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Tini a Tangaroa

Dredge survey of scallops in Marlborough Sounds, May 2019

New Zealand Fisheries Assessment Report 2019/69

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Williams, J.R.; Bian, R.; Olsen, L.; Stead, J.; Tuck, I.D. (2019). Dredge survey of scallops in Marlborough Sounds, May 2019.

***New Zealand Fisheries Assessment Report 2019/69.* 50 p.**

A dredge survey of scallops (*Pecten novaezelandiae*) in Marlborough Sounds (within the Southern scallop fishery area, SCA 7) was conducted from 13 to 18 May 2019. The fishery is currently closed due to sustainability concerns about the low status of the stock. The overall objective of the May 2019 survey was to evaluate the status of the Marlborough Sounds scallop substock within SCA 7. Specific objectives 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 [90 mm or larger] per square metre; and comparing the estimates with other relevant data from previous surveys.

The May 2019 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 and stratification were identical to those used in the January 2018 survey. A total of 119 valid stations (dredge tows) were sampled within the 28 strata in the May 2019 survey. The highest catches of recruited scallops 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.

The scallop population at the time of the survey in May 2019 was estimated, and projections were run to predict population estimates for September 2019. The analytical approach included two key changes from previous analyses: 1) we applied new estimates of SCA 7 ring-bag dredge efficiency (available from research conducted in Marlborough Sounds in 2018), and 2) projections were conducted using scallop tag-return data modelled with an inverse logistic model. To enable comparisons across years, data from 21 previous annual SCA 7 dredge surveys (from 1997 to 2018) were also reanalysed using the same analytical approach, producing revised time series of survey (May) and projected (September) biomass, with associated estimates of uncertainty. Abundance indices for pre-recruits (defined as scallops 53–89 mm in length) and recruited scallops (90 mm or larger) were produced and examined. Live scallop and dead clucker shell data available from annual surveys in May 2015, January 2017, January 2018, and May 2019 were also examined.

The key finding is that the Marlborough Sounds recruited biomass estimate for 2019 in the overall area surveyed is the lowest on record. Virtually all the recruited biomass at potentially fishable densities is held in five scallop beds, at Guards Bay, Ship Cove, the Chetwodes, Wynens Bank, and Dieffenbach Point. Population projections predicted the Marlborough Sounds recruited biomass in September 2019 to be 203 t meat weight. The estimated abundance of pre-recruit scallops (53–89 mm) in 2019 is low compared with historical estimates, especially from the early 2000s, suggesting that recruitment in the short term is likely to be relatively poor. Live scallop and dead clucker shell data, together with pre-recruit and recruited scallop abundance indices, provided new information useful for improving our understanding of scallop population dynamics in SCA 7.

1. INTRODUCTION

1.1 Overview

Scallops (*Pecten novaezelandiae*) support regionally important commercial and non-commercial (customary and recreational) fisheries in New Zealand. The Southern scallop stock area 'SCA 7', at the north of the South Island, comprises the regions (substocks) of Golden Bay, Tasman Bay, and Marlborough Sounds (Figure 1).

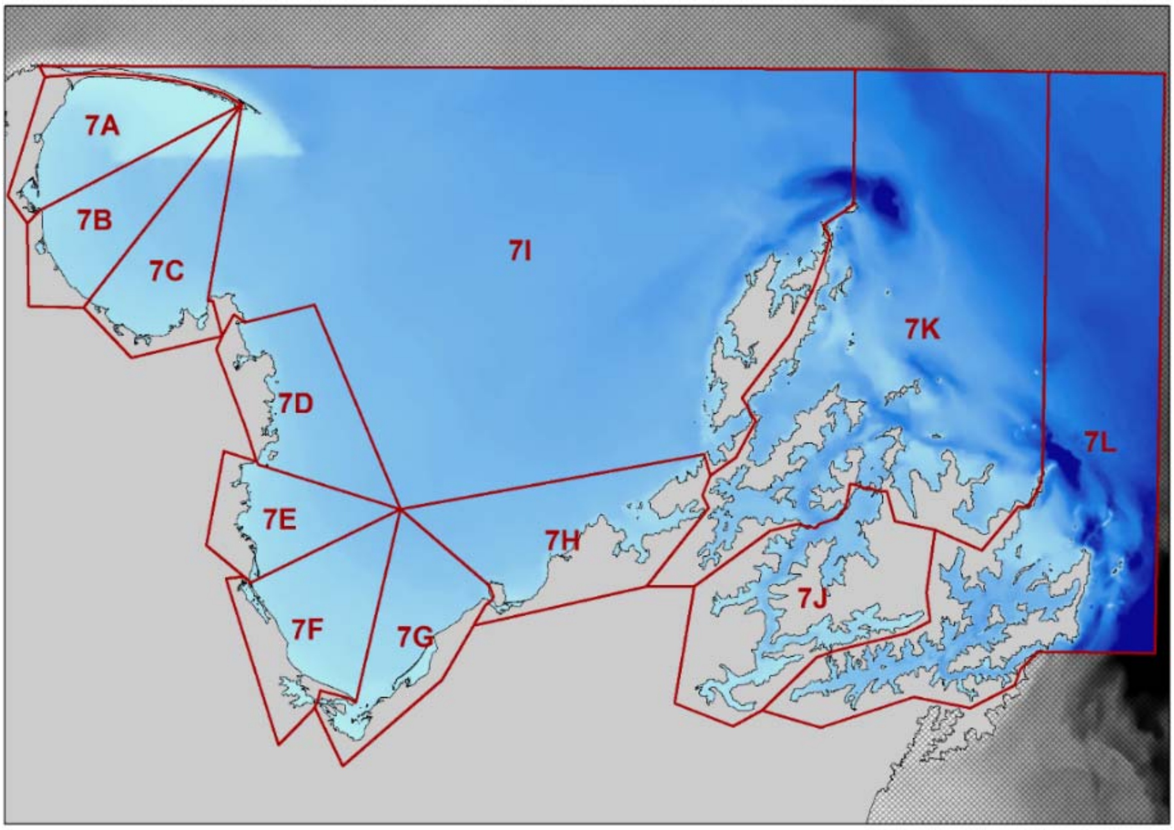

Figure 1: Map of the SCA 7 stock area which is subdivided into Statistical Reporting Areas ('stat areas') 7A–7C (Golden Bay), 7D–7H (Tasman Bay), 7I (outer Golden/Tasman Bays), and 7J–7L (Marlborough Sounds).

Due to sustainability concerns about the low status of the stocks, a temporary partial area closure for the taking and possession of scallops in Marlborough Sounds and area 7H in Tasman Bay was implemented for the 2016–17 scallop season (15 July 2016 to 14 February 2017) (Ministry for Primary Industries 2016). The 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). The closure was continued in 2018–19 and will remain in place until such a time as the scallop population has recovered (Fisheries New Zealand 2018).

The status of the SCA 7 stock is assessed using data collected from fishery-independent dredge surveys (see Appendix B: Table 7). The survey data are analysed to estimate the spatial distribution, size structure, abundance, and biomass of the population of scallops within the area covered by the survey (Williams et al. 2014b). Dredges are not 100% efficient at catching all scallops within the area of seabed swept by the dredge, making it necessary to apply dredge efficiency corrections to the raw survey data to obtain estimates of absolute biomass and annual recruitment. Information on dredge efficiency, the proportion of the scallops in the path of the gear that are caught, has been generated from a dedicated study using paired sampling by divers and dredges (Tuck et al. 2018). Efficiency-corrected dredge survey estimates form the basis of SCA 7 science advice to fisheries management.

The surveys show that the biomass of recruited scallops (90 mm or larger) in Golden and Tasman Bays declined substantially in the 2000s and has since remained at negligible levels. In Marlborough Sounds, recruited biomass followed a declining trend from 2009 to 2015, which appeared to have ceased during the period 2015 to 2018. Most of the recruited biomass during this recent period was held in a limited number of scallop beds in the outer Sounds.

1.2 Objectives

The overall research objective for the present study (project SCA201801) was to evaluate the status of the Marlborough Sounds scallop substock within SCA 7. The specific research objectives for this project were 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;
- Estimate the biomass of scallops using a range of commercial density thresholds from 0.00 to 0.2 recruited scallops per square metre;
- Compare the estimates from objective 1 with other relevant data from previous surveys and, if available, all relevant fine scale catch data.

2. METHODS

2.1 Survey design

A dredge survey of scallops in Marlborough Sounds was conducted in May 2019 using a single-phase stratified random sampling allocation design. To allow comparisons with previous surveys, the sample extent (survey coverage) and stratification (Figure 2) was identical to that used in the January 2018 survey (Williams et al. 2018). A total of 120 stations were allocated to the 28 strata for the May 2019 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, May 2019 (trip code OKA1901). All stations were sampled with a single dredge (the standard CSEC 2.4 m wide survey ring-bag dredge), using a standard tow length of 0.4 n.mile, or 0.2 n.mile in expected high density strata.

Stat area	Biotoxin	Location	Stratum	Area (km^2)	Stratum name	Tow length (n.miles)	Stns allocated	Stns sampled
7K	G100	Admirality/Penguin	20a	9.810	Admirality/Penguin Bays High	0.4	3	3
			20b	7.012	Admirality/Penguin Bays Low	0.4	3	3
		Chetwodes	21	5.512	Chetwode Is	0.2	9	9
	G43	Waitata	22	3.450	Waitata Bay	0.2	3	3
			23	1.454	Waitata Bank	0.2	3	3
		Clara Island	24	2.704	Clara Island	0.2	3	3
		Waitata Reach	25	14.382	Waitata Reach	0.4	3	3
	G42	Horseshoe Bay	26a	1.036	Horseshoe Bay	0.2	3	3
		Tawhitinui High	26b	3.634	Tawhitinui High	0.2	3	3
		Tawhitinui Low	27	22.080	Tawhitinui Low	0.4	3	3
	G43	Richmond Bay	28	3.563	Richmond Bay	0.2	3	3
		Ketu Bay	29	2.374	Ketu Bay	0.2	6	6
	G45	Wynens Bank	30	2.291	Wynens Bay	0.2	8	8
		Forsyth Bay Low	31	10.920	Forsyth Bay Low	0.4	3	3
	G46	Guards	32	5.902	Guards Bank Outer	0.2	8	8
			321	6.419	Guards Bank Fishing Area	0.2	6	6
			33	10.774	Guards Bay Low	0.4	3	3
			34	1.199	Anakoha Bank	0.4	3	3
	G90	Waitui/Port Gore	35	37.572	Waitui/Port Gore Low	0.4	3	3
			36	5.971	Port Gore Bank	0.4	3	3
7L	G29	Ship	37a	6.052	Motuara Is Medium	0.2	6	6
			37b	9.927	Motuara Is Low	0.4	3	3
			38	4.647	Ship Cove	0.2	9	9
		Bay of Many Coves	39a	1.287	Bay of Many Coves Bank	0.2	3	3
			39b	3.115	Bay of Many Coves Main Bay	0.4	3	3
		Dieffenbach	40	1.135	Dieffenbach Low	0.4	3	3
			41	1.486	Dieffenbach High	0.2	8	8
			42	0.299	Dieffenbach West	0.2	3	3
			28 strata	**186.006**			**120**	**120**

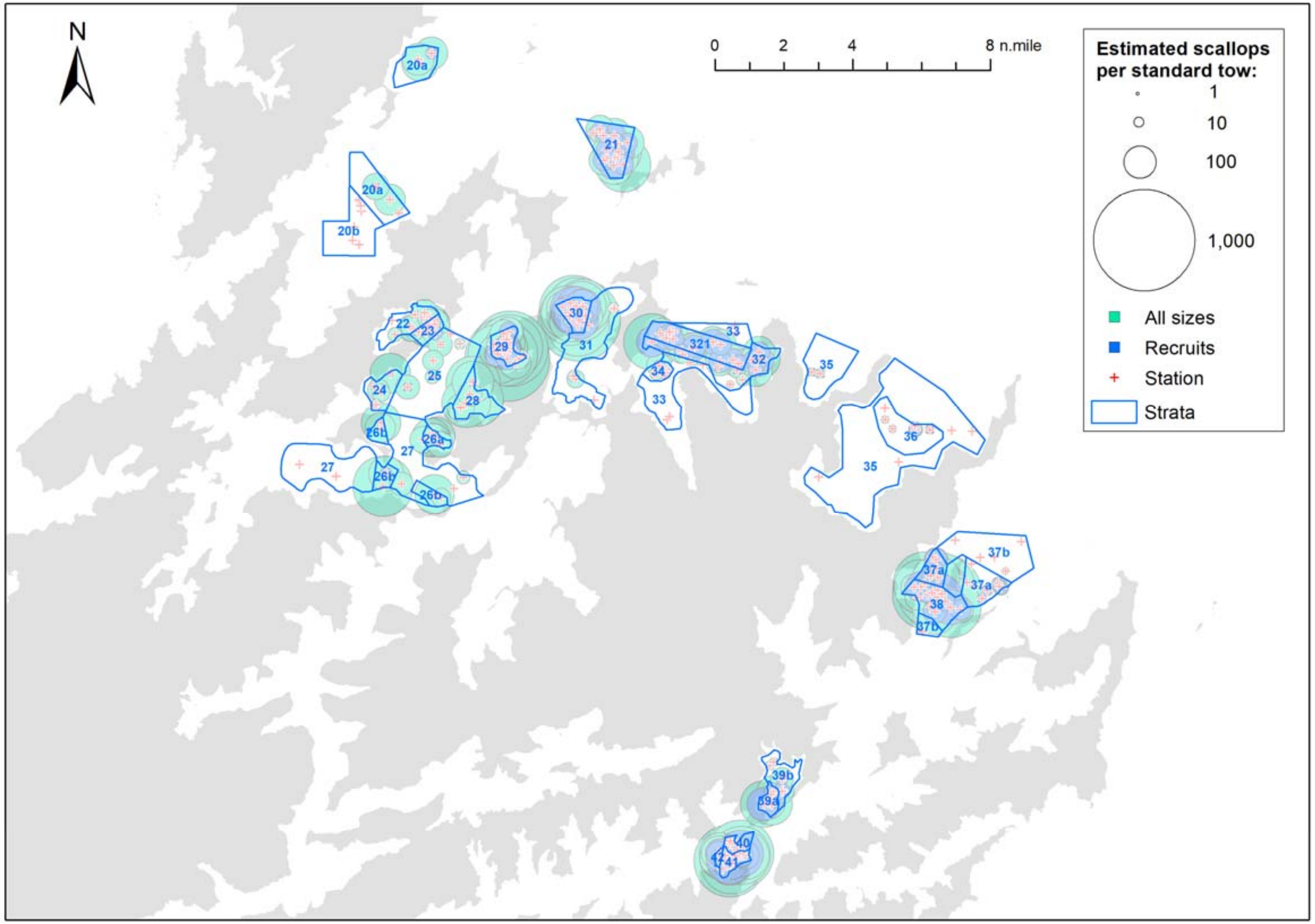

Figure 2: Stratification for the Marlborough Sounds dredge survey, May 2019. Strata 20, 26, 27, 33, 35, 37a and 37b are multi-part strata (each stratum is made up of geographically separate areas that in combination are treated as a single stratum). Circles show the abundance of recruited scallops (90 mm or larger shell length; dark shaded circles) and scallops of any size (light shaded circles) caught in the 2017 and 2018 surveys, 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 based on historical survey station scallop catch data and the estimated areas of the current strata. For each stratum, a mean catch density is calculated as an (unweighted) average of the station catch densities from each of the previous surveys in that stratum (by the current stratum boundary definitions). Potential catch densities in that stratum, in the current year, are then generated by multiplying the mean catch density by a residual randomly chosen (with equal probabilities) from that stratum, where the residuals are calculated by dividing the catch density at a station by the mean catch density in that stratum in that survey (still using current stratum boundaries). However, *allocate* does not actually generate catch densities – it just calculates their variance and uses that to determine the optimal allocation (by an iterative method - starting with the minimum number of stations and repeatedly adding one station wherever it will provide the most improvement in the CV).

The strata for the May 2019 survey were intersected with station data from the 2013–18 SCA 7 surveys (the most recent five years of annual 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.

A minimum allocation of three stations was required for all strata. With 28 strata, this meant that a minimum of 84 stations was required. Based on experience, in the proposed design we estimated that a fixed survey duration of six days was needed, during which we expected to complete up to 120 stations, with the aim of meeting a CV target of 20% (or less) for each of the scallop beds (individual or groups of strata) that comprise the core areas in the Marlborough sounds substock.

Initial *allocate* runs were conducted using three different time periods: 5 years (2013, 2014, 2015, 2017, 2018), 2 years, (2017 and 2018) and 1 year (2018 only). It was decided that data from the most recent two surveys (2017 and 2018) would be used to optimise the allocation; this was the period following the fishery closure. Boxplots of scallop density by stratum from the 2017 and 2018 surveys are shown in Appendix A (Figure 26).

First, specifying that a minimum CV of 17% needed to be met for the Marlborough Sounds substock overall, *allocate* determined that only three stations were required per stratum, producing a predicted substock CV of 10.9%. Alternatively, using a total of 120 stations, a substock CV of 7.1% was predicted.

Second, specifying that a minimum CV of 17% needed to be met for each of the seven main scallop beds (locations) that held most of the recruited biomass in 2018, and allowing only 3 stations per stratum in all other strata, would require an allocation of 161 stations, producing an overall CV of 6.8%. But trying to achieve the large number of tows that would be required in Ketu Bay and Bay of Many Coves was considered unfeasible given the relatively small areas of those strata (Table 1; Figure 2).

The final allocation was based on the second allocation approach, with some minor adjustments to the number of stations allocated to certain strata, to help meet expected logistics. Additional 'spare' stations (n = 3 per stratum) were allocated for use in the event that any particular 'primary' allocated station could not be sampled appropriately. Using the 2017–18 survey data, the final allocation predicted that a substock CV of 8% would be achieved (on basic parametric estimates, uncorrected for dredge efficiency). 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 commercial fishing vessel (FV *Okarito*) 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 *Okarito* has been used in all surveys of SCA 7 since 2009 except for part of the May 2015 survey, and all of the January 2017 and January 2018 surveys, in which the similar FV *Rongatea II* was used (see Appendix B: Table 7).

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 3) and towed for a standard tow length of 0.4 n.miles, but the tow length is 0.2 n.miles in certain 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 photographed, and a visual estimate of the dredge percentage fullness is made before the dredge catch is emptied onto a sorting tray at the stern of the vessel.

Figure 3: Stern of FV *Okarito* showing deployment of ring-bag dredge in Marlborough Sounds (May 2014 survey). Photo credit: J. Williams.

2.4 Catch sampling

A standard dredge catch sampling procedure was followed. In this procedure, the unsorted catch is photographed and its total volume 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 4 and Figure 5) and placed into bins by scallop life status category (live scallops or dead 'cluckers' which are the articulated shells of dead scallops with the shell hinge still intact; note that in May 2019 the dead cluckers were also further categorised and recorded as clean or fouled). 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 scallops and dead cluckers (further distinguished in May 2019 as either clean or fouled clucker shells) are measured for shell length (along the anterior–posterior axis, using digital callipers / 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.

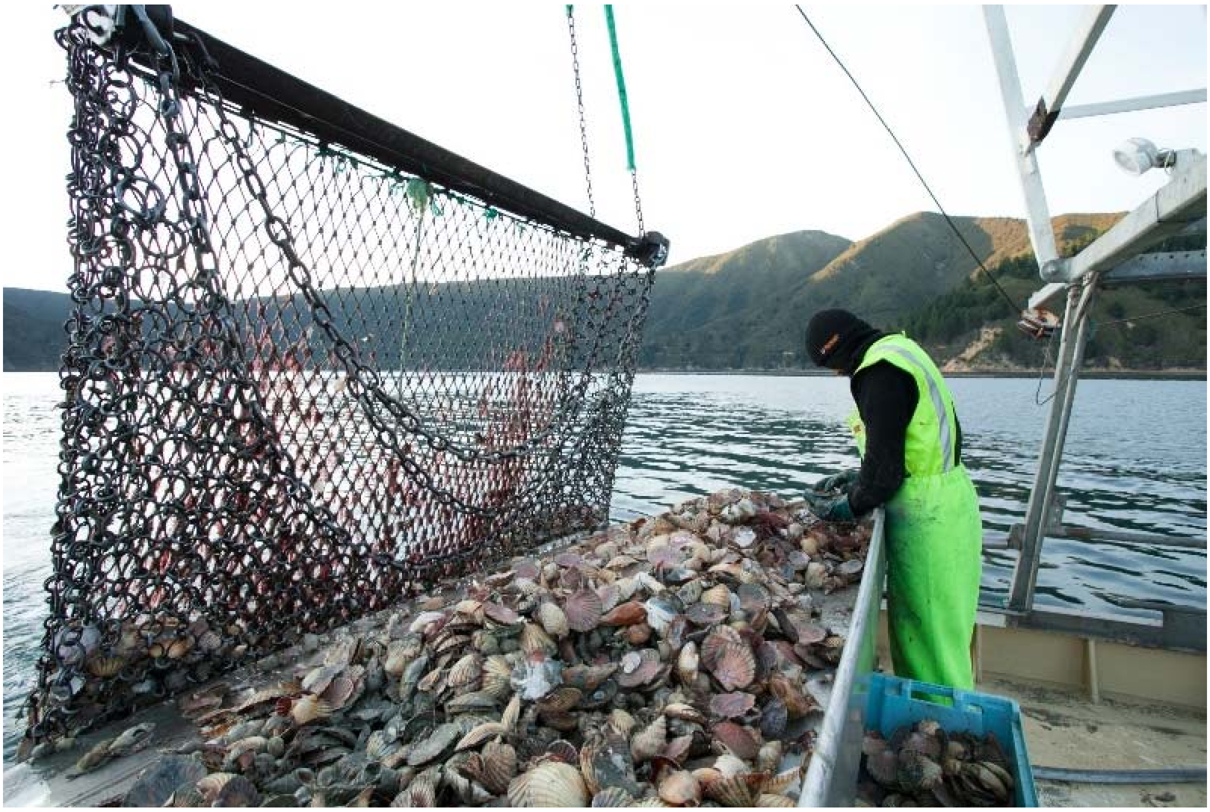

Figure 4: Example of a ring-bag dredge survey catch being sorted at the stern of the vessel (May 2014 survey). Photo credit: J. Williams.

