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Dive surveys of sea cucumbers in Queen Charlotte Sound (SCC 7A) and Hauraki Gulf (SCC 1B), 2014

New Zealand Fisheries Assessment Report 2016/58

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Dive transect surveys of sea cucumbers, *Australostichopus mollis* (Echinodermata: Holothuroidea), were conducted in 2014 at two locations identified by fishers as important areas that currently support commercial sea cucumber harvesting by breath-hold diving: 1) Queen Charlotte Sound in the Marlborough Sounds (within SCC 7A); and 2) Waiheke Island in the Hauraki Gulf (within SCC 1B). The objective of the surveys was to estimate sea cucumber biomass in key fishery areas to inform fisheries management on sustainable harvest limits. The surveys included estimated coastline lengths of 109 km (within SCC 7A) and 78 km (within SCC 1B), and covered the depth range 2–15 m. A stratum area method of biomass estimation generated commercial size sea cucumber biomass estimates of 88 t (95%CI = 58–115 t) in SCC 7A and 38 t (95%CI = 22–59 t) in SCC 1B within the areas surveyed. These estimates may be conservative because the transect searches did not account for cryptic sea cucumbers hidden from the divers (e.g., in inaccessible reef cracks and crevices). The surveys did not account for sea cucumbers in waters deeper than 15 m, which could be available to fishers using underwater breathing apparatus (UBA), and clearly the areas surveyed represent only small proportions of the overall SCC stock areas, for which catch limits are set. The Total Allowable Commercial Catches (TACCs) for SCC are currently 5 t in SCC 7A and 2 t in SCC 1B. In each stock, theoretically, if all of the TACC is caught from within the surveyed areas, catches at the level of the TACC would equate to exploitation rates of 6% in SCC 7A and 5% in SCC 1B. Given the large size of the SCC stock areas, it was not possible to estimate the biomass at the stock-wide level within this project. Yield estimation and assessment methods for sea cucumbers, and recommendations for longer term monitoring and biological studies, are discussed.

1. INTRODUCTION

1.1 Overview

New Zealand manages its fisheries with a Quota Management System (QMS), but sustainable exploitation of some species is hampered by a lack of robust scientific knowledge required to inform management decisions. While some fisheries are constrained by nominal quotas, risking under-utilisation, others remain unconstrained outside the management system, risking over-exploitation. Most research required to inform management is funded through the cost recovery system, but for some of the smallest fisheries, or for species outside the QMS, this is not practical. New research is required to address knowledge gaps to enable utilisation of un-developed and developing inshore fisheries. As with the pattern observed worldwide, the under-developed and developing fisheries tend to be for shellfish species (which, following the MPI definition, includes all molluscs, crustaceans, echinoderms, sponges and seaweeds). Although tonnages in these fisheries tend to be low compared to finfish fisheries, unit value for shellfish can be very high, and so relatively small changes in catches (e.g., a few tonnes) can make substantial differences to fishery viability and export values.

Sea cucumbers (Echinodermata: Holothuroidea) support high-value developing fisheries in New Zealand; these fisheries are currently small (often one fisher) operations which lack the capability and resources to undertake research to enable sustainable utilisation. New Zealand currently lands about 20 tonnes of sea cucumber (SCC) annually, most of which is exported to China where demand is high, particularly for high quality hand collected and processed sea cucumber (rather than trawl caught, which tends to be often damaged, and not gutted). Other export markets exist in Taiwan, Singapore, Korea and Malaysia. Dried sea cucumber has a value of up to $450 per kg ($30 per kg greenweight).

To our understanding, the only sea cucumber species of commercial value in New Zealand is *Australostichopus mollis* (formerly *Stichopus mollis*), which is fished in a number of areas around the country. Sea cucumbers are targeted commercially by breath hold diving, although the use of underwater breathing apparatus, UBA, has been permitted since 1 October 2013 (Ministry for Primary Industries 2013). Sea cucumbers are also caught as a bycatch in trawl and dredge fisheries, although the bycatch product is generally of lower quality (A. Zhou, SCC exporter, pers. comm.).

