5.6
	39b	3	3	0.055	0.43	0.053	0.013–0.106	0.172	0.43	0.165	0.042–0.331	79.0	79.0	13.6	0.45	13.0	3.3–26.6	1.8	0.45	1.7	0.4–3.5
	40	1	3	0.084	0.22	0.081	0.055–0.127	0.095	0.22	0.092	0.062–0.144	87.6	87.8	8.3	0.24	8.0	5.2–12.9	1.1	0.25	1.1	0.7–1.7
	41	1	7	0.595	0.30	0.581	0.29–0.978	0.884	0.30	0.864	0.431–1.453	80.2	80.2	71.0	0.30	69.2	34.7–116.8	9.3	0.30	9.1	4.6–15.9
	42	0	3	0.269	0.19	0.263	0.184–0.387	0.081	0.19	0.079	0.055–0.116	80.7	80.5	6.5	0.19	6.3	4.5–9.4	0.9	0.20	0.8	0.6–1.3

10. APPENDIX D: Survey biomass trends by substock and total SCA 7 stock

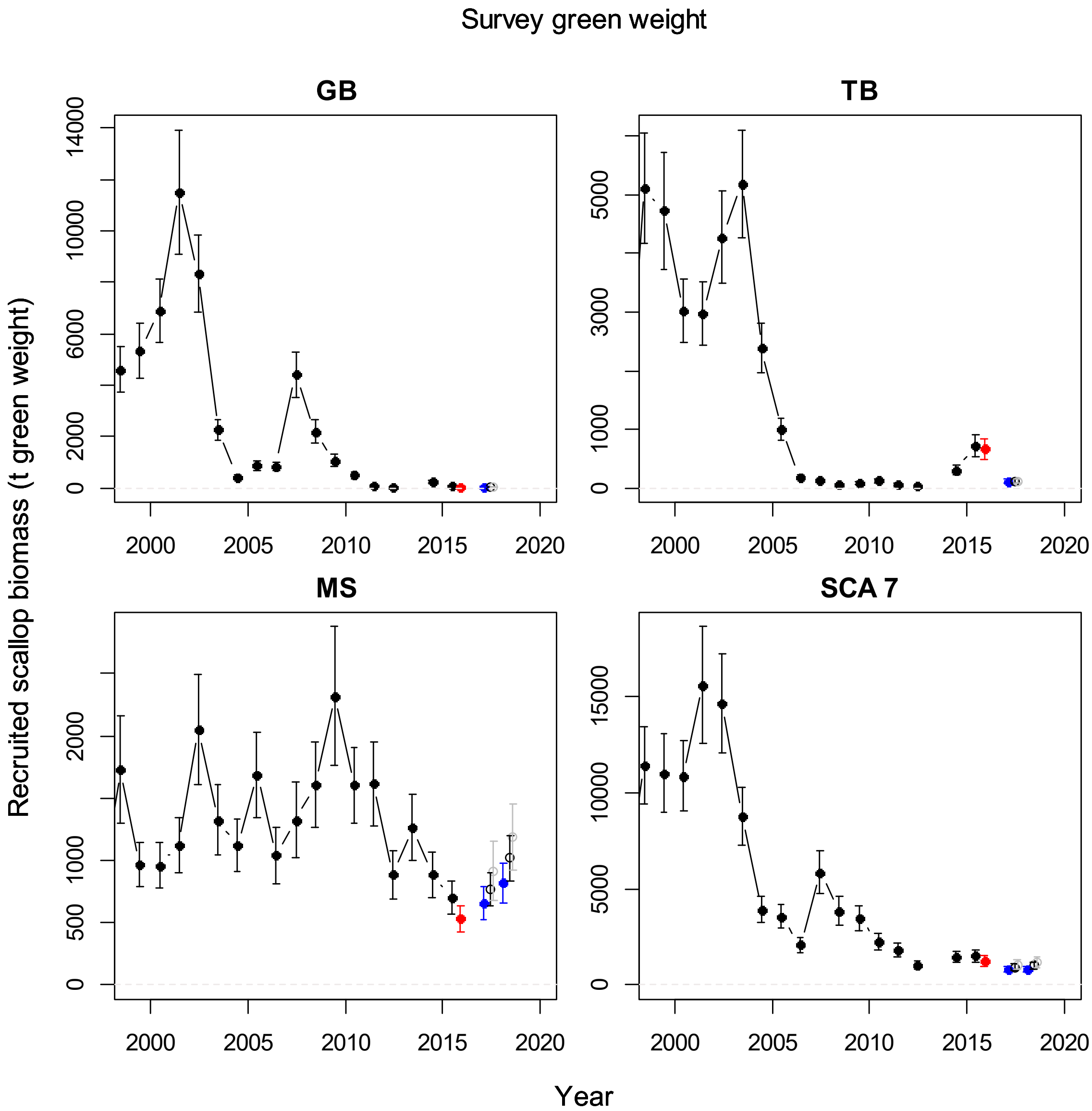

Figure 19: Trends in <u>time of survey</u> (nominally May, black symbols) biomass (t <u>green weight</u>) of recruited scallops (90 mm or larger) by substock and for the total SCA 7 stock, 1998–2018. Estimates from the November 2015 post-season survey (red symbol) and the January 2017 and 2018 surveys (blue symbols) are also shown. Two projected estimates for 2017 and 2018 are shown, derived from two different January to May projection approaches: 1) using growth estimated from tag-return data (hollow black symbols); 2) using growth estimated from Multifan analysis of multiple length frequencies (hollow grey symbols, slightly offset for clarity). Values are the estimated mean and CV of the recruited biomass. The stock was not surveyed in 2016, and Golden and Tasman Bays were not surveyed in 2018.

