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Survey of scallops in SCA 7, May 2020

New Zealand Fisheries Assessment Report 2021/09

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A survey to evaluate the population status of scallops (*Pecten novaezelandiae*) within the Southern scallop stock SCA 7 was conducted from 18 to 22 May 2020 in Golden Bay and Tasman Bay, and from 27 May to 1 June 2020 in the Marlborough Sounds. The fishery is currently closed due to sustainability concerns about the low status of the stock. Specific objectives of the survey 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 2020 survey used a stratified random sampling allocation design, with sampling conducted using a chartered commercial fishing vessel and ring-bag scallop dredge at most stations, and 'Tow-Cam' video transects at six other stations. A total of 225 stations were sampled within the 28 strata. Five stations had non-random (targeted) dredge tows in areas which the survey skipper suspected to contain scallops, but these were excluded from the stratified random survey analysis. This left 220 valid survey stations for the analysis. The highest catches of recruited scallops were from tows in key strata in the Marlborough Sounds, located mainly in the outer Pelorus Sound region and in Queen Charlotte Sound. Catches in Golden Bay and Tasman Bay were generally very low, except for a single tow in Tasman Bay sector 7G which had an unexpectedly high catch of recruited scallops, plus horse mussels *Atrina zelandica*. The May 2020 dredge survey and a subsequent 23–24 June 2020 Tow-Cam video survey provided evidence of a bed of scallops and horse mussels in 25–35 m water depth offshore to the northwest of The Glen in Tasman Bay.

The scallop population at the time of the survey in May 2020 was estimated, and projections were run to predict population estimates for September 2020. The analytical approach repeated that used in the 2019 survey analysis which had two key changes from previous analyses: 1) the application of 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 growth estimates from tag-return data modelled with an inverse logistic model. To enable comparisons across years, the 1997–2019 time series of estimates produced in 2019 using data from previous annual SCA 7 dredge surveys were updated by including the 2020 estimates, producing updated 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, May 2019, and May 2020 were also examined.

The key finding is that the SCA 7 recruited biomass for 2020 was low. Recruited biomass in Golden and Tasman bays was very low overall, and in Marlborough Sounds virtually all the recruited biomass at potentially commercially fishable densities was 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 2020 to be 242 t meat weight, which was not statistically different from that in 2019. The estimated abundance of Marlborough Sounds pre-recruit scallops (53–89 mm) in 2020 was low compared with historical estimates, especially from the early 2000s, suggesting that recruitment in the short term was likely to be relatively poor in most areas. However, the abundance of small juvenile scallops (less than 60 mm) in Marlborough Sounds was noticeably higher in 2020 than in recent years, presumably the result of favourable larval settlement and spat survivorship since the 2019–20 spring-summer spawning period.

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 the Marlborough Sounds (Figure 1). 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).

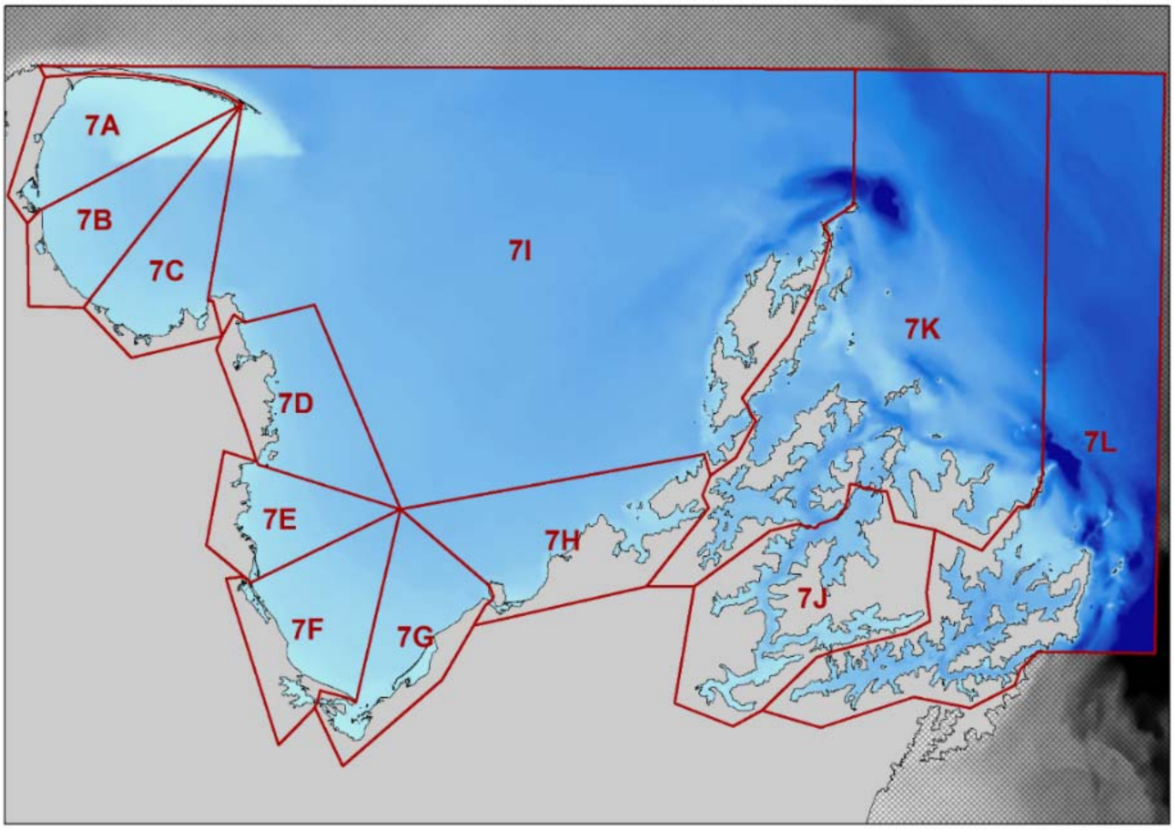

Figure 1: Map of the SCA 7 stock area which is subdivided into its Statistical Reporting Areas ('stat areas') 7A–7C (Golden Bay), 7D–7H (Tasman Bay), 7I (outer Golden/Tasman Bays), and 7J–7L (Marlborough Sounds).

The status of the SCA 7 stock is assessed using data collected from fishery-independent dredge surveys (see Appendix A: Table A.1). 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 (Williams et al. 2017). In Marlborough Sounds, recruited biomass exhibited a declining trend from 2009 to 2015, followed by a period of little change between 2015 to 2018, and a further decline occurred between 2018 and 2019; the 2019 recruited biomass estimate was the lowest on record, with 99% of that biomass held in a limited number of scallop beds, mainly in the outer Sounds (Williams et al. 2019).

1.2 Objectives

The overall research objective for the present study (project SCA201901) was to evaluate the status of the scallop stocks in SCA 7. The two specific research objectives for this project were:

Objective 1

- Conduct a biomass survey that will provide estimates of current relative and absolute abundance (numbers and biomass in tonnes green weight and meat weight), 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.

Objective 2

- Conduct a biomass survey that will provide estimates of current relative and absolute abundance (numbers and biomass in tonnes green weight and meat weight), length frequency profile, density and distribution of recruited and pre-recruit scallops in Golden Bay and Tasman Bay.

Data collection was achieved by conducting dredge survey sampling in the Marlborough Sounds (Objective 1) and in Golden and Tasman bays (Objective 2) in May 2020. The resulting survey data were analysed to estimate scallop population status, assess the sensitivity of the estimated scallop biomass to a range of commercial density thresholds, and compare the 2020 estimates with those from the survey time series. The project findings will inform fisheries management on the status of the SCA 7 stock.

2. METHODS

2.1 Survey design

A dredge survey of scallops in Marlborough Sounds was conducted in May 2020 using a single-phase stratified random sampling allocation design. To allow comparisons with previous surveys, the 2020 sample extent (survey coverage) was identical to that used in the most recent surveys of the Marlborough Sounds in May 2019 (Williams et al. 2019) and Golden and Tasman bays in January 2017 (Williams et al. 2017). The 2020 stratification was also identical with one minor exception: Tasman Bay stratum 174a was subdivided using the 35 m depth contour into two parts, 174c and 174d, based on the results of the 2017 survey which showed higher densities of recruited scallops in the deeper area (174c). A total of 220 stations were allocated to the 53 strata for the May 2020 survey (40 stations within 10 strata in Golden Bay; 60 stations within 15 strata in Tasman Bay; and 120 stations within 28 strata in the Marlborough Sounds). The total area of the survey extent was 1461 km^2 (area calculated using ArcGIS®) (Table 1, Figure 2)

Table 1: Stratum details for the SCA 7 survey, May 2020 (trip code OKA2001). All stations were sampled with a single dredge (CSEC 2.4 m wide ring-bag dredge), using a tow length of 0.4 n. mile or 0.2 n. mile in small area and/or expected high density strata (strata highlighted in grey). The combined total survey area is 1461 km^2.

Substock	Stat area	Biotoxin	Stratum	Area (km^2)	Name	Stns allocated
Golden Bay	7A	A	1	71.9	–	5
	7B	B	2	41.7	–	3
			3	32.7	–	5
			4	106.7	–	7
	7C	C	5	19.0	–	3
			6	32.2	–	3
			7	73.9	–	5
			8	77.0	–	3
			9a	3.9	Farewell Spit East	3
	7I	I	9b	9.9	Farewell Spit West	3
Tasman Bay	7D	D	10	8.6	Awaroa Bay	3
			11	246.1	–	7
	7E	E	12	47.6	–	3
			13	68.7	–	3
	7F	F	14	45.5	–	3
			15	62.0	–	3
	7G	G	16	87.9	–	6
	7H	H	171	2.9	7H Delaware Bay	3
			172	29.1	7H 20-30m	3
			173	8.3	7H Triangle 30m+	3
			174b	82.7	7H East 30m+	4
			174c	29.7	7H West 30-35m	4
			174d	77.9	7H West 35-40m	9
			17	5.3	Croisilles Low	3
			18	3.6	Croisilles High	3
Marlborough Sounds	7K	G100	20a	9.8	Admirality/Penguin High	3
			20b	7.0	Admirality/Penguin Low	3
			21	5.5	Chetwode Is	9
		G43	22	3.4	Waitata Bay	3
			23	1.5	Waitata Bank	3
			24	2.7	Clara Island	3
			25	14.4	Waitata Reach	3
		G42	26a	1.0	Horseshoe Bay	3
			26b	3.6	Tawhitinui High	3
			27	22.1	Tawhitinui Low	3
		G43	28	3.6	Richmond Bay	3
			29	2.4	Ketu Bay	4
		G45	30	2.3	Wynens Bank	8
			31	10.9	Forsyth Bay Low	3
		G46	32	5.9	Guards Bank Outer	8
			321	6.4	Guards Bank Fishing Area	12
			33	10.8	Guards Bay Low	3
			34	1.2	Guards Anakoha Bank	3
		G90	35	37.6	Waitui/Port Gore Low	3
			36	6.0	Port Gore Bank	3
	7L	G29	37a	6.1	Motuara Is Medium	3
			37b	9.9	Motuara Is Low	3
			38	4.6	Ship Cove	9
			39a	1.3	Bay of Many Coves Bank	3
			39b	3.1	Bay of Many Coves Main Bay	3
			40	1.1	Dieffenbach Low	3
			41	1.5	Dieffenbach High	7
			42	0.3	Dieffenbach West	3

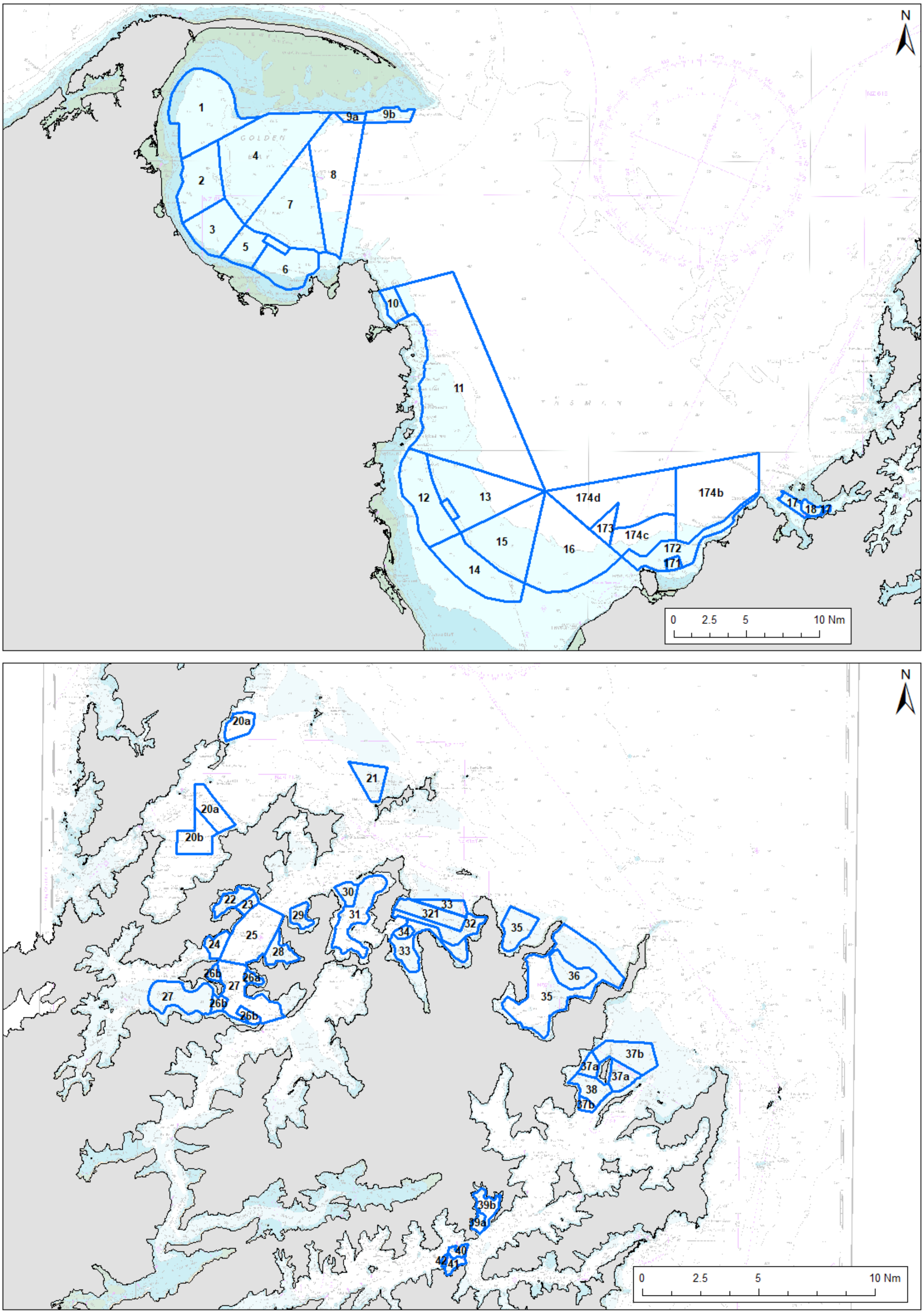

Figure 2: Stratification for the SCA 7 dredge survey, May 2020: Golden Bay and Tasman Bay (top) and Marlborough Sounds (bottom).

2.2 Station allocation

Station allocation was examined using the R function *allocate* (Francis 2006), which allocates stations to strata 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 2020 survey were intersected with station data from the previous 1994–2019 time series of SCA 7 surveys to assign the previous catch densities (number of recruited scallops 90 mm or larger per standard tow of 0.4 n. mile in length, uncorrected for dredge efficiency) to the 2020 survey strata.

A minimum allocation of three stations was required for all strata. With 53 strata, this meant that a minimum of 159 stations was required. Based on previous surveys we estimated that a fixed survey duration of 10 sampling days was needed, during which we expected to complete up to 220 stations, with the aim of meeting a CV target of 20% (or less) for SCA 7 overall, for each of the three substocks (Golden Bay, Tasman Bay, Marlborough Sounds), and for selected locations (individual or groups of strata) which hold the main scallop beds known from previous surveys.

Initial *allocate* optimisation runs were conducted using data from the most recent three surveys: runs were conducted for Golden and Tasman bays (using the 2014–17 survey data) separately to the Marlborough Sounds (using the 2017–19 data). Boxplots of scallop density by stratum from the relevant survey years were used to help interpret the *allocate* outputs.

The final allocation for the survey was based on the output of the optimisation runs, with some minor adjustments to the number of stations allocated to certain strata. 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 final allocation, *allocate* predicted that a substock CV of 7% would be achieved for the Marlborough Sounds (on basic parametric estimates, uncorrected for dredge efficiency).

Station positions within strata were randomised using GIS software, constrained to keep stations a minimum distance of a dredge tow length apart (0.4 or 0.2 n. mile minimum distance depending on stratum size, but shorter distances were required in very small strata); this software was also used to estimate the area of each stratum

2.3 Dredging procedures

Survey sampling was conducted by dredging 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 A: Table A.1).

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) 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.

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 4). We repeated the use of video and depth logger attached to the dredge during the May 2020 survey. 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. Future analysis could help to improve our understanding of how the dredge samples the seabed.

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

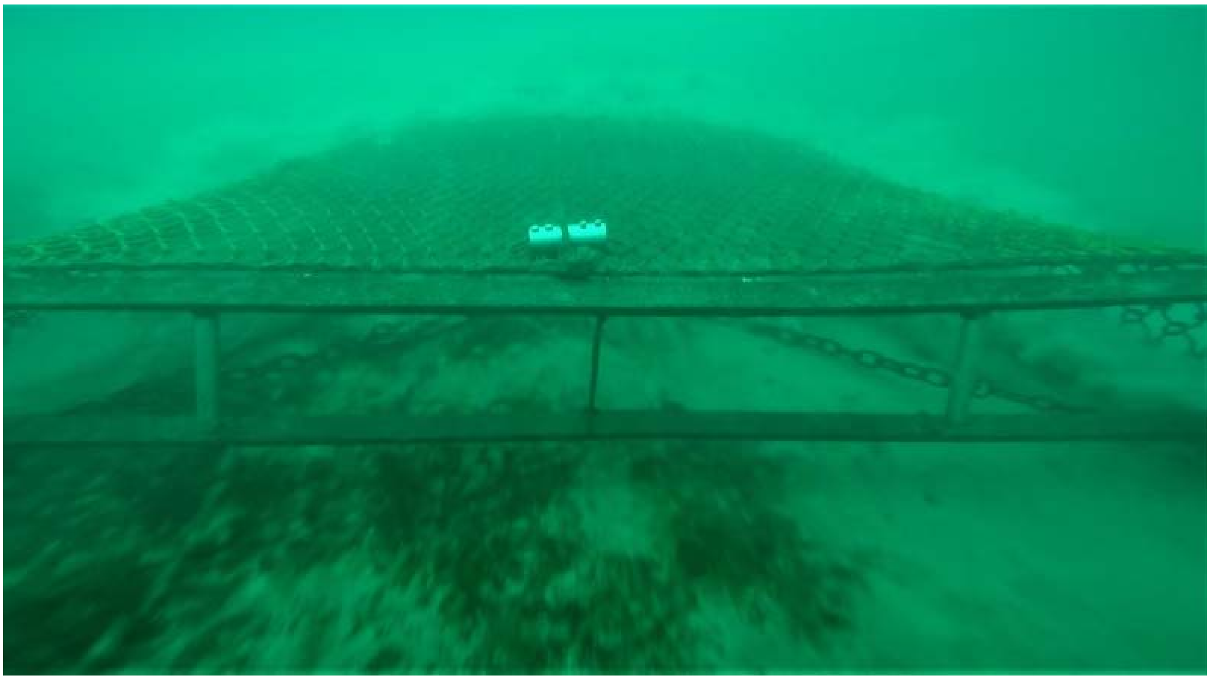

Figure 4: GoPro video frame grab showing survey ring-bag dredge during a tow, Marlborough Sounds, May 2019. Note the metal housing containing the depth logger is attached to the top of the dredge.

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 5) and placed into bins by scallop life status category (live scallops or dead 'cluckers'; 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 and 2020 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.

The station data (including date, station number, tow start and finish times and positions, wind force, water depth, dredge fullness, bottom type) and catch data (species counts, oyster sizes, 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.

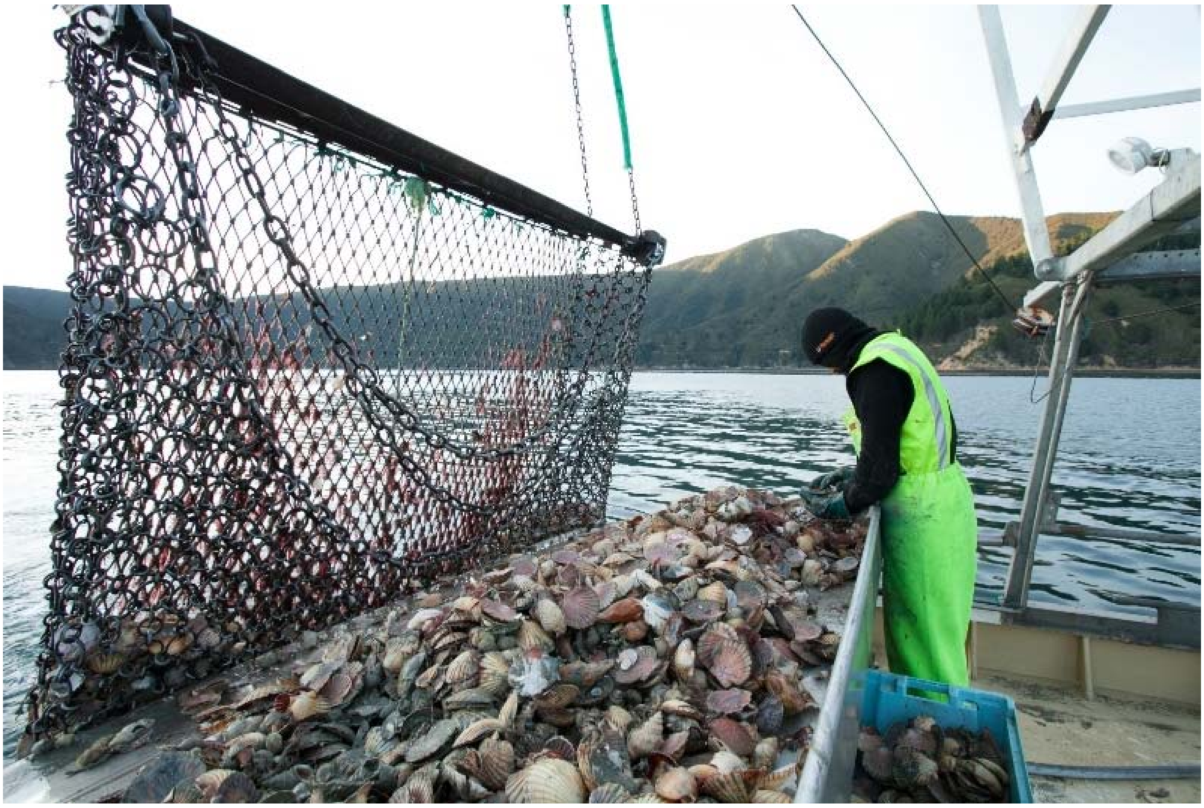

Figure 5: Example of a ring-bag dredge survey catch being sorted at the stern of the vessel (May 2014 survey). Photo credit: J. Williams.