The existing nominal low TACC limits were set when SCC was introduced into the QMS in 2004 (reflecting the limited information on stocks available). Catch limits are currently being met or exceeded in sea cucumber stocks SCC 1B, 3, 7A and 7B, which, with the exception of SCC 3, are largely from breath hold diving. Anecdotal reports from fishers suggest considerable stock abundance, and with the recent change to allow UBA in harvesting this species, far greater habitat could become available to the fishery, increasing the accessible biomass. Harvesting by breath hold diving is likely to be limited to about 10 m depth, but the use of UBA will not only improve harvest efficiency, but also enable fishing to take place beyond this depth.

In this project, we conducted dive transect surveys to estimate sea cucumber biomass in key fishery areas to inform fisheries management on sustainable harvest limits. This is the fundamental information needed to inform appropriate harvest strategies, potential changes in TACC limits or other regulatory controls before they are able to enter the self-sustaining model of cost recovered research. Transect sampling methods were developed based on those used previously in dive surveys of sea cucumbers in British Columbia, Canada (Campagna & Hand 2004).

1.2 Objectives

The Overall Objective of this project was to 'provide stock assessment information that will enable accelerated development of a small-scale inshore shellfish species with potential for growth'. The Specific Objective was to: 'provide biomass estimates of sea cucumber (SCC) to inform fisheries management on sustainable harvest limits'.

2. METHODS

2.1 Survey locations

Dive transect surveys of sea cucumbers were conducted in 2014 at two key fishing locations identified by commercial sea cucumber fishers: 1) Queen Charlotte Sound in the Marlborough Sounds (within SCC 7A); and 2) Waiheke Island in the Hauraki Gulf (within SCC 1B). The surveys included estimated coastline lengths of 109 km (within SCC 7A) and 78 km (within SCC 1B), and therefore represent only small proportions of the overall coastline within the two sea cucumber stocks.

2.2 Survey design

Each survey used a stratified random sampling allocation design. At each location, the survey area (i.e. sample extent) was delimited alongshore based on prior information acquired from a local commercial sea cucumber fisher. Fishers were asked to draw on nautical charts, to indicate the stretches of coastline that were known to hold fishable densities of sea cucumbers ('known areas') or potentially hold fishable densities ('potential areas'). Stretches of coastline known or thought to contain few sea cucumbers were not marked on the charts. Within the known areas, fishers were asked to mark the positions of fishing sites on the charts, and provide associated site information (depth, substrate, habitat type) and typical catch and effort data (e.g. number and/or weight of sea cucumbers caught per dive, size range caught, dive duration, and approximate area of seabed searched during the dive).

Within the SCC 7A Queen Charlotte Sound survey area, because only coastlines known to support sea cucumber fishing had been identified, and catch rates were reported to be similar among areas, coastlines were allocated to three strata on the basis of geographical location within the Sound (strata 1 and 2, Inner and Outer QCS, respectively; stratum 3, Tory Channel). A fourth stratum (in Pelorus Sound) was included in the survey design but was not sampled due to limited time available in the field. Within the SCC 1B Waiheke Island survey area, coastlines were allocated to two strata on the basis of known 'hotspot' coastlines of higher catch rates (stratum 1) and adjacent coastlines of lower catch rates (stratum 2). A third stratum (Western Coromandel) was included in the survey design but was not sampled due to unfavourable weather conditions for that area at the time of the survey and the limited time available.

We aimed to survey each of the two locations over three days of diving using a team of five divers, with a target of 30 stations (transects) per survey. The transect sampling took longer than estimated, and the actual number of random survey stations completed was 20 in SCC 7A and 15 in SCC 1B.

Station allocation was proportional to coastline length in the SCC 7A survey, whereas Neyman allocation (Francis 2006) was used in the SCC 1B survey because catch rates and their variability were expected to be higher in the known 'hotspots' (13% of total coastline) than in adjacent coastlines. A minimum of three stations was specified for each stratum. The positions of stations were randomised within strata using ArcGIS software by ESRI, constrained by a minimum distance of 200 m between stations. Strata and station positions are shown in Figure 1.