Figure 5: Example of a dredge survey catch being sorted at the stern of the vessel in the May 2019 survey. Photo credit: L. Olsen.

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 using digital vernier callipers. All data were checked and verified, ready for loading to the Fisheries New Zealand '*scallop*' database. Raw data forms were scanned.

2.5 Population estimation

The scallop 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. (2013b), but a further update of the documentation is warranted. 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 estimation approach uses 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.

In the 2019 survey analysis, two key changes were made:

1. We applied new estimates of ring-bag dredge efficiency for the SCA 7 survey dredge based on new data collected by diver and dredge sampling in Marlborough Sounds in January 2018 within project SCA2017-02 (Tuck et al. 2018);
2. Population projections were conducted using tag-return growth increment data as used in previous analyses, but modelled with an inverse-logistic model (Tuck & Williams 2012)

Using the new dredge efficiency correction and a different growth projection model will both have affected both the biomass estimates and their 95% confidence limits compared with previously generated estimates.

Except for these changes, the approach for the 2019 survey analysis was the same as that used in 2018, 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 September, accounting for growth and natural mortality.

Stratum length frequency distributions were 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 were 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, were considered to be known without error.

In 2009, CSEC (Campbell 2009) indicated that there are areas of SCA 7 (especially in Tasman Bay and parts of the Marlborough Sounds) that hold large quantities of pre-recruit scallops that are unlikely to ever recruit into the fishable population (attain 90 mm or larger), and that excluding these scallops from growth projections between survey and season would provide more realistic estimates of projected scallop density. On that basis, in analyses conducted since 2009, zero growth has been applied in projections in all Tasman Bay strata and in Marlborough Sounds strata in Admiralty/Penguin bays, at the Chetwode Islands, and in Pelorus Sound west of Forsyth Bay (i.e. 2019 strata 20 to 29 inclusive; Table 1).

2.6 Comparative analysis

Data from the 21 previous annual SCA 7 dredge surveys conducted from 1997 to 2018 were reanalysed to produce revised time series of scallop population estimates. The original survey stratification for each survey was used in each respective survey year, and the same bootstrapping analytical approach as that used in the May 2019 analysis was employed (i.e. correcting for 2018 dredge efficiency, and projecting using inverse-logistic growth).

Temporal anomalies due to the January timing of the 2017 and 2018 surveys were addressed by projecting these surveys forward to the nominal May timing of the other surveys, producing a ‘time of survey (May) biomass’ time series. Population projections through to the traditional September start of the commercial fishing season were also conducted for each survey, producing a ‘September projected biomass’ time series. Projections were conducted using the same methodology as that used in the May 2019 survey analysis (see Section 2.5 Population estimation).

The new time series of scallop estimates generated were examined to establish whether changes have occurred in the scallop populations. The examination was 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, locations, and in total). These outputs were used to describe and interpret the status of the scallop population over time. Abundance indices for pre-recruits (defined as scallops 53–89 mm in length) and recruited scallops (90 mm or larger) were produced and examined. Live scallop and dead clucker shell data available from annual surveys in May 2015, January 2017, January 2018, and May 2019 were also examined.

3. RESULTS

3.1 Sampling conducted

The 2019 Marlborough Sounds SCA 7 dredge survey was carried out during six days at sea from 13 to 18 May. A total of 120 stations (dredge tows) were sampled within the 28 strata (Figure 6), but one station (station_no 12 in Chetwodes stratum 21) was excluded from the analysis because the tow performance was unsatisfactory (GoPro video footage confirmed the dredge was off the bottom during the tow, resulting in zero catch). This left 119 valid stations for analysis. Overall, 20 710 live scallops were caught on the dredge survey, of which 15 028 (73%) were measured and the rest counted; a total of 2403 dead clucker scallops were caught, of which 1772 (74%) were measured and the rest counted.

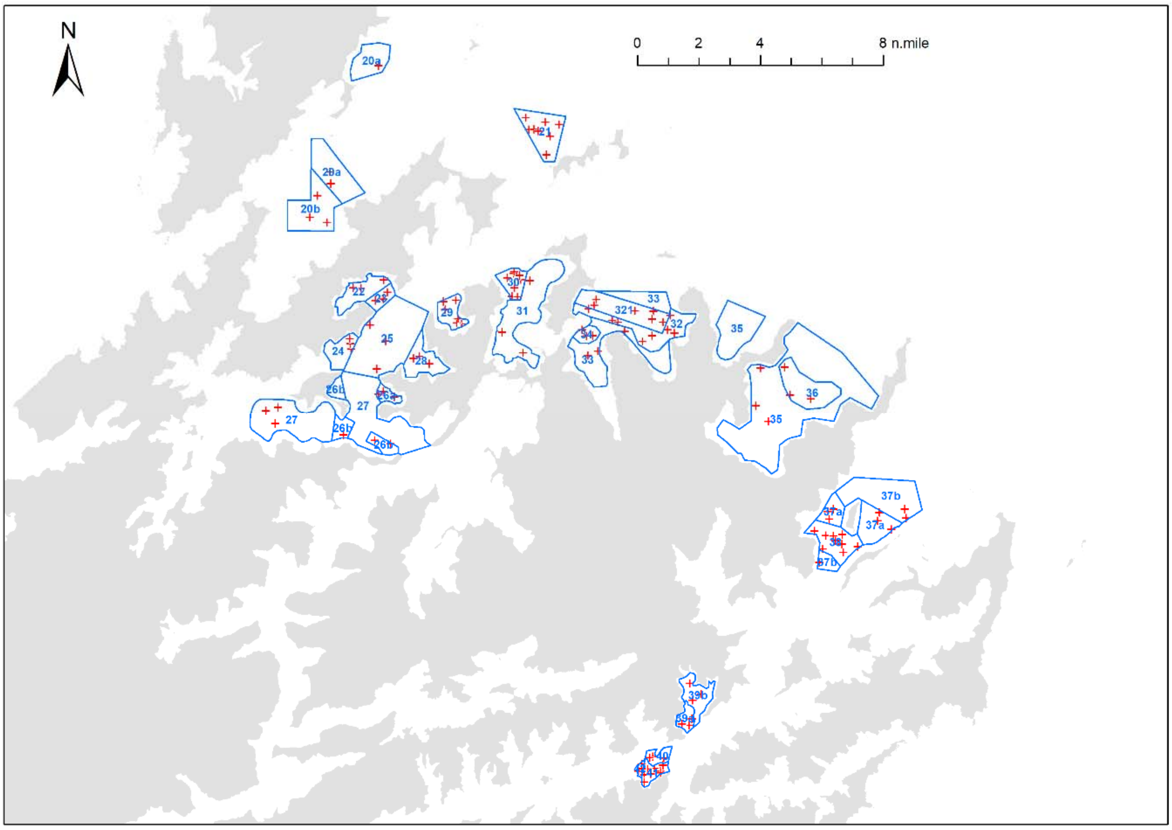

Figure 6: Station positions sampled, Marlborough Sounds dredge survey, May 2019.

Additional to recording the vessel GPS coordinates logged from the start to the end of each dredge tow (determined using SeaPlot software), on the May 2019 survey a GoPro video camera and lighting setup, and a depth/temperature logger, were attached to the dredge to provide new observations of how the dredge behaves on the seabed (Figure 7). Video (GoPro) footage of the dredge in operation was recorded on most of the dredge tows, and the depth logger was attached on all tows; the video and depth data were archived on the project drive but were not analysed within the present study. Unfortunately, the additional planned use of a bottom contact sensor was not possible because the unit was damaged during a previous survey and could not be repaired in time for the May 2019 survey.

Parchment tubeworms (*Chaetopterus*) were also quantified on the survey (see Appendix I: Figure 34). Shortly before the survey, a local diver (S. Rossiter) reported an abundance of tubeworms, suspected to be *Chaetopterus* sp., in an area of Queen Charlotte Sound, and samples of both the worms and scallops from the area were submitted to the Marine Invasives Taxonomic Service at NIWA and the MPI Animal Health Laboratory. The ensuing 'REW 15908 scallop and parchment worm investigation' confirmed the tubeworms as *Chaetopterus chaetopterus-B*.

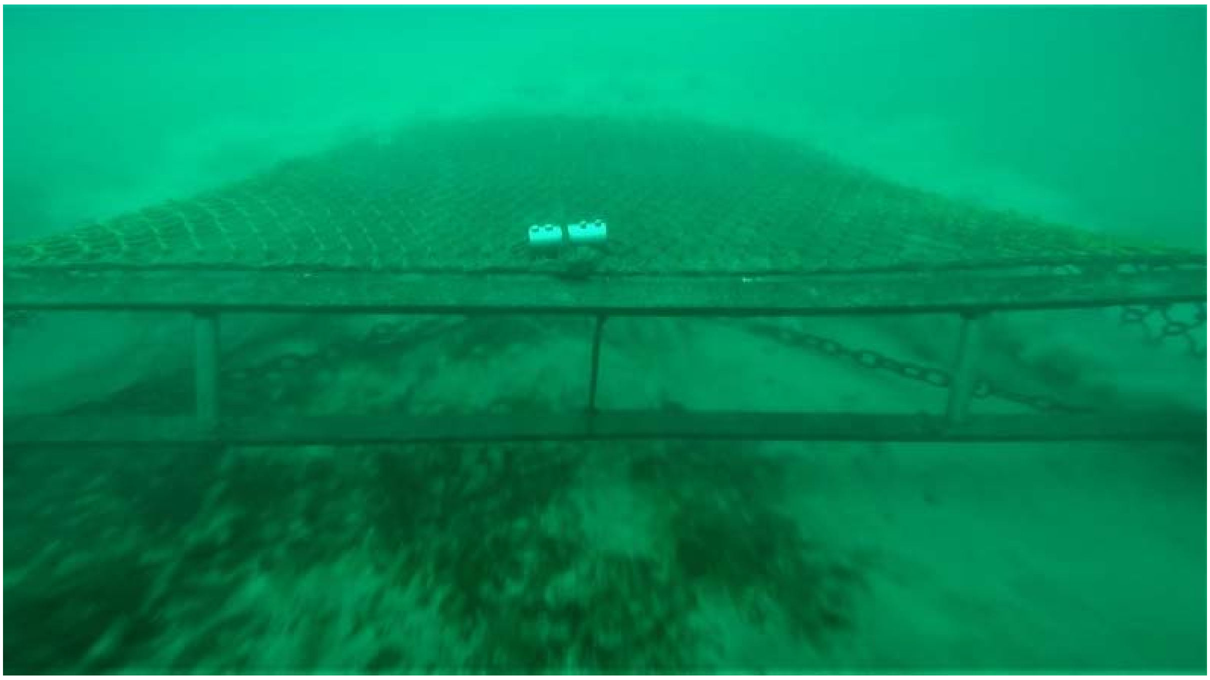

Figure 7: GoPro video frame grab showing survey ring-bag dredge during a tow, Marlborough Sounds, May 2019. Note the metal housing containing the depth logger is attached to the top of the dredge.

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 in the survey design (Table 2). Recruited estimates with high precision (target CVs of 20% or lower) were achieved at the substock and statistical reporting area levels, and at two of the locations (the Chetwodes and Guards Bay), targeted in the design; CVs for the other five locations targeted in the design were slightly higher than the 20% CV target, at Wynens Bank (25%), Ship Cove (25%), and Dieffenbach Point (CV = 26%); CVs were high at the Bay of Many Coves (30%) and Ketu Bay (56%) locations, where catches were highly variable within strata.

At the stratum level, CVs achieved were in the range 15–28% at all key individual strata which exhibited the highest catch rates (greater than 100 recruited scallops per standard 0.4 n.mile tow).

Table 2: Comparison of the coefficient of variation (CV) values predicted in the design with those achieved by the valid survey tows, May 2019. 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	
		design	survey	survey	m^{-2}	tow^{-2}
Substock	MS	120	119	0.12	0.02	29
Stat area	7K	82	81	0.15	0.02	27
	7L	38	38	0.17	0.02	38
Location	Wynens Bank (30)	8	8	0.25	0.07	129
	Guards Bay (32, 321, 33,	14	20	0.20	0.07	125
	Dieffenbach Point (40, 41,	20	14	0.26	0.07	117
	Chetwodes (21)	18	8	0.15	0.07	116
	Ship Cove (37a, 37b, 38)	9	18	0.25	0.02	30
	Bay of Many Coves (39a,	6	6	0.30	0.01	23
	Ketu Bay (29)	6	6	0.56	0.01	14
Stratum	321	6	6	0.21	0.22	388
	41	8	8	0.28	0.12	212
	38	9	9	0.25	0.07	129
	30	8	8	0.25	0.07	129
	21	8	8	0.15	0.07	116
	32	8	8	0.65	0.05	87
	42	3	3	0.39	0.04	65
	39a	3	3	0.33	0.04	63

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 largest 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 in five locations (Guards Bay, Ship Cove, the Chetwodes, Wynens Bank and Dieffenbach Point). Catches of recruited scallops were very low in other strata.

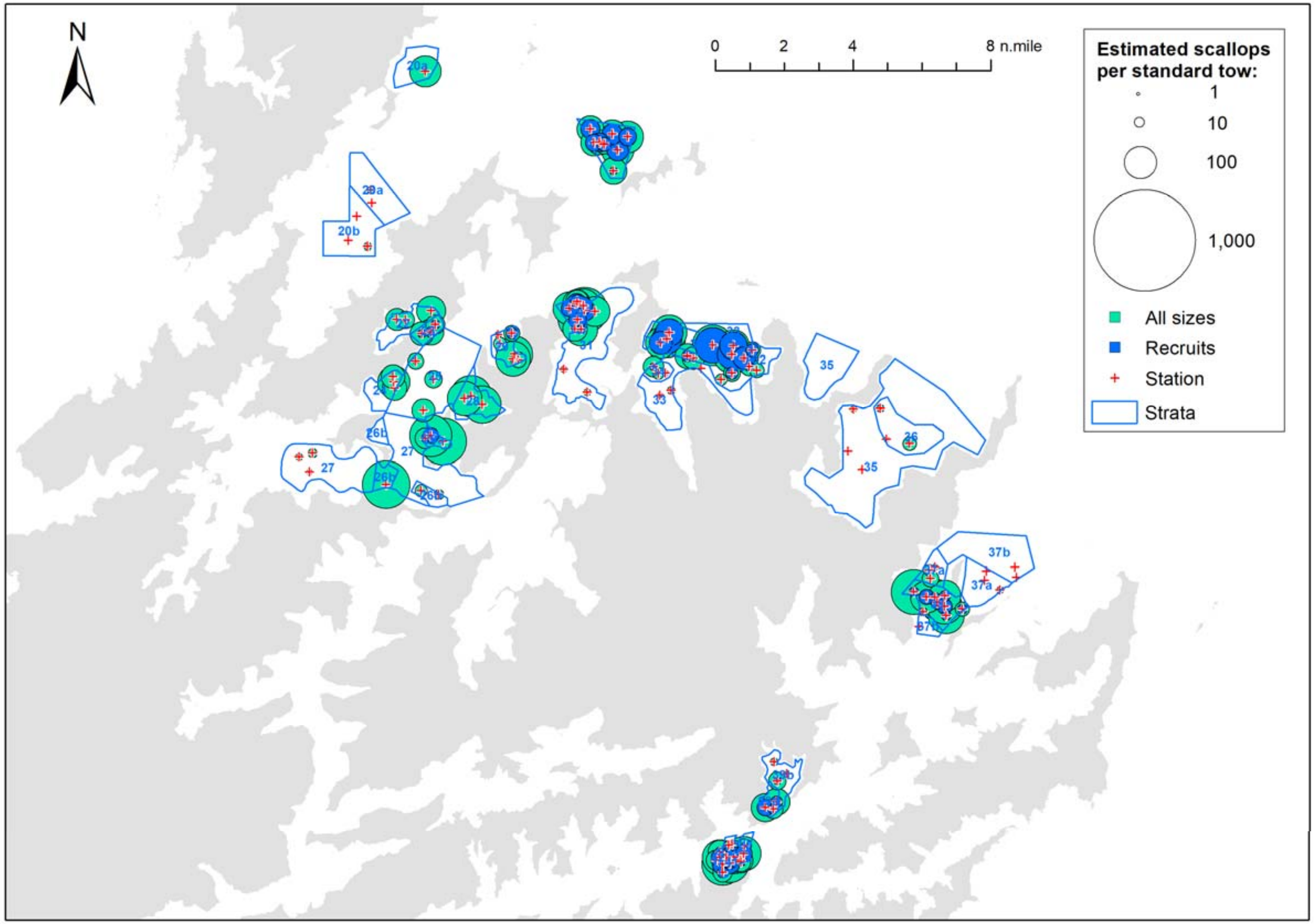

Figure 8: Catch per standard tow, Marlborough Sounds dredge survey, May 2019. Circle area is proportional to the number of scallops caught per standard distance towed (0.4 n.miles). Dark blue shaded circles denote scallops of recruited size (90 mm or larger), green shaded circles denote scallops of any size, crosses denote tow positions. Values are uncorrected for dredge efficiency. Polygons denote survey strata boundaries.

3.4 Population estimates

Analysis of the 2019 dredge survey data used the standard estimation approach, but corrected for dredge efficiency using the 2018 efficiency estimates (Tuck et al. 2018) and conducted projections using tag-return growth data modelled using an inverse logistic growth model.

For the full survey extent, the Marlborough Sounds recruited biomass in May 2019 was 1167 t (t green weight median value, 95% CI =819–1620 t; mean = 1174, CV = 0.17; Figure 9). The May 2019 time of survey population estimates are tabulated in detail at different levels of grouping in Appendix C (see Table 8 for estimates grouped by location and Table 9 for individual stratum estimates).

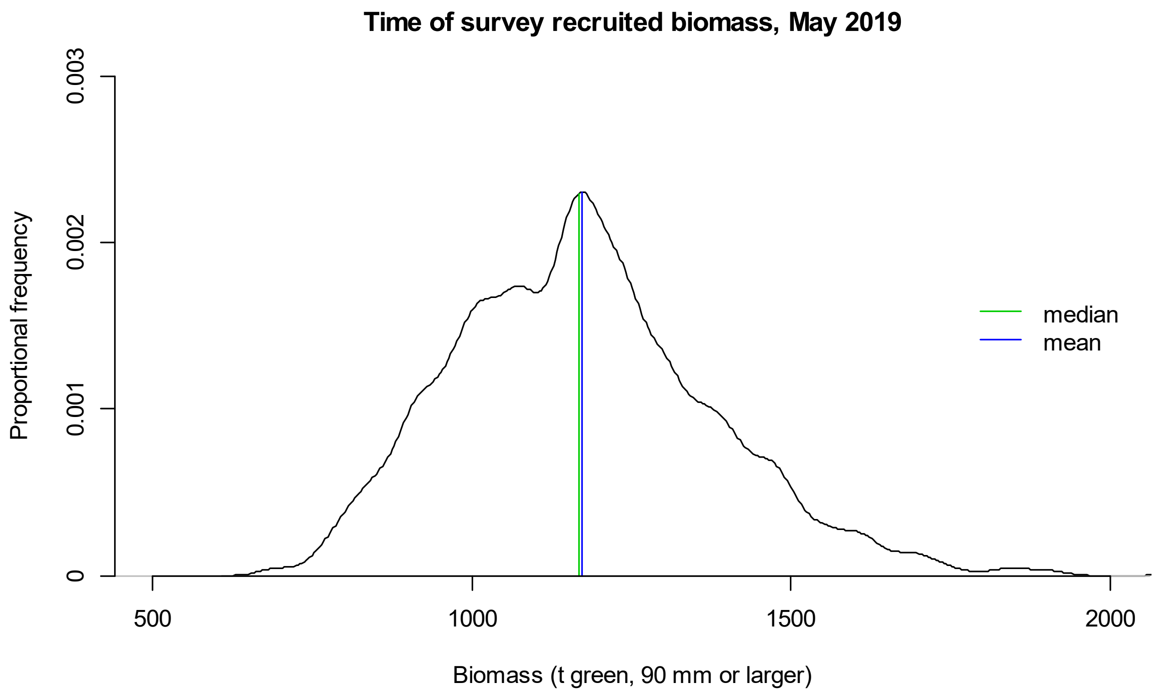

Figure 9: Proportional frequency distribution of the biomass (t green weight) of recruited scallops (90 mm or larger) in Marlborough Sounds at the time of the survey, May 2019. The distribution was derived using a non-parametric resampling with replacement approach to estimation (1000 bootstraps). Corrected for dredge efficiency (Tuck et al. 2018).