2.5 Video transects

Two small strata could not be surveyed by dredge in May 2020: 1) Marlborough Sounds stratum 34 on Anakoha Bank, at which a bed of horse mussels had been detected in previous surveys; and 2) Tasman Bay stratum 171 located within the Whakapuaka (Delaware Bay) Taiāpure. Stations in these strata were sampled by conducting underwater video transects using NIWA Nelson's 'Tow-Cam' system instead of dredge tows. The 'Tow-Cam' has two parts: the topside display (SplashCam ProPacl200 HD, Ocean Systems Inc©) and recording unit (GeoAudio+ GPS audio encoder, Intuitive Circuits©), and the underwater towed camera unit comprising an underwater video camera (SplashCam Delta Vision HD and HD cable, Ocean Systems Inc©), video lights and lasers (Bigblue VL8000P Tri Colour lights & Bigblue Spot Light lasers, Bigblue Dive Lights©), and a second video camera (GoPro Hero 3+, GoPro Inc.), all attached to a NIWA-designed custom tow frame.

A standard protocol for Tow-Cam video transects was followed. In this protocol, the vessel is positioned at each random station position allocated with non-differential GPS. The camera is lowered until it is approximately 0.5–1 m above the seafloor and 'towed' for a standard distance of 100 m (8–10 mins run time depending on the strength of the current). The actual transect length (distance towed) is calculated from the vessel GPS positions logged at the start of the tow (when the camera first starts filming the seabed) and at the end of the tow (when hauling commences). The skipper is responsible for towing the camera system as slowly as possible (at approximately 0.5–1 knots), usually by drifting with the tidal current, and the camera is maintained at a target height of 0.5–1.0 m above the seabed to provide a sufficient field of view of the seabed within the prevailing water visibility conditions. During the tow the camera operator views the monitor showing the live feed and records notes on scallop presence, substrate type, habitat features, and water depth in real time. The footage also automatically records GPS position and date/time stamp. At the end of the tow, the camera system is retrieved.

The recorded video footage was analysed in the laboratory. Scallops and other identifiable organisms were quantified by life status (live or dead) and measured. Laserpoints visible in the recorded video images were used to convert measurements in image pixels to millimetres. Scallop numbers at length were converted to densities at length using the estimated area swept by the camera (transect length × mean image width). We assumed 100% efficiency of detection from video footage, which likely results in conservative estimates from the Tow-Cam.

Using the same methods, additional Tow-Cam video transects were conducted during a separate trip off The Glen in Tasman Bay from 23 to 24 June 2020 using a Nelson trailer boat, to investigate the distributional extent of the putative scallop and horse mussel bed detected during the dredge survey. The resulting imagery were archived at NIWA but not analysed within the present study.

2.6 Population estimation

NIWA's scallop population estimation approach was originally developed for analysing survey data from the North Island scallop fishery areas (SCA CS and SCA 1) and was first described by Cryer & Parkinson (2006); an updated, and more detailed, description of the method is given by Williams et al. (2013). The approach has been applied in SCA 7 survey analyses since 2008 (Tuck & Brown 2008), and parameters specific to SCA 7 were summarised by Williams et al. (2014b), and also detailed in section 2.6 of the May 2015 survey report (Williams et al. 2015a). In the 2019 survey analysis (Williams et al. 2019), two key changes were made:

1. New estimates of ring-bag dredge efficiency for the SCA 7 survey dredge were applied, based on new data collected by diver and dredge sampling in Marlborough Sounds in January 2018 within project SCA2017-02 (Tuck 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).

Except for these changes, the estimation approach for the 2019 survey analysis was the same as that used in 2018, and the same approach was used again in the 2020 survey analysis.

The approach involves 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 the following September (the start of the fishing season), accounting for growth and natural mortality. The 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 the sample, and the 95% confidence interval (CI) is used to express the uncertainty in the estimate.

Stratum length frequency distributions are calculated at the time of the survey as the mean station length frequency for that stratum scaled by the stratum area. Substock length frequency distributions are calculated as the sum of the stratum length frequencies for the strata within each substock.

2.7 Comparative analysis

In the 2019 survey project (Williams et al. 2019), SCA 7 survey data from 22 annual surveys conducted between 1997 and 2019 (excluding 2016 when there was no survey) were reanalysed using the original survey design (stratification) in each respective survey year, applying the new dredge efficiency curve (Tuck 2018) and conducting growth projections using an inverse logistic model (Tuck & Williams 2012). The reanalysis produced the following for the Marlborough Sounds:

- revised time series for survey (May) and start of season (September) recruited biomass
- abundance indices for pre-recruits (scallops 53–89 mm) and recruited scallops (90 mm or larger)
- live scallop and dead clucker shell estimates from the annual surveys in May 2015, January 2017, January 2018, and May 2019

The results of the 2020 survey analysis were used to update these time series of revised estimates and establish if changes have occurred in the scallop population. The examination was based on readily available outputs from the analysis, comprising population length frequency distribution 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 were used to describe and interpret the status of the scallop population over time.

The spatial extent of the 2020 survey was identical to that surveyed in recent SCA 7 surveys, enabling direct comparison of the 2020 estimates with those from the revised time series outlined above, since at least 2015. However, the spatial extent and the performance of the stratifications of earlier surveys has varied over time which complicates interpretation (e.g., surveys before 2009 covered a greater spatial extent). Addressing these spatial differences requires substantive further work on the SCA 7 survey data, which was beyond the scope of the 2020 survey project, and which requires a separate research project. In the present study, trends in scallop abundance and biomass were analysed at the finest spatial scale possible given the nature of the survey data available: by scallop statistical reporting area (sector) in Golden and Tasman bays (Figure 1), and by scallop biotoxin reporting area (subareas within sectors) in Marlborough Sounds (Figure 6).

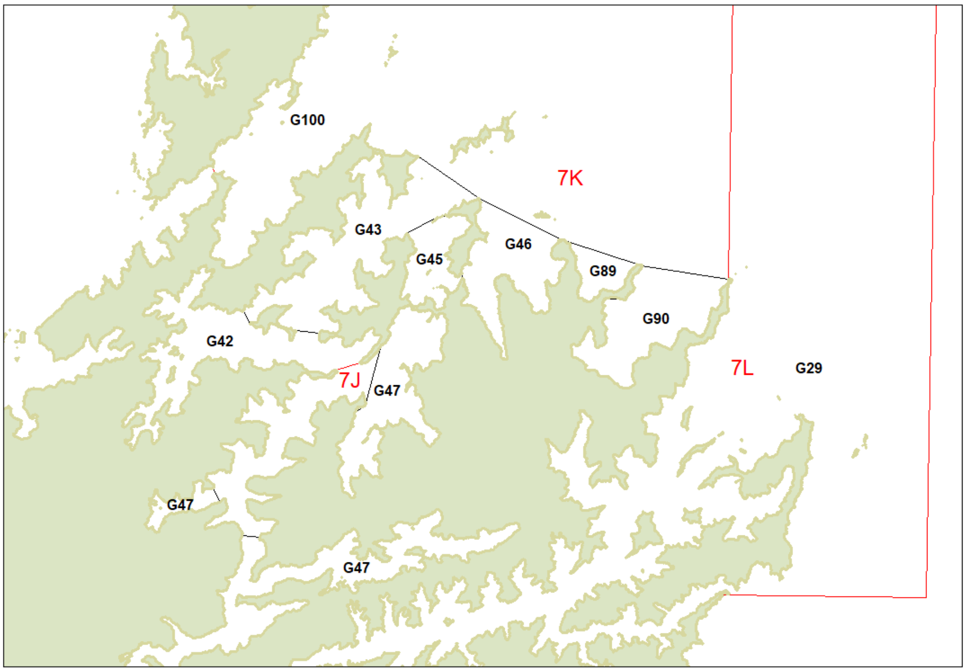

Figure 6: Marlborough Sounds scallop biotoxin reporting areas, which are subareas within scallop Statistical Reporting Areas 7J, 7K, and 7L. Trends in Marlborough Sounds scallop abundance and biomass in the present study were analysed at the biotoxin area scale.

3. RESULTS

3.1 Sampling conducted

The 2020 SCA 7 survey was completed during 11 days at sea: 18–22 May in Golden and Tasman bays, and 27 May to 1 June in the Marlborough Sounds. A total of 225 stations were sampled within the 28 strata (Figure 7). Five stations had non-random (targeted) dredge tows in areas which the survey skipper suspected to contain scallops, but these were excluded from the stratified random survey analysis. This left 220 valid survey stations for the analysis, with a total of 24 863 scallops observed, of which 91% were measured and the remainder were counted (Table 2).

Table 2: Scallop numbers counted and measured, SCA 7 survey, May 2020. Life status is the code assigned to each individual to distinguish between live and dead scallop shells. Prop., proportion measured.

Station type	Method	Life status	Description	Counted	Measured	Prop.
Survey (stratified random stations)	Dredge (n = 214 tows)	1	live	22 735	20 635	0.91
		20	dead, clean shell w. tissue	4	4	1.00
		21	dead, clean shell	1 405	1 321	0.94
		22	dead, fouled shell	681	653	0.96
	Tow-Cam (n = 6 transects)	1	live	36	36	1.00
		2	dead	2	2	1.00
			Survey total	24 863	22 651	0.91
Targeted (non-random stations)	Dredge (n = 5 tows)	1	live	859	859	1.00
		21	dead, clean shell	11	11	1.00
			Targeted total	870	870	1.00
			Overall total	25 733	23 521	0.91

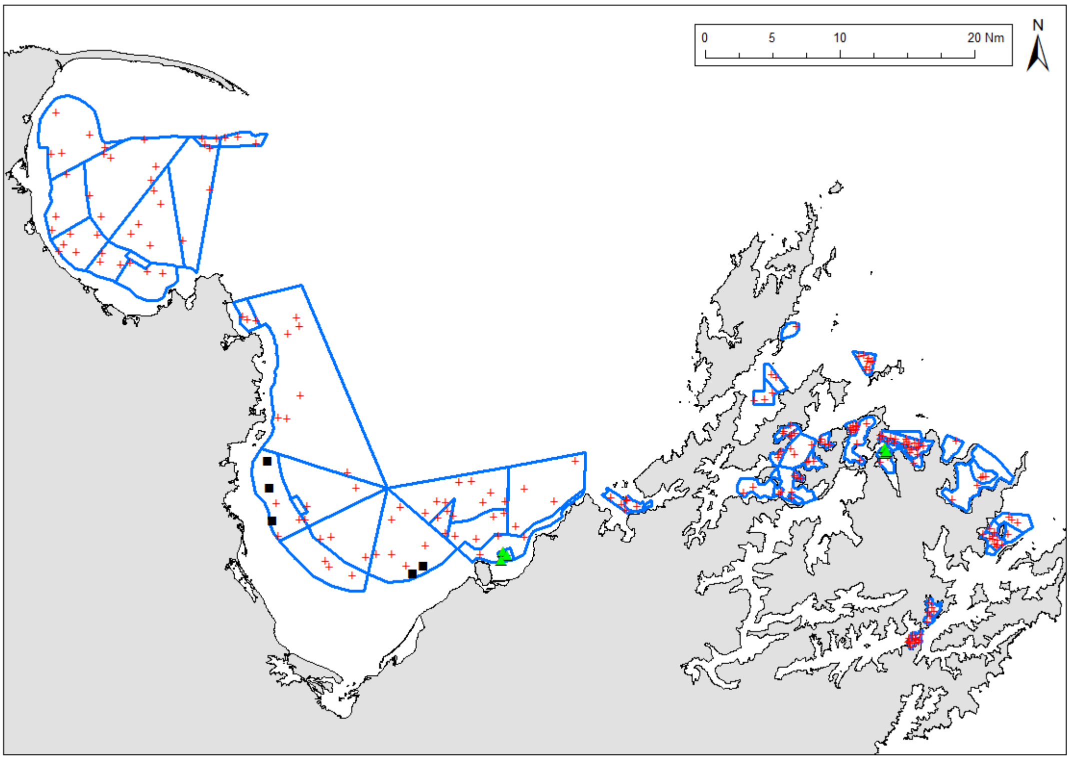

Figure 7: Stations sampled, SCA 7 survey, May 2020. Symbols distinguish the stratified random dredge tows (red crosses) and Tow-Cam video transects (green triangles) from the targeted non-random dredge tows (black squares, n = 5) which were excluded from the analysis to estimate scallop biomass.

3.2 Spatial distribution

Scallop catch density (the survey catch of scallops per standard 0.4 n. mile tow, uncorrected for dredge efficiency) is mapped in Figure 8 and shown in boxplots by stratum in Appendix B (see Figure B.1 to Figure B.4).

In Golden Bay, catch densities of recruited scallops (90 mm or larger) were very low in the main bay (0 to 8 per tow) and were only slightly higher in strata 9a and 9b (0 to 41 per tow) which represent a consistent scallop bed to the south of the tip of Farewell Spit.

In Tasman Bay, recruited scallop catch densities were also very low in most areas (0–12 per tow) and were only slightly higher in Croisilles Harbour scallop bed strata 17 and 18 (6 to 34 per tow), and in stratum 16 in sector 7G (0–22 per tow) except for a single tow in stratum 16 (station 83) which had an unexpectedly high catch density of 300 recruited scallops (plus a mix of live and dead horse mussels of a similar size, all around 215 mm shell length). Two non-random (targeted) dredge tows within a similar part of stratum 16 had recruited scallop catch densities of 206 and 4 per tow (also with a mix of live and dead horse mussels). In combination, the May 2020 dredge survey and a subsequent 23–24 June 2020 'Tow-Cam' video survey (Figure 9) provided evidence of a bed of scallops and horse mussels in 25–35 m water depth in the south-eastern portion of stratum 16, offshore to the northwest of The Glen, Tasman Bay.

In the Marlborough Sounds, catch densities of recruited scallops (numbers scaled to a 0.4 n. mile standard tow distance) were highest at key strata which represent the main scallop beds within the area surveyed, located mainly in the outer Pelorus Sound region and in Queen Charlotte Sound: Ship Cove (stratum 38: 63–401 per tow), Wynens Bank (stratum 30: 38–310 per tow), Guards Bank (strata 321 and 32: 54–787 and 4–324 per tow, respectively), Waitata Bank (stratum 23: 88–202 per tow), Chetwodes (stratum 21: 108–208 per tow), and Dieffenbach Point (primarily stratum 41: 80–576 per tow, but also strata 42 and 40: 58–164 and 8–179 per tow, respectively). Recruited densities were notable in Horseshoe Bay stratum 26a (16–180 per tow), Bay of Many Coves stratum 39a (25–110 per tow), and Port Gore stratum 36 (73–100 per tow). Recruited densities were low in other strata which represent other scallop beds on banks and in bays elsewhere within the survey area.

Parchment tubeworms (*Chaetopterus*) were also quantified on the survey and examined in comparison with the 2019 survey findings (see Appendix I: Table I.1 and Figure I.1). Shortly before the May 2019 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.

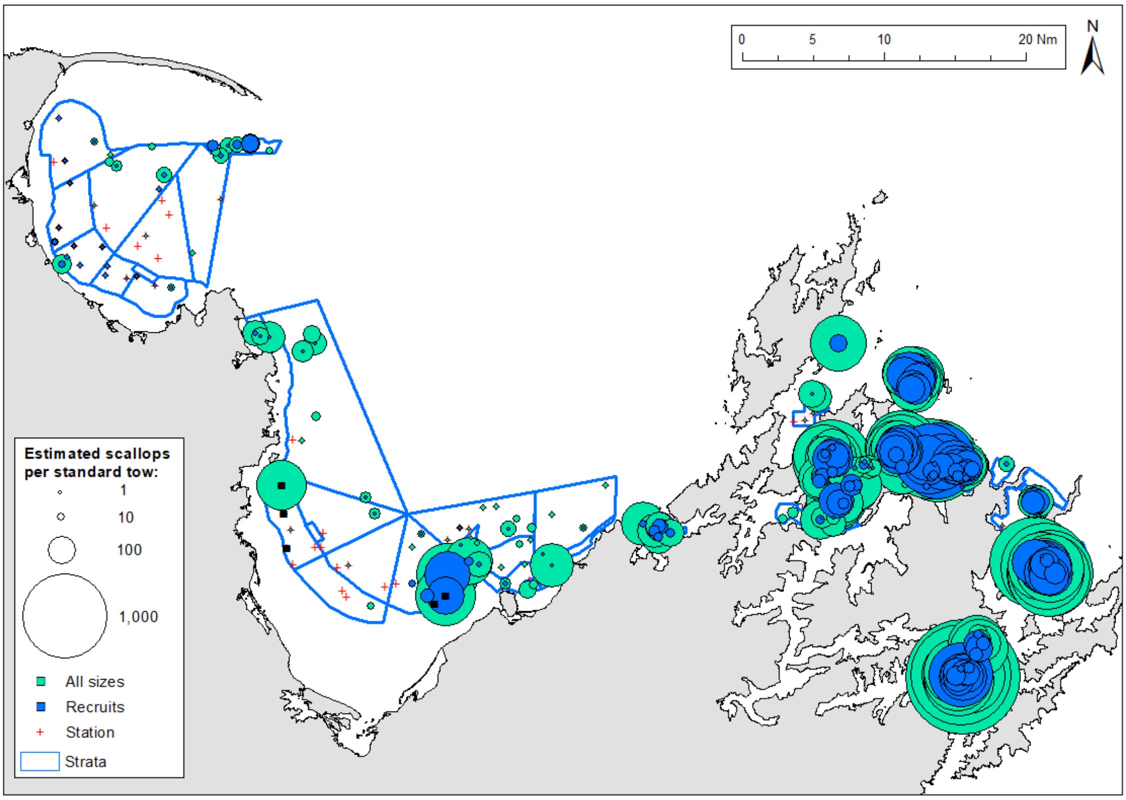

Figure 8: Catch per standard tow, SCA 7 survey, May 2020. Circle area is proportional to the number of scallops caught per standard distance towed (0.4 n. miles), uncorrected for dredge efficiency. Dark blue shaded circles denote scallops of recruited size (90 mm or larger), green shaded circles denote scallops of any size, crosses denote tow positions. Polygons denote survey strata boundaries.

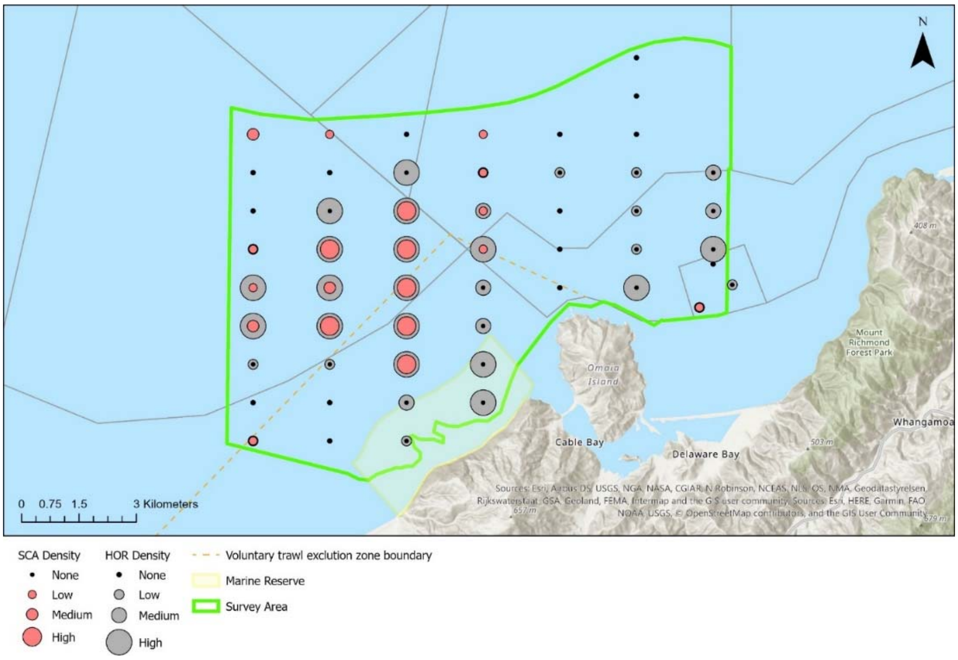

Figure 9: Distribution of scallops (*Pecten novaezelandiae*) and horse mussels (*Atrina zelandica*) estimated from field notes made during a Tow-Cam video transect survey off The Glen, southeastern Tasman Bay, 23–24 June 2020. The survey objective was to assess the distributional extent of a putative bed of *Pecten* and *Atrina* initially detected during the May 2020 SCA 7 dredge survey. Quantitative estimates could be made in future work by analysing the Tow-Cam video footage.

3.3 Length frequency

Scallop length frequency distributions at the time of the survey in May 2020, uncorrected for dredge efficiency, are shown by substock (Figure 10), by Golden Bay and Tasman Bay sectors (Figure 11 and Figure 12) and for the 2015 to 2020 time series for key scallop beds in Marlborough Sounds: Wynens Bank, Ship Cove, and Guards Bay (Figure 13); Waitata Bank, Ketu Bay, and Dieffenbach Point (Figure 14); and the Chetwode Islands (Figure 15). Time series of length frequency distributions are also shown for strata at Horsehoe Bay/Tawhitinui High, Bay of Many Coves, and Port Gore (Figure 16).

At least three different size groups of scallops were detectable, referred to here as juveniles (about 20–52 mm, poorly selected by the dredge), pre-recruits (53 to 89 mm), and recruited scallops (90 mm or larger) (Figure 10). Juveniles were prominent in Marlborough Sounds in May 2020, being evident in most of the key scallop beds that hold the highest densities of recruited size scallops (strata shown in Figure 13 and Figure 14, and especially at the Chetwodes shown in Figure 15).

The length frequency time series also show signs of a recovery of the scallop population at Waitata Bank following the large decline observed between the 2015 and 2017 surveys, and, in contrast, a decline in the scallop population at Ketu Bay in recent years (Figure 14).