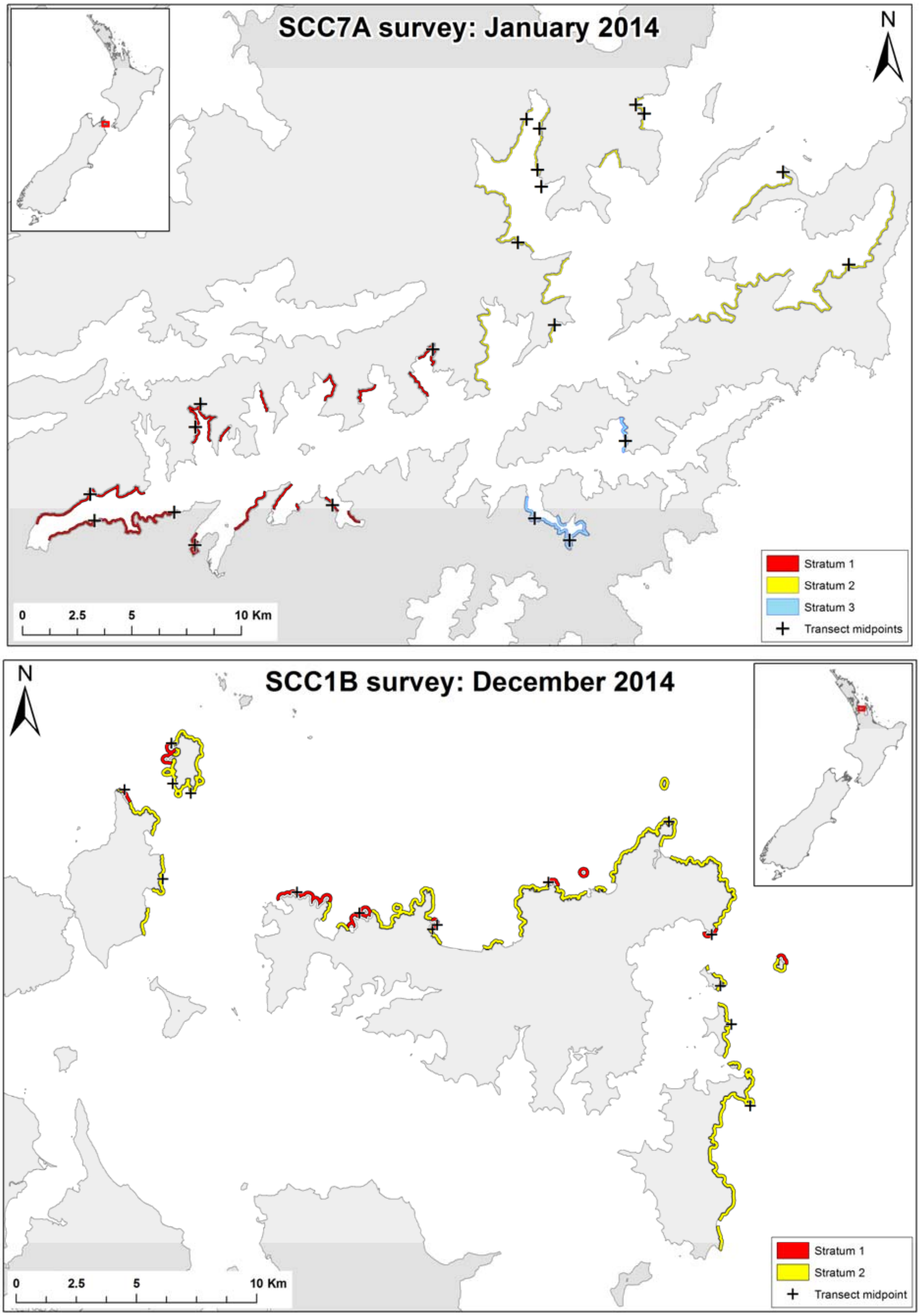


Figure 1: Strata and station positions sampled in the SCC 7A (top) and SCC 1B (bottom) surveys, 2014.