3.5 Length frequency

Scallop length frequency distributions at the time of the survey in May 2019, uncorrected for dredge efficiency, are shown for the overall substock of Marlborough Sounds (Figure 10), and for key strata (Figure 11).

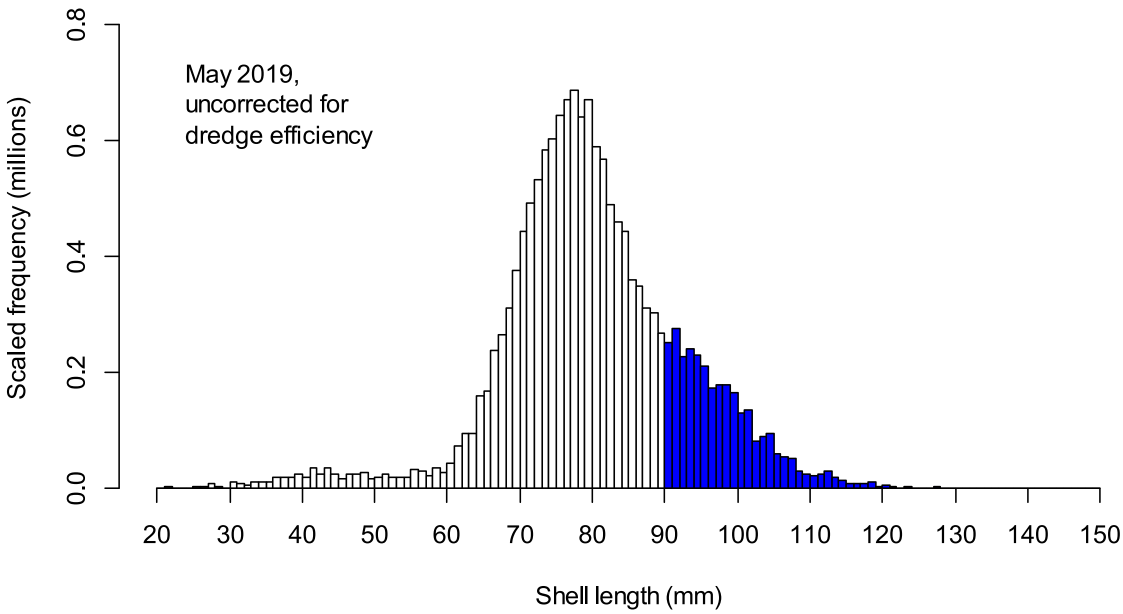

Figure 10: Substock length frequency distribution for scallops in the Marlborough Sounds at the time of the survey, May 2019. Data uncorrected for dredge efficiency. Dark shaded bars show recruited scallops (90 mm shell length or larger).

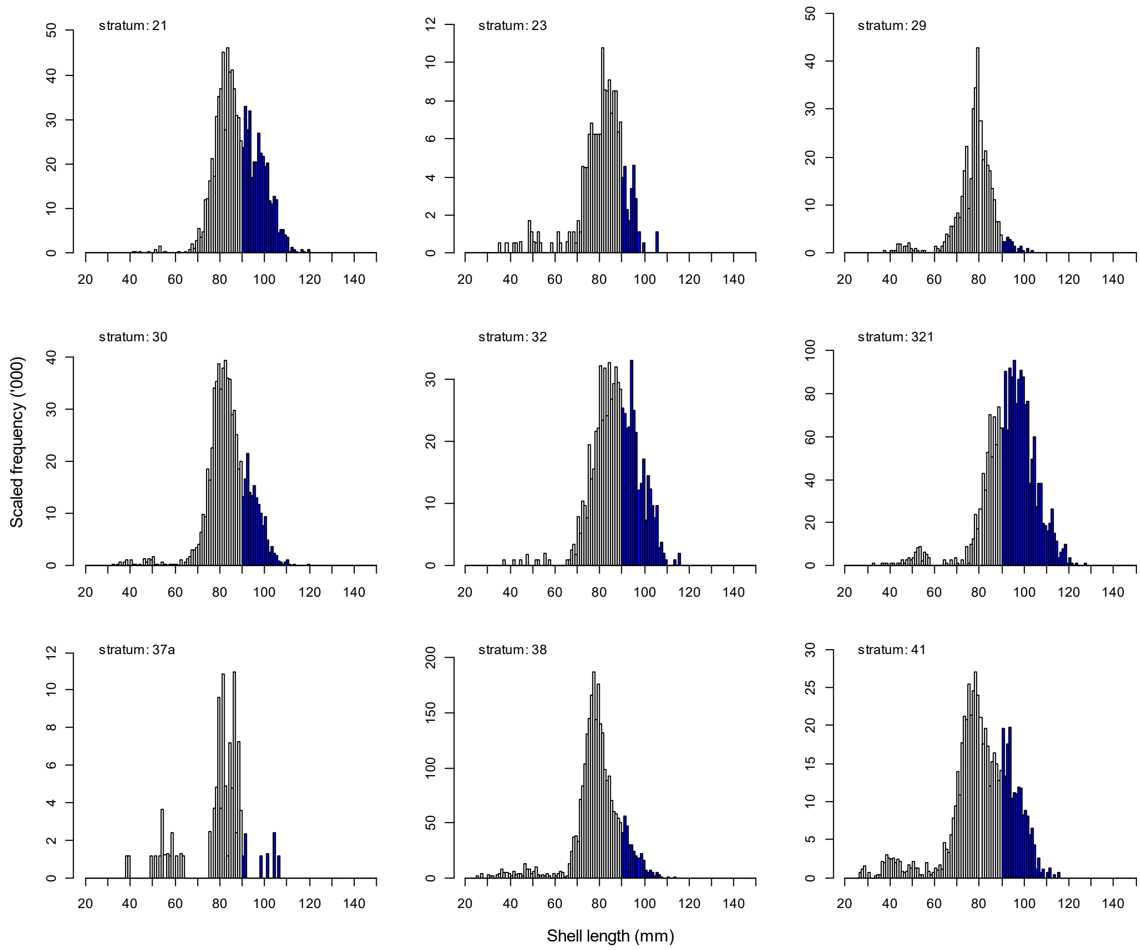

Figure 11: Stratum length frequency distributions for scallops in the Marlborough Sounds at the time of the survey, May 2019, for key strata of interest. Data uncorrected for dredge efficiency. Dark blue shaded bars show recruited scallops (90 mm shell length or larger). Note y-axis varies between plots.

3.6 Time of survey (May) biomass

Estimates of absolute green weight biomass in 2015, 2017, 2018 and 2019 in Marlborough Sounds at the time of the surveys (and from Jan–May population projections in 2017 and 2018) were tabulated for comparison (Table 3), and plotted together with the revised time series of May survey estimates for the overall Marlborough Sounds substock (Figure 12) and for each biotoxin area (Figure 13). The revised time series shows there was little change in the Marlborough Sounds recruited biomass from 2015 to 2018, but that the biomass was significantly lower in 2019 (see Appendix D). 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 Appendix E (Figure 28).

Table 3: Summary of absolute recruited biomass (t green weight) in Marlborough Sounds estimated from surveys between 2015 and 2019, correcting for dredge efficiency (Tuck et al. 2018). Time of survey estimates are shown, together with Jan–May projected estimates in 2017 and 2018 to address the different survey timing in those years; projections used growth estimated from tag-return data, modelled using an inverse logistic model. Cells shaded grey are the survey or projected median biomass estimates for May.

Year	Month	Type of estimate	Region	Area (km^2)	*n* stns	Mean Bgr	CV Bgr	Median Bgr	2.5% Bgr	97.5% Bgr
2015	May	Time of survey	MS	186	89	1 941	0.16	1 909	1 430	2 616
2017	Jan	Time of survey	MS	186	110	1 732	0.14	1 699	1 330	2 257
	May	Projected from Jan	MS	186	110	1 922	0.16	1 878	1 415	2 629
2018	Jan	Time of survey	MS	186	123	1 780	0.15	1 762	1 330	2 335
	May	Projected from Jan	MS	186	123	2 073	0.16	2 048	1 500	2 831
2019	May	Time of survey	MS	186	119	1 174	0.17	1 167	819	1 620

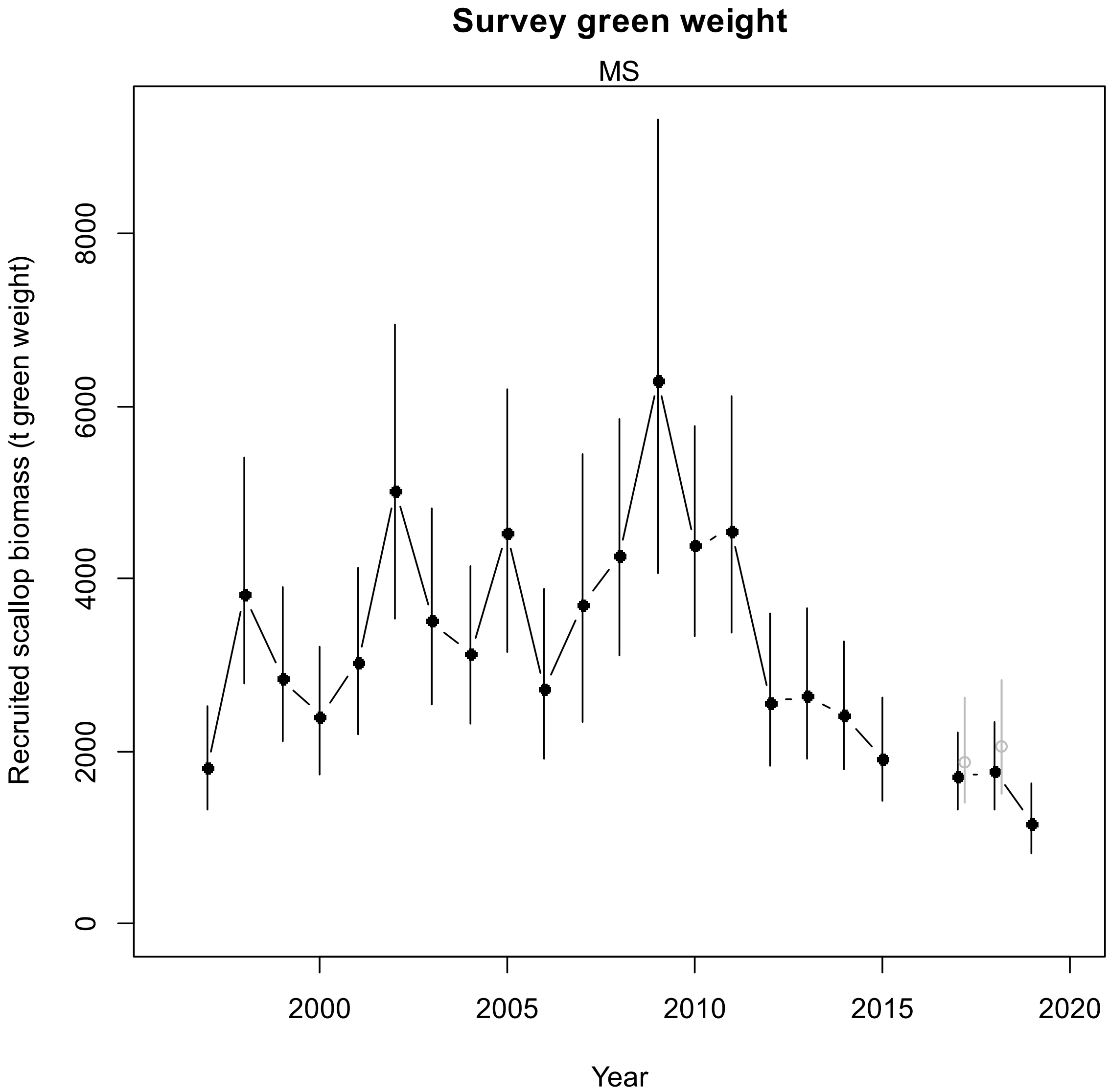

Figure 12: Trends in <u>time of survey</u> biomass (t <u>green weight</u>) of recruited scallops (90 mm or larger) for the Marlborough Sounds substock, 1997–2019. Values are the median and 95% confidence intervals of the estimated biomass. Surveys were conducted in May (sometimes April–May or May–June) in all years except for in 2017 and 2018 when the surveys were in January (see Appendix B: Table 7); May-projected estimates for 2017 and 2018 are shown for comparison (hollow grey symbols, offset for clarity). There was no survey in 2016.

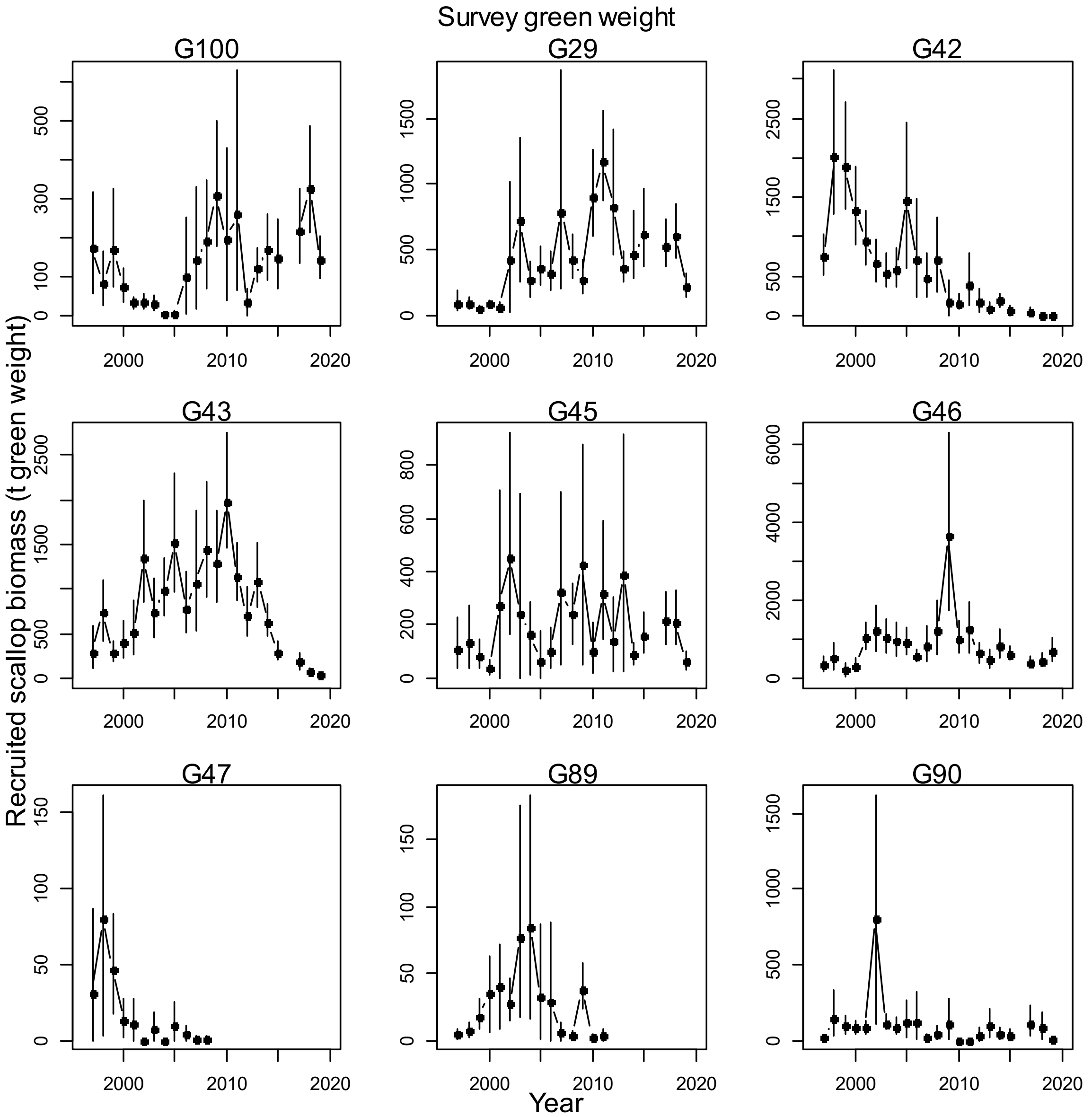

Figure 13: Trends in <u>time of survey</u> biomass (t <u>green weight</u>) of recruited scallops (90 mm or larger) by biotoxin area in Marlborough Sounds, 1997–2019. Values are the median and 95% confidence intervals of the estimated biomass at the <u>actual time each survey was conducted</u>. Surveys were conducted in May (sometimes April–May or May–June) in all years except for in 2017 and 2018 when the surveys were in January (see Appendix B: Table 7). There was no survey in 2016.

3.7 September projected biomass

Projected recruited biomass in September 2019 (Figure 14) was estimated to be:

- 1539 t green weight (median value, 95% CI=986–1947 t; mean = 1393 t, CV = 18%), or
- 203 t meat weight (median value, 95% CI=129–256 t; mean = 184 t, CV = 19%).

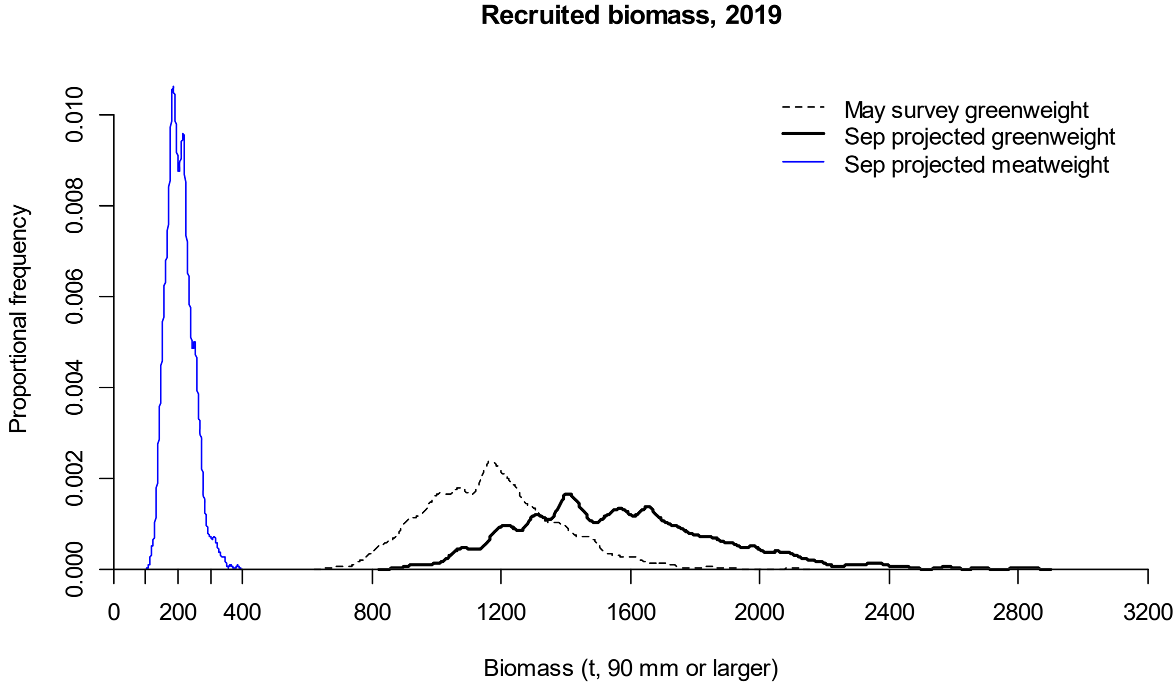

Figure 14: Distributions of the estimated biomass of recruited scallops (90 mm or larger) in Marlborough Sounds at the time of the survey in May 2019 (t green weight) and from projections to 1 September 2019 (Sep) (in t green weight and t meat weight).

Projected estimates for 1 September 2015, 2017, 2018 and 2019 in Marlborough Sounds were tabulated (Table 4).

Table 4: Summary of absolute recruited meat weight biomass estimates (t meat weight) in September 2015, 2017, 2018 and 2019. Estimates were produced applying dredge efficiency (Tuck et al. 2018) and from a projection approach that estimated growth from tag-return data using an inverse logistic growth model.

Year	Month	Type of estimate	Region	Area (km^2)	*n* stns	Mean Bmt	CV Bmt	Median Bmt	2.5% Bmt	97.5% Bmt
2015	Sep	Projected from May	MS	186	89	311	0.17	305	224	431
2017	Sep	Projected from Jan	MS	186	110	352	0.19	345	237	512
2018	Sep	Projected from Jan	MS	186	123	337	0.17	335	232	457
2019	Sep	Projected from May	MS	186	119	206	0.20	203	140	300

Projected estimates of September recruited biomass were also plotted to assess longer term trends for the overall Marlborough Sounds substock (Figure 15) and for each biotoxin area (Figure 16). The trends in meat weight biomass for Marlborough Sounds were also plotted alongside those for Golden and Tasman Bays, and for the overall SCA 7 stock, in Appendix F (Figure 29).