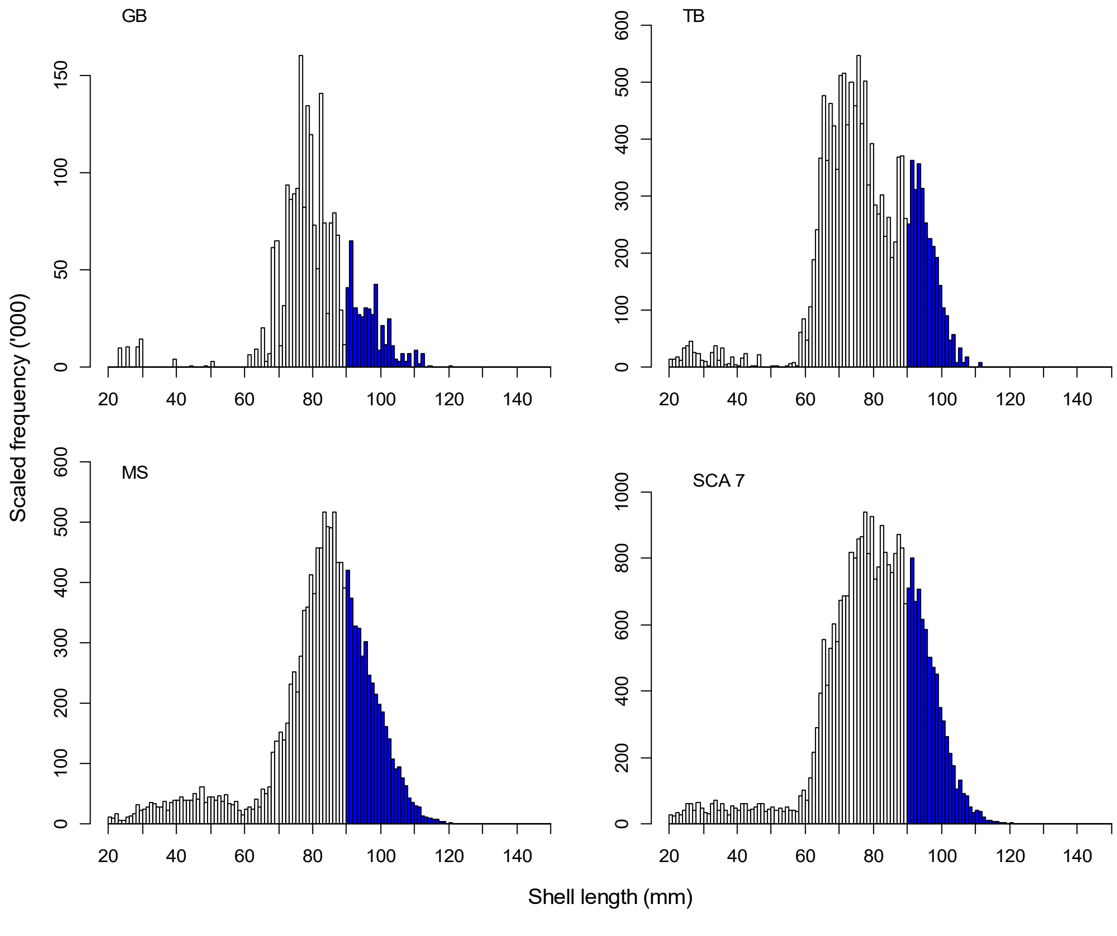

Figure 10: Substock length frequency distribution for scallops in Golden Bay (GB), Tasman Bay (TB), and Marlborough Sounds (MS) at the time of the survey, May 2020. Data are uncorrected for dredge efficiency. Dark shaded bars show recruited scallops (90 mm shell length or larger). Note y-axis varies between plots.

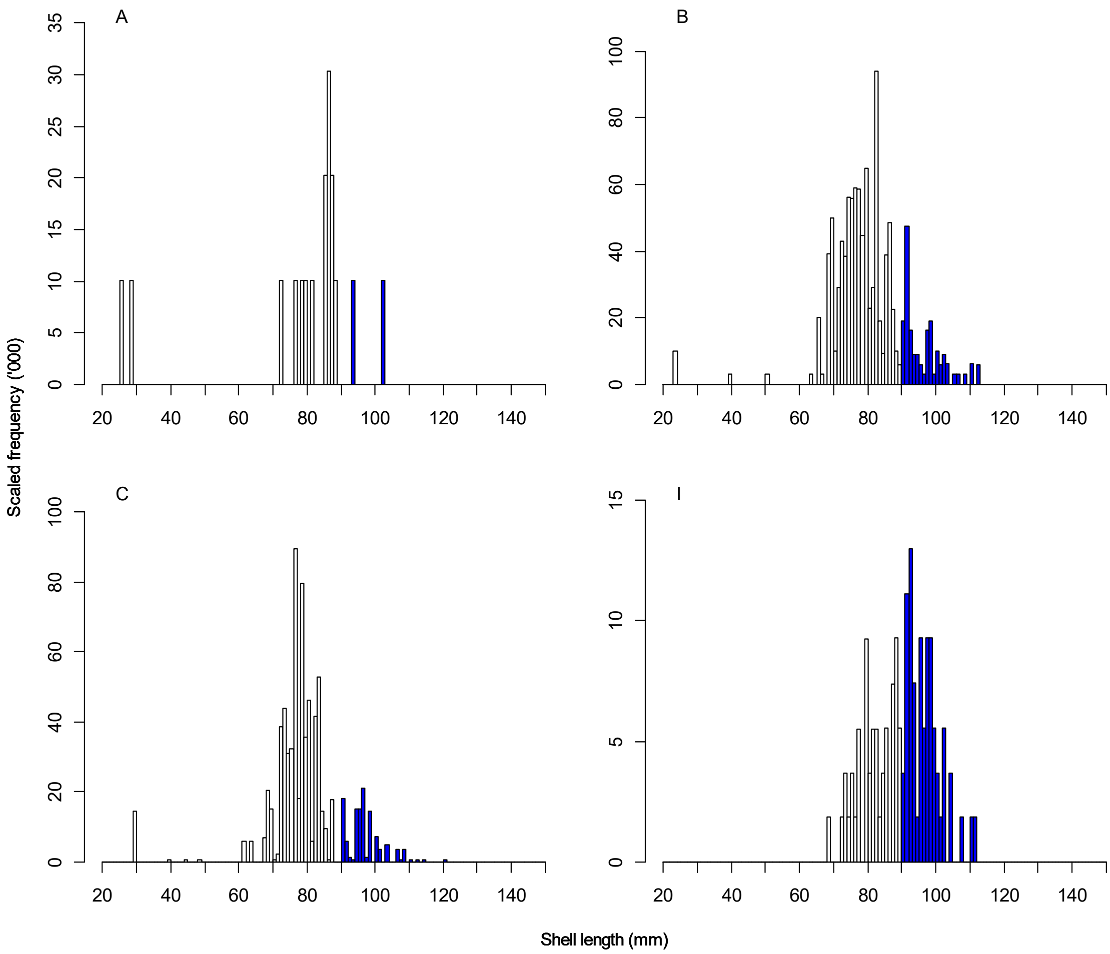

Figure 11: Sector length frequency distribution for scallops in Golden Bay at the time of the survey, May 2020. Data are uncorrected for dredge efficiency. Dark shaded bars show recruited scallops (90 mm shell length or larger). Note y-axis varies between plots.

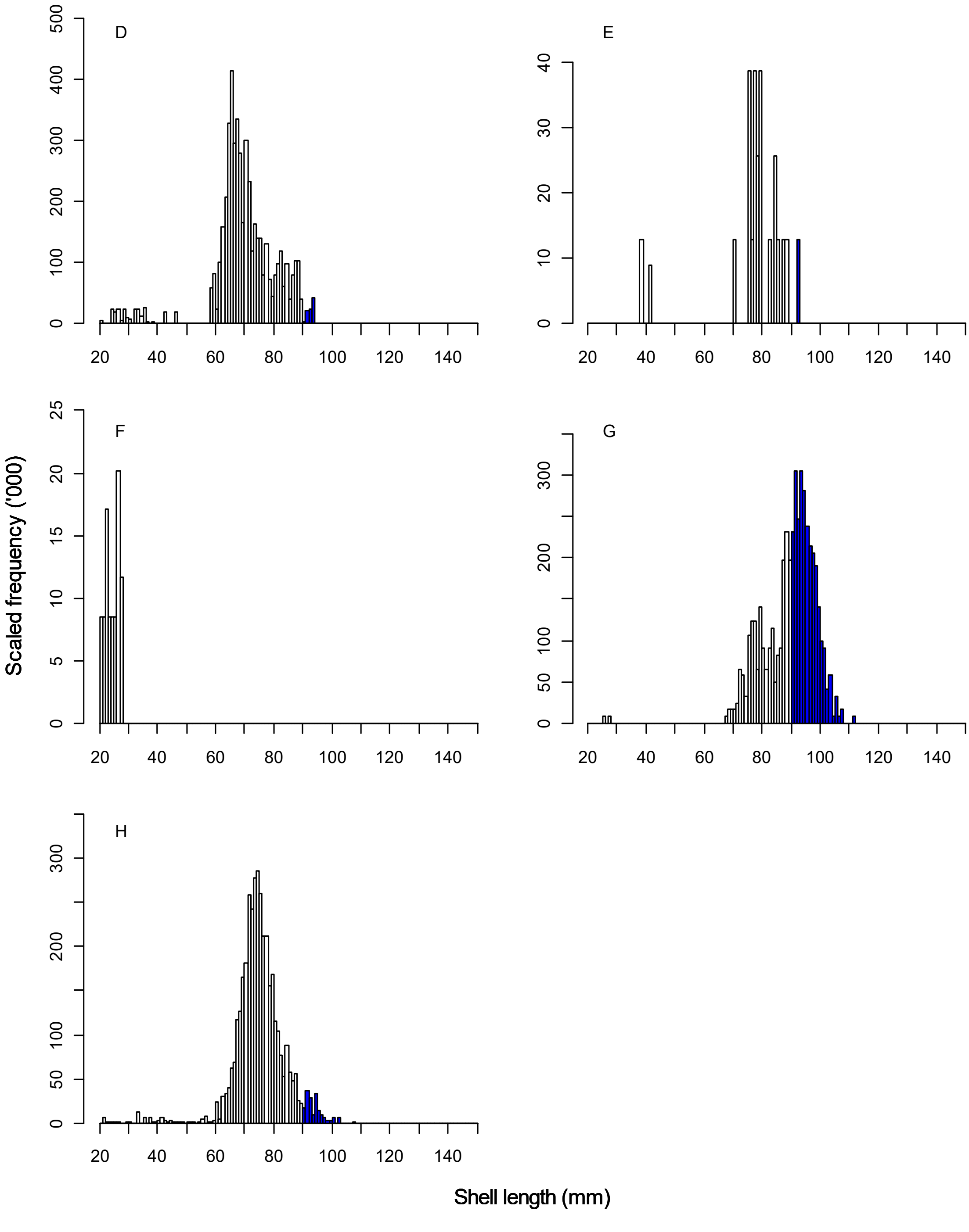

Figure 12: Sector length frequency distribution for scallops in Tasman Bay at the time of the survey, May 2020. Data are uncorrected for dredge efficiency. Dark shaded bars show recruited scallops (90 mm shell length or larger). Note y-axis varies between plots.

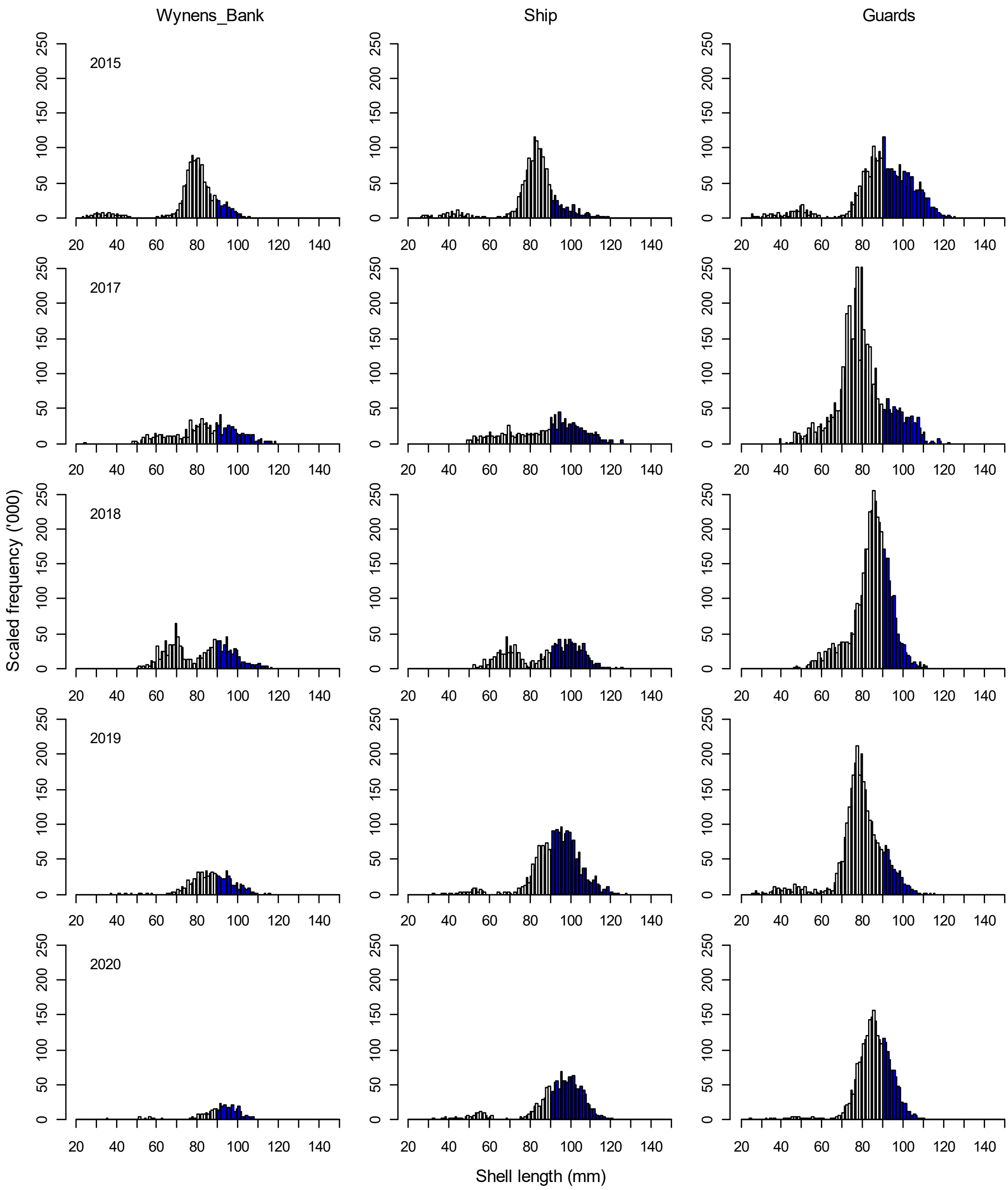

Figure 13: Stratum length frequency distributions for scallops in Marlborough Sounds at the time of the surveys 2015–2020, for key beds of interest: Wynens Bank (stratum 30), Ship Cove (stratum 38), and Guards Bank (strata 321 and 32 combined). Data are uncorrected for dredge efficiency. Dark blue shaded bars show recruited scallops (90 mm shell length or larger). Surveys were conducted in May except in 2017 and 2018 when the surveys were in January (see Appendix A: Table A.1).

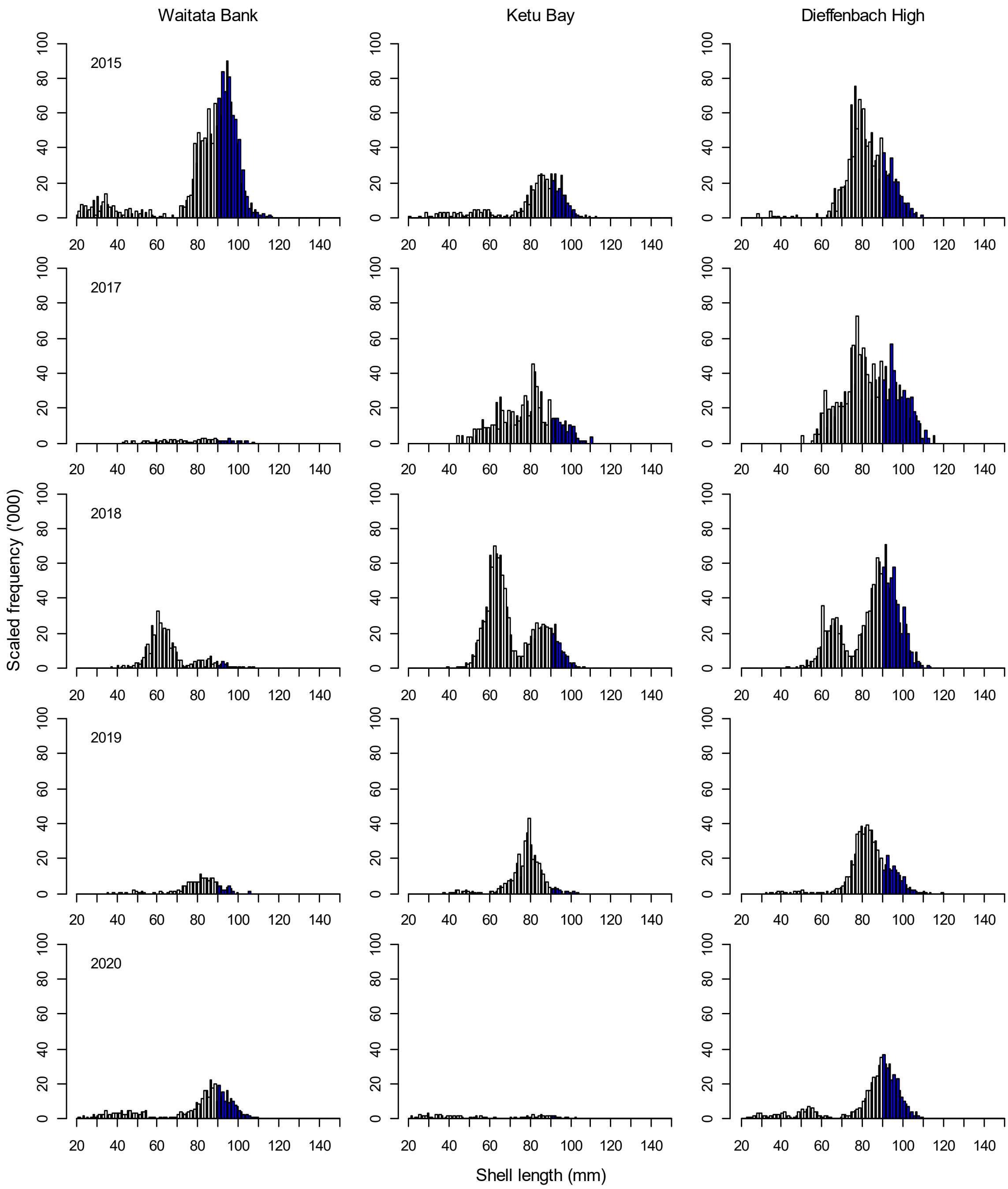

Figure 14: Stratum length frequency distributions for scallops in Marlborough Sounds at the time of the surveys 2015–2020, for key beds of interest: Waitata Bank (stratum 23), Ketu Bay (stratum 29), and Dieffenbach High (stratum 41). Data uncorrected for dredge efficiency. Dark blue shaded bars show recruited scallops (90 mm shell length or larger). Surveys were conducted in May except in 2017 and 2018 when the surveys were in January (see Appendix A: Table A.1).

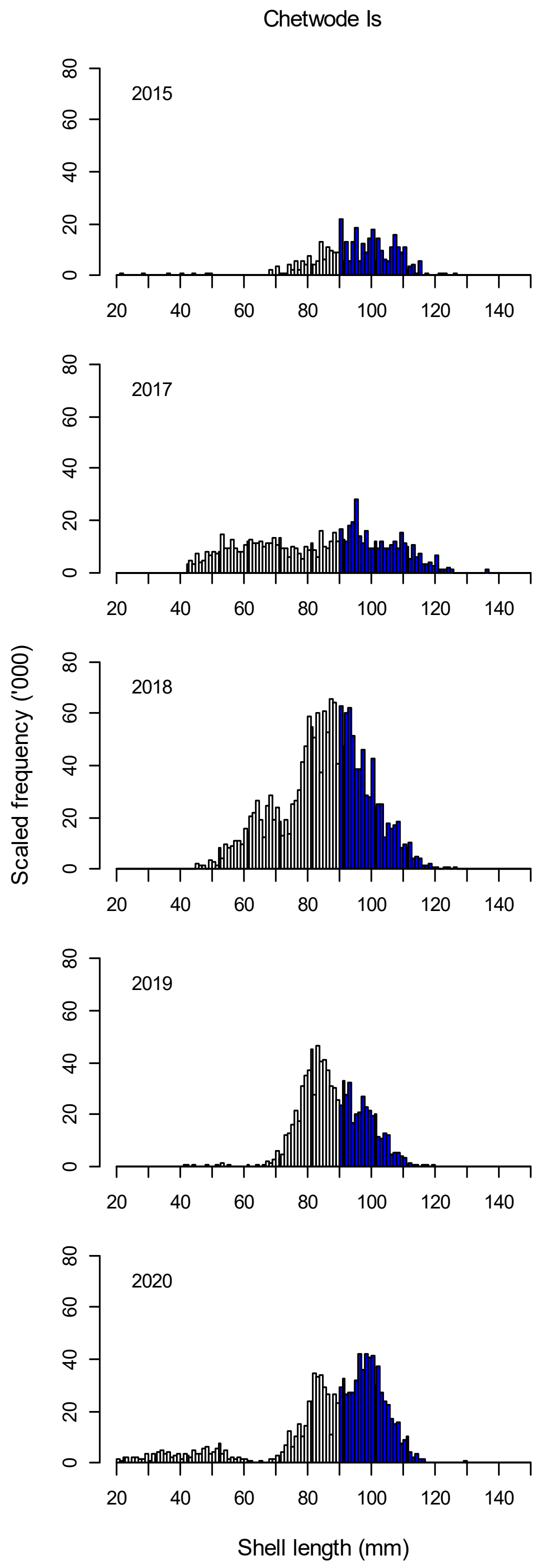

Figure 15: Stratum length frequency distributions for scallops in the Marlborough Sounds at the time of the surveys 2015–2020, for key beds of interest: Chetwode Islands (stratum 21). Data are uncorrected for dredge efficiency. Dark blue shaded bars show recruited scallops (90 mm shell length or larger). Surveys were conducted in May except in 2017 and 2018 when the surveys were in January (see Appendix A: Table A.1).

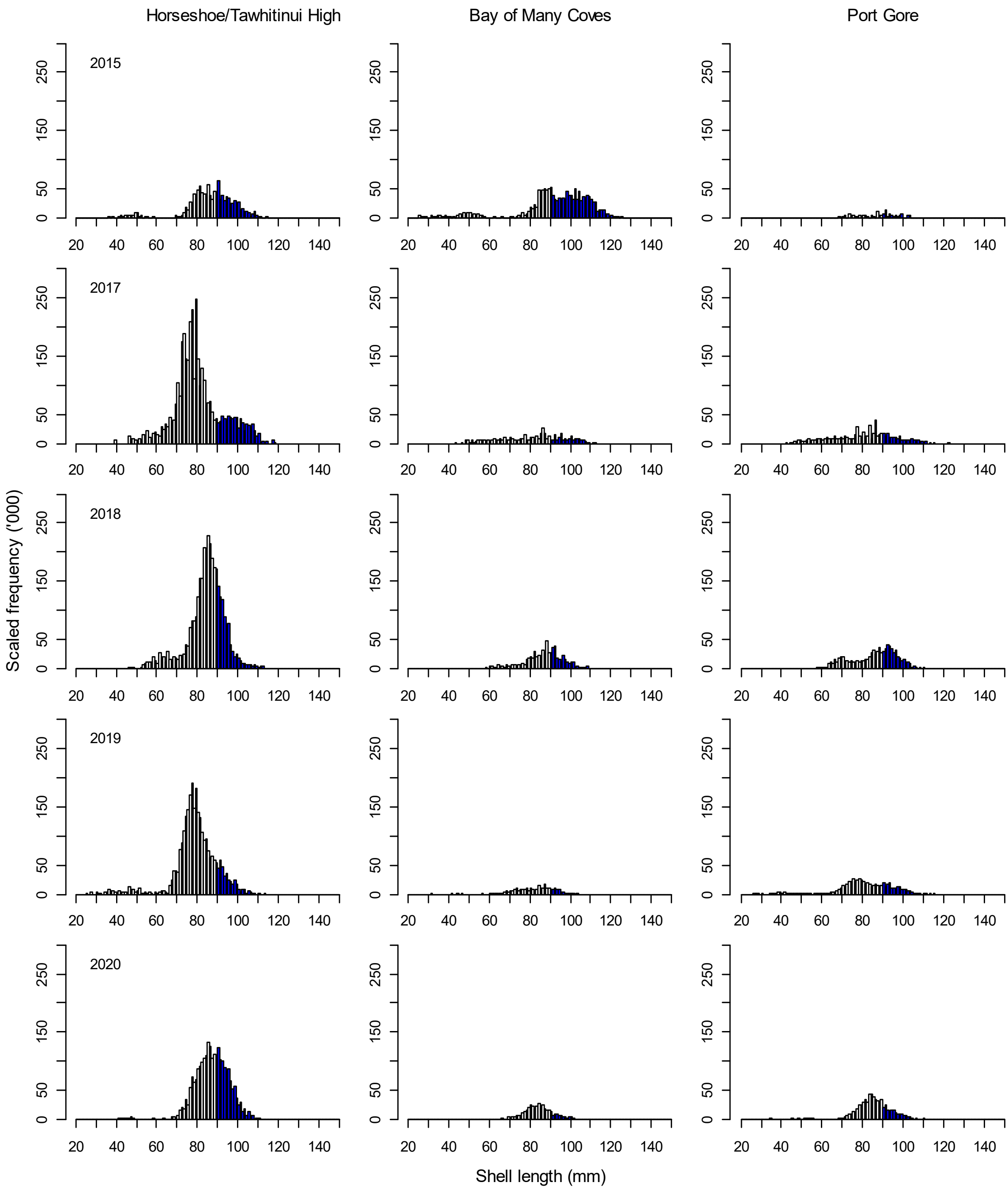

Figure 16: Stratum length frequency distributions for scallops in the Marlborough Sounds at the time of the surveys 2015–2020, for key beds of interest: Horseshoe Bay (stratum 26a) combined with Tawhitinui High (stratum 26b); Bay of Many Coves (strata 39a and b combined); and Port Gore (stratum 36). Data are uncorrected for dredge efficiency. Dark blue shaded bars show recruited scallops (90 mm shell length or larger). Surveys were conducted in May except in 2017 and 2018 when the surveys were in January (see Appendix A: Table A.1).