11. APPENDIX E: Projected biomass trends by substock and total SCA 7 stock

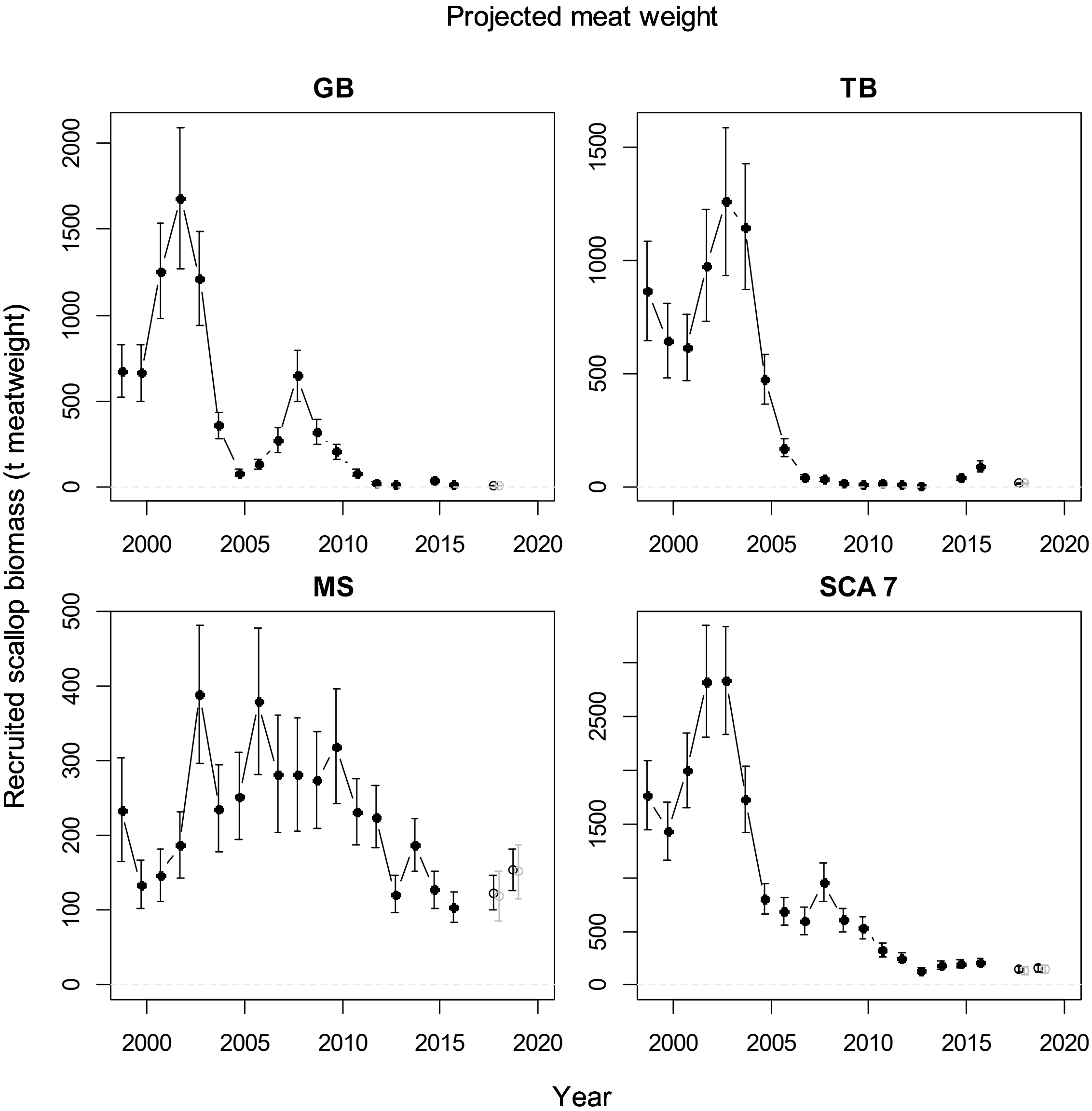

Figure 20: Trends in <u>projected start of season</u> (1 September, black symbols)) biomass (t <u>meat weight</u>) of recruited scallops (90 mm or larger) by substock and for the total SCA 7 stock, 1998–2018. Two projected estimates for 2017 and 2018 are shown, derived from two different January to May projection approaches: 1) using growth estimated from tag-return data (hollow black symbols); 2) using growth estimated from Multifan analysis of multiple length frequencies (hollow grey symbols, slightly offset for clarity). Values are the estimated mean and CV of the recruited biomass. The stock was not surveyed in 2016, and Golden and Tasman Bays were not surveyed in 2018.

12. APPENDIX F: Tabulated biomass sensitivity estimates, September 2018

Table 10: Sensitivity of the Marlborough Sounds September 2018 projected estimates of recruited scallop biomass (t meat weight) to the exclusion of areas of low scallop density. Estimates were produced using the Multifan projection approach. Critical density thresholds in the range 0–0.20 scallops m^{-2} were examined. The estimates were produced using a non-parametric resampling with replacement approach (1000 bootstraps) to estimation. Critical density corrections were applied after correcting for dredge efficiency.