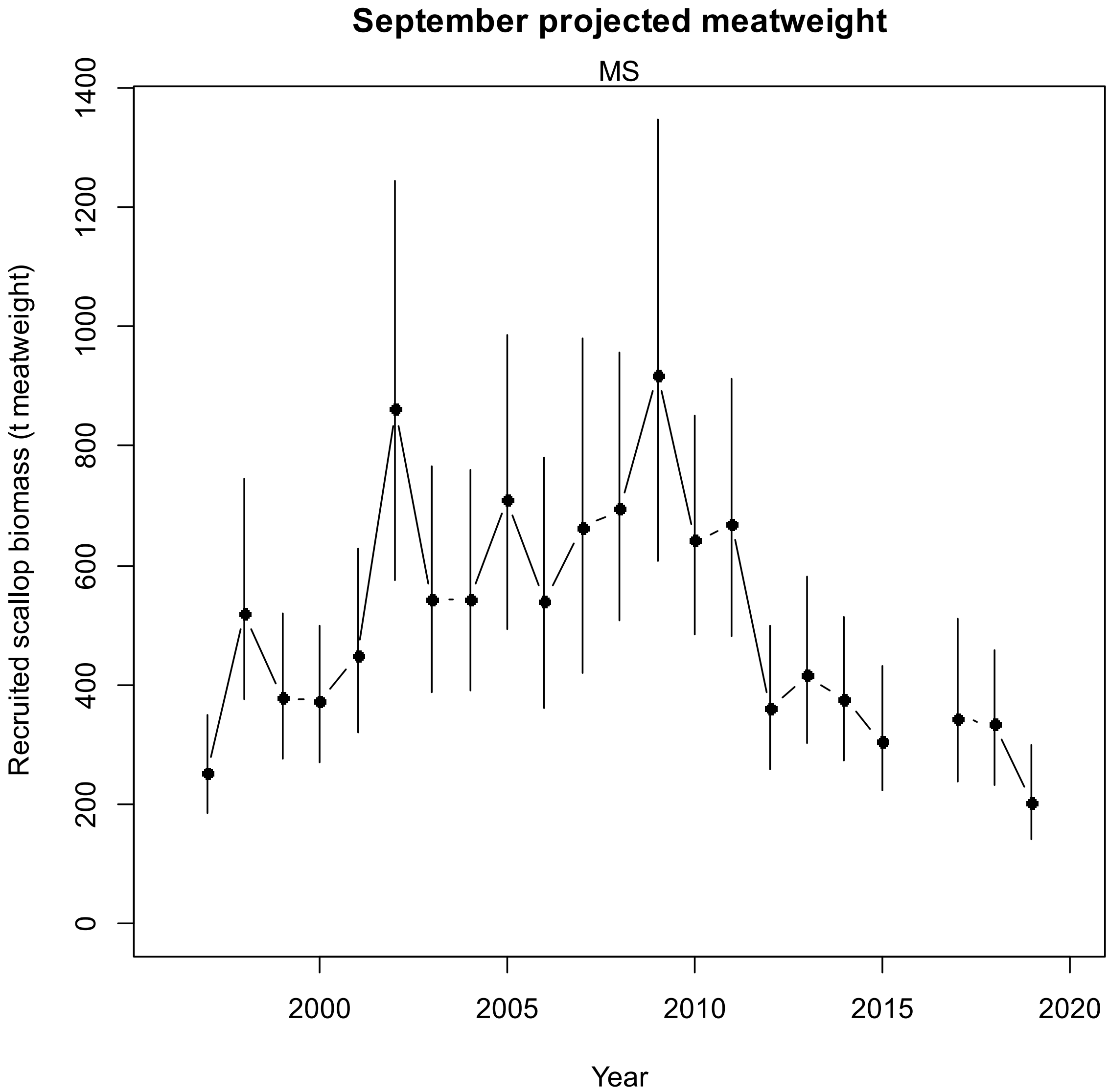

Figure 15: Trends in September projected biomass (t meat weight) of recruited scallops (90 mm or larger) for the Marlborough Sounds substock, 1997–2019. Values are the median and 95% confidence intervals of the estimated projected biomass. There was no survey in 2016.

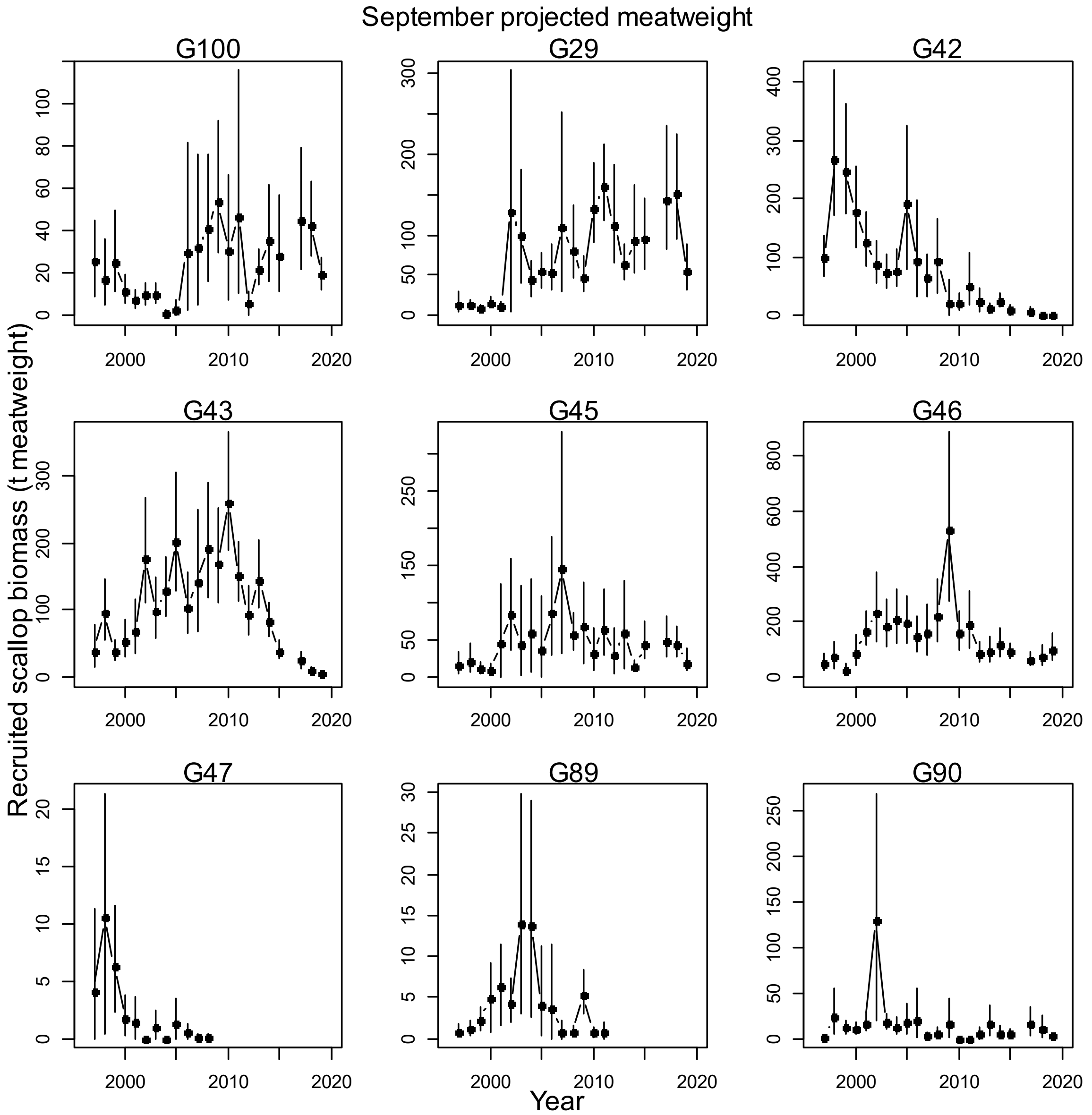

Figure 16: Trends in September projected biomass (t meat weight) of recruited scallops (90 mm or larger) by biotoxin area in Marlborough Sounds, 1997–2019. Values are the estimated median and 95% confidence intervals. There was no survey in 2016.

The population projection predicted a transition of the mode of recruit-sized scallops (modal length of about 78 mm) in May 2019 into the recruited size by September 2019 (modal length of about 88 mm) (illustrated by the modal shift to the right in Figure 17) which largely accounts for the increase in predicted biomass in September 2019 (Figure 14).

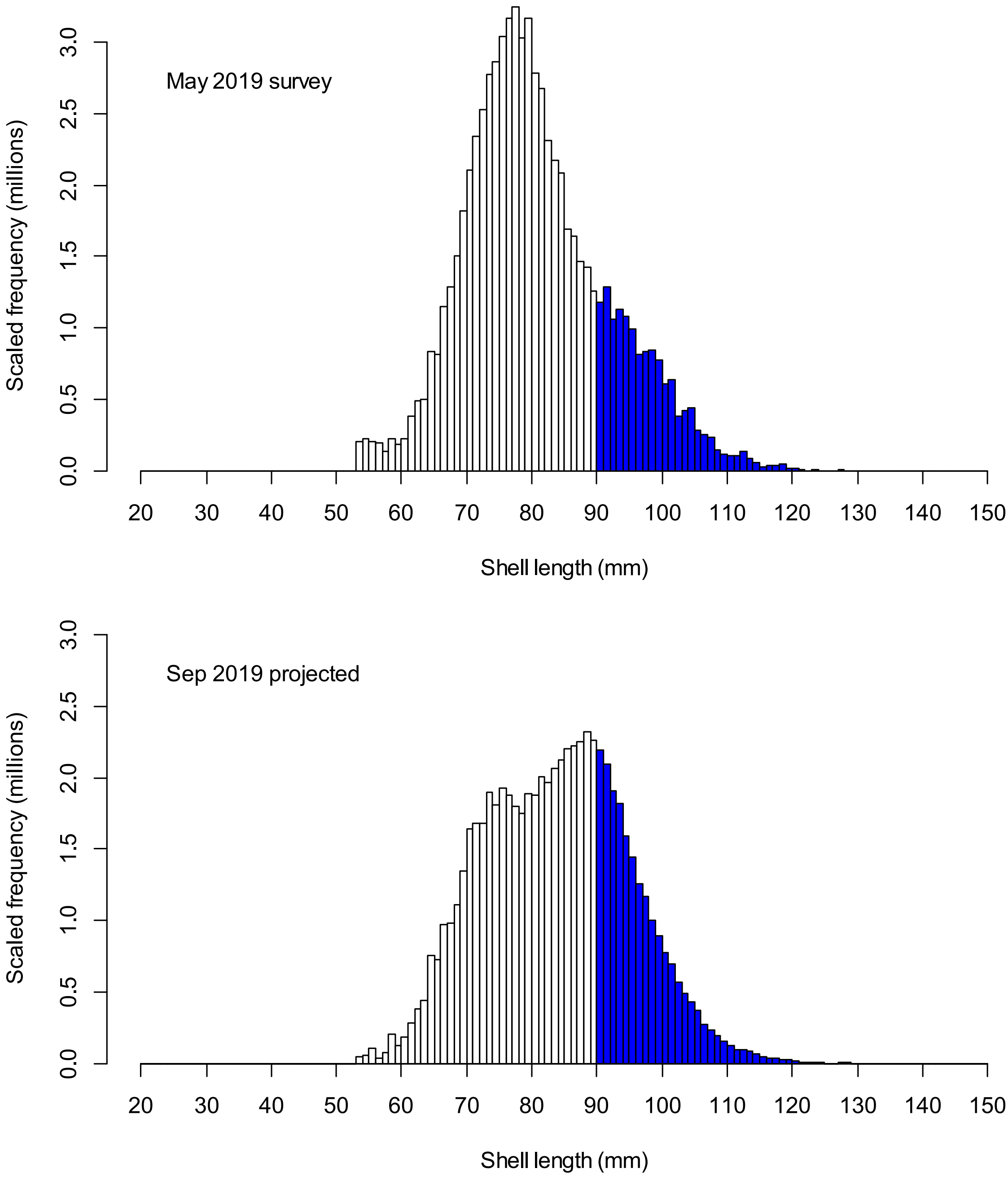

Figure 17: Length frequency distributions for scallops in the Marlborough Sounds substock in 2019, in May at the time of the survey (top) compared with the September projected distribution (bottom). Data corrected for dredge efficiency (Tuck et al. 2018). Dark shaded bars show recruited scallops (90 mm shell length or larger).

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. high larval production) and for fisheries utilisation (i.e. high catch rates). It is possibly more useful for management purposes to focus on biomass trends in the higher density areas.

Estimates of biomass are sensitive to the exclusion of areas of low scallop density, and in the past, it was generally assumed that 0.04 m^{-2} (one recruited scallop for each 25 m^{-2} of seabed) was a reasonable working definition for the lowest limit of economic fishing. Correcting for historical average dredge efficiency which was estimated to have a central tendency of about 56% (Tuck & Brown 2008), a recruited scallop density of 0.04 m^{-2} on the seabed equated to a catch of about 40 scallops per standard 0.4 n.mile survey tow using a single dredge.

However, new research on dredge efficiency (Tuck et al. 2018) estimated that the efficiency of the SCA 7 ring-bag dredge is only about 20%, substantially lower than previously estimated (56%). Assuming a dredge efficiency of 20%, a recruited scallop density of 0.04 m^{-2} on the seabed equates to a (very low) catch of only about 14 scallops per standard 0.4 n.mile survey tow using a single dredge; a recruited scallop density of 0.2 m^{-2} on the seabed equates to a catch of about 71 scallops per standard 0.4 n.mile survey tow (Table 5).

Table 5: 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 or 0.20

Density (scallops.m^{-2})	Survey catch rate (scallops.tow) Assuming 0.56 efficiency	Survey catch rate (scallops.tow) Assuming 0.20 efficiency
0.01	10	4
0.04	40	14
0.08	80	28
0.10	100	36
0.12	119	43
0.16	159	57
0.20	199	71

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}. Further assessments should consider using critical densities higher than 0.2, given the new information on SCA 7 ring-bag efficiency.

Estimates of September 2019 projected biomass gradually decreased with increasing critical threshold density (Appendix G: Figure 18 and Table 10). Of the Marlborough Sounds absolute projected biomass (203 t), 84% (171 t) was held in areas with a critical density of 0.04 m^{-2} or higher; with increasing critical density, the available biomass reduced: 115 t (57%) was held in areas with a critical density of 0.2 m^{-2} or higher. These are median point estimates, which have increasingly large uncertainty as the critical density threshold increases (Appendix G: Table 10).

Of the Marlborough Sounds recruited biomass available at the 0.2 m^{-2} density level, 99% was held within five locations (Appendix G: Table 10): Guards Bay, Ship Cove, the Chetwodes, Wynens Bank, and Dieffenbach Point.

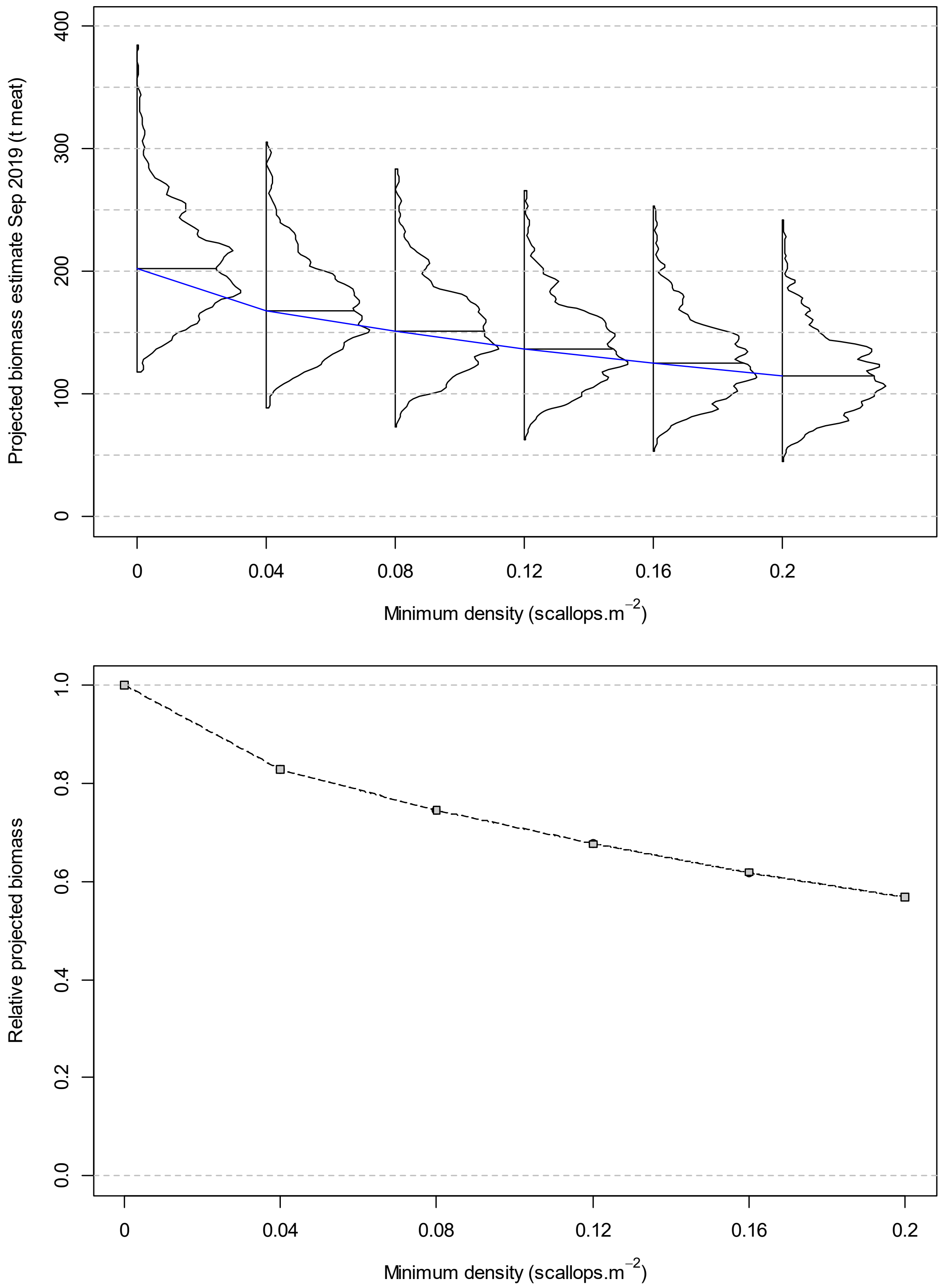

Figure 18: Effect of excluding areas of low scallop density on September projected estimates of recruited biomass, Marlborough Sounds, 2019. Critical density corrections were applied after correcting for dredge efficiency (Tuck et al. 2018). Top plot: for each minimum ('critical') density, the distribution and median (horizontal line) of the recruited biomass estimates are shown. Bottom plot: Trend in the proportion of the total recruited biomass with increasing critical density.

3.9 Biomass sensitivity to dredge efficiency

Examination of the dredge efficiency model (Tuck et al. 2018) fitted to individual strata (Figure 19) suggested there were two groups: 1) higher efficiency (strata 21 and 29); 2) lower efficiency (strata 30, 321, 37a, 38 and 41). Fitting the model to the combined data in each group produced two different selectivity curves (Figure 20; i.e. two sets of dredge efficiency parameters, Table 6).

To assess the sensitivity of the estimated biomass to the dredge efficiency applied, the population estimation procedure was rerun, applying the 'higher efficiency' curve to strata 21 and 29, and the lower efficiency curve to the remaining strata.

Using this approach, the overall projected absolute recruited biomass in September 2019 was 227 t meatweight, which was similar to the 203 t biomass estimated using the base run (see Section 3.7).