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, May 2019, and May 2020 surveys in the Marlborough Sounds, length frequency distributions (uncorrected for dredge efficiency) were constructed for live scallops and dead cluckers (note that in May 2019 and 2020 the dead cluckers had been further categorised into either 'new' cluckers with clean shells, presumably recently dead, or 'old' cluckers with fouled, presumably older, shells). In May 2020, at the level of the overall Marlborough Sounds scallop population, the modal length of new cluckers was slightly smaller than the model length of live scallops and old cluckers (Figure 17). Examination at the finer spatial scale of biotoxin areas reveals greater numbers of smaller 'new' cluckers in G43 (Pelorus Sound) and to a lesser extent in G100 (Chetwodes), whereas live scallop and clucker shell distributions are well matched in other areas (G42, G45, G46, G29) (see Appendix H: Figure H.1).

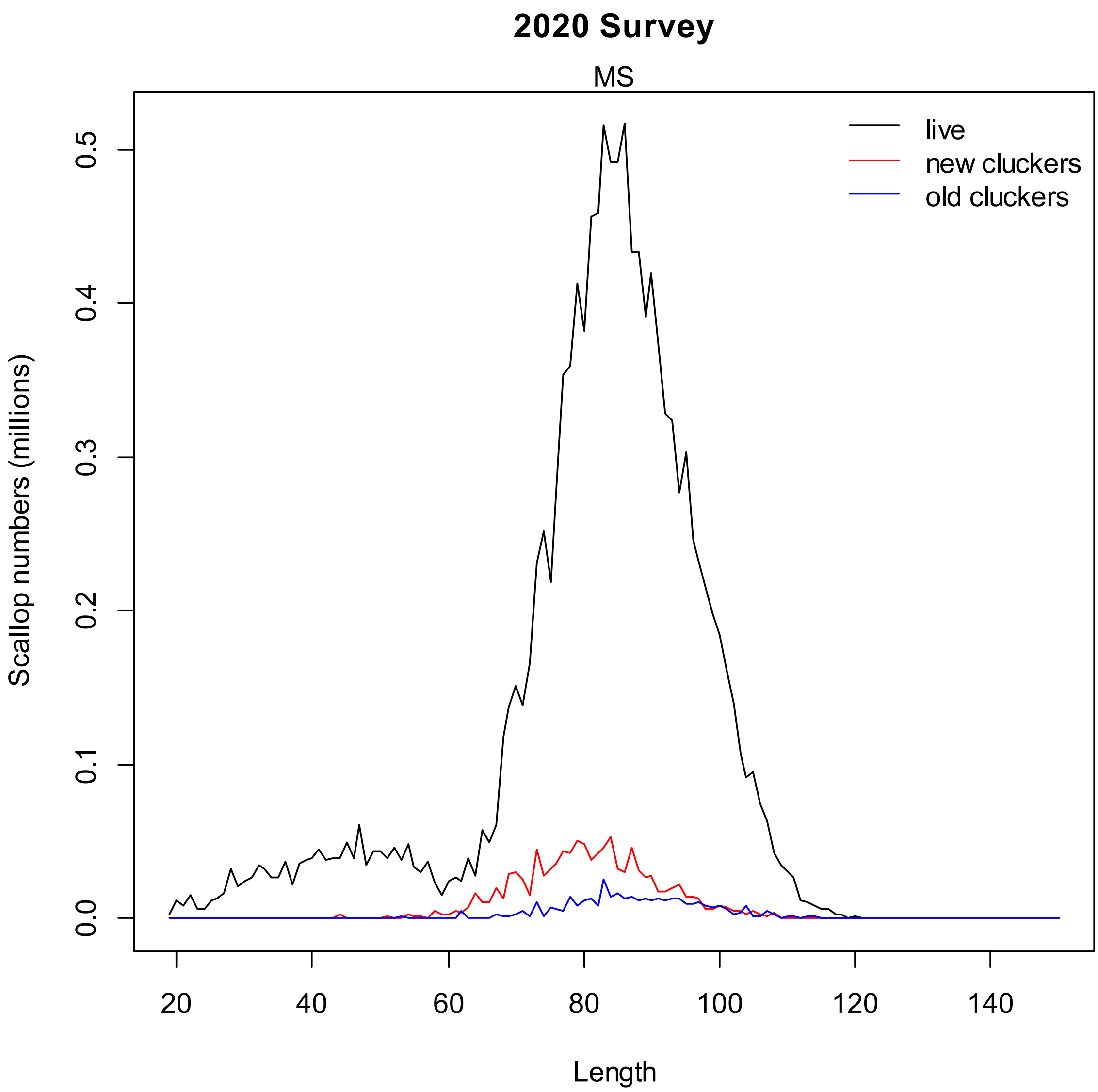

Figure 17: Live scallop versus new (clean) and old (fouled) dead clucker shell length (mm) distributions, Marlborough Sounds, May 2020.

3.4 Abundance indices

From the revised SCA 7 survey series analysis conducted in the 2019 survey analysis (Williams et al. 2019), 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 and overall SCA 7 stock (Figure 18), by sector (statistical reporting area) for Golden and Tasman bays (Figure 19), and by biotoxin area for Marlborough Sounds (Figure 20). 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 the 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.

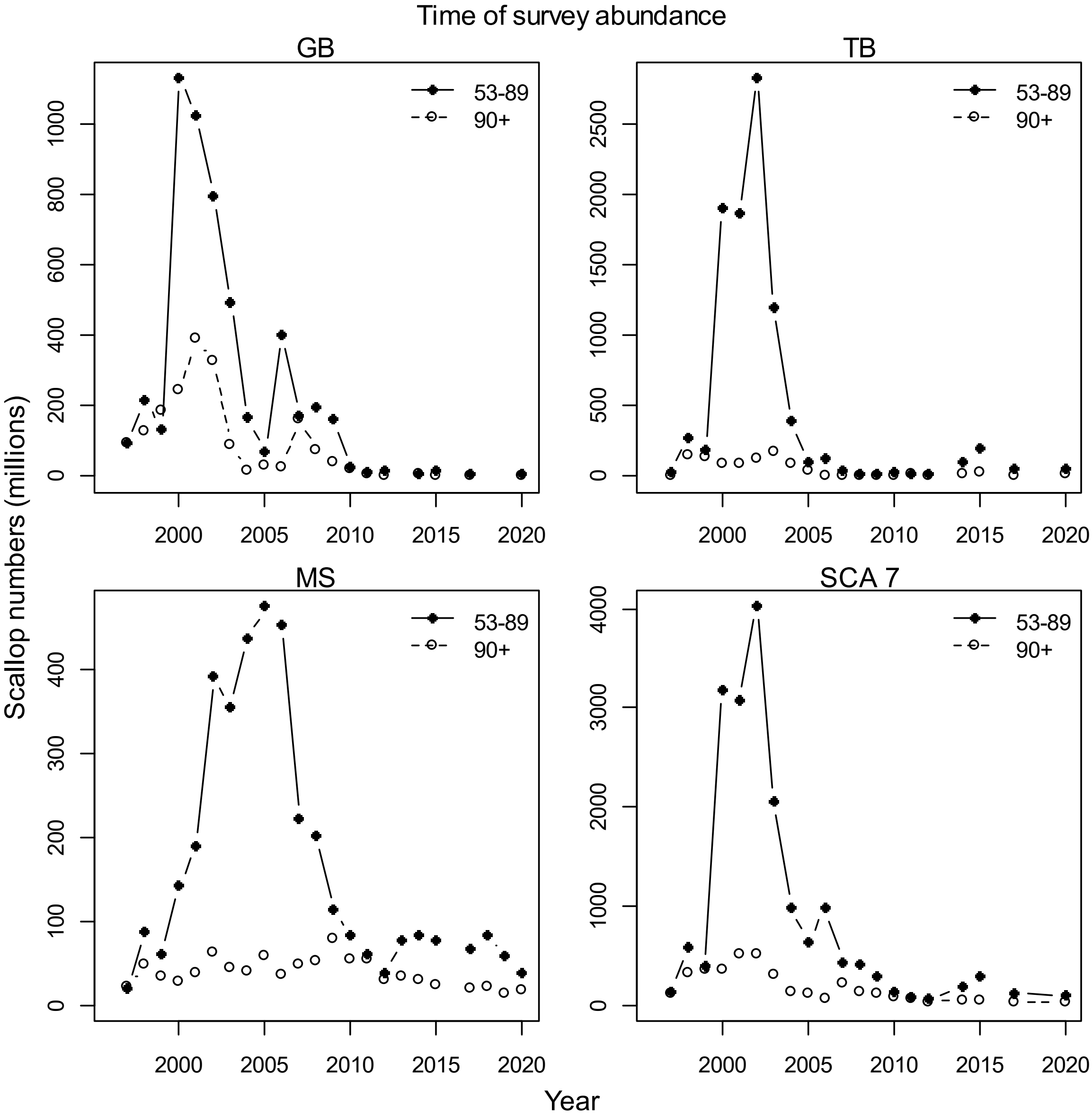

Figure 18: Time of survey abundance indices for pre-recruits (53–89 mm) and recruited scallops (90 mm or larger) from 1997 to 2020 by substock (Golden Bay, GB; Tasman Bay, TB; Marlborough Sounds, MS) and total SCA 7 stock. There was no survey in 2016, and Golden and Tasman bays were not surveyed in 2013, 2018, or 2019. Values are median estimates of abundance (scallop numbers), corrected for dredge efficiency (Tuck et al. 2018).

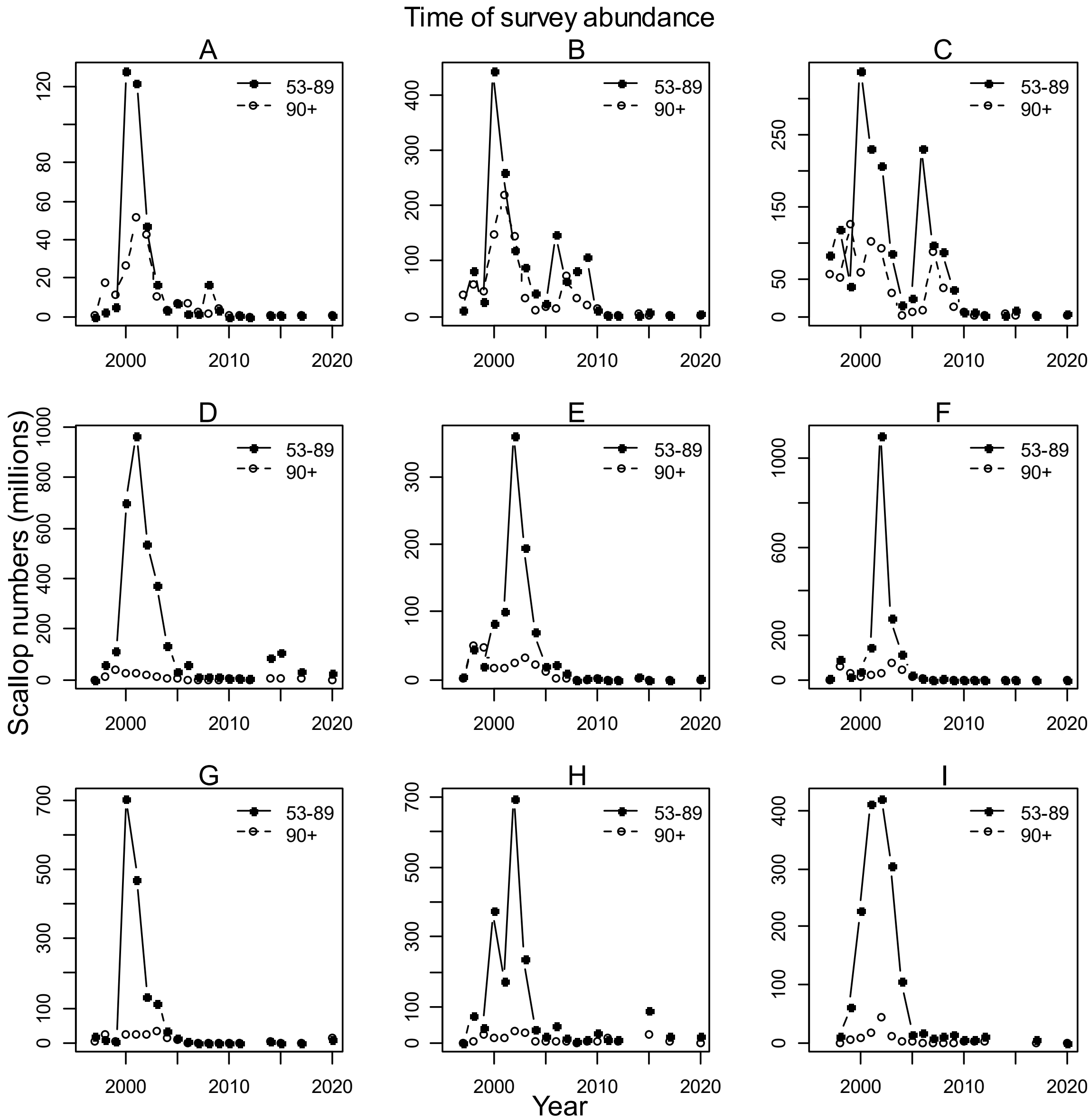

Figure 19: Time of survey abundance indices for pre-recruits (53–89 mm) and recruited scallops (90 mm or larger) from 1997 to 2020 by sector (statistical reporting area) in Golden Bay (A–C and I) and Tasman Bay (D–H). There was no SCA 7 survey in 2016, and Golden and Tasman bays were not surveyed in 2013, 2018, or 2019. Values are median estimates of abundance (scallop numbers), corrected for dredge efficiency (Tuck et al. 2018).

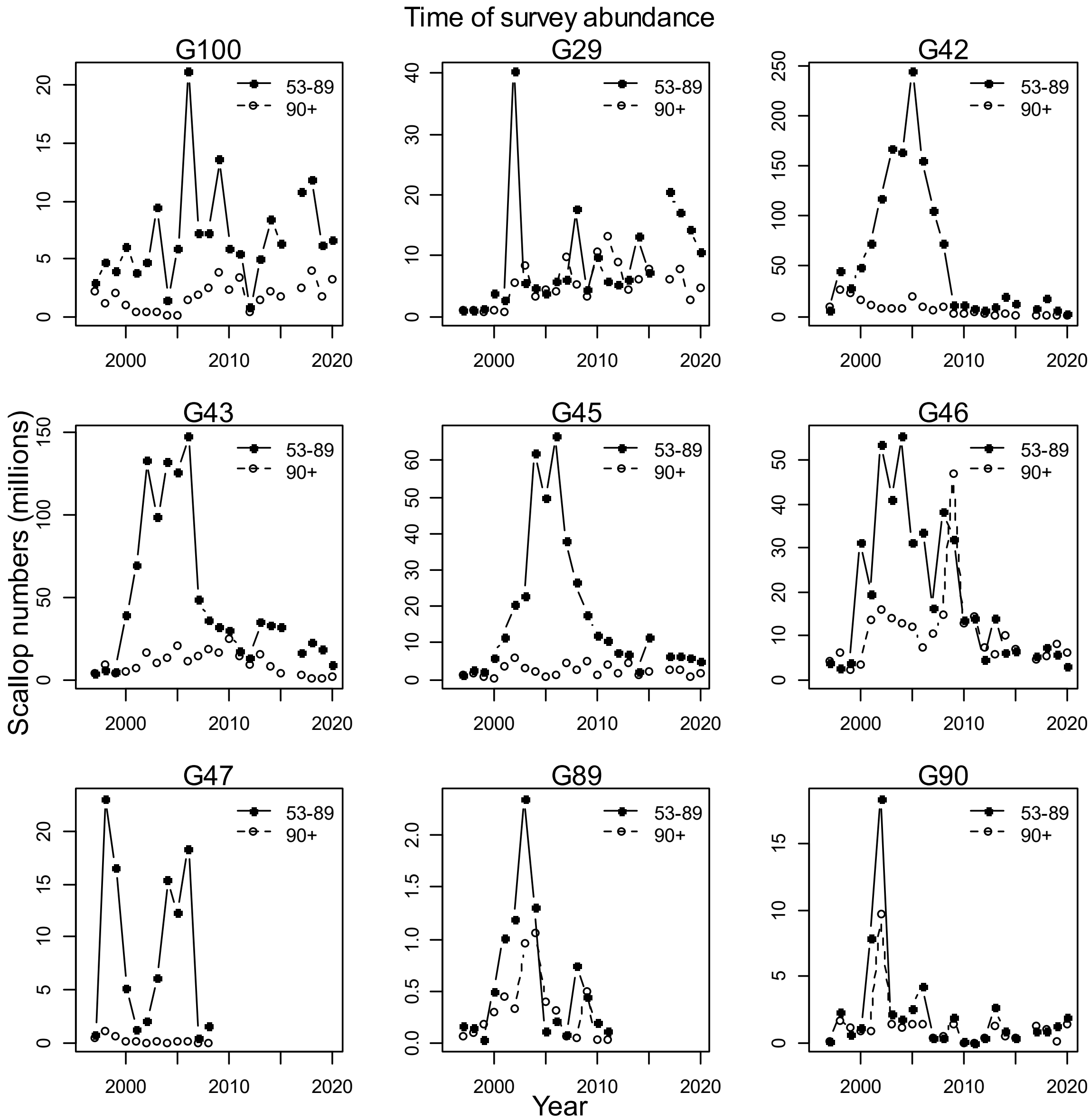

Figure 20: Time of survey abundance indices for pre-recruits (53–89 mm) and recruited scallops (90 mm or larger) from 1997 to 2020 by biotoxin area in Marlborough Sounds. There was no survey in 2016. Values are median estimates of abundance (scallop numbers), corrected for dredge efficiency (Tuck et al. 2018).

3.5 Time of survey (May) biomass

Scallop population estimates at the May 2020 time of survey were derived from the standard analysis using the full survey extent, including all 220 stratified random stations sampled by dredge tows (n = 214) and by Tow-Cam video transects in strata 34 and 171 (n = 6) and excluding the targeted non-random dredge tows in Tasman Bay (n = 5). Population estimates are tabulated in detail at different levels of grouping in Appendix C (see Table C.1 for estimates grouped by statistical reporting area/biotoxin area, substock, and total SCA 7 stock; see Table C.2 and Table C.3 for individual stratum estimates).

The May 2020 time of survey estimates of recruited biomass (t green weight, median values) by substock and stock were:

- 163 t in Golden Bay (95% CI = 99–252 t; mean = 167 t, CV = 24%)
- 1044 t in Tasman Bay (95% CI = 120–3100 t; mean = 1069 t, CV = 75%)
- 1535 t in Marlborough Sounds (95% CI = 1145–2029 t; mean = 1546 t, CV = 15%)

- 2680 t in SCA 7 (95% CI = 1519–4943 t; mean = 2782 t, CV = 32%)

The high uncertainty (i.e., low precision) of the Tasman Bay estimate stems from the influence of the single high catch at station 83 in stratum 16 whereas catches at all other stations in stratum 16 were low or zero. The effect of the single high catch can be seen in the multimodal distribution of the bootstrapped estimates for Tasman Bay (Figure 21). Consequently, uncertainty in the overall SCA 7 biomass estimate was higher than anticipated (CV = 32%).

Time series of May survey green weight estimates by substock (Golden Bay, Tasman Bay, Marlborough Sounds) and for the overall SCA 7 stock are shown in Figure 22. Trends in time of survey green weight biomass are also plotted in Appendix E, by sector (statistical reporting area) in Golden and Tasman bays (see Figure E.1) and by biotoxin area (see Figure E.2).

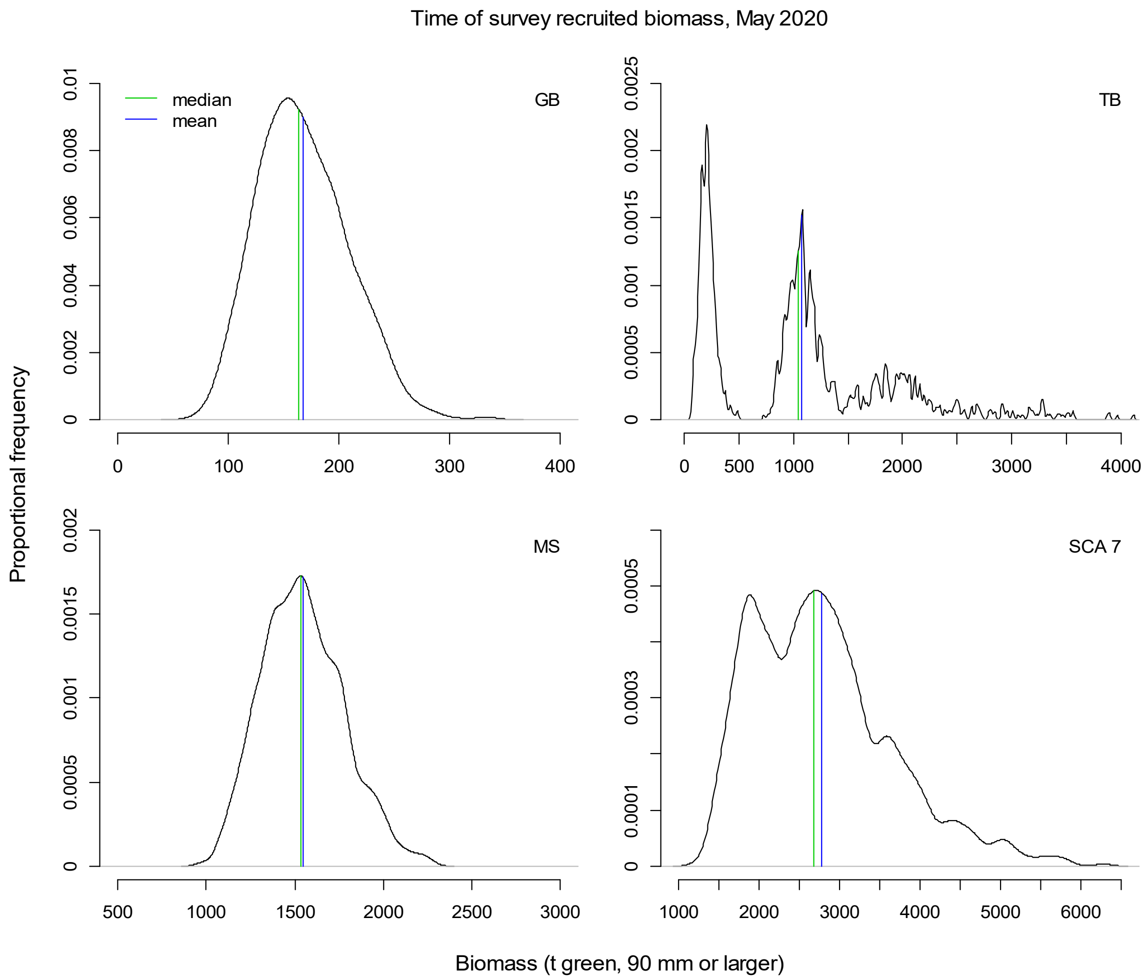

Figure 21: Proportional frequency distribution of the biomass (t green weight) of recruited scallops (90 mm or larger) in Golden Bay (GB), Tasman Bay (TB), and the Marlborough Sounds (MS) at the time of the survey, May 2020. The distribution was derived using a non-parametric resampling with replacement approach to estimation (1000 bootstraps), corrected for dredge efficiency (Tuck et al. 2018). Note a different bandwidth smoothing was required to plot the Tasman Bay distribution.