Grouping	Location	Critical density (scallops.m^{-2})																	
		0			0.04			0.08			0.12			0.16			0.20		
RECRUITED		mean	CV	median	mean	CV	median	mean	CV	median	mean	CV	median	mean	CV	median	mean	CV	median
Stratum	38 (Ship)	42	0.37	40	37	0.38	35	33	0.40	31	28	0.42	26	24	0.46	22	20	0.50	18
	321 (Guards Bank Fishing Area)	22	0.29	21	19	0.32	18	16	0.37	15	12	0.45	11	9	0.55	9	7	0.69	6
	21 (Chetwode Is)	20	0.28	19	17	0.32	17	15	0.37	14	13	0.43	12	10	0.49	10	9	0.55	8
	30 (Wynens Bank)	18	0.29	18	16	0.31	16	15	0.33	14	13	0.34	13	12	0.36	12	11	0.38	11
	41 (Dieffenbach High)	13	0.36	12	12	0.37	11	11	0.39	11	11	0.41	10	10	0.42	9	9	0.44	8
	32 (Guards Bank Outer)	11	0.55	10	9	0.62	8	7	0.69	6	5	0.79	5	4	0.90	3	3	1.06	2
	39a (Bay of Many Coves Bank)	4	0.47	4	4	0.56	3	3	0.62	3	2	0.72	2	2	0.86	2	1	0.93	1
	37a (Motuara Is Medium)	4	0.46	4	2	0.62	2	1	0.87	1	1	1.13	0	0	1.59	0	0	3.56	0
	29 (Ketu Bay)	3	0.32	3	2	0.40	2	2	0.49	1	1	0.58	1	1	0.67	1	1	0.81	0
	39b (Bay of Many Coves Main Bay)	3	0.43	3	1	0.71	1	0	1.20	0	0	4.72	0	0	16.27	0	0	NA	0
Sector	7K	84	0.23	81	64	0.25	61	54	0.28	51	45	0.32	42	37	0.36	35	30	0.40	28
	7L	68	0.31	65	57	0.33	55	49	0.35	47	42	0.37	40	36	0.39	34	30	0.42	29
Substock	MS	152	0.24	147	121	0.26	118	102	0.28	99	86	0.31	83	72	0.34	69	60	0.36	56