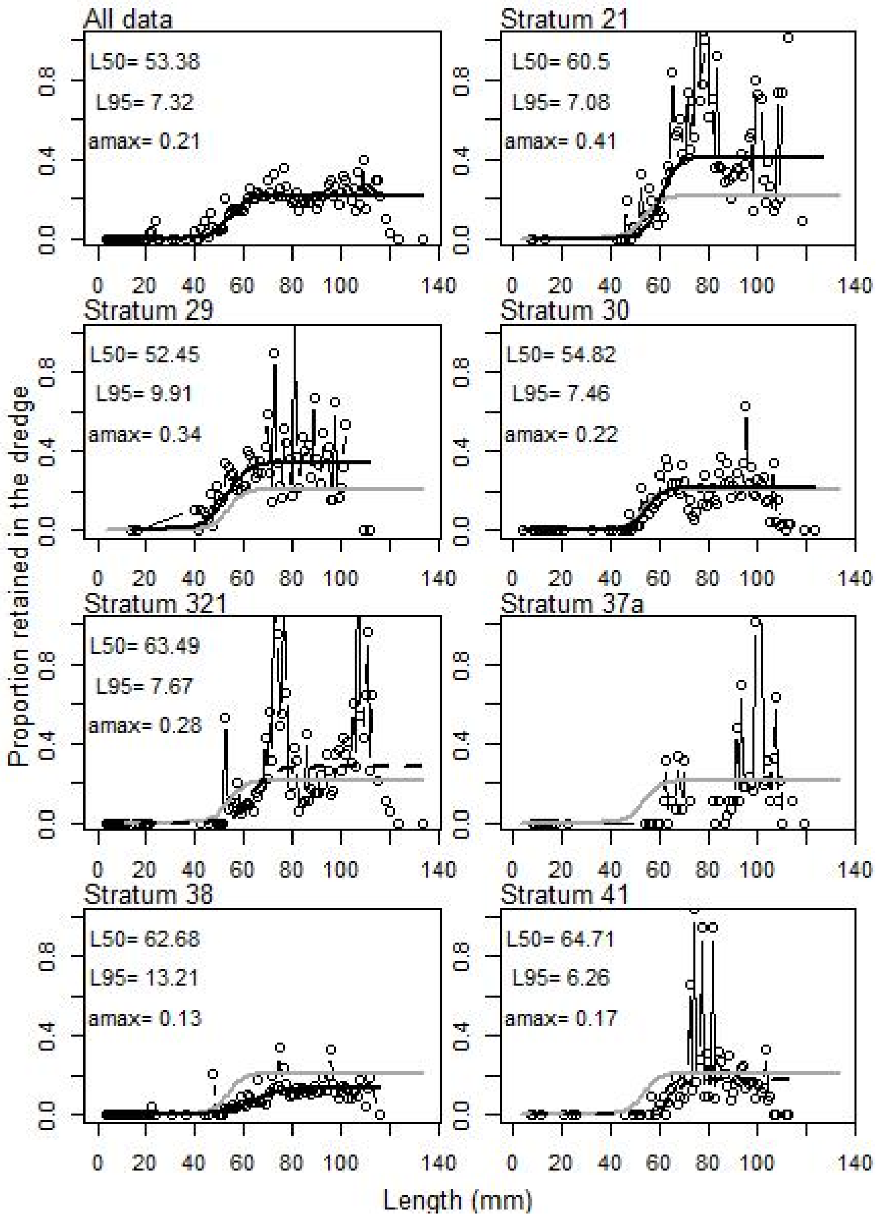

Figure 19: Logistic selectivity curves fitted to the overall dataset and individual stratum data. Parameters provided in each plot for "best" model, although those plotted in dash line had not converged.

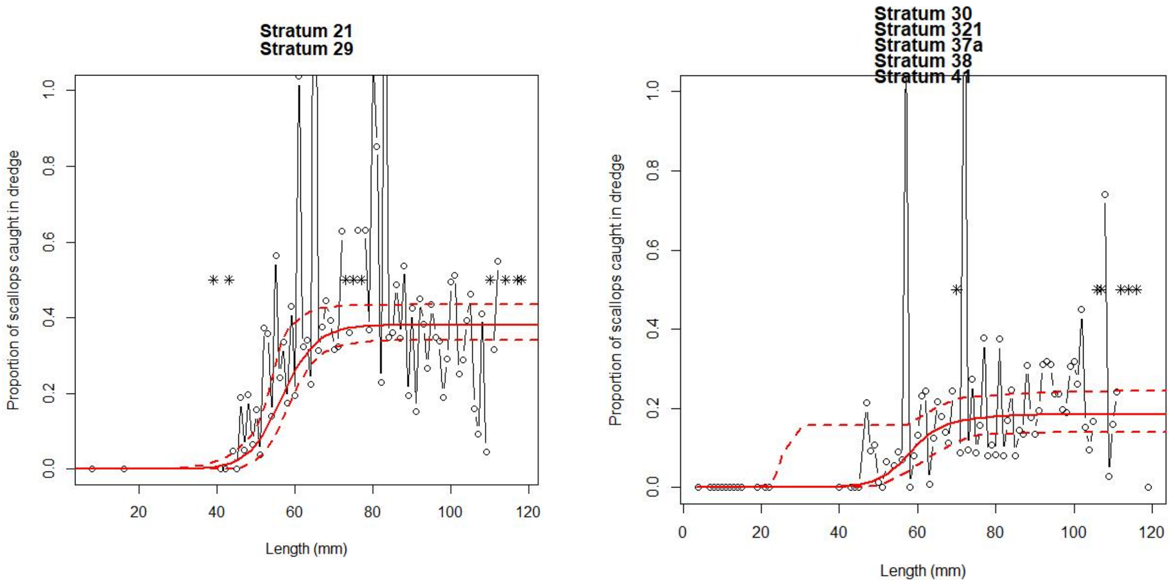

Figure 20: Logistic selectivity curves fitted to data from two groupings: 1) higher efficiency (left) and 2) lower efficiency (right).

Table 6: Dredge efficiency parameter estimates for the model fitted to two data groupings: 1) higher efficiency and 2) lower efficiency.

		Percentile estimates		
Grouping	Parameter	2.50%	50%	97.50%
Higher efficiency	L_{50}	52.89	56.56	59.54
(using combined data from	L_{95}	4.81	9.48	12.5
strata 21 and 29)	a_{max}	0.34	0.38	0.43
Lower efficiency	L_{50}	26.22	58.23	67.57
(using combined data from	L_{95}	3.29	9.21	22.76
strata 30, 321, 37a, 38 and 41)	a_{max}	0.14	0.19	0.24

3.10 Live scallop and dead clucker shell length frequency distributions

In addition to live scallops, dead clucker shells have been quantified on the SCA 7 survey since May 2015. For the May 2015, January 2017, January 2018 and May 2019 surveys, length frequency distributions (uncorrected for dredge efficiency) were constructed for live scallops and dead cluckers (note that in May 2019 the dead cluckers had been further categorised into either cluckers with clean shells presumably recently dead or cluckers with fouled presumably older shells). In May 2019, the length structure of clean cluckers closely matched that of live scallops, whereas the length structure of fouled cluckers was made up of slightly larger shells (Figure 21). Live scallop and clucker shell distributions for all years 2015–2019, by overall substock and by biotoxin area, are shown as line plots in Appendix H (Figure 30 to Figure 33).

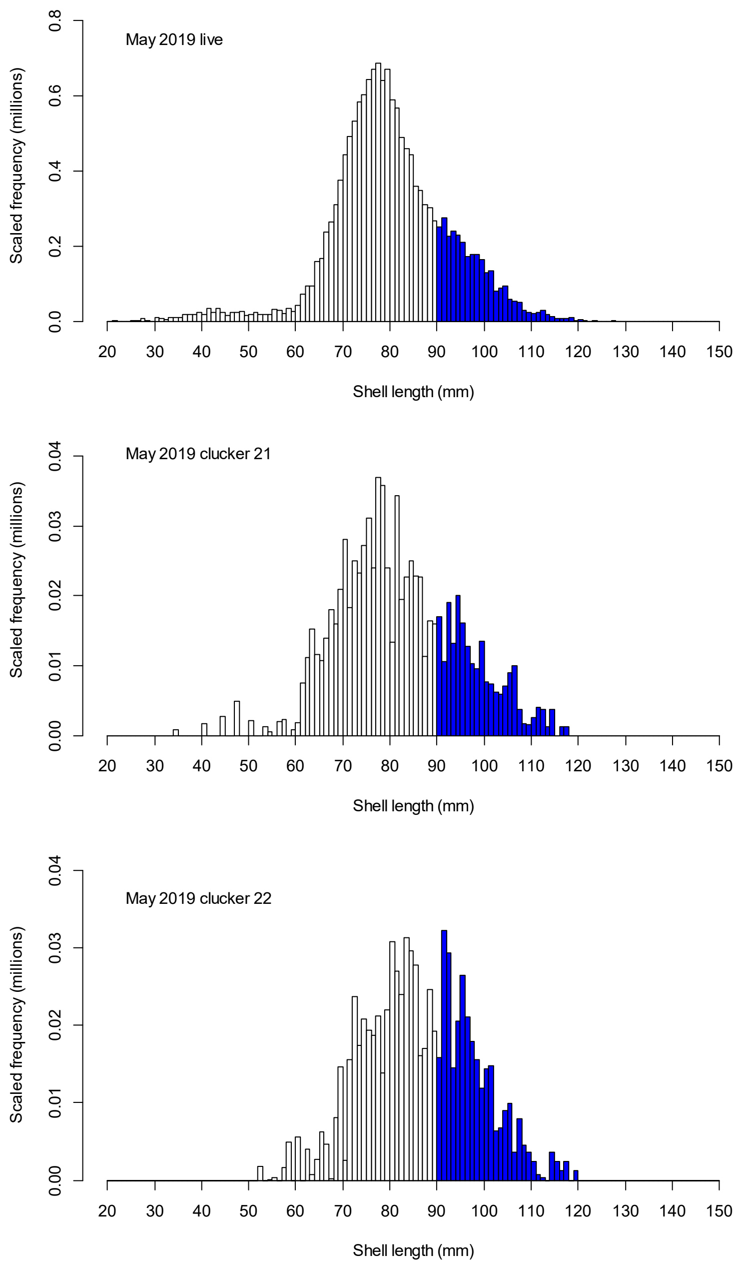

Figure 21: Length frequency distributions for live scallops (top) and clucker shells (middle, clean shells; bottom, fouled shells) in the Marlborough Sounds at the time of the survey, May 2019. Data uncorrected for dredge efficiency. Dark shaded bars show scallops shells of recruited size (90 mm shell length or larger).

3.11 Abundance indices for pre-recruit and recruited scallops

From the revised SCA 7 survey series analysis conducted in the present study, abundance indices were generated for pre-recruits (undersize scallops 53–89 mm in length) and recruited scallops (90 mm or larger). These are presented by substock for Marlborough Sounds (Figure 22), Golden Bay (Figure 23), and Tasman Bay (Figure 24), and also by biotoxin area for Marlborough Sounds (Figure 25). Strong patterns of recruitment are evident in some areas, illustrated by peaks in recruited numbers lagging one year after peaks in pre-recruit scallop numbers. In Marlborough Sounds, recruitment (as measured by the abundance of pre-recruits) has been low (or following a declining trend in some areas) in recent years.

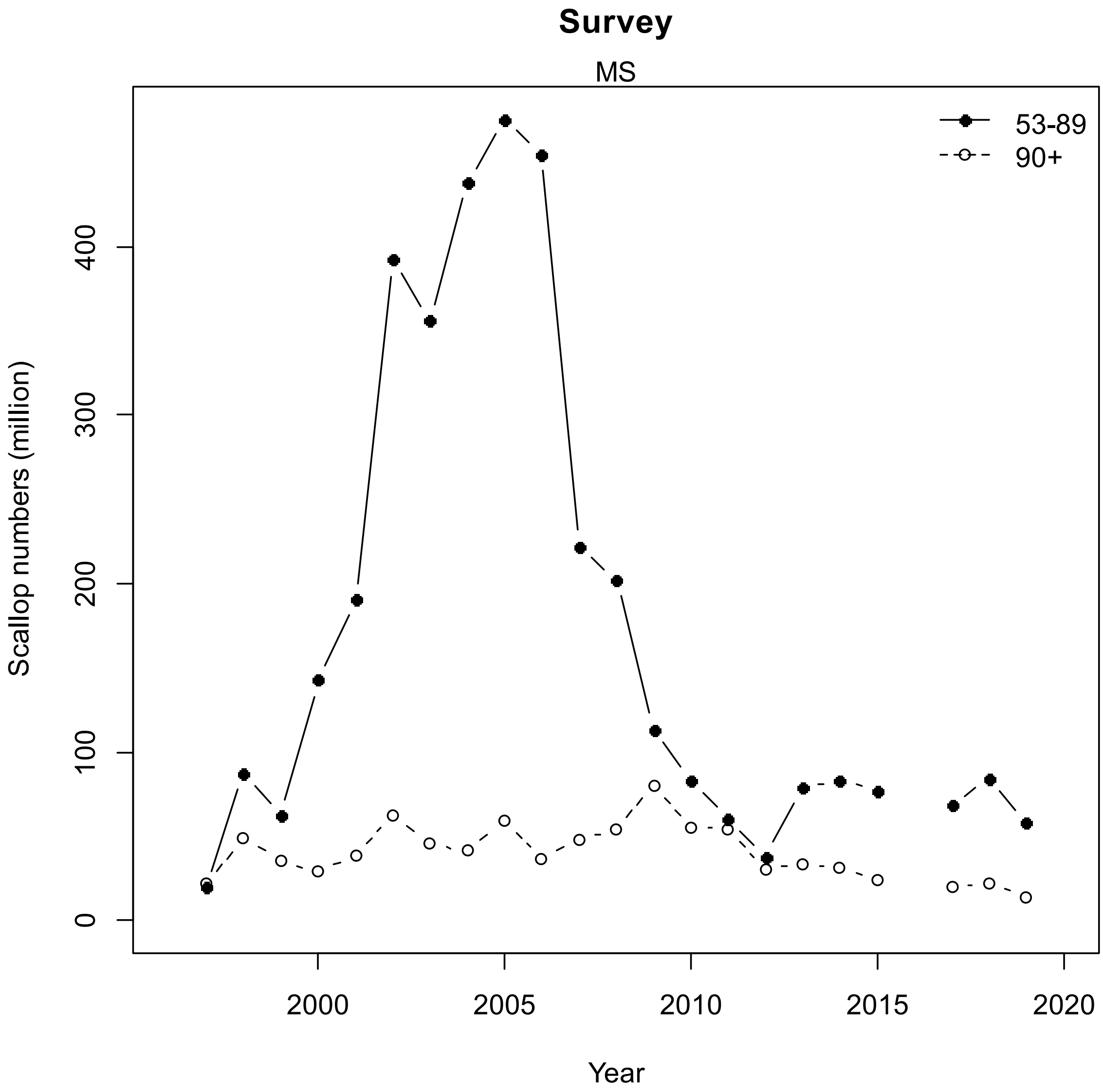

Figure 22: Time of survey abundance indices for pre-recruits (53– 89 mm) and recruited scallops (90 mm or larger) in Marlborough Sounds, 1997 to 2019. There was no survey in 2016. Values are median estimates of abundance (scallop numbers), corrected for dredge efficiency (Tuck et al. 2018).

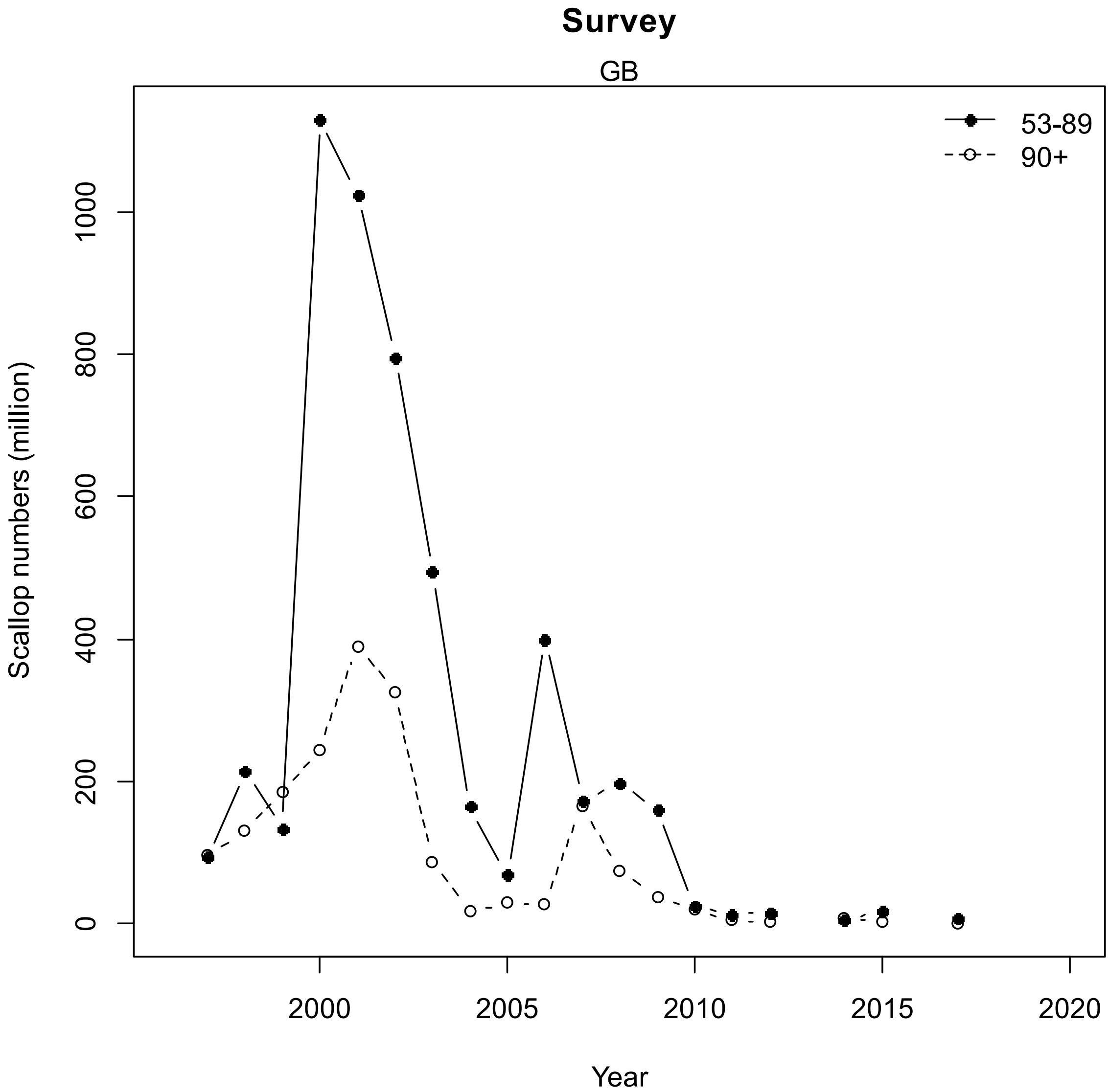

Figure 23: Time of survey abundance indices for pre-recruits (53– 89 mm) and recruited scallops (90 mm or larger) in Golden Bay, 1997 to 2019. Golden Bay was not surveyed in 2013, 2016, 2018 or 2019. Values are median estimates of abundance (scallop numbers), corrected for dredge efficiency (Tuck et al. 2018).

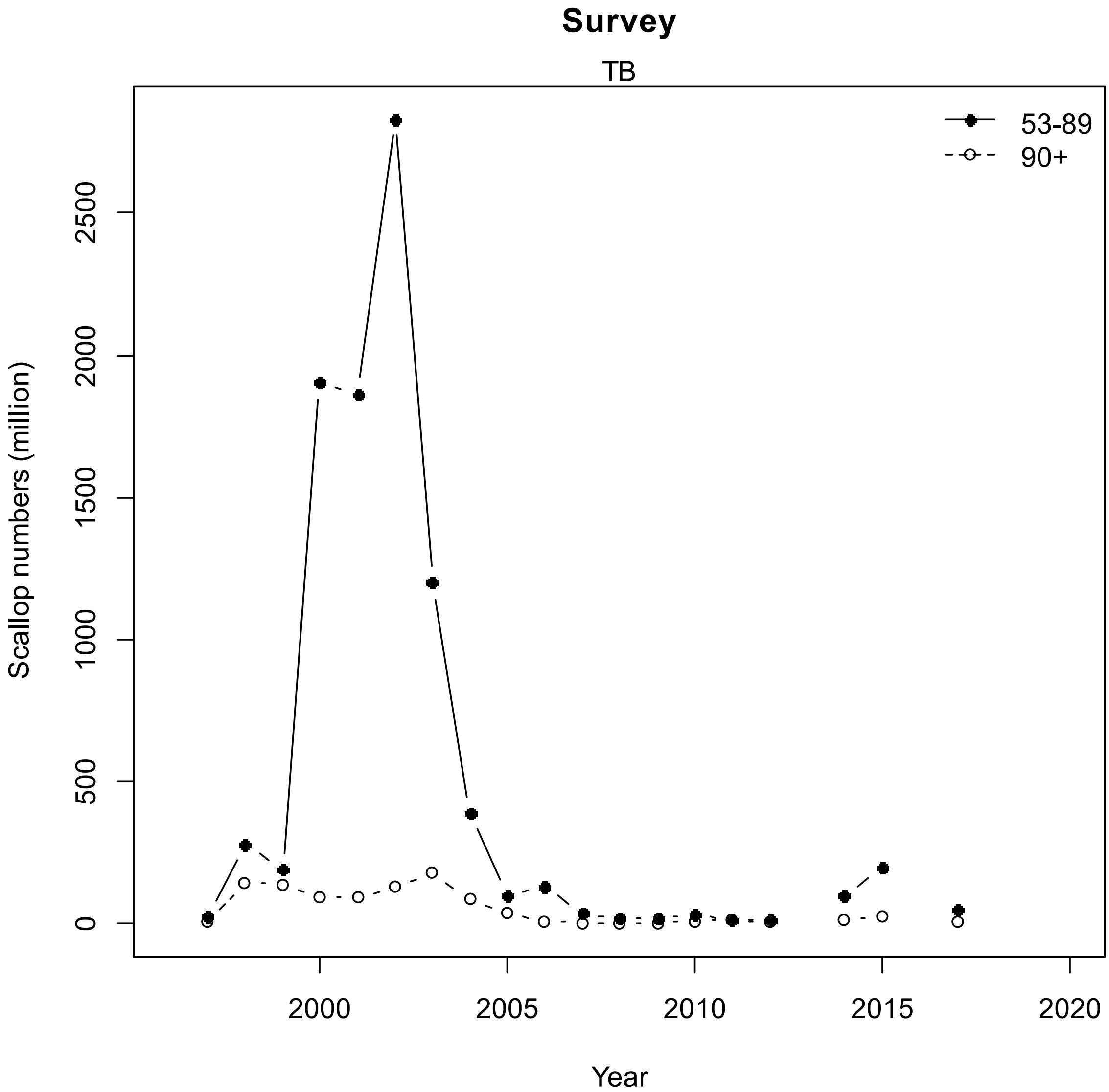

Figure 24: Time of survey abundance indices for pre-recruits (53– 89 mm) and recruited scallops (90 mm or larger) in Tasman Bay, 1997 to 2019. Tasman Bay was not surveyed in 2013, 2016, 2018 or 2019. Values are median estimates of abundance (scallop numbers), corrected for dredge efficiency (Tuck et al. 2018).