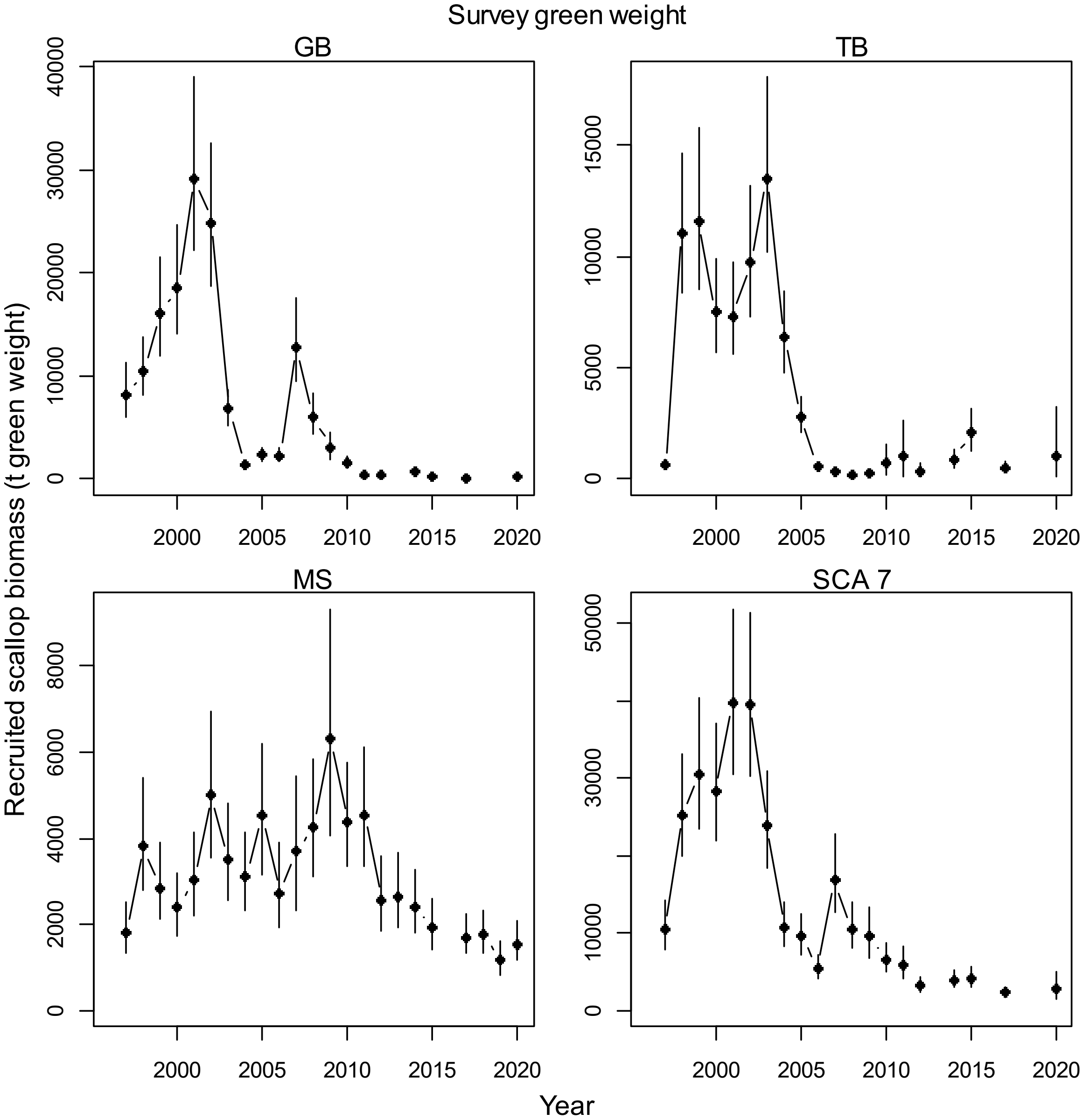

Figure 22: Trends in time of survey biomass (t green weight) of recruited scallops (90 mm or larger) by substock (GB, Golden Bay; TB, Tasman Bay; MS, Marlborough Sounds) and SCA 7 stock, 1997–2020. Values are the median and 95% confidence intervals of the estimated biomass. Surveys were conducted in May (sometimes April–May or May–June) in all years except in 2017 and 2018 when the surveys were in January (see Appendix A: Table A.1). There was no survey in 2016, and Golden and Tasman bays were not surveyed in 2013, 2018, or 2019.

Marlborough Sounds continues to hold most of the scallop biomass remaining within the SCA 7 survey extent. Estimates of green weight biomass in the Marlborough Sounds at the time of the surveys from 2015 to 2020 (and from January–May population projections in 2017 and 2018) were tabulated for comparison (Table 3). There was little change in the Marlborough Sounds recruited biomass estimates from 2015 to 2018, but the estimate was significantly lower in 2019. The 2020 estimate was slightly higher than the estimate in 2019.

Table 3: Summary of absolute recruited biomass (t green weight, denoted as Bgr) in Marlborough Sounds estimated from surveys between 2015 and 2020, correcting for dredge efficiency (Tuck et al. 2018). Time of survey estimates is shown, together with January–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
2020	May	Time of survey	MS	186	120	1 546	0.15	1 535	1 145	2 029

3.6 Projected (September) biomass

To allow comparisons with the nominal start of fishing season estimates from previous years, scallop population estimates for September 2020 were derived from projections from the time of the survey to 1 September 2020. Projected population estimates are tabulated in detail at different levels of grouping in Appendix F (see Table F.1 for estimates grouped by statistical reporting area/biotoxin area, substock, and total SCA 7 stock; see Table F.2 and Table F.3 for individual stratum estimates).

Projected biomass in September is estimated as meat weight because the commercial scallop fishery catch is managed in meat weight. The September 2020 projected recruited biomass estimates (t meat weight) by substock and stock were:

- 31 t in Golden Bay (95% CI = 17– 51 t; mean = 32 t, CV = 28%)
- 122 t in Tasman Bay (95% CI = 14–369 t; mean = 126 t, CV = 75%)
- 242 t in Marlborough Sounds (95% CI = 176–331 t; mean = 244 t, CV = 16%)

- 387 t in SCA 7 (95%CI = 238–655 t; mean = 401 t, CV = 27%)

Distributions of the 1000 bootstrapped estimates of projected biomass by substock are shown in Figure 23.

Projected estimates of September recruited biomass were plotted as time series to assess longer term trends by substock and for the overall SCA 7 stock (Figure 24). To aid comparisons in recent years, projected biomass estimates were tabulated for Marlborough Sounds for 2015–2020 (Table 4).

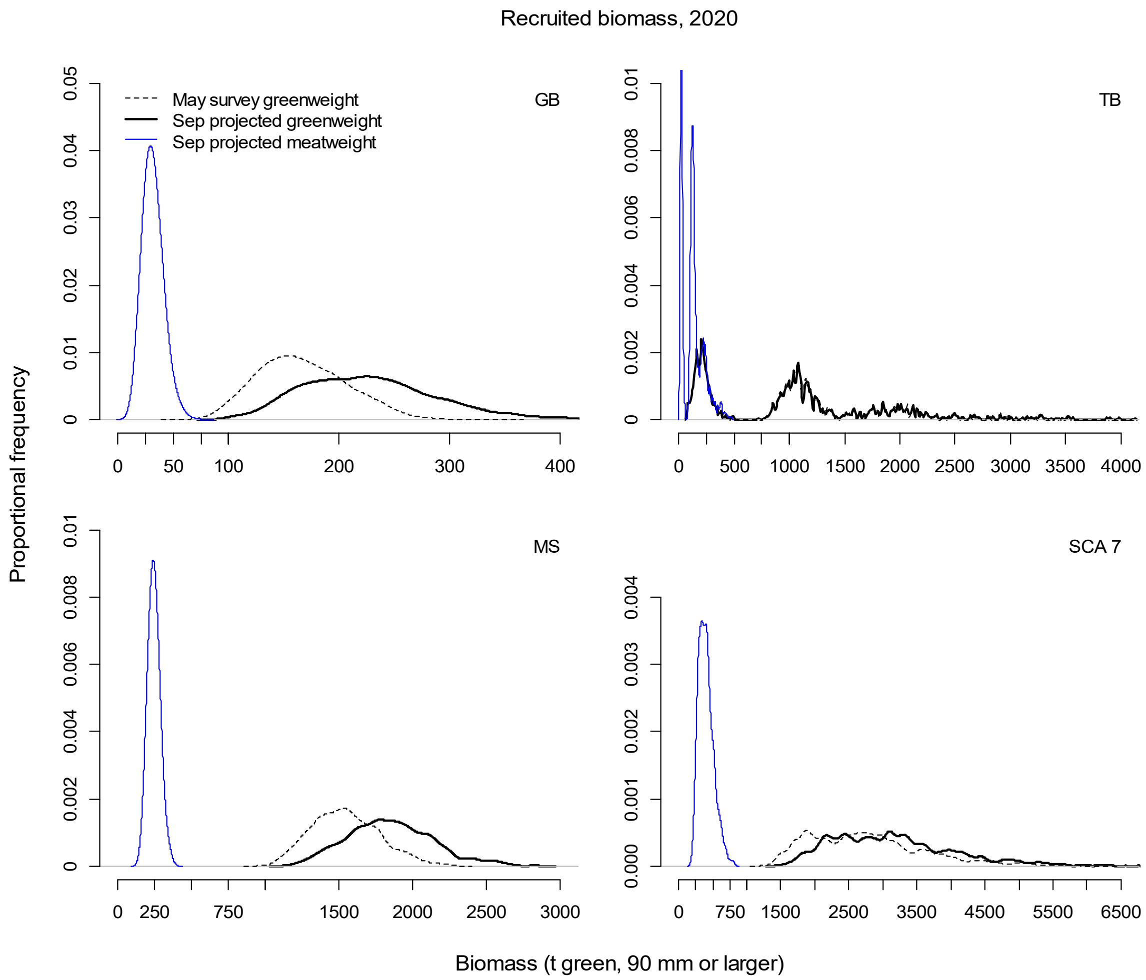

Figure 23: Proportional frequency distributions of the biomass of recruited scallops (90 mm or larger) in Golden Bay (GB), Tasman Bay (TB), and the Marlborough Sounds (MS) at the time of the survey in May 2020 (t green weight) and from projections to 1 September 2020 (Sep; in t green weight and t meat weight). Note that the Tasman Bay green weight distributions for May and September are not distinguishable on the plot because they are very similar (primarily because zero growth was applied in the May to September projection for Tasman Bay).

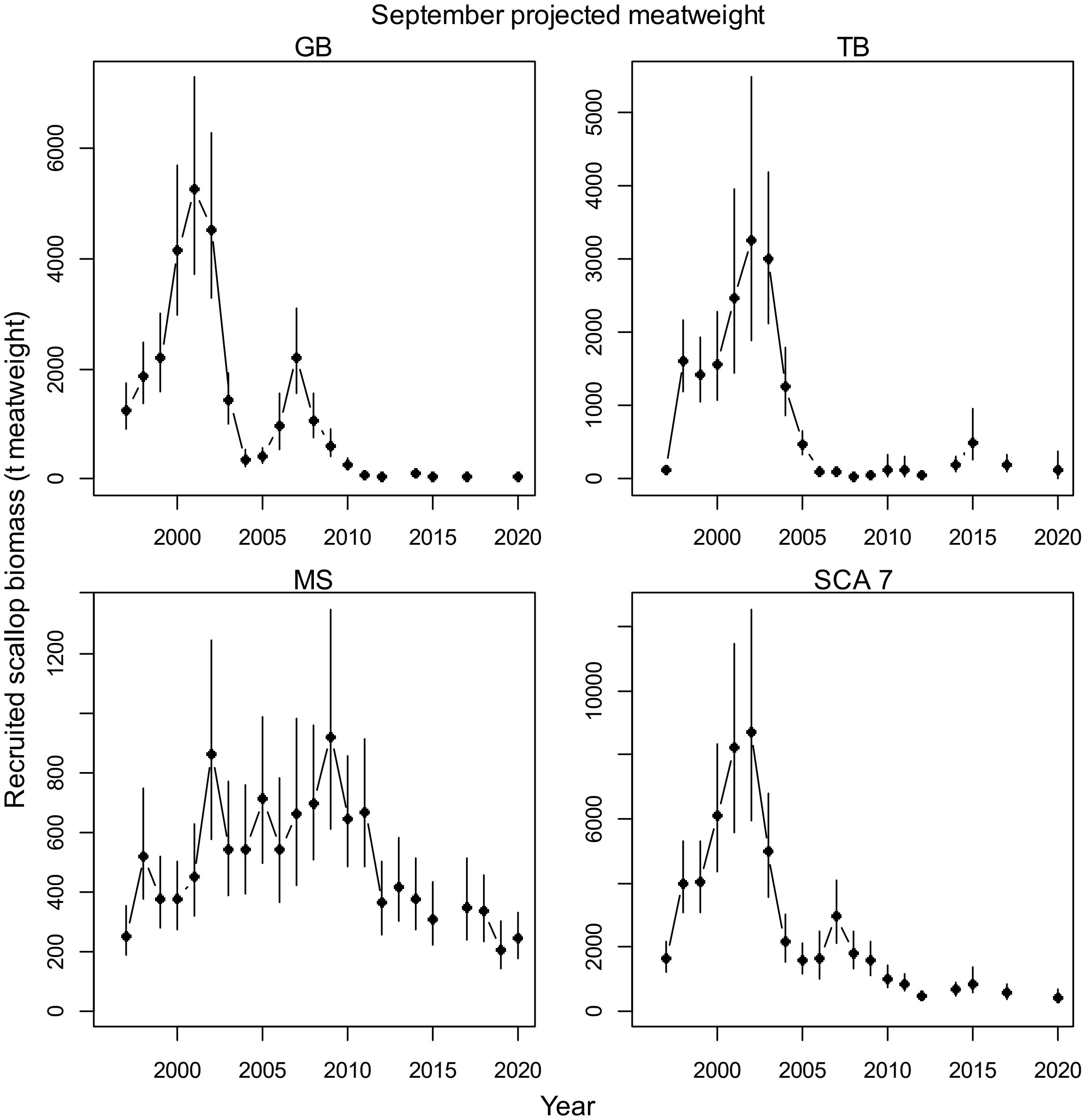

Figure 24: Trends in September projected biomass (t meat weight) of recruited scallops (90 mm or larger) by substock (GB, Golden Bay; TB, Tasman Bay; MS, Marlborough Sounds) and for the overall SCA 7 stock, 1997–2020. Values are the median and 95% confidence intervals of the estimated projected biomass. There was no survey in 2016, and Golden and Tasman bays were not surveyed in 2013, 2018, or 2019.

Table 4: Marlborough Sounds recruited biomass estimates (t meat weight) in September 2015, 2017, 2018, 2019, and 2020. 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
2020	Sep	Projected from May	MS	186	120	244	0.16	242	176	331

3.7 Projected biomass sensitivity to density

Biomass occurs 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 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 (one recruited scallop for each 5 m^2 of 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 2020 survey data were reanalysed assuming that all stations where scallops were scarcer than 0.04 m^{-2} have zero density, and stations where scallops were denser than 0.04 m^{-2} have a density of the actual density minus 0.04 m^{-2}. This was conducted for critical densities in the range 0 to 0.2 scallops m^{-2} as specified. Given the new estimate of SCA 7 ring-bag efficiency, we suggest future biomass sensitivity analyses should consider using critical densities higher than 0.2 m^{-2}.

Estimates of September 2020 projected biomass decreased with increasing critical threshold density: the decrease was rapid in Golden Bay where recruited densities were especially low, but more gradual in Tasman Bay and Marlborough Sounds (Figure 25; estimates tabulated in Appendix G: Table G.1). Of the Marlborough Sounds absolute projected biomass (243 t), 53% (130 t) was in areas with a critical density of 0.2 m^{-2} or higher. These are median point estimates of biomass, which have increasingly large uncertainty as the critical density threshold increases (see Appendix G: Table G.1).

Of the Marlborough Sounds 130 t recruited biomass available at the 0.2 m^{-2} density level, 94% was within five locations (see Appendix G: Table G.1): Guards Bay, Ship Cove, the Chetwodes, Dieffenbach Point, and Wynens Bank.

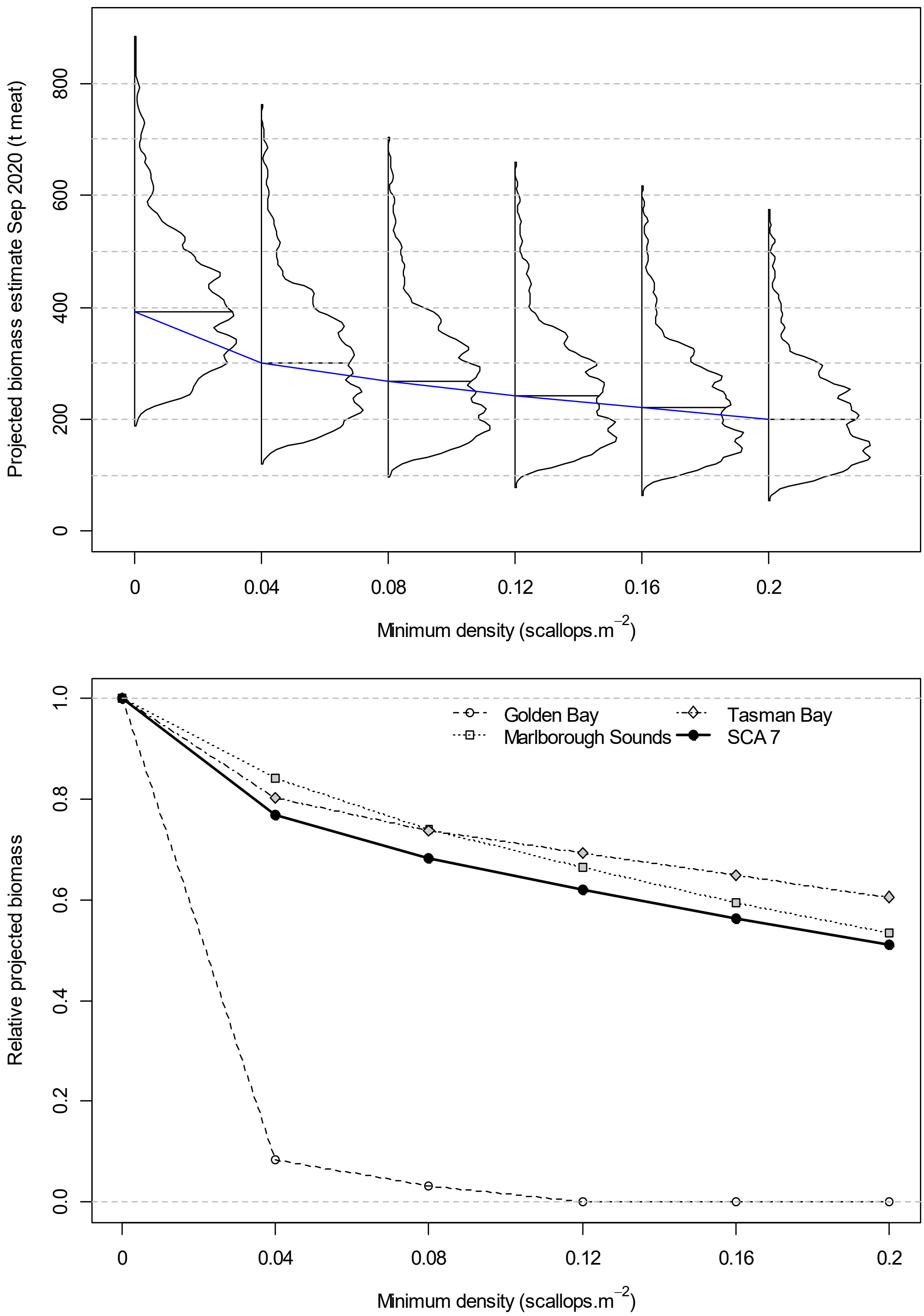

Figure 25: Effect of excluding areas of low scallop density on September projected estimates of recruited biomass, SCA 7, 2020. Critical density corrections were applied after correcting for dredge efficiency (Tuck et al. 2018). Top plot: for each minimum ('critical') density, the distribution and median (horizontal line) of the overall recruited biomass estimates are shown, with the blue line showing the trend in the median biomass estimates over time. Bottom plot: Trend in the proportion of the total recruited biomass with increasing critical density by substock and for the overall SCA 7 stock.

4. DISCUSSION

The May 2020 survey provides the most recent information to assess the status of SCA 7 scallop population. The key finding is that the SCA 7 recruited biomass for 2020 remains low.

Recruited scallop biomass in Golden Bay remains very low, and the only evidence of a scallop bed within the area surveyed is to the south of the tip of Farewell Spit. Recruited biomass was also very low in Tasman Bay, apart from slightly higher levels in Croisilles Harbour and in sector G where the 2020 sampling provides evidence of a bed of scallops and horse mussels off The Glen in south-eastern Tasman Bay that was not detected in the previous survey there in 2017 (Williams et al. 2017).

Recruited scallop biomass in the Marlborough Sounds also remains low, at a level similar to that in 2019 (Williams et al. 2019), with most of the biomass in the same five locations: Guards Bay, Ship Cove, the Chetwodes, Dieffenbach Point, and Wynens Bank. Recruitment, as measured by the abundance of pre-recruit scallops, continues to follow a declining trend or remain consistently low, except for at the Chetwode Islands where the level of recruitment is similar to the 1997–2020 historical average. Recruitment in Queen Charlotte Sound is following a declining trend, but is currently at the average level for that area. However, the abundance of small juvenile scallops in the Marlborough Sounds was noticeably higher in 2020 than in recent years, presumably the result of favourable larval settlement and spat survivorship since the 2019–20 spring-summer spawning period. The scallop bed at Waitata Bank in Pelorus Sound which underwent a large mortality event between 2015 and 2017 (Williams et al. 2017) appears to have been recovering since.