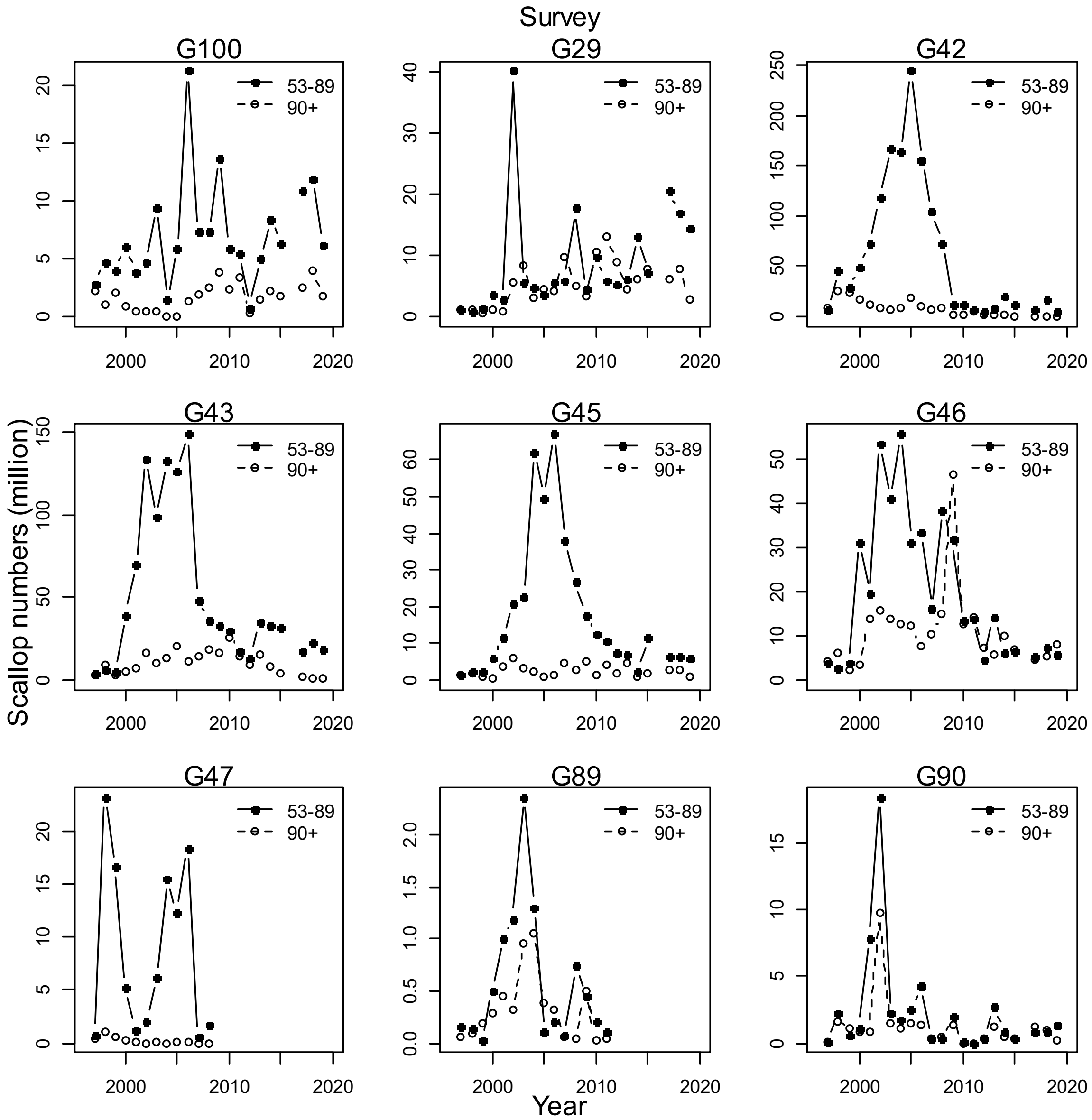

Figure 25: Time of survey abundance indices for pre-recruits (53– 89 mm) and recruited scallops (90 mm or larger) by biotoxin area in Marlborough Sounds, 1997 to 2019. Values are median estimates of abundance (scallop numbers), corrected for dredge efficiency (Tuck et al. 2018).

4. DISCUSSION

The May 2019 survey analysis provides the most recent information to assess the status of the Marlborough Sounds scallop population. Significant outputs from the analysis are the re-analysed 1997–2019 time series for survey (May) biomass and start-of-season (September-projected) biomass in the Marlborough Sounds using the new dredge efficiency curve (Tuck et al. 2018) and growth projections using an inverse logistic model (Tuck & Williams 2012).

The key finding is that the Marlborough Sounds recruited biomass estimate for 2019 within the area surveyed is the lowest on record. Although the spatial extent of surveys has varied over time, which complicates interpretation of temporal trends, the overall decline observed between 2018 and 2019 is also evident in most fine-scale (biotoxin) areas. Virtually all the 2019 recruited biomass at potentially fishable densities is held in five scallop beds: Guards Bay, Ship Cove, the Chetwodes, Wynens Bank, and Dieffenbach Point.

The estimated abundance of small 'pre-recruit' scallops (53–89 mm) in 2019 is low compared with historical estimates, especially from the early 2000s, suggesting that recruitment in the short term is likely to be relatively poor. It is hypothesised that the observed low recruitment is a consequence of low habitat suitability rather than larval supply.

During the analysis conducted in the present study, it became apparent that the small increase in biomass previously observed between 2017 and 2018 (Williams et al. 2018) was actually an artefact; the revised analysis suggests there was little change in biomass between 2017 and 2018 (and the biomass has declined since). The artefact resulted from an error detected in the analytical code used in the 2018 analysis: the 2018 survey required the use of two dredges at selected stations as part of the dredge efficiency study, but estimation of biomass should use only the data from one dredge; unfortunately the code did not distinguish between the two dredges used, thus included data from both dredges, resulting in the overestimation of biomass. The revised time series produced in the present study has corrected this error.

The present study used a different dredge efficiency correction and a different growth projection model compared with previous analyses, both of which have affected the biomass estimates and their 95% confidence limits, but they have not affected the biomass trends observed. It is important to note that the calculated uncertainties associated with the biomass estimates (illustrated by the error bars in the time series plots) cannot capture all uncertainties. For instance, there is uncertainty in whether (how) dredge efficiency varies among tows (e.g. in relation to depth and substrate type), uncertainty over how much mortality has actually occurred each year between the time of the survey and the nominal start of the fishing season, and whether the growth model derived using mostly North Island data (Tuck & Williams 2012) is accurate for the Marlborough Sounds (and to each particular year).

Although the temporal issue of the different (i.e. January) survey timing in the 2017 and 2018 surveys was addressed in the present study through population projections, spatial issues with the time series are more difficult to address. The spatial extent of the 2019 survey was the same as that surveyed in 2018, so direct comparison of the 2019 estimates with those from the January 2018, January 2017, and May 2015 surveys was possible. However, comparisons across earlier years are confounded somewhat by changes to survey coverage (e.g. surveys before 2009 covered a far greater spatial extent). To address these spatial differences requires further reanalysis of the SCA 7 survey series data, work that was not feasible within the present study. Ideally such an analysis would generate a new set of 'time of survey' and 'start of season' population estimates from the same spatial extent, and thus allow examination of population trends in different geographical areas within Marlborough Sounds, particularly in relation to fishery harvests (exploitation rates) and environmental conditions.

It is recommended that the design of the survey be reviewed before the next survey is conducted in 2020. Excluding low catch-rate strata and refocussing the survey to cover the 'core areas' which contain the main scallop beds has been recommended previously (Smith et al. 2016, Williams et al. 2017), noting that surveys using the larger historical extent could be conducted periodically to inform whether there has been any recovery in areas that lie outside the core areas. In addition to a review of the dredge survey coverage and stratification, additional survey sampling using divers and the development of camera-based survey methods could provide new insights into the status of the overall scallop population and associated habitats, while minimising benthic disturbance. This would be especially important in providing information on the status of non-commercial scallop beds that cannot be surveyed using dredges, which lie outside of the traditionally dredge-surveyed areas.

5. ACKNOWLEDGEMENTS

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7. APPENDIX A: Historical scallop density by stratum

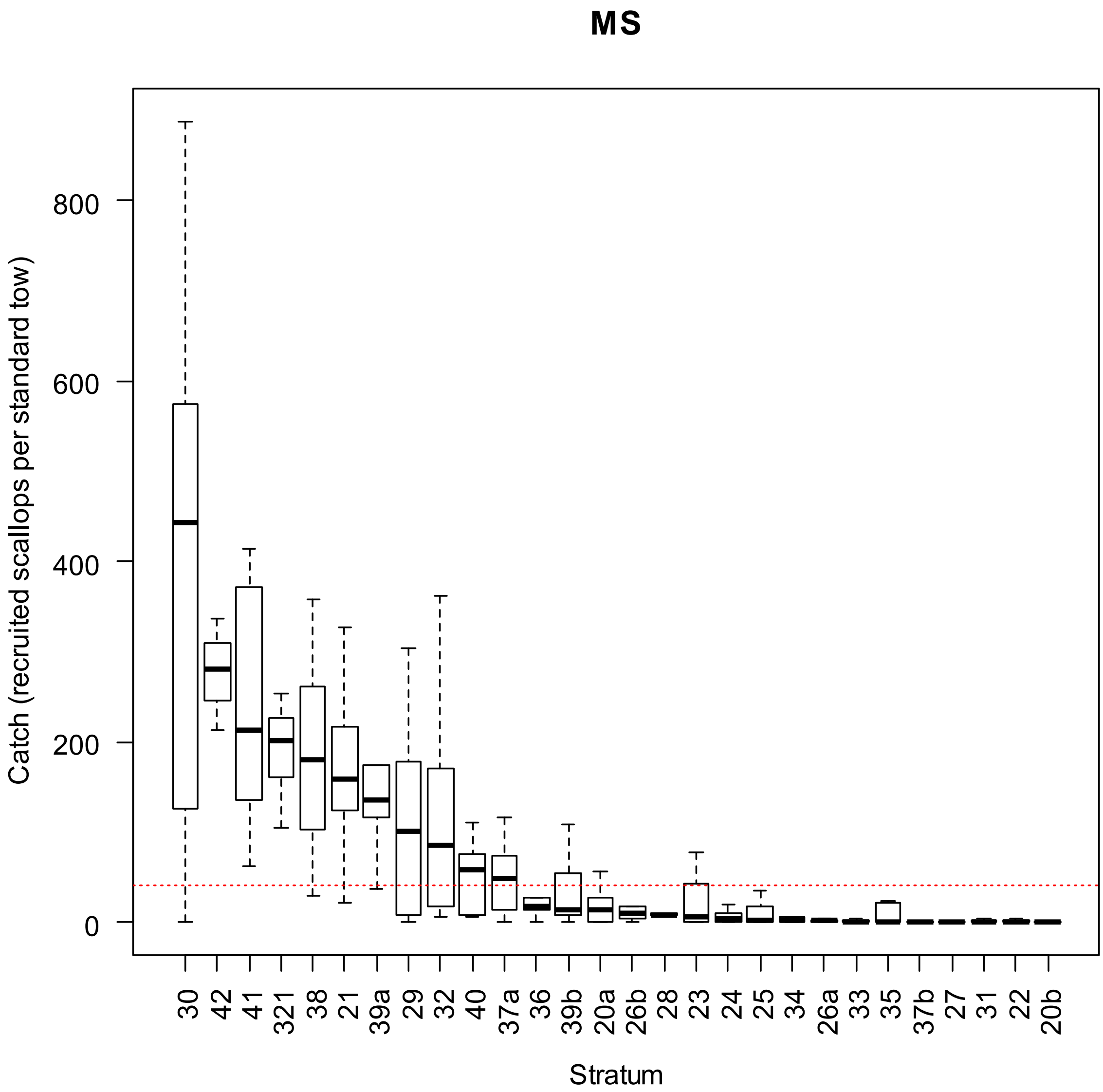

Figure 26: Boxplot of historical scallop density (recruited scallops per standard 0.4 n.mile tow, 2017–18 surveys) by stratum (2019 stratification) in decreasing order of median density (x-axis left to right). Outliers have been excluded. Horizontal dashed line denotes a median density of 40 recruited scallops per standard tow.

8. APPENDIX B: SCA 7 surveys

Early surveys in SCA 7 conducted between 1959 and 1993, and the annual surveys conducted by industry since 1994, were summarised in a review of the Southern Scallop fishery in 2014 (Williams et al. 2014b). 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. 2015c) and post-season in November (Williams et al. 2015b). In 2016 no survey was conducted. The most recent SCA 7 stock-wide survey (Golden Bay, Tasman Bay, and Marlborough Sounds) was conducted in January 2017 (Williams et al. 2017). In January 2018, a survey of the Marlborough Sounds substock was conducted (Williams et al. 2018), together with additional research on dredge efficiency and fine scale analysis (Tuck et al. 2018). The present study documents the May 2019 survey of scallops in Marlborough Sounds. Details of the surveys conducted since 1994 are shown in Table 7.

Table 7: SCA 7 surveys since 1994. no survey in 2016. 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). The MAF 2.45 m wide ring-bag dredge was used on surveys from 1994–96, and the CSEC 2.4 m wide ring-bag dredge was used on surveys since 1997.

Year	Month	Trip code	Areas	Vessel (and Master, if known)	Reference
1994	6	HIN9401	GB; TB, MS	*Hinewai*	Drummond (1994)
1995	6	TAS9501	GB, TB, MS	*Tasman Challenger* (Paul Botica)	Vignaux et al. (1995)
1996	5–6	TAS9601	GB, TB, MS	*Tasman Challenger*	Cranfield et al. (1996)
1997	5–6	TAS9701	GB, TB, MS	*Tasman Challenger*	Cranfield et al. (1997)
1998	5–6	TAS9801	GB, TB, MS	*Tasman Challenger* (Paul Botica)	Osborne (1998)
1999	5–6	TAS9901	GB, TB, MS	*Tasman Challenger*	Breen & Kendrick (1999)
2000	5–6	TAS0001	GB, TB, MS	*Tasman Challenger*	Breen (2000)
2001	5	TAS0101	GB, TB, MS	*Tasman Challenger*	Horn (2001)
2002	5	TAS0201	GB, TB, MS	*Tasman Challenger* (Paul Botica)	Horn (2002)
2003	5–6	TAS0301	GB, TB, MS	*Tasman Challenger* (Paul Botica)	Horn (2003)
2004	5–6	TAS0401	GB, TB, MS	*Tasman Challenger* (Paul Botica)	Horn (2004)
2005	5–6	TAS0501	GB, TB, MS	*Tasman Challenger* (Paul Botica)	Horn (2005)
2006	5–6	TAS0601	GB, TB, MS	*Tasman Challenger* (Paul Botica)	Horn (2006)
2007	4–5	FAL0701	GB, TB, MS	*Falcon III*	Brown (2007)
2008	5	CAL0801	GB, TB, MS	*Calypso* (Phillip Trewavas)	Tuck & Brown (2008)
2009	5	OKA0901	GB, TB, MS	*Okarito* (Grant Roberts)	Williams (2009)
2010	5–6	OKA1001	GB, TB, MS	*Okarito* (Grant Roberts)	Williams et al. (2010)
2011	5	OKA1101	GB, TB, MS	*Okarito* (Cris West)	Williams & Michael (2011)
2012	5–6	OKA1201	GB, TB, MS	*Okarito* (Cris West)	Williams & Bian (2012)
2013	5	OKA1301	MS	*Okarito* (Cris West)	Williams et al. (2013a)
	10	OKA1302	MS (Ketu)	*Okarito* (Cris West)	Tuck (2013)
2014	5	OKA1401	GB, TB, MS	*Okarito* (Cris West)	Williams et al. (2014a)
	9	OKA1402	MS (Guards)	*Okarito* (Cris West)	Williams (2014)
2015	5	OKA1501	GB, TB, MS	*Okarito* & *Rongatea II* (Cris West)	Williams et al. (2015a)
	10	OKA1502	MS (3 areas)	*Okarito* (Cris West)	Williams et al. (2015c)
	10–11	OKA1503	GB, TB, MS	*Okarito* (Cris West)	Williams et al. (2015b)
2016	–	–	–	–	–
2017	1	RON1701	GB, TB, MS	*Rongatea II* (Cris West)	Williams et al. (2017)
2018	1	RON1801	MS	*Rongatea II* (Cris West)	Williams et al. (2018)
2019	5	OKA1901	MS	*Okarito* (Cris West)	Present study

9. APPENDIX C: Survey population estimates, May 2019

Table 8: Population estimates of scallops in Marlborough Sounds, May 2019 at different spatial scales: location, statistical reporting area (stat area), substock total. These estimates were produced for recruited scallops (90 mm or larger), correcting for dredge efficiency (Tuck et al. 2018), and predicting green weight from length. The analysis used a non-parametric resampling with replacement approach to estimation (1000 bootstraps). Location estimates are shown in decreasing order of mean density (scallops.m^{-2}).

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Grouping	Name/code	Area(km^2)	n	Density(scallops m^{-2})					Abundance(millions)					Scallop weight(g)		Biomass(t green)				
				mean	CV	median	95%CI		mean	CV	median	95%CI		mean	median	mean	CV	median	95%CI	
Location	Wynens Bank	2	8	0.340	0.28	0.332	0.181	0.539	0.780	0.28	0.759	0.414	1.236	78.6	78.8	61	0.28	60	32	97
	Guards Bay	24	20	0.332	0.23	0.327	0.208	0.499	8.073	0.23	7.949	5.059	12.122	85.9	86.2	694	0.23	685	431	1049
	Dieffenbach Point	3	14	0.314	0.27	0.310	0.155	0.493	0.916	0.27	0.906	0.452	1.440	79.7	79.7	73	0.28	72	35	117
	Chetwodes	6	8	0.310	0.19	0.306	0.201	0.429	1.707	0.19	1.687	1.109	2.364	82.7	82.7	141	0.19	140	92	196
	Horseshoe Bay	1	3	0.117	0.64	0.111	0.000	0.271	0.121	0.64	0.115	0.000	0.281	72.6	72.6	9	0.64	8	0	20
	Ship Cove	21	18	0.080	0.27	0.078	0.044	0.127	1.648	0.27	1.618	0.906	2.617	76.3	76.4	126	0.27	124	70	199
	BayofManyCoves	4	6	0.062	0.27	0.060	0.034	0.099	0.273	0.27	0.264	0.150	0.438	74.1	74.2	20	0.28	20	11	33
	Ketu Bay	2	6	0.038	0.54	0.036	0.007	0.088	0.091	0.54	0.084	0.017	0.208	74.7	75.0	7	0.54	6	1	16
	Waitata	5	6	0.031	0.17	0.030	0.022	0.042	0.151	0.17	0.148	0.106	0.206	73.5	73.6	11	0.18	11	8	15
	Richmond Bay	4	3	0.018	0.21	0.018	0.011	0.026	0.066	0.21	0.066	0.040	0.093	73.7	73.6	5	0.22	5	3	7
	Waitata Reach	14	3	0.008	0.84	0.008	0.000	0.023	0.121	0.84	0.118	0.000	0.330	70.9	71.1	9	0.84	8	0	23
	Clara Island	3	3	0.005	0.81	0.005	0.000	0.015	0.014	0.81	0.014	0.000	0.039	66.6	66.6	1	0.81	1	0	3
	AdmiralityPenguin	17	6	0.004	0.83	0.004	0.000	0.010	0.064	0.83	0.063	0.000	0.174	73.8	73.7	5	0.83	5	0	13
	WaituiPortGore	44	6	0.004	0.40	0.004	0.001	0.006	0.154	0.40	0.154	0.033	0.271	78.2	78.2	12	0.40	12	2	22
	Tawhitinui High	4	3	0.002	0.82	0.002	0.000	0.005	0.006	0.82	0.006	0.000	0.018	66.6	66.6	0	0.82	0	0	1
	Forsyth Bay Low	11	3	0.001	0.82	0.001	0.000	0.002	0.010	0.82	0.010	0.000	0.026	74.9	75.0	1	0.82	1	0	2
	Tawhitinui Low	22	3	0.000	NA	0.000	0.000	0.000	0.000	NA	0.000	0.000	0.000	NA	NA	0	NA	0	0	0
Stat area	7K	158	81	0.072	0.19	0.071	0.049	0.101	11.357	0.19	11.245	7.747	16.023	84.1	83.8	955	0.19	942	640	1350
	7L	28	38	0.102	0.20	0.100	0.067	0.147	2.837	0.20	2.801	1.862	4.110	77.2	77.3	219	0.20	217	143	317
Substock	MS	186	119	0.076	0.17	0.076	0.054	0.104	14.194	0.17	14.089	9.994	19.348	82.7	82.8	1174	0.17	1167	819	1620

Table 9: Time of survey population estimates of scallops in Marlborough Sounds in May 2019 (full survey extent) by stratum, statistical reporting area (stat area) and substock total. These estimates were produced for recruited scallops (90 mm or larger), correcting for dredge efficiency (Tuck et al. 2018), and predicting green weight from length. The analysis used a non-parametric resampling with replacement approach to estimation (1000 bootstraps).

CORRECTED FOR DREDGE EFFICIENCY

Grouping	Name/code	Area(km^2)	n	Density(scallops m^{-2})					Abundance(millions)					Scallop weight(g)		Biomass(t green)				
				mean	CV	median	95%CI		mean	CV	median	95%CI		mean	median	mean	CV	median	95%CI	
Stratum	20a	10	3	0.007	0.83	0.006	0.000	0.018	0.064	0.83	0.063	0.000	0.174	73.8	73.7	5	0.83	5	0	13
	20b	7	3	0.000	NA	0.000	0.000	0.000	0.000	NA	0.000	0.000	0.000	NA	NA	0	NA	0	0	0
	21	6	8	0.310	0.19	0.306	0.201	0.429	1.707	0.19	1.687	1.109	2.364	82.7	82.7	141	0.19	140	92	196
	22	3	3	0.008	0.26	0.007	0.005	0.012	0.026	0.26	0.026	0.016	0.041	69.0	68.7	2	0.26	2	1	3
	23	1	3	0.085	0.18	0.084	0.059	0.119	0.124	0.18	0.122	0.085	0.173	74.5	74.3	9	0.19	9	6	13
	24	3	3	0.005	0.81	0.005	0.000	0.015	0.014	0.81	0.014	0.000	0.039	66.6	66.6	1	0.81	1	0	3
	25	14	3	0.008	0.84	0.008	0.000	0.023	0.121	0.84	0.118	0.000	0.330	70.9	71.1	9	0.84	8	0	23
	26a	1	3	0.117	0.64	0.111	0.000	0.271	0.121	0.64	0.115	0.000	0.281	72.6	72.6	9	0.64	8	0	20
	26b	4	3	0.002	0.82	0.002	0.000	0.005	0.006	0.82	0.006	0.000	0.018	66.6	66.6	0	0.82	0	0	1
	27	22	3	0.000	NA	0.000	0.000	0.000	0.000	NA	0.000	0.000	0.000	NA	NA	0	NA	0	0	0
	28	4	3	0.018	0.21	0.018	0.011	0.026	0.066	0.21	0.066	0.040	0.093	73.7	73.6	5	0.22	5	3	7
	29	2	6	0.038	0.54	0.036	0.007	0.088	0.091	0.54	0.084	0.017	0.208	74.7	75.0	7	0.54	6	1	16
	30	2	8	0.340	0.28	0.332	0.181	0.539	0.780	0.28	0.759	0.414	1.236	78.6	78.8	61	0.28	60	32	97
	31	11	3	0.001	0.82	0.001	0.000	0.002	0.010	0.82	0.010	0.000	0.026	74.9	75.0	1	0.82	1	0	2
	32	6	8	0.227	0.61	0.218	0.052	0.554	1.341	0.61	1.289	0.307	3.270	80.6	80.8	108	0.62	104	25	265
	321	6	6	1.033	0.23	1.020	0.649	1.545	6.633	0.23	6.546	4.168	9.919	87.2	87.3	579	0.23	571	365	870
	33	11	3	0.006	0.68	0.006	0.000	0.015	0.068	0.68	0.068	0.000	0.160	68.9	69.0	5	0.69	5	0	11
	34	1	3	0.025	0.56	0.025	0.006	0.056	0.030	0.56	0.030	0.008	0.067	73.4	73.4	2	0.58	2	1	5
	35	38	3	0.001	0.84	0.001	0.000	0.003	0.034	0.84	0.033	0.000	0.100	66.6	66.7	2	0.84	2	0	7
	36	6	3	0.020	0.43	0.020	0.000	0.036	0.120	0.43	0.118	0.000	0.215	81.6	82.2	10	0.44	10	0	18
	37a	6	6	0.008	0.44	0.007	0.002	0.014	0.046	0.44	0.045	0.012	0.087	84.9	85.5	4	0.43	4	1	7
	37b	10	3	0.000	NA	0.000	0.000	0.000	0.000	NA	0.000	0.000	0.000	NA	NA	0	NA	0	0	0
	38	5	9	0.345	0.28	0.339	0.185	0.549	1.603	0.28	1.576	0.861	2.553	76.0	76.2	122	0.27	120	66	194
	39a	1	3	0.168	0.30	0.164	0.092	0.275	0.216	0.30	0.211	0.118	0.354	73.5	73.6	16	0.30	16	9	26
	39b	3	3	0.018	0.58	0.017	0.000	0.041	0.057	0.58	0.054	0.000	0.129	76.3	76.3	4	0.59	4	0	10
	40	1	3	0.017	0.53	0.016	0.000	0.035	0.019	0.53	0.018	0.000	0.040	82.0	81.2	2	0.54	1	0	3
	41	1	8	0.569	0.29	0.564	0.261	0.922	0.845	0.29	0.838	0.388	1.371	79.8	79.4	67	0.30	67	31	111
	42	0	3	0.172	0.34	0.170	0.086	0.303	0.051	0.34	0.051	0.026	0.090	77.6	77.4	4	0.35	4	2	7
Stat area	7K	158	81	0.072	0.19	0.071	0.049	0.101	11.357	0.19	11.245	7.747	16.023	84.1	83.8	955	0.19	942	640	1350
	7L	28	38	0.102	0.20	0.100	0.067	0.147	2.837	0.20	2.801	1.862	4.110	77.2	77.3	219	0.20	217	143	317
Substock	MS	186	119	0.076	0.17	0.076	0.054	0.104	14.194	0.17	14.089	9.994	19.348	82.7	82.8	1174	0.17	1167	819	1620

10. APPENDIX D: Comparison of 2018 and 2019 biomass

A randomisation test was conducted to determine whether the estimated biomass in 2019 was lower than that in 2018. In this test, the time of survey biomass in both years was estimated using a standard parametric analysis, without correcting for dredge efficiency. The May 2019 biomass divided by the January 2018 biomass generates the actual (observed) biomass ratio. This actual ratio was compared with a distribution of 1000 biomass ratios generated by a randomisation and bootstrapping procedure. In this procedure, the data from the 2019 and 2018 surveys were combined at the stratum level, before randomly selecting a new set of 2019 survey data from the combined set to equal the original sample size per stratum; the remaining stations per stratum were then assigned to the 2018 survey. This was conducted for each stratum, and the whole process repeated for 1000 iterations. Dividing the 2019 randomised biomass by the 2018 randomised biomass generates the randomised 2019/2018 biomass ratio. From the 1000 iterations results 1000 randomised biomass ratios; plotting these shows their distribution (Figure 27). The actual 2019/2018 biomass ratio falls within the lower 2.5% of the randomised 2019/2018 ratio distribution (Figure 27), showing that the 2019 biomass was significantly lower than in 2018.

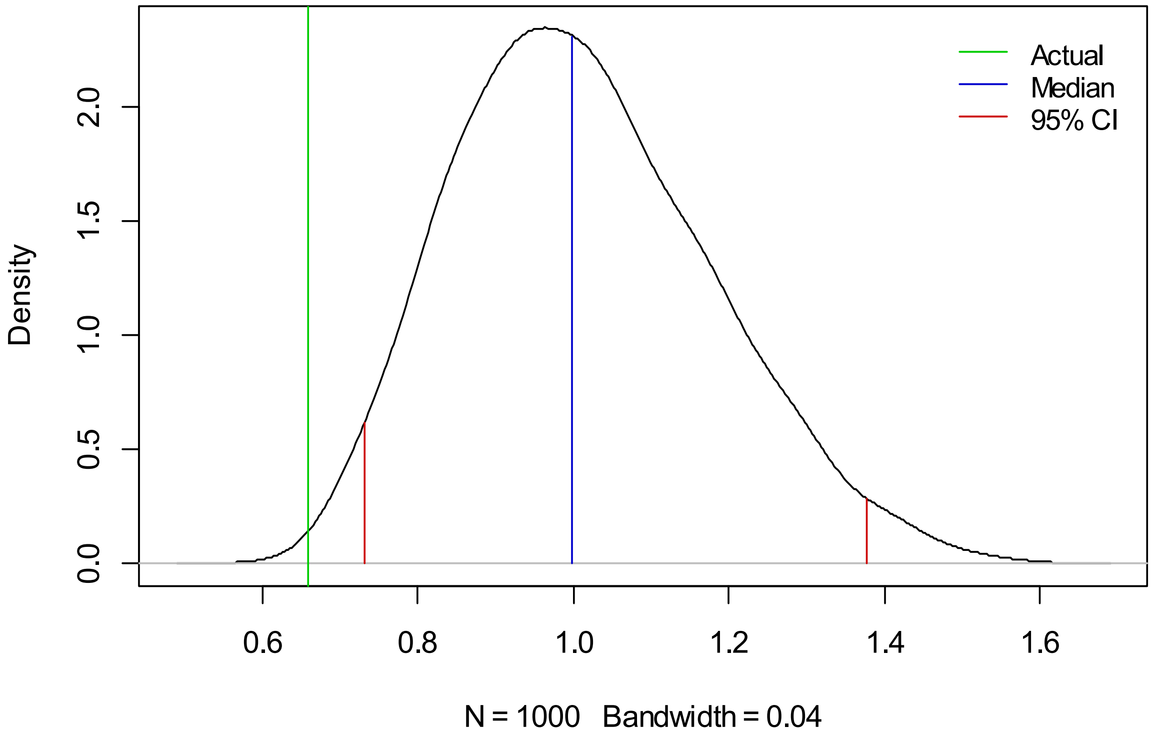

Figure 27: Distribution of biomass ratios generated from a randomisation and boostrapping procedure using the 2018 and 2019 survey data. The actual 2019/2018 biomass ratio is shown as a green vertical line on the left-hand side of the plot.

11. APPENDIX E: Survey biomass series by substock and total SCA 7 stock

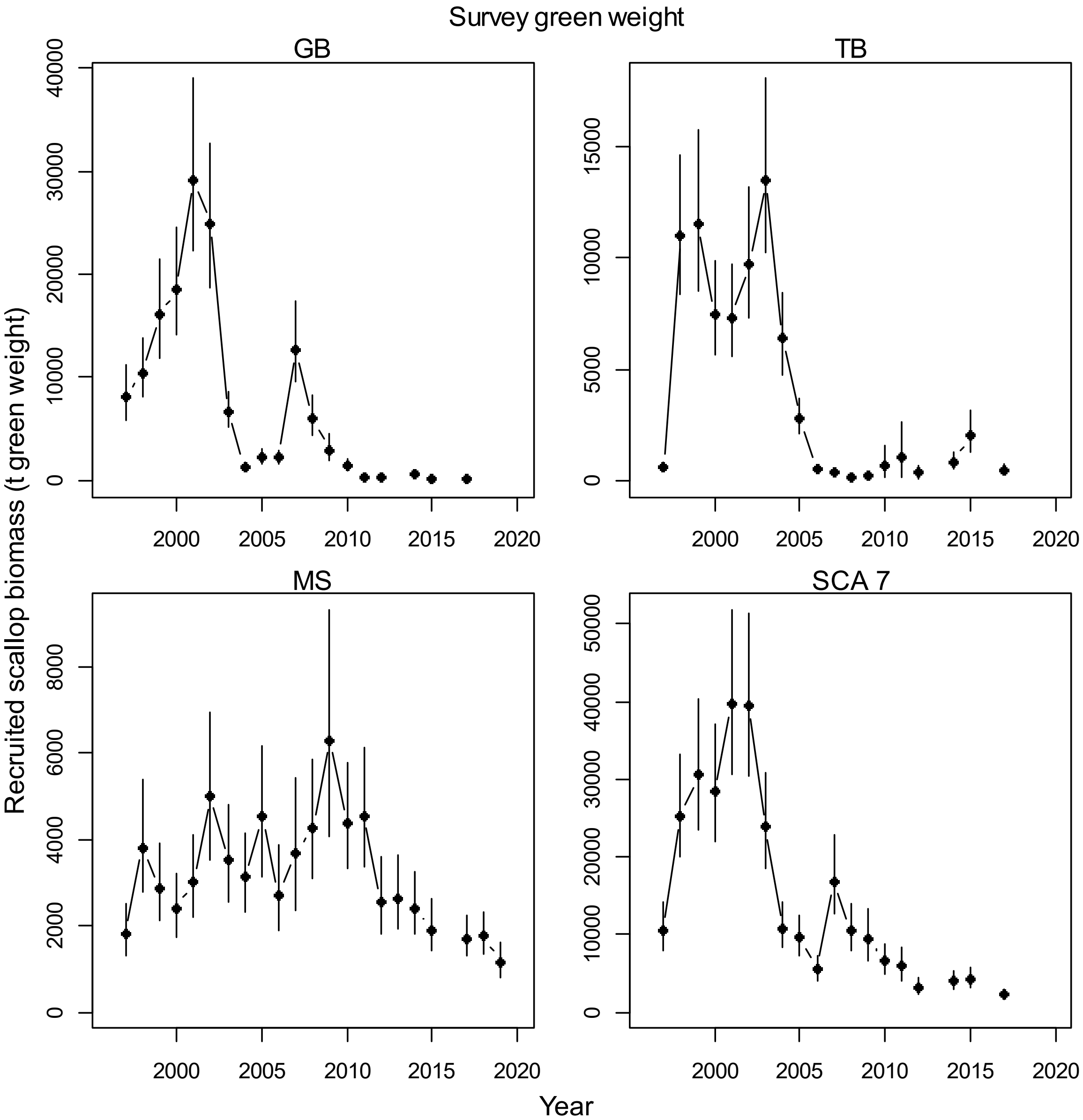

Figure 28: Trends in <u>time of survey</u> (nominally May, but January in 2017 and 2018) biomass (t <u>green weight</u>) of recruited scallops (90 mm or larger) by substock and for the total SCA 7 stock, 1997–2019. Values are the estimated median and 95% confidence intervals. There was no survey in 2016, and Golden and Tasman Bays were not surveyed in 2013, 2016, 2018 or 2019.

12. APPENDIX F: Projected biomass series by substock and total SCA 7 stock

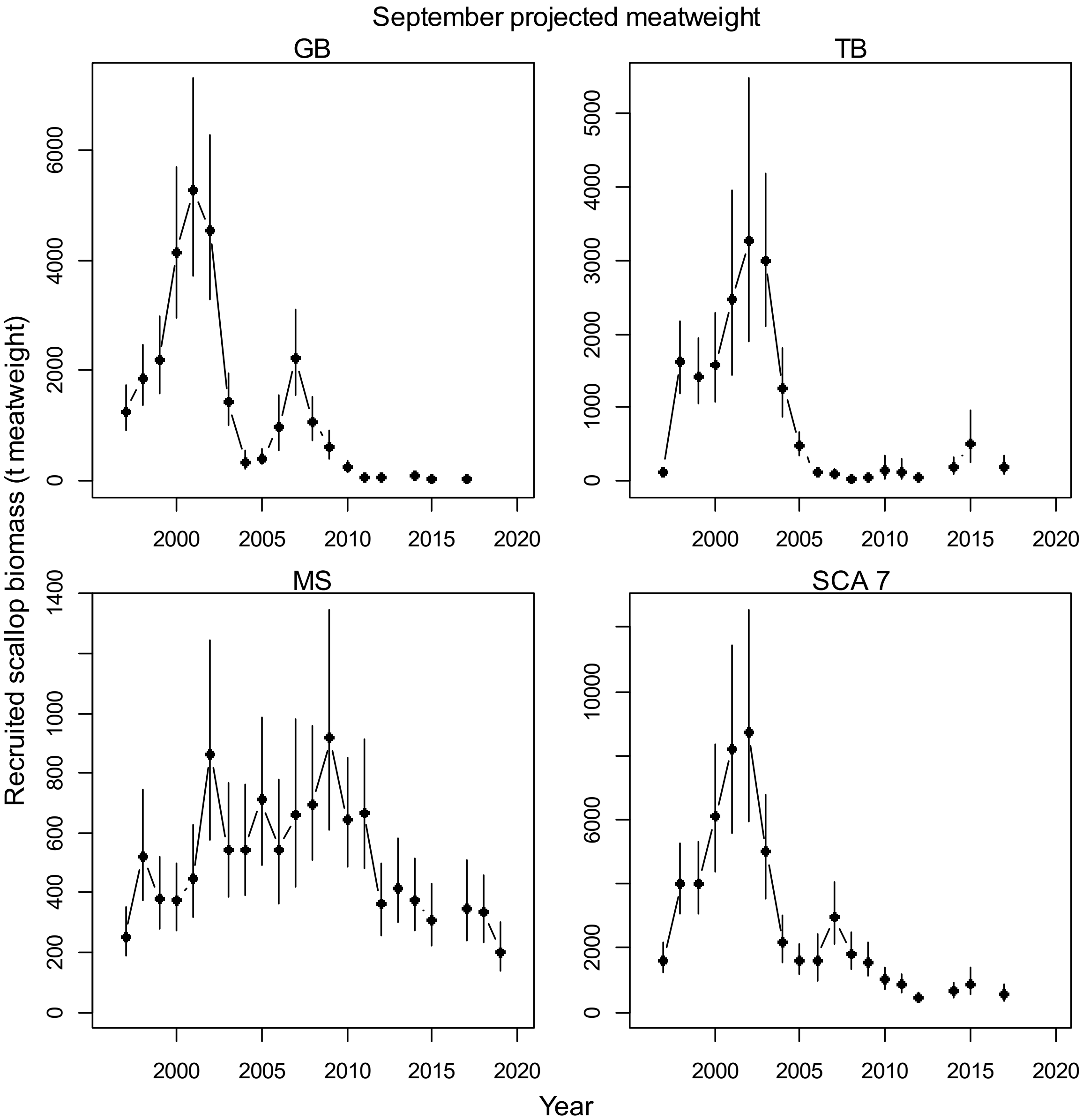

Figure 29: Trends in <u>projected start of season</u> (1 September) biomass (t <u>meat weight</u>) of recruited scallops (90 mm or larger) by substock and for the total SCA 7 stock, 1997–2019. Values are the estimated median and 95% confidence intervals. There was no survey in 2016, and Golden and Tasman Bays were not surveyed in 2013, 2016, 2018 or 2019.

13. APPENDIX G: Projected biomass sensitivity estimates, September 2019

Table 10: Sensitivity of the Marlborough Sounds September 2019 projected estimates of recruited scallop biomass (t meat weight) to the exclusion of areas of low scallop density. Critical density thresholds in the range 0–0.20 scallops m^{-2} were examined. The estimates were produced by location (individual or groups of strata in the same location) using a non-parametric resampling with replacement approach (1000 bootstraps) to estimation, using tag-return data modelled using an inverse logistic growth model. Critical density corrections were applied after correcting for dredge efficiency (Tuck et al. 2018). Location estimates are shown in decreasing order of mean absolute biomass (t meat weight).