The present study produced updated time series of survey (May) biomass and start-of-season (September-projected) biomass using the new dredge efficiency curve (Tuck et al. 2018) and growth projections using an inverse logistic model (Tuck & Williams 2012). As discussed by Williams et al. (2019), the calculated uncertainties associated with the biomass estimates cannot capture all uncertainties, and comparisons across years are confounded somewhat by changes to survey coverage (e.g., surveys before 2009 covered a far greater spatial extent).

To date, the annual dredge survey has been used as the primary method to monitor the scallop population in SCA 7 (or in Marlborough Sounds only in some years). Although the dredge survey provides good estimates of the scallop population over large spatial scales within the areas historically fished commercially, it provides no information on the status of non-commercial scallop beds that cannot be surveyed using dredges, which lie outside the traditionally dredge-surveyed areas. Anecdotal information from customary fishers and recreational divers suggests scallops are abundant in some areas (e.g., inner Queen Charlotte Sounds) that lie outside the dredge survey coverage. There is interest in conducting a non-contact survey of scallops in non-commercial fishing areas within Marlborough Sounds in 2021, using divers and the development of camera-based survey methods to provide new insights on the status of the overall scallop population and associated habitats, while minimising benthic disturbance. Combining diver/camera-based survey sampling with some dredge sampling in the commercial areas in 2021 could provide additional information to improve understanding of dredge efficiency in SCA 7 (Tuck et al. 2018).

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APPENDIX A: SCA 7 surveys 1994–2020

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). For 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. A SCA 7 stock-wide survey (Golden Bay, Tasman Bay, and Marlborough Sounds) was conducted in January 2017 (Williams et al. 2017), and 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 2020 survey of scallops in Marlborough Sounds. Details of the surveys conducted since 1994 are shown in Table A.1.

Table A.1: 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. (2013)
	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)	Williams et al. (2019)
2020	5	OKA2001	GB, TB, MS	*Okarito* (Cris West)	Present study

APPENDIX B: Scallop catch density by stratum, May 2020

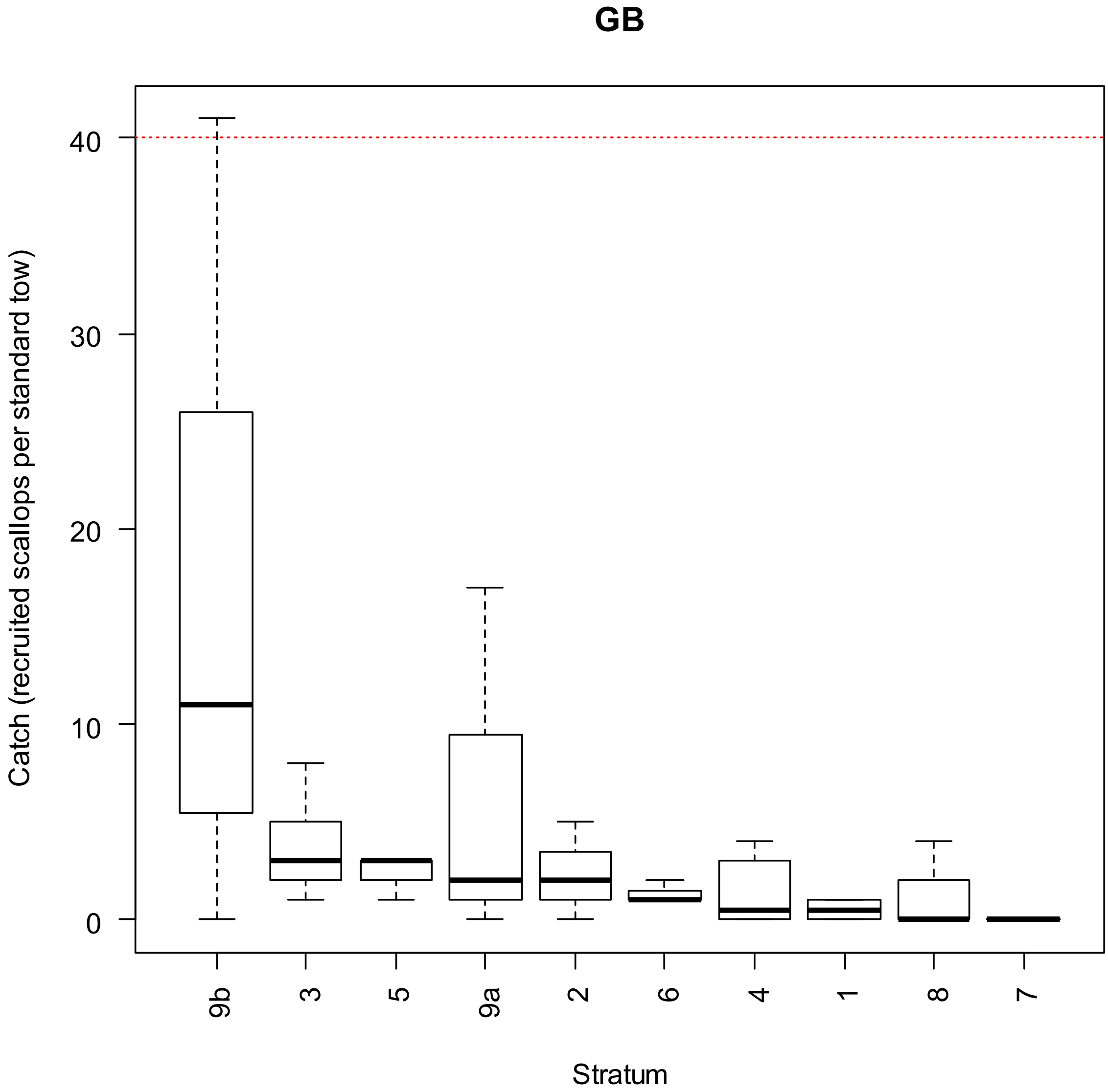

Figure B.1: Boxplot of catch density (recruited scallops per standard 0.4 n. mile tow) by stratum in Golden Bay, May 2020. Strata in decreasing order of median density (x-axis left to right). Horizontal dashed line denotes a median density of 40 recruited scallops per standard tow.

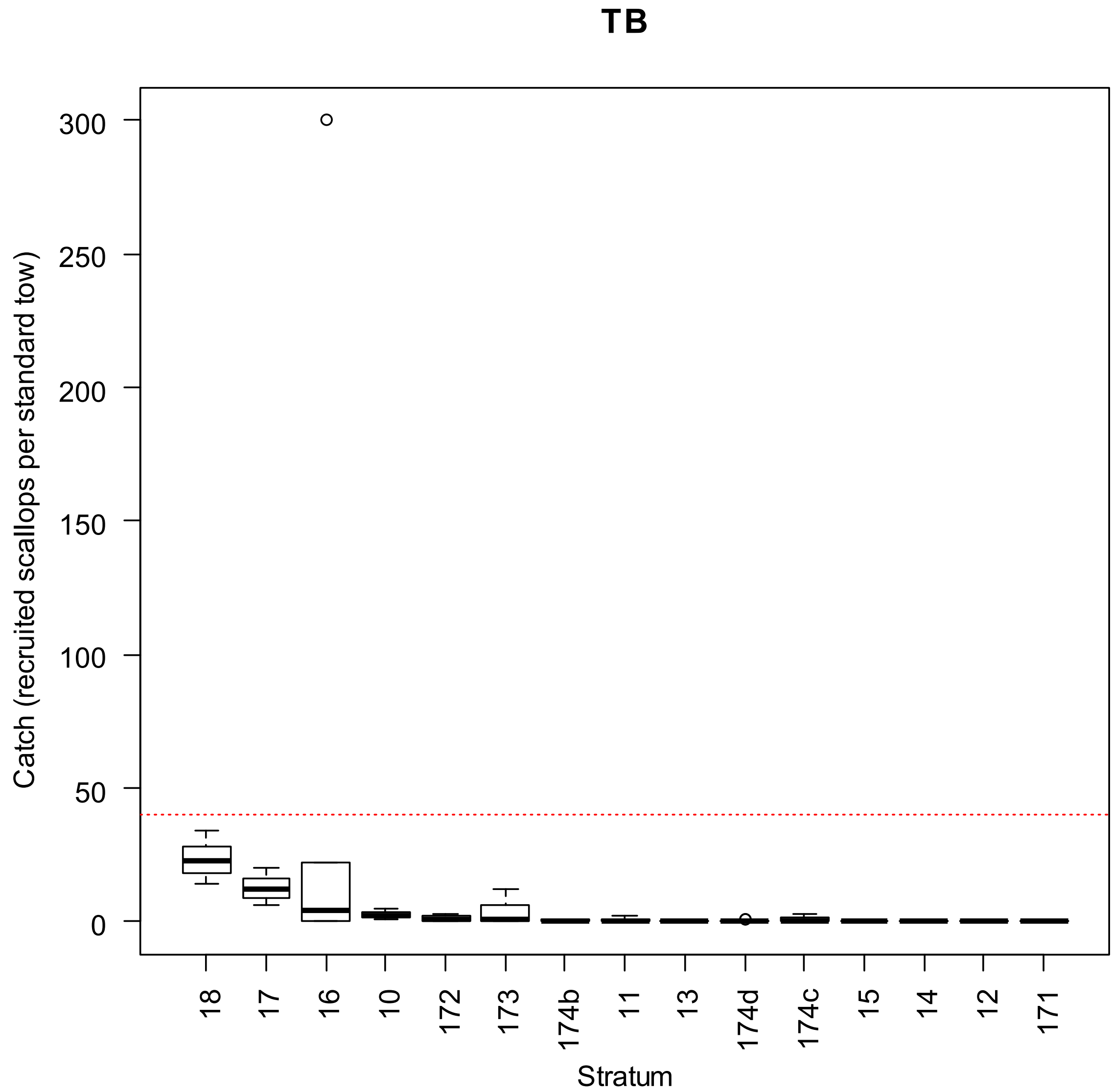

Figure B.2: Boxplot of scallop catch density (recruited scallops per standard 0.4 n. mile tow) by stratum in Tasman Bay, May 2020. Strata in decreasing order of median density (x-axis left to right). Horizontal dashed line denotes a median density of 40 recruited scallops per standard tow.

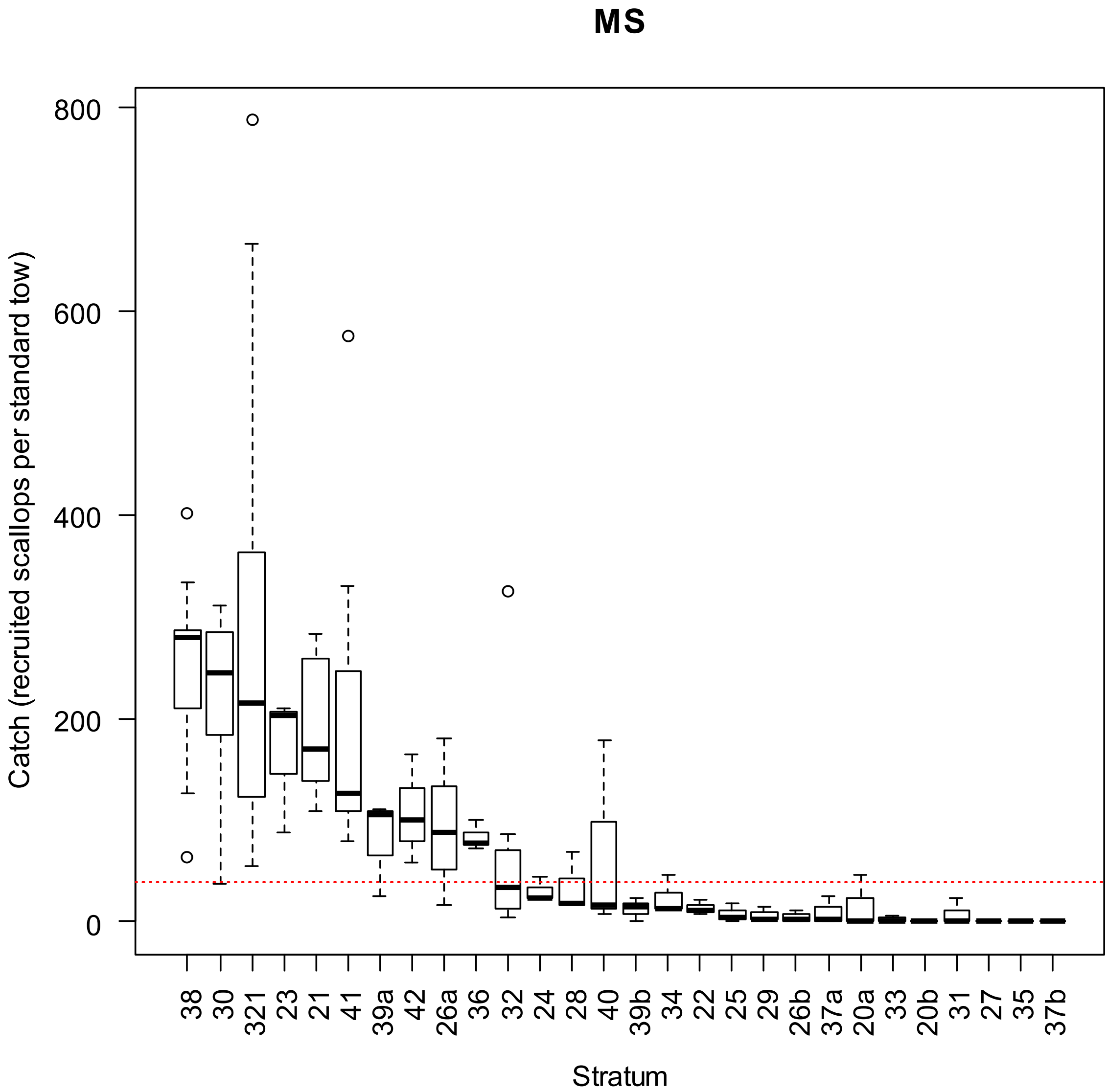

Figure B.3: Boxplot of scallop catch density (recruited scallops per standard 0.4 n. mile tow) by stratum in Marlborough Sounds, May 2020. Strata in decreasing order of median density (x-axis left to right). Horizontal dashed line denotes a median density of 40 recruited scallops per standard tow.

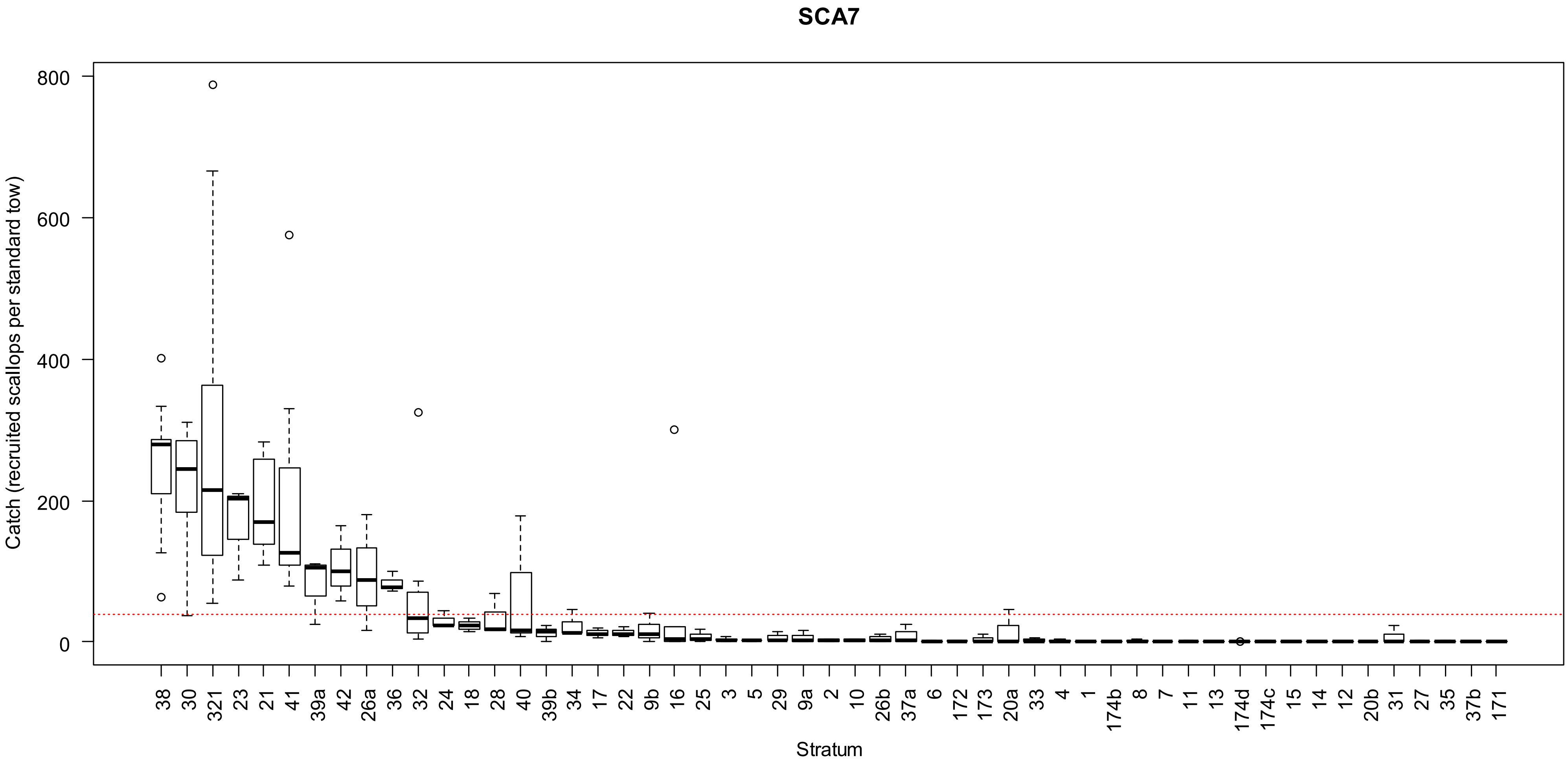

Figure B.4: Boxplot of scallop catch density (recruited scallops per standard 0.4 n. mile tow) by stratum in SCA 7, May 2020. Strata in decreasing order of median density (x-axis left to right). Horizontal dashed line denotes a median density of 40 recruited scallops per standard tow.

APPENDIX C: Survey population estimates, May 2020

Table C.1: Time of survey population estimates of scallops in SCA 7 in May 2020 (full survey extent) at different spatial scales: statistical reporting area (stat area), biotoxin area, substock, and 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 (W = aL^b where mean values for these parameters are a = 0.00037 and b = 2.69, using length and weight data from Cryer & Parkinson 2006). The analysis used a non-parametric resampling with replacement approach to estimation (1000 bootstraps).

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	Code	Area		Density (scallops m^{-2})					Abundance (millions)					Scallop weight (g)		Biomass (t green)				
Grouping		(km^2)	n	mean	CV	median	95%CI		mean	CV	median	95%CI		mean	median	mean	CV	median	95%CI	
Stat area	A	72	4	0.001	0.52	0.001	0.000	0.003	0.097	0.52	0.096	0.000	0.201	83.1	83.7	8	0.52	8	0	17
	B	181	16	0.005	0.27	0.005	0.003	0.008	0.952	0.27	0.930	0.511	1.498	80.4	80.1	76	0.27	75	42	120
	C	206	17	0.003	0.43	0.003	0.001	0.005	0.570	0.43	0.550	0.210	1.114	80.8	81.1	46	0.40	45	18	87
	I	10	3	0.046	0.61	0.045	0.000	0.103	0.456	0.61	0.440	0.000	1.022	80.7	80.7	37	0.61	36	0	83
	D	255	10	0.002	0.44	0.002	0.000	0.003	0.436	0.44	0.421	0.114	0.840	71.1	71.1	31	0.45	30	8	60
	E	116	6	0.000	0.88	0.001	0.000	0.001	0.058	0.88	0.059	0.000	0.163	70.7	70.6	4	0.88	4	0	12
	F	108	6	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
	G	88	6	0.143	0.83	0.140	0.004	0.441	12.547	0.83	12.273	0.352	38.766	77.6	77.8	974	0.82	955	30	2 990
	H	240	32	0.003	0.21	0.003	0.002	0.005	0.817	0.21	0.800	0.523	1.181	74.0	74.0	60	0.21	59	39	88
Biotoxin	G100	22	15	0.147	0.19	0.146	0.100	0.203	3.288	0.19	3.252	2.228	4.531	85.1	85.4	280	0.18	278	191	386
	G43	28	19	0.059	0.19	0.059	0.039	0.083	1.650	0.19	1.634	1.076	2.305	73.7	73.7	122	0.19	120	80	170
	G42	27	9	0.013	0.35	0.013	0.005	0.022	0.343	0.35	0.341	0.122	0.595	75.3	75.2	26	0.37	26	9	45
	G45	13	11	0.118	0.21	0.117	0.074	0.169	1.560	0.21	1.544	0.980	2.235	76.7	76.8	120	0.21	119	76	170
	G46	24	26	0.248	0.24	0.242	0.142	0.374	6.018	0.24	5.889	3.444	9.093	87.2	87.1	525	0.25	513	299	791
	G90	44	6	0.033	0.16	0.032	0.024	0.044	1.423	0.16	1.406	1.031	1.936	80.6	80.7	115	0.15	113	84	155
	G29	28	34	0.169	0.16	0.167	0.120	0.225	4.710	0.16	4.670	3.340	6.294	76.3	76.1	359	0.16	355	254	481
Substock	GB	469	40	0.004	0.25	0.004	0.003	0.007	2.076	0.25	2.022	1.213	3.115	80.7	80.7	167	0.24	163	99	252
	TB	806	60	0.017	0.75	0.017	0.002	0.050	13.857	0.75	13.503	1.558	40.286	77.2	77.3	1 069	0.75	1 044	120	3 100
	MS	186	120	0.102	0.15	0.101	0.076	0.134	18.992	0.15	18.837	14.145	24.868	81.4	81.5	1 546	0.15	1 535	1 145	2 029
Stock	SCA 7	1 461	220	0.024	0.32	0.023	0.013	0.043	34.925	0.32	33.626	18.835	62.442	79.7	79.7	2 782	0.32	2 680	1 519	4 943

Table C.2: Time of survey population estimates of scallops in Golden and Tasman Bays in May 2020 (full survey extent) by stratum. 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 ($W = aL^b$ where mean values for these parameters are a = 0.00037 and b = 2.69, using length and weight data from Cryer & Parkinson 2006). The analysis used a non-parametric resampling with replacement approach to estimation (1000 bootstraps).