Grouping	**Name/code**	**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
Location	Guards Bay	102	0.24	100	93	0.26	91	88	0.27	86	83	0.28	81	79	0.29	77	75	0.30	73
	Ship Cove	39	0.32	37	32	0.34	31	28	0.37	27	24	0.39	23	21	0.41	20	18	0.44	17
	Chetwodes	19	0.20	18	16	0.23	16	14	0.26	14	12	0.29	12	10	0.33	9	8	0.38	7
	Wynens Bank	14	0.30	14	12	0.34	12	11	0.37	10	10	0.40	9	8	0.42	8	7	0.46	7
	Dieffenbach Point	13	0.30	13	12	0.33	12	11	0.35	11	10	0.37	10	9	0.38	9	9	0.39	9
	BayofManyCoves	5	0.29	5	3	0.37	3	2	0.53	2	1	0.80	1	1	0.92	1	1	1.02	0
	Forsyth Bay Low	5	1.05	4	0	NA	0	0	NA	0	0	NA	0	0	NA	0	0	NA	0
	WaituiPortGore	3	0.46	3	0	17.32	0	0	NA	0	0	NA	0	0	NA	0	0	NA	0
	Waitata	1	0.19	1	1	0.36	1	0	0.95	0	0	2.99	0	0	NA	0	0	NA	0
	Horseshoe Bay	1	0.64	1	1	0.74	1	1	0.87	1	1	0.89	0	0	0.93	0	0	1.05	0
	Waitata Reach	1	0.84	1	0	NA	0	0	NA	0	0	NA	0	0	NA	0	0	NA	0
	Ketu Bay	1	0.54	1	0	0.87	0	0	1.01	0	0	1.41	0	0	4.18	0	0	31.62	0
	Richmond Bay	1	0.23	1	0	NA	0	0	NA	0	0	NA	0	0	NA	0	0	NA	0
	AdmiralityPenguin	1	0.83	1	0	NA	0	0	NA	0	0	NA	0	0	NA	0	0	NA	0
	Clara Island	0	0.82	0	0	NA	0	0	NA	0	0	NA	0	0	NA	0	0	NA	0
	Tawhitinui High	0	0.83	0	0	NA	0	0	NA	0	0	NA	0	0	NA	0	0	NA	0
	Tawhitinui Low	0	NA	0	0	NA	0	0	NA	0	0	NA	0	0	NA	0	0	NA	0
Substock	MS	206	0.20	203	171	0.21	168	154	0.23	151	140	0.24	137	129	0.25	125	118	0.27	115

14. APPENDIX H: Live scallop and dead clucker shell length distributions

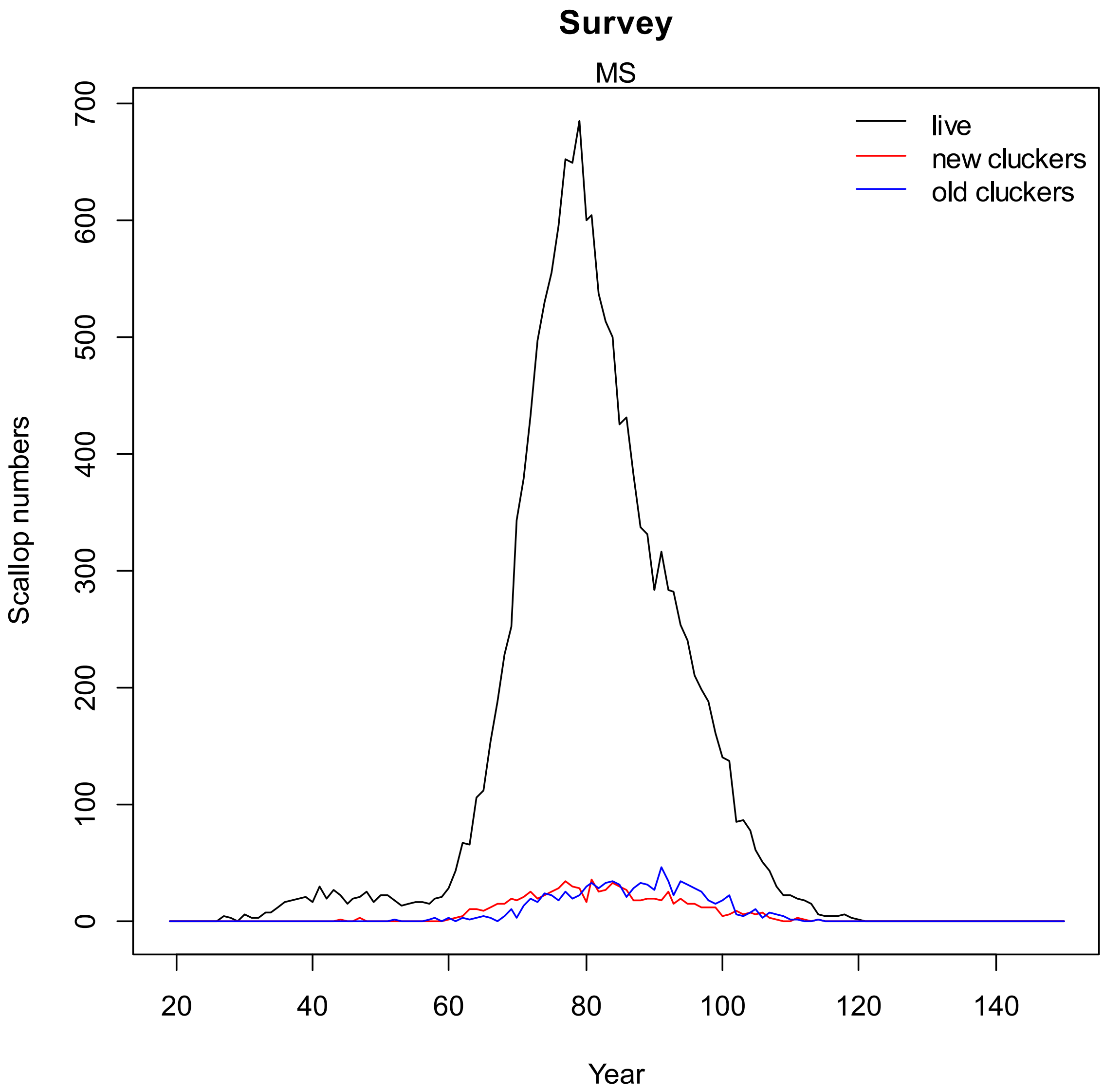

Figure 30: Live scallop versus new (clean) and old (fouled) dead clucker shell length distributions, Marlborough Sounds, May 2019.

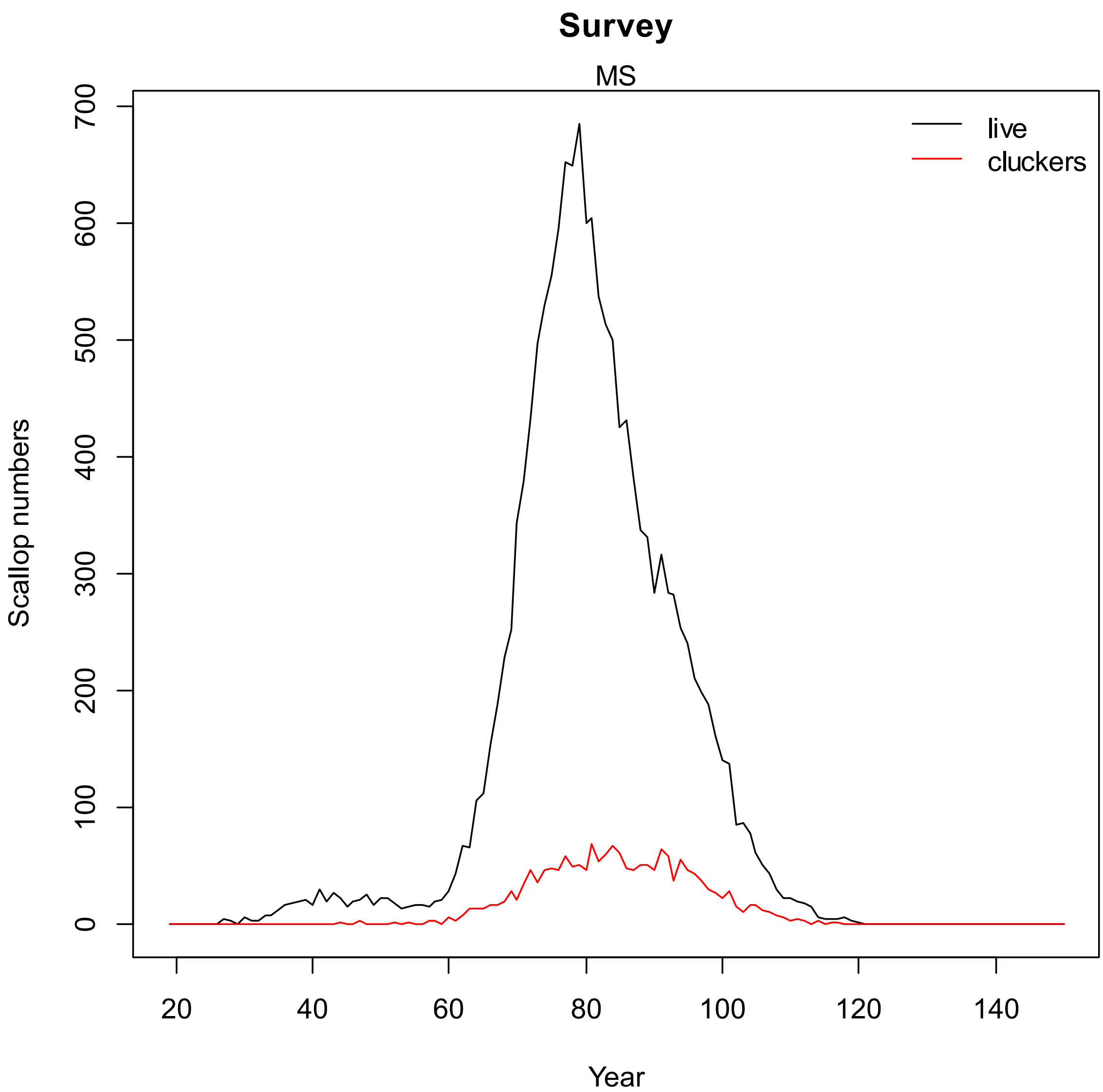

Figure 31: Live scallop versus dead clucker (clean and fouled combined) shell length distributions, Marlborough Sounds, May 2019.

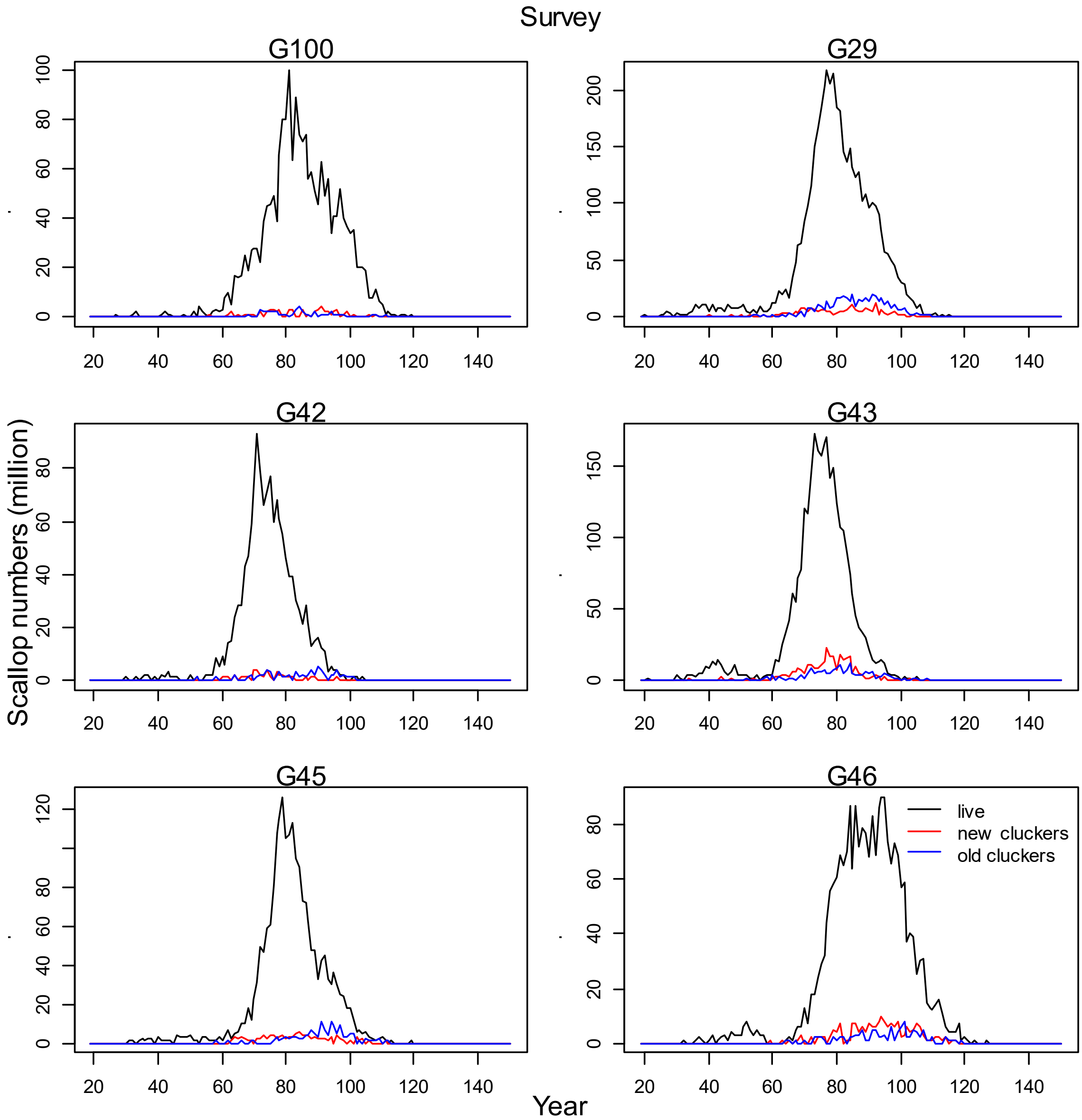

Figure 32: Live scallop versus new (clean) and old (fouled) dead clucker shell length distributions, by biotoxin area, Marlborough Sounds, May 2019.

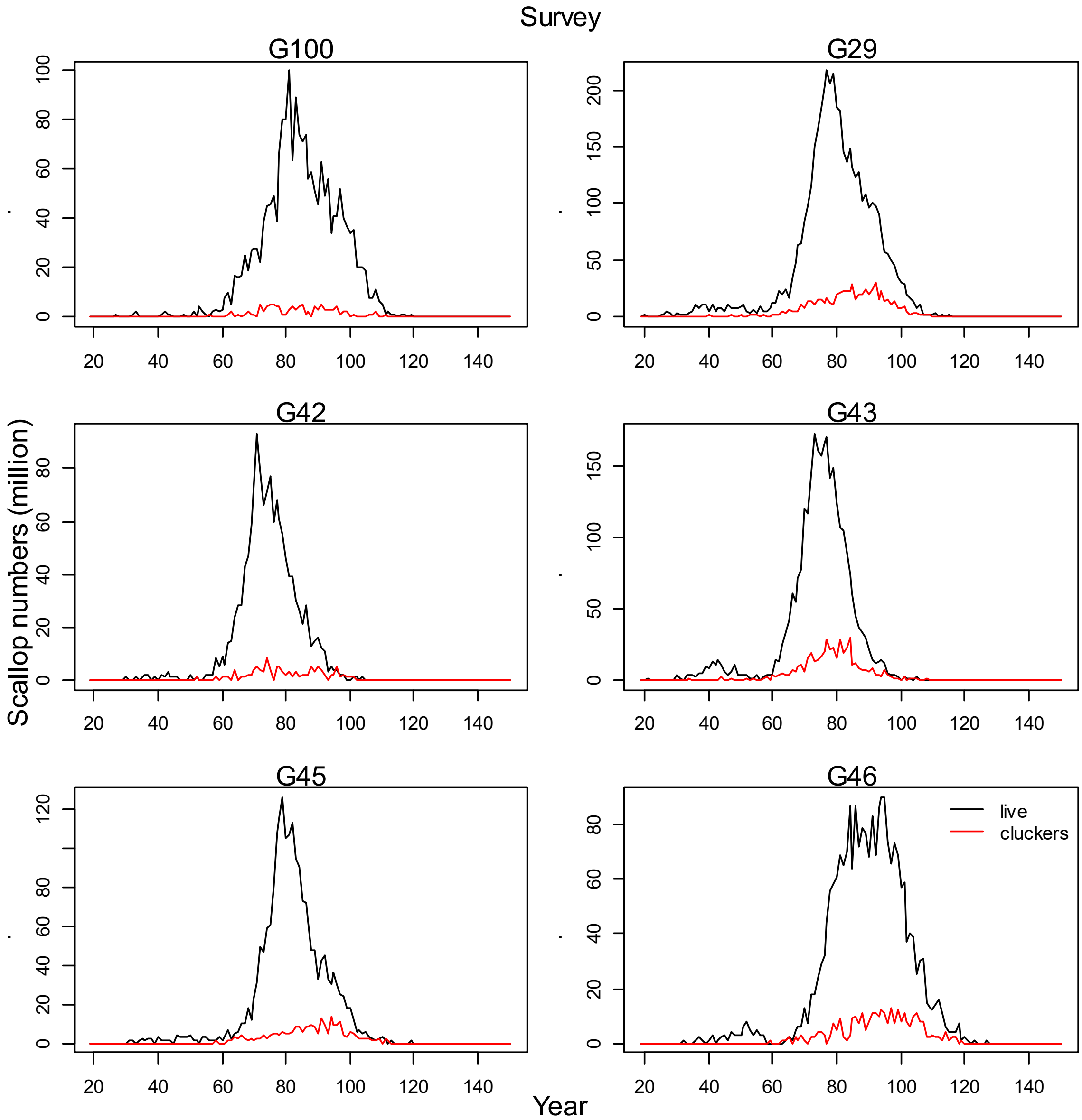

Figure 33: Live scallop versus dead clucker (clean and fouled combined) shell length distributions, by biotoxin area, Marlborough Sounds, May 2019.

15. APPENDIX I: *Chaetopterus* tubeworm

The parchment tubeworm *Chaetopterus* sp. was present in the catch at 35 survey stations (29% presence), distributed within areas of Pelorus Sound (Horsehoe Bay, Waitata Bank, Ketu Bay, Guards Bay) and Queen Charlotte Sound (Ship Cove) (Figure 34). When present, volumes caught were low (mean = 5.21 L, CV=18%; range = 0.59–20.78 L).

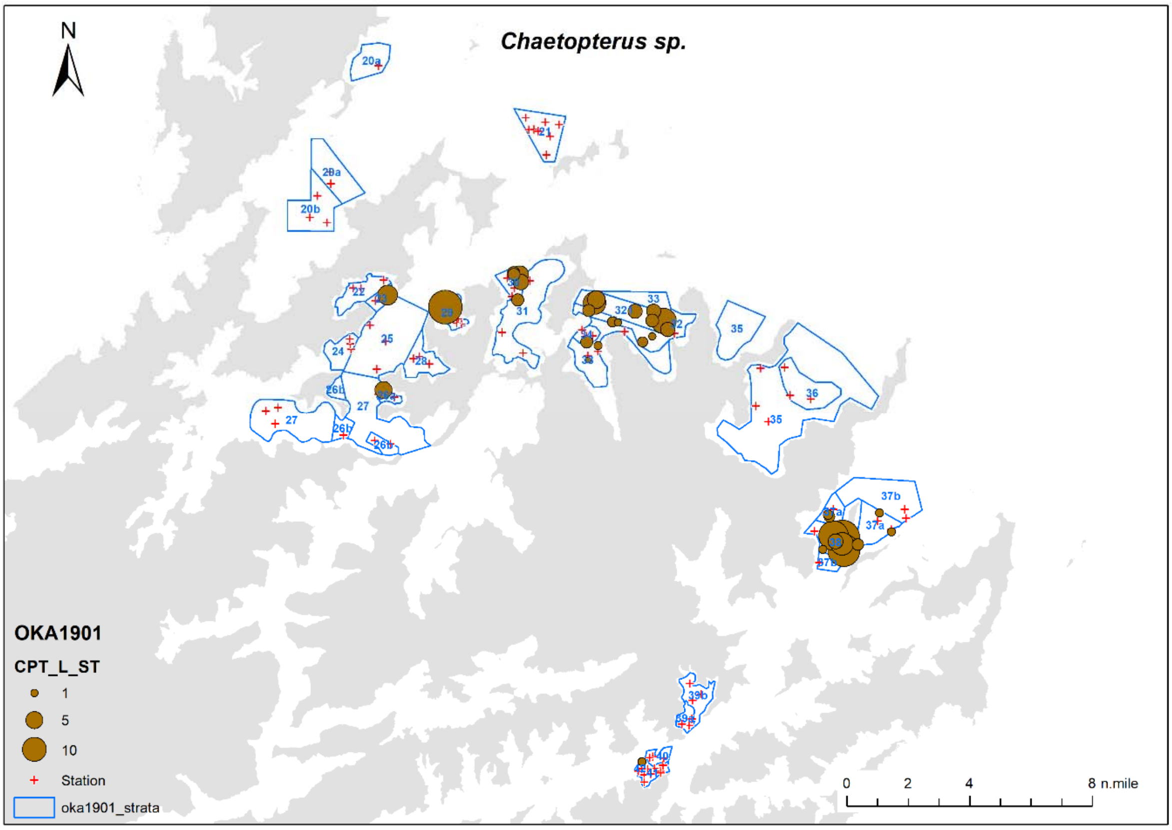

Figure 34: *Chaetopterus* sp. catch per standard tow, Marlborough Sounds dredge survey, May 2019. Circle area is proportional to the estimated volume (L) caught per standard distance towed (0.4 n.miles). Values are uncorrected for dredge efficiency. Polygons denote survey strata boundaries.