CORRECTED FOR DREDGE EFFICIENCY

		Area		Density (scallops m^{-2})					Abundance (millions)					Scallop weight (g)		Biomass (t green)				
Grouping	Code	(km^2)	n	mean	CV	median	95%CI		mean	CV	median	95%CI		mean	median	mean	CV	median	95%CI	
Stratum	1	72	4	0.001	0.52	0.001	0.000	0.003	0.097	0.52	0.096	0.000	0.201	83.1	83.7	8	0.52	8	0	17
	2	42	4	0.006	0.40	0.006	0.001	0.011	0.247	0.40	0.241	0.058	0.461	80.3	80.1	20	0.45	19	4	40
	3	33	6	0.010	0.28	0.010	0.005	0.016	0.323	0.28	0.314	0.177	0.525	87.2	87.4	28	0.28	27	15	46
	4	107	6	0.004	0.51	0.004	0.000	0.007	0.382	0.51	0.377	0.043	0.793	74.6	73.8	28	0.51	28	3	59
	5	19	3	0.006	0.27	0.006	0.003	0.009	0.116	0.27	0.117	0.053	0.179	90.3	89.5	11	0.25	10	5	16
	6	32	3	0.004	0.24	0.004	0.002	0.005	0.114	0.24	0.113	0.071	0.172	79.9	79.0	9	0.22	9	6	13
	7	74	5	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
	8	77	3	0.004	0.84	0.003	0.000	0.011	0.275	0.84	0.268	0.000	0.810	74.4	74.3	20	0.84	20	0	60
	9a	4	3	0.017	0.73	0.016	0.000	0.043	0.065	0.73	0.063	0.000	0.167	92.4	92.3	6	0.74	6	0	16
	9b	10	3	0.046	0.61	0.045	0.000	0.103	0.456	0.61	0.440	0.000	1.022	80.7	80.7	37	0.61	36	0	83
	10	9	3	0.007	0.40	0.007	0.003	0.013	0.061	0.40	0.059	0.025	0.115	71.0	71.0	4	0.39	4	2	8
	11	246	7	0.002	0.51	0.001	0.000	0.003	0.375	0.51	0.357	0.078	0.790	71.2	71.3	27	0.51	25	5	56
	12	48	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
	13	69	3	0.001	0.88	0.001	0.000	0.002	0.058	0.88	0.059	0.000	0.163	70.7	70.6	4	0.88	4	0	12
	14	46	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
	15	62	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
	16	88	6	0.143	0.83	0.140	0.004	0.441	12.547	0.83	12.273	0.352	38.766	77.6	77.8	974	0.82	955	30	2 990
	171	3	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
	172	29	3	0.004	0.58	0.004	0.000	0.008	0.106	0.58	0.102	0.000	0.240	77.5	77.5	8	0.59	8	0	19
	173	8	3	0.012	0.75	0.011	0.000	0.031	0.097	0.75	0.094	0.000	0.260	73.4	73.2	7	0.74	7	0	19
	174b	83	4	0.001	0.52	0.001	0.000	0.003	0.109	0.52	0.109	0.000	0.222	72.8	72.9	8	0.52	8	0	16
	174c	30	4	0.002	0.90	0.002	0.000	0.006	0.058	0.90	0.058	0.000	0.183	68.6	68.6	4	0.90	4	0	12
	174d	78	9	0.001	0.65	0.001	0.000	0.001	0.045	0.65	0.043	0.000	0.111	82.7	82.0	4	0.65	4	0	9
	17	5	3	0.033	0.29	0.033	0.016	0.053	0.177	0.29	0.176	0.085	0.280	73.4	73.5	13	0.30	13	6	21
	18	4	3	0.063	0.24	0.062	0.038	0.094	0.225	0.24	0.221	0.134	0.334	73.5	73.8	17	0.23	16	10	24

Table C.3: Time of survey population estimates of scallops in Marlborough Sounds in May 2020 (full survey extent) by stratum. 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 ($W = aL^b$ where mean values for these parameters are $a = 0.00037$ and $b = 2.69$, using length and weight data from Cryer & Parkinson 2006). The analysis used a non-parametric resampling with replacement approach to estimation (1000 bootstraps).

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		Area		Density (scallops m^{-2})					Abundance (millions)					Scallop weight (g)		Biomass (t green)				
Grouping	Code	(km^2)	n	mean	CV	median	95%CI		mean	CV	median	95%CI		mean	median	mean	CV	median	95%CI	
Stratum	20a	10	3	0.043	0.78	0.042	0.000	0.117	0.425	0.78	0.412	0.000	1.145	71.7	71.6	30	0.78	30	0	82
	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	9	0.519	0.16	0.515	0.372	0.697	2.863	0.16	2.840	2.050	3.840	87.1	86.7	249	0.17	246	175	339
	22	3	3	0.037	0.27	0.036	0.020	0.058	0.128	0.27	0.125	0.070	0.202	69.9	70.0	9	0.26	9	5	14
	23	1	3	0.443	0.23	0.446	0.254	0.641	0.645	0.23	0.648	0.369	0.933	77.2	76.7	50	0.22	50	30	72
	24	3	3	0.081	0.22	0.079	0.053	0.122	0.220	0.22	0.214	0.143	0.330	72.5	72.6	16	0.22	16	10	24
	25	14	3	0.021	0.61	0.020	0.000	0.049	0.301	0.61	0.286	0.000	0.698	72.9	73.0	22	0.61	21	0	51
	26a	1	3	0.248	0.43	0.248	0.044	0.461	0.257	0.43	0.257	0.045	0.478	76.4	75.9	20	0.44	20	3	37
	26b	4	3	0.013	0.65	0.012	0.001	0.033	0.047	0.65	0.045	0.005	0.118	72.9	72.6	3	0.66	3	0	9
	27	22	3	0.002	0.85	0.002	0.000	0.005	0.039	0.85	0.038	0.000	0.117	70.7	70.7	3	0.84	3	0	8
	28	4	3	0.090	0.43	0.089	0.038	0.173	0.321	0.43	0.316	0.134	0.617	69.7	69.8	22	0.43	22	9	43
	29	2	4	0.015	0.47	0.014	0.005	0.031	0.036	0.47	0.034	0.012	0.074	74.4	74.4	3	0.49	3	1	6
	30	2	8	0.585	0.19	0.578	0.384	0.817	1.340	0.19	1.325	0.879	1.872	77.2	77.4	103	0.19	103	68	144
	31	11	3	0.020	0.83	0.020	0.000	0.058	0.220	0.83	0.218	0.000	0.629	73.8	73.9	16	0.83	16	0	46
	32	6	8	0.186	0.54	0.175	0.051	0.441	1.098	0.54	1.035	0.303	2.605	80.6	80.6	88	0.54	83	24	209
	321	6	12	0.754	0.26	0.740	0.418	1.186	4.837	0.26	4.753	2.684	7.614	88.7	88.2	429	0.27	419	237	686
	33	11	3	0.006	0.65	0.006	0.000	0.015	0.067	0.65	0.065	0.000	0.162	80.2	80.5	5	0.66	5	0	13
	34	1	3	0.013	0.37	0.014	0.007	0.026	0.016	0.37	0.016	0.009	0.031	100.3	99.5	2	0.30	2	1	3
	35	38	3	0.003	0.85	0.003	0.000	0.008	0.100	0.85	0.097	0.000	0.294	78.2	78.2	8	0.85	8	0	23
	36	6	3	0.222	0.15	0.220	0.164	0.293	1.323	0.15	1.315	0.982	1.751	80.8	81.0	107	0.15	106	80	141
	37a	6	3	0.024	0.75	0.024	0.000	0.066	0.148	0.75	0.146	0.000	0.398	73.1	72.7	11	0.74	11	0	29
	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	0.658	0.18	0.654	0.437	0.898	3.058	0.18	3.038	2.030	4.174	75.8	75.7	232	0.18	230	155	316
	39a	1	3	0.213	0.32	0.216	0.067	0.338	0.275	0.32	0.278	0.086	0.435	76.1	76.2	21	0.32	21	6	33
	39b	3	3	0.034	0.46	0.034	0.000	0.063	0.105	0.46	0.106	0.000	0.196	74.4	74.4	8	0.46	8	0	14
	40	1	3	0.175	0.71	0.173	0.023	0.448	0.199	0.71	0.197	0.026	0.508	78.6	78.6	16	0.71	15	2	40
	41	1	7	0.565	0.32	0.550	0.276	0.967	0.840	0.32	0.817	0.410	1.437	78.1	77.6	66	0.33	63	32	114
	42	0	3	0.286	0.28	0.281	0.151	0.449	0.086	0.28	0.084	0.045	0.134	78.1	78.0	7	0.28	7	3	11

APPENDIX D: Comparison of 2019 and 2020 biomass in Marlborough Sounds

A randomisation test was conducted to determine whether the estimated Marlborough Sounds biomass in 2020 was different to that in 2019. 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 2020 biomass divided by the May 2019 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 2020 surveys were combined at the stratum level, before randomly selecting a new set of 2020 survey data from the combined set to equal the original sample size per stratum; the remaining stations per stratum were then assigned to the 2019 survey. This was conducted for each stratum, and the whole process was repeated for 1000 iterations. Dividing the 2020 randomised biomass by the 2019 randomised biomass generates the randomised 2020/2019 biomass ratio. From the 1000 iterations results 1000 randomised biomass ratios; plotting these shows their distribution (Figure D.1). The actual 2020/2019 biomass ratio falls just inside the upper 2.5% of the randomised 2019/2018 ratio distribution, showing that the 2020 biomass was not significantly higher than in 2019.

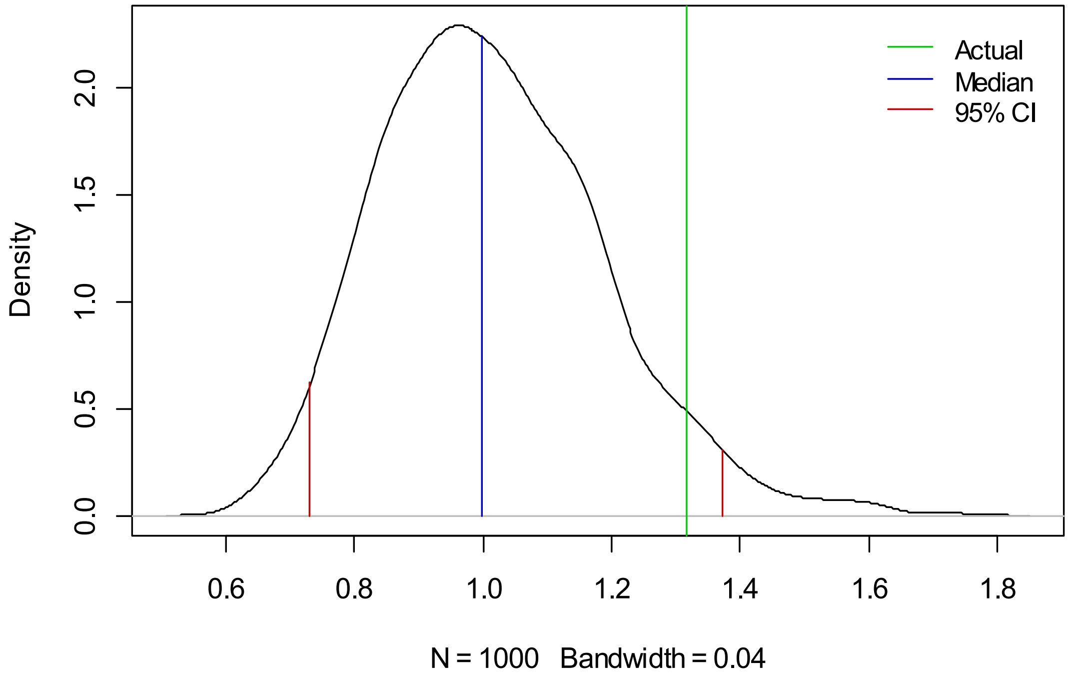

Figure D.1: Distribution of Marlborough Sounds biomass ratios generated from a randomisation and bootstrapping procedure using the 2019 and 2020 survey data. The actual 2020/2019 biomass ratio is shown as a green vertical line on the right-hand side of the plot.

APPENDIX E: Survey biomass series by sector / biotoxin area

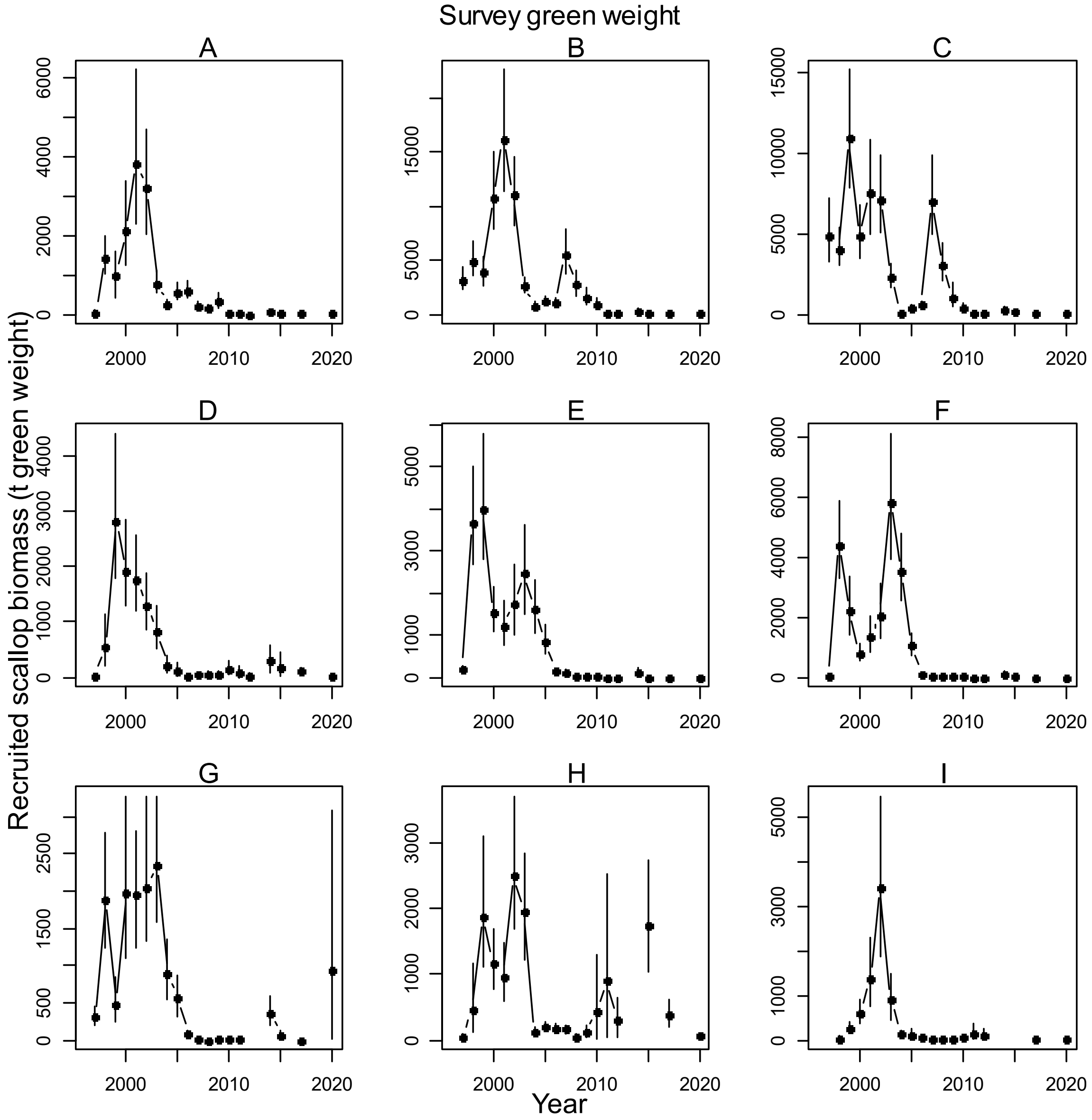

Figure E.1: Trends in <u>time of survey</u> biomass (t <u>green weight</u>) of recruited scallops (90 mm or larger) by sector (statistical reporting area) in Golden Bay (A–B and I) and Tasman Bays (D–H), 1997–2020. Values are the median and 95% confidence intervals of the estimated biomass. Surveys were conducted in May (sometimes April–May or May–June) in all years except in 2017 when the survey was in January (see Appendix A: Table A.1). There was no survey in 2016, and Golden and Tasman bays were not surveyed in 2013, 2018, or 2019.

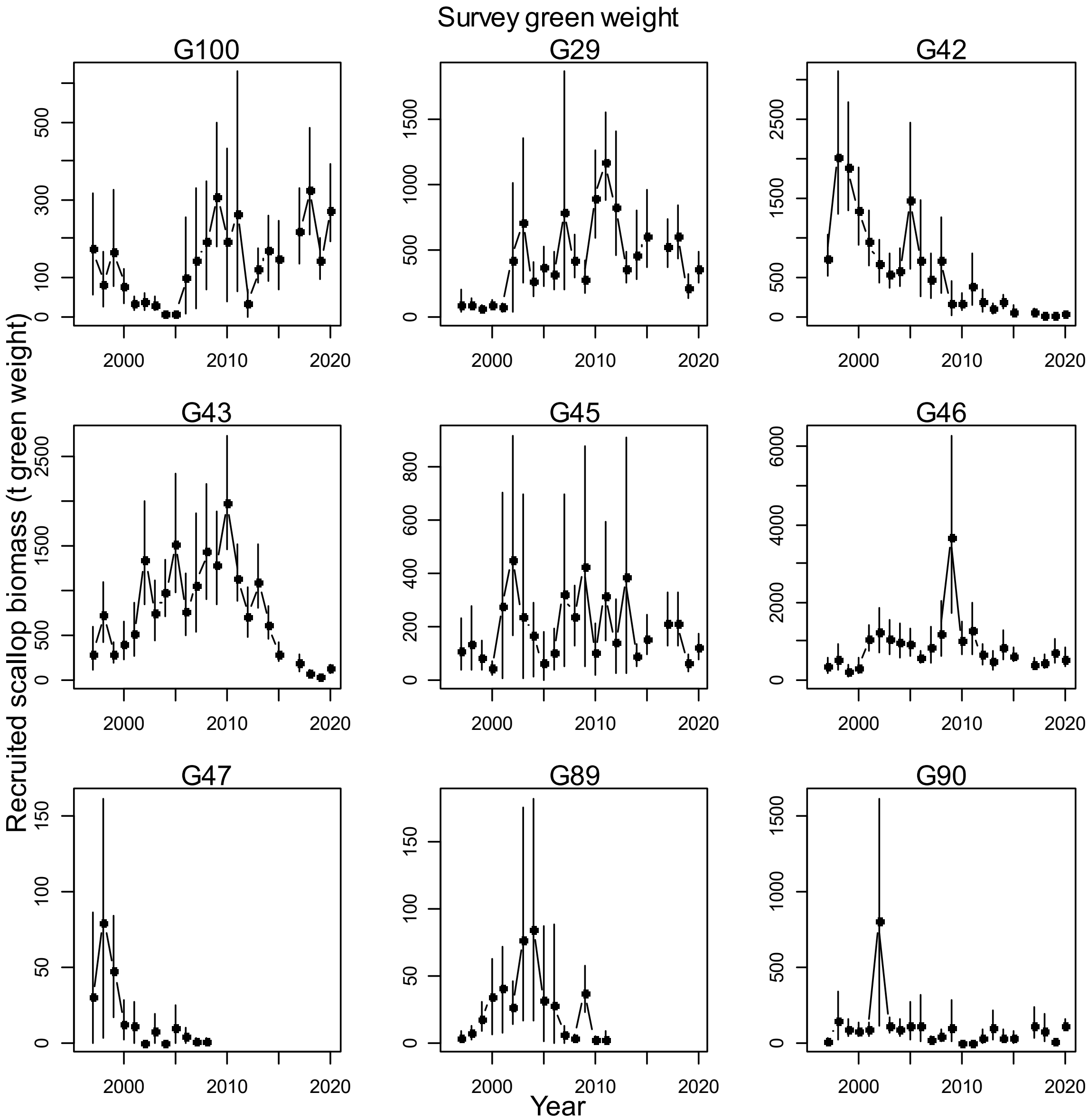

Figure E.2: Trends in <u>time of survey</u> biomass (t <u>green weight</u>) of recruited scallops (90 mm or larger) by biotoxin area in Marlborough Sounds, 1997–2020. Values are the median and 95% confidence intervals of the estimated biomass. Surveys were conducted in May (sometimes April–May or May–June) in all years except in 2017 and 2018 when the surveys were in January (see Appendix A: Table A.1). There was no survey in 2016.

APPENDIX F: Projected population estimates, September 2020

Table F.1: Projected population estimates of scallops in SCA 7 in September 2020 (full survey extent) at different spatial scales: statistical reporting area (stat area), biotoxin area, substock, and total. These estimates were produced for recruited scallops (90 mm or larger), correcting for dredge efficiency (Tuck et al. 2018), predicting green weight from length, and conducting May to September projections using tag-return data modelled using an inverse logistic growth model. The analysis used a non-parametric resampling with replacement approach to estimation (1000 bootstraps).

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Group Code	Area (km^2)	n	Density (scallops m^{-2})					Abundance (millions)					Scallop weight (g)		Biomass (t green)					Biomass (t meat)				
			mean	CV	median	95%CI		mean	CV	median	95%CI		mean	median	mean	CV	median	95%CI		mean	CV	median	95%CI	
Stat area																								
A	72	4	0.004	0.54	0.004	0.000	0.008	0.295	0.54	0.289	0.000	0.609	76.3	76.4	22	0.54	22	0	47	3	0.55	3	0	7
B	181	16	0.007	0.32	0.006	0.003	0.012	1.219	0.32	1.173	0.593	2.130	80.5	81.0	98	0.31	95	48	165	14	0.31	13	7	23
C	206	17	0.004	0.55	0.004	0.001	0.009	0.860	0.55	0.801	0.263	1.951	79.1	79.8	68	0.52	64	22	151	9	0.52	9	3	21
I	10	3	0.050	0.55	0.048	0.000	0.105	0.493	0.55	0.476	0.000	1.037	82.3	82.4	41	0.56	39	0	87	6	0.57	5	0	12
D	255	10	0.002	0.44	0.002	0.000	0.003	0.436	0.44	0.421	0.114	0.840	71.1	71.0	31	0.45	30	8	60	4	0.45	4	1	7
E	116	6	0.000	0.88	0.001	0.000	0.001	0.058	0.88	0.059	0.000	0.163	70.7	70.7	4	0.88	4	0	11	0	0.88	0	0	1
F	108	6	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	0	NA	0	0	0
G	88	6	0.143	0.83	0.140	0.004	0.441	12.547	0.83	12.273	0.352	38.766	77.6	77.8	974	0.82	955	29	3002	115	0.83	111	4	352
H	240	32	0.003	0.21	0.003	0.002	0.005	0.817	0.21	0.800	0.523	1.181	74.0	74.1	60	0.21	59	39	88	7	0.21	7	5	10
Biotoxin																								
G100	22	15	0.147	0.19	0.146	0.100	0.203	3.288	0.19	3.252	2.228	4.531	85.1	85.4	280	0.18	278	192	386	37	0.20	37	25	53
G43	28	19	0.059	0.19	0.059	0.039	0.083	1.650	0.19	1.634	1.076	2.305	73.7	73.7	122	0.19	120	80	170	16	0.19	16	11	23
G42	27	9	0.013	0.35	0.013	0.005	0.022	0.343	0.35	0.341	0.122	0.595	75.3	75.2	26	0.37	26	9	45	3	0.37	3	1	6
G45	13	11	0.186	0.36	0.178	0.092	0.338	2.457	0.36	2.348	1.219	4.468	77.1	76.9	189	0.34	181	96	340	25	0.35	24	12	45
G46	24	26	0.251	0.23	0.245	0.147	0.372	6.105	0.23	5.951	3.582	9.035	88.2	88.9	539	0.24	529	314	804	71	0.24	69	41	108
G90	44	6	0.037	0.18	0.036	0.026	0.053	1.617	0.18	1.586	1.126	2.296	81.8	82.0	132	0.18	130	93	185	18	0.18	17	12	24
G29	28	34	0.261	0.19	0.258	0.170	0.361	7.291	0.19	7.209	4.747	10.079	77.0	77.1	561	0.19	556	367	778	74	0.19	74	49	103
Substock																								
GB	469	40	0.006	0.28	0.006	0.003	0.010	2.867	0.28	2.788	1.608	4.680	79.9	80.2	229	0.28	224	130	371	32	0.28	31	17	51
TB	806	60	0.017	0.75	0.017	0.002	0.050	13.857	0.75	13.503	1.558	40.286	77.2	77.0	1069	0.75	1040	120	3113	126	0.75	122	14	369
MS	186	120	0.122	0.16	0.121	0.088	0.164	22.752	0.16	22.594	16.280	30.443	81.3	81.2	1849	0.16	1835	1336	2505	244	0.16	242	176	331
Stock																								
SCA 7	1461	220	0.027	0.30	0.026	0.015	0.046	39.476	0.30	38.252	22.282	67.004	79.7	79.9	3148	0.29	3056	1807	5290	401	0.27	387	238	655

Table F.2: Projected population estimates of scallops in Golden and Tasman bays in September 2020 (full survey extent) by stratum code. These estimates were produced for recruited scallops (90 mm or larger), correcting for dredge efficiency (Tuck et al. 2018), predicting green weight from length, and conducting May to September projections using tag-return data modelled using an inverse logistic growth model. The analysis used a non-parametric resampling with replacement approach to estimation (1000 bootstraps).

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Stratum code	Area (km^2)	n	Density (scallops m^{-2})					Abundance (millions)					Scallop weight (g)		Biomass (t green)					Biomass (t meat)				
			mean	CV	median	95%CI		mean	CV	median	95%CI		mean	median	mean	CV	median	95%CI		mean	CV	median	95%CI	
1	72	4	0.004	0.54	0.004	0.000	0.008	0.295	0.54	0.289	0.000	0.609	76.3	76.4	22	0.54	22	0	47	3	0.55	3	0	7
2	42	4	0.006	0.37	0.006	0.002	0.010	0.245	0.37	0.244	0.065	0.429	83.4	82.0	20	0.40	20	5	38	3	0.41	3	1	5
3	33	6	0.012	0.42	0.011	0.006	0.024	0.398	0.42	0.376	0.181	0.784	85.1	85.1	34	0.39	32	15	64	5	0.40	4	2	9
4	107	6	0.005	0.52	0.005	0.001	0.011	0.576	0.52	0.541	0.132	1.220	76.0	76.3	44	0.52	41	10	94	6	0.52	6	1	13
5	19	3	0.006	0.23	0.006	0.004	0.010	0.122	0.23	0.120	0.074	0.182	90.1	90.0	11	0.24	11	7	17	2	0.25	1	1	2
6	32	3	0.005	0.21	0.005	0.003	0.007	0.160	0.21	0.158	0.105	0.236	79.2	79.3	13	0.20	13	8	18	2	0.21	2	1	3
7	74	5	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	0	NA	0	0	0
8	77	3	0.007	0.89	0.006	0.000	0.021	0.507	0.89	0.469	0.000	1.587	74.7	74.8	38	0.89	35	0	119	5	0.90	5	0	16
9a	4	3	0.018	0.57	0.018	0.000	0.040	0.071	0.57	0.069	0.000	0.154	90.8	89.8	6	0.61	6	0	15	1	0.61	1	0	2
9b	10	3	0.050	0.55	0.048	0.000	0.105	0.493	0.55	0.476	0.000	1.037	82.3	82.4	41	0.56	39	0	87	6	0.57	5	0	12
10	9	3	0.007	0.40	0.007	0.003	0.013	0.061	0.40	0.059	0.025	0.115	71.0	71.1	4	0.39	4	2	8	1	0.40	0	0	1
11	246	7	0.002	0.51	0.001	0.000	0.003	0.375	0.51	0.357	0.078	0.790	71.2	71.3	27	0.51	25	5	56	3	0.51	3	1	7
12	48	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	0	NA	0	0	0
13	69	3	0.001	0.88	0.001	0.000	0.002	0.058	0.88	0.059	0.000	0.163	70.7	70.7	4	0.88	4	0	11	0	0.88	0	0	1
14	46	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	0	NA	0	0	0
15	62	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	0	NA	0	0	0
16	88	6	0.143	0.83	0.140	0.004	0.441	12.547	0.83	12.273	0.352	38.766	77.6	77.8	974	0.82	955	29	3002	115	0.83	111	4	352
171	3	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	0	NA	0	0	0
172	29	3	0.004	0.58	0.004	0.000	0.008	0.106	0.58	0.102	0.000	0.240	77.5	77.7	8	0.59	8	0	19	1	0.60	1	0	2
173	8	3	0.012	0.75	0.011	0.000	0.031	0.097	0.75	0.094	0.000	0.260	73.4	73.4	7	0.74	7	0	19	1	0.74	1	0	2
174b	83	4	0.001	0.52	0.001	0.000	0.003	0.109	0.52	0.109	0.000	0.222	72.8	72.9	8	0.52	8	0	16	1	0.53	1	0	2
174c	30	4	0.002	0.90	0.002	0.000	0.006	0.058	0.90	0.058	0.000	0.183	68.6	68.7	4	0.90	4	0	13	0	0.91	0	0	2
174d	78	9	0.001	0.65	0.001	0.000	0.001	0.045	0.65	0.043	0.000	0.111	82.7	82.0	4	0.65	4	0	9	0	0.66	0	0	1
17	5	3	0.033	0.29	0.033	0.016	0.053	0.177	0.29	0.176	0.085	0.280	73.4	73.3	13	0.30	13	6	21	2	0.30	2	1	2
18	4	3	0.063	0.24	0.062	0.038	0.094	0.225	0.24	0.221	0.134	0.334	73.5	73.7	17	0.23	16	10	24	2	0.25	2	1	3

Table F.3: Projected population estimates of scallops in Marlborough Sounds in September 2020 (full survey extent) by stratum code. These estimates were produced for recruited scallops (90 mm or larger), correcting for dredge efficiency (Tuck et al. 2018), predicting green weight from length, and conducting May to September projections using tag-return data modelled using an inverse logistic growth model. The analysis used a non-parametric resampling with replacement approach to estimation (1000 bootstraps).

CORRECTED FOR DREDGE EFFICIENCY

Stratum code	Area (km^2)	n	Density (scallops m^{-2})					Abundance (millions)					Scallop weight (g)		Biomass (t green)					Biomass (t meat)				
			mean	CV	median	95%CI		mean	CV	median	95%CI		mean	median	mean	CV	median	95%CI		mean	CV	median	95%CI	
20a	10	3	0.043	0.78	0.042	0.000	0.117	0.425	0.78	0.412	0.000	1.145	71.7	71.6	30	0.78	30	0	82	4	0.78	4	0	11
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	0	NA	0	0	0
21	6	9	0.519	0.16	0.515	0.372	0.697	2.863	0.16	2.840	2.050	3.840	87.1	86.8	249	0.17	246	175	339	33	0.18	33	23	47
22	3	3	0.037	0.27	0.036	0.020	0.058	0.128	0.27	0.125	0.070	0.202	69.9	70.1	9	0.26	9	5	14	1	0.27	1	1	2
23	1	3	0.443	0.23	0.446	0.254	0.641	0.645	0.23	0.648	0.369	0.933	77.2	76.7	50	0.22	50	30	72	7	0.23	7	4	10
24	3	3	0.081	0.22	0.079	0.053	0.122	0.220	0.22	0.214	0.143	0.330	72.5	72.6	16	0.22	16	10	24	2	0.23	2	1	3
25	14	3	0.021	0.61	0.020	0.000	0.049	0.301	0.61	0.286	0.000	0.698	72.9	72.8	22	0.61	21	0	51	3	0.61	3	0	7
26a	1	3	0.248	0.43	0.248	0.044	0.461	0.257	0.43	0.257	0.045	0.478	76.4	75.9	20	0.44	20	3	37	3	0.44	3	0	5
26b	4	3	0.013	0.65	0.012	0.001	0.033	0.047	0.65	0.045	0.005	0.118	72.9	72.9	3	0.66	3	0	9	0	0.67	0	0	1
27	22	3	0.002	0.85	0.002	0.000	0.005	0.039	0.85	0.038	0.000	0.117	70.7	70.7	3	0.85	3	0	8	0	0.85	0	0	1
28	4	3	0.090	0.43	0.089	0.038	0.173	0.321	0.43	0.316	0.134	0.617	69.7	69.8	22	0.43	22	9	43	3	0.43	3	1	6
29	2	4	0.015	0.47	0.014	0.005	0.031	0.036	0.47	0.034	0.012	0.074	74.4	74.3	3	0.49	3	1	6	0	0.49	0	0	1
30	2	8	0.703	0.20	0.688	0.468	1.004	1.611	0.20	1.577	1.073	2.301	79.2	79.3	128	0.20	125	85	181	17	0.21	16	11	24
31	11	3	0.077	0.89	0.073	0.000	0.236	0.846	0.89	0.794	0.000	2.575	73.1	72.7	62	0.89	58	0	189	8	0.90	8	0	25
32	6	8	0.199	0.51	0.187	0.060	0.458	1.173	0.51	1.103	0.351	2.702	82.4	82.8	97	0.51	91	29	223	13	0.51	12	4	30
321	6	12	0.749	0.25	0.733	0.427	1.144	4.809	0.25	4.702	2.739	7.346	89.8	89.2	432	0.25	420	244	677	57	0.26	55	31	90
33	11	3	0.010	0.69	0.010	0.000	0.026	0.108	0.69	0.105	0.000	0.277	78.8	78.7	9	0.70	8	0	22	1	0.70	1	0	3
34	1	3	0.013	0.35	0.012	0.007	0.023	0.015	0.35	0.015	0.008	0.027	101.6	102.0	2	0.30	2	1	3	0	0.31	0	0	0
35	38	3	0.004	0.96	0.004	0.000	0.014	0.155	0.96	0.136	0.000	0.513	77.4	78.3	12	0.95	11	0	39	2	0.95	1	0	5
36	6	3	0.245	0.16	0.241	0.178	0.329	1.462	0.16	1.442	1.065	1.964	82.3	82.4	120	0.16	119	88	162	16	0.17	16	11	22
37a	6	3	0.028	0.75	0.027	0.000	0.074	0.168	0.75	0.165	0.000	0.446	77.1	77.0	13	0.75	13	0	34	2	0.75	2	0	4
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	0	NA	0	0	0
38	5	9	0.973	0.20	0.965	0.598	1.392	4.523	0.20	4.485	2.777	6.468	77.0	76.9	348	0.20	345	215	499	46	0.21	45	28	66
39a	1	3	0.399	0.37	0.402	0.100	0.694	0.513	0.37	0.517	0.129	0.893	76.1	76.0	39	0.37	39	10	68	5	0.37	5	1	9
39b	3	3	0.074	0.55	0.071	0.000	0.166	0.232	0.55	0.220	0.000	0.517	74.7	75.3	17	0.54	17	0	38	2	0.55	2	0	5
40	1	3	0.229	0.68	0.225	0.044	0.567	0.259	0.68	0.256	0.049	0.644	79.5	79.5	21	0.68	20	4	51	3	0.69	3	0	7
41	1	7	0.967	0.30	0.946	0.485	1.619	1.437	0.30	1.406	0.721	2.405	77.3	76.7	111	0.31	108	55	186	15	0.31	14	7	24
42	0	3	0.531	0.27	0.518	0.274	0.833	0.159	0.27	0.155	0.082	0.249	76.9	76.9	12	0.28	12	6	19	2	0.29	2	1	3

APPENDIX G: Sensitivity of projected biomass, September 2020.

Table G.1: Sensitivity of the September 2020 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). Analysis excluded stations sampled by Tow-Cam video transects (*n* = 6).

				September projected biomass (t meat)					
				0 critical density			0.2m^{-2} critical density		
Grouping	Location	Area (km^2)	n	mean	c.v.	median	mean	c.v.	median
Golden Bay strata group	GB_shallow	197.520	20	14	0.24	14	0	NA	0
	GB_deep	257.647	14	11	0.54	11	0	NA	0
	Farewell Spit	13.737	6	7	0.50	6	0	NA	0
Tasman Bay strata group	TB_deep	464.619	19	122	0.83	115	80	0.98	74
	TB_7H_exclCrois	227.807	23	4	0.33	4	0	NA	0
	Croisilles	8.855	6	3	0.21	3	0	NA	0
	Awaroa Bay	8.633	3	1	0.40	1	0	NA	0
	TB_shallow	93.109	6	0	NA	0	0	NA	0
M. Sounds strata group	Guards	23.096	23	72	0.24	70	49	0.33	47
	Ship	20.626	15	49	0.21	48	33	0.28	32
	Chetwodes	5.512	9	33	0.19	32	20	0.29	20
	Dieffenbach	2.920	13	19	0.28	19	11	0.42	11
	Wynens Bank	2.291	8	17	0.20	17	11	0.27	11
	WaituiPortGore	43.543	6	17	0.18	17	2	0.94	1
	Forsyth Bay Low	10.920	3	8	0.87	8	0	NA	0
	Waitata	4.904	6	8	0.22	8	4	0.44	4
	BayofManyCoves	4.402	6	7	0.33	7	1	0.63	1
	AdmiralityPenguin	16.821	6	4	0.80	4	0	NA	0
	Richmond Bay	3.563	3	3	0.43	3	0	3.63	0
	Waitata Reach	14.382	3	3	0.64	3	0	NA	0
	Horseshoe Bay	1.036	3	3	0.46	2	1	0.78	1
	Clara Island	2.704	3	2	0.23	2	0	NA	0
	Tawhitinui High	3.634	3	0	0.66	0	0	NA	0
	Tawhitinui Low	22.080	3	0	0.83	0	0	NA	0
	Ketu Bay	2.374	4	0	0.53	0	0	NA	0
Substock	GB	468.903	40	32	0.28	31	0	NA	0
	TB	803.024	57	130	0.78	122	80	0.98	74
	MS	184.807	117	246	0.16	243	132	0.24	130
Stock	SCA 7	1456.735	214	408	0.28	392	213	0.42	200

APPENDIX H: Live and dead scallop shell length frequency by biotoxin area, 2020

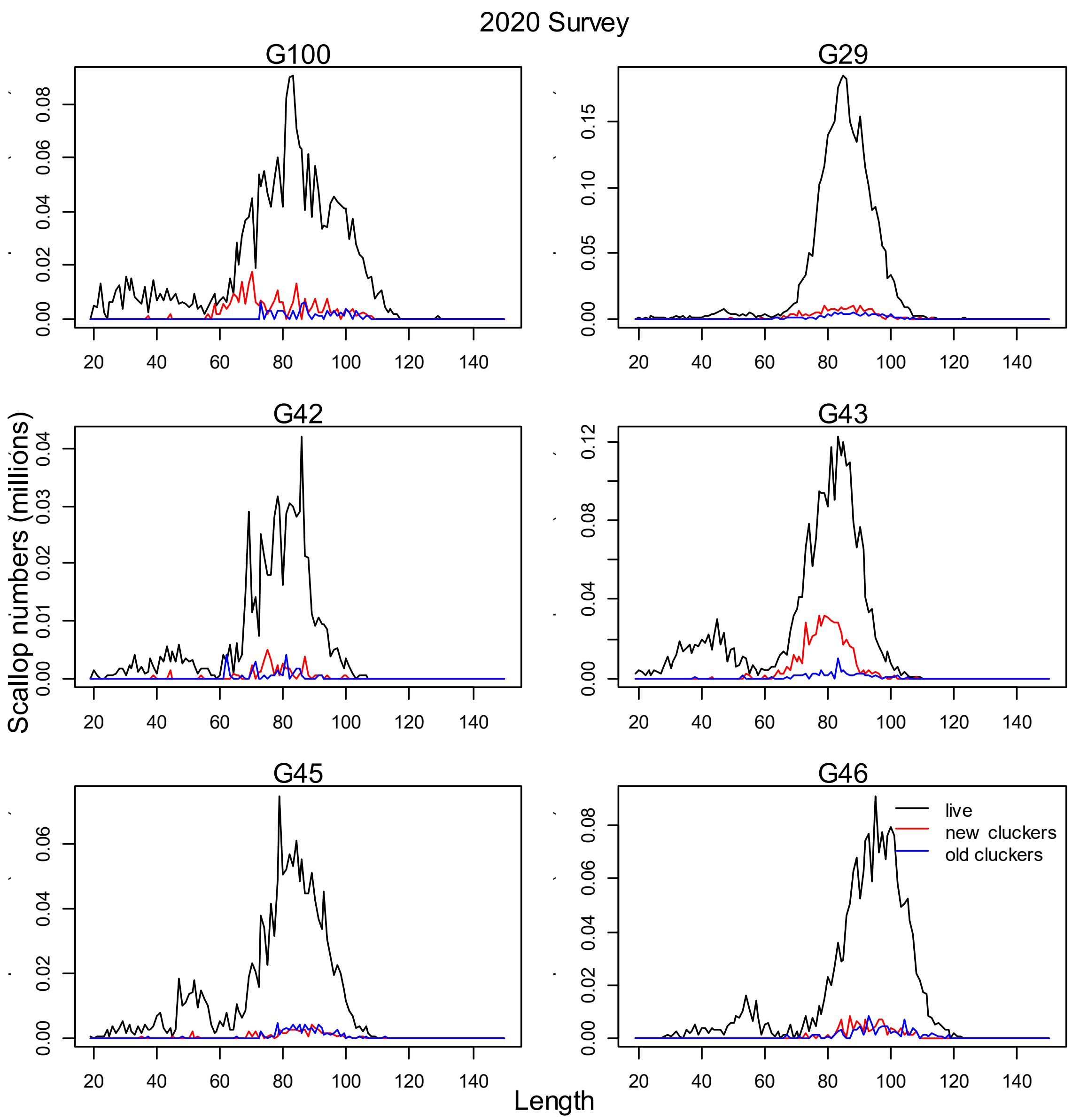

Figure H.1: Live scallop versus new (clean) and old (fouled) dead scallop ('clucker') shell length (mm) distributions, by biotoxin area, Marlborough Sounds, May 2020.

APPENDIX I: *Chaetopterus* tubeworm

In 2019 (Williams et al. 2019), the parchment tubeworm *Chaetopterus* sp. was present in the catch at 35 survey stations (29% presence), distributed within areas of Pelorus Sound (Horseshoe Bay, Waitata Bank, Ketu Bay, Guards Bay) and Queen Charlotte Sound (Ship Cove); when present, volumes (estimated in litres) caught were low (mean = 5.21 L, CV=18%; range = 0.59–20.78 L).

In 2020, *Chaetopterus* sp. was present in the catch at 59 stations, distributed within the same areas as in 2019 and at areas where it was previously absent (the Chetwodes and the Bay of Many Coves), plus at Croisilles Harbour which was not surveyed in 2019. Catch volumes in 2019 and 2020 were similar at most stations, but large volumes were caught in 2020 at a few stations in Ship Cove stratum 38 (Table I.1; Figure I.1). *Chaetopterus* sp was absent at all other stations surveyed in 2020 in Tasman Bay and Golden Bay.

Table I.1: Catch of parchment tubeworm *Chaetopterus* sp. (CPT) on the May 2019 Marlborough Sounds survey (trip code OKA1901) and the May 2020 SCA 7 survey. Stations, where CPT was present.

Survey	Stations	CPT proportion of total catch			CPT volume (L) per 0.4 nm tow		
	n	mean	min	max	mean	min	max
OKA1901	35	0.02	0.01	0.10	5.2	0.6	20.8
OKA2001	59	0.04	0.01	0.62	16.3	0.2	405.0

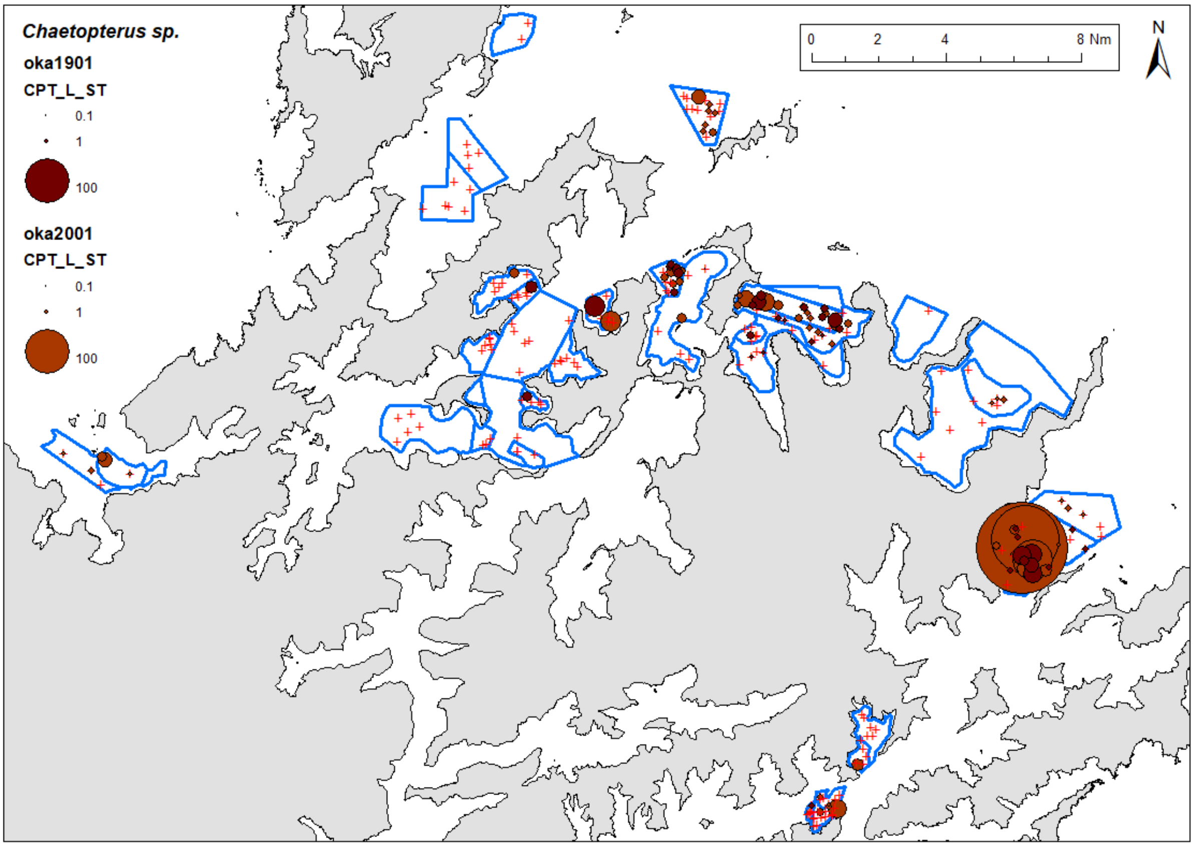

Figure I.1: *Chaetopterus* sp. catch per standard tow, Marlborough Sounds dredge surveys, May 2019 (dark brown circles) and May 2020 (light brown circles). Circle area is proportional to the estimated volume (L) caught per standard distance towed (0.4 n. miles). Values are uncorrected for dredge efficiency. Polygons denote survey strata boundaries.