2.3 Transect sampling

In each survey, all diving was conducted from a local charter vessel. The vessel was navigated to each station position using GPS. At each station, a single transect was placed by orienting a weighted transect line, marked at 5 m intervals, perpendicular to the shore from 2 m to 15 m depth (uncorrected for tidal height). We used the reciprocal of a bearing judged by eye to be the shortest distance from the vessel (nearest to random station position allocated) to the shoreline. An alternative method being developed by NIWA (QGIS survey plugin) for prescribing transect bearings *a priori* could be a methodological improvement in future surveys. The 2 m to 15 m depth range was chosen after examination of previous survey data from a nationwide survey of subtidal reefs (Shears & Babcock 2007) which suggested that this depth range encompassed the distribution of *A. mollis* within practical diveable depths.

A dropper line was deployed at the shallow end of the transect, its GPS position was recorded, and the vessel was moved away on the bearing perpendicular to the shore while the transect line was laid out. A second dropper line was deployed to mark the deep end of the transect, and its GPS position was recorded. The transect line was of 100 m in length, as it was expected that at most stations the distance between the 2 m and 15 m ends of the transect would be less than 100 m. If the 15 m maximum depth was not reached (e.g., on gradual slopes), the full 100 m transect length was sampled between the 2 m depth and the maximum depth available. Diving logistics (dive time and depth limits) determined the maximum depth (15 m) and transect distance that could be surveyed in a single transect at each station. Nitrox was used on the second of the two surveys (SCC 1B) because of its benefits in relation to no-stop decompression limits and surface intervals on dives in this depth range.

The transect was searched along its length from deep to shallow water by two divers, each holding a 2-m wide bar on either side of the transect line, counting and collecting all sea cucumbers under the bar in each 5 m section. In this way, each diver sampled a 2 m × 5 m quadrat (of 10 m^2 area) every 5 m along the transect line, with one quadrat on the left side and one on the right side of the transect line. Macroalgae (e.g. *Ecklonia* and *Carpophyllum* spp.) were moved aside by hand to assist searching, but rocks and boulders were not overturned to look for hidden individuals. Sea cucumber counts were tallied while searching each quadrat, recording the count data in two nominal size categories: commercial size and ‘juveniles’ (those judged to be less than 15 cm in length). All sea cucumbers found were removed from the quadrat and placed into separate catch bags by habitat type (soft sediment and rocky reef). The diver on the left counted and collected those sea cucumbers that were on or under the transect line. At the end of each 5 m section, divers stopped and separately recorded the total number of commercial size and juvenile size sea cucumbers observed in their 10 m^2 quadrat, the depth, the two most prevalent substrate types (e.g., bedrock reef, broken rock/boulders, sand, silt), the two most abundant macroalgae genera, the percent cover of algae, and other comments on obvious macrofauna present (e.g., horse mussels, *Atrina zelandica*) including predators (e.g., starfish, *Luidia maculata*). Divers continued to survey the transect line to the shallow dropper line. If the shallow dropper line was in more than 2 m depth, the lead diver attached a dive reel finger spool to the end of the main transect line and let out the spool line to extend sampling of the transect continuing in the same direction until 2 m depth was attained. The line on the spool was marked in 5 m increments.

From each transect, all sea cucumbers collected were returned to the surface and sorted by size category (commercial or ‘juvenile’) and habitat type (sediment or reef), giving four size/habitat groups. Sorting by size in SCC 7A was conducted by a commercial sea cucumber fisher assisting with the survey, whereas in SCC 1B commercial size was defined *a priori* as a split (gutted) weight of 75 g or greater (see Section 3.4). In each group, all sea cucumbers, or a random subsample for very large catches, were counted and subsequently processed or ‘split’ (by inserting scissors into the anus, making a ventral cut longitudinally about two thirds of the way along the body length, and draining/wiping away the guts and any fluid) and the aggregate split-weight of all processed sea cucumbers in each size/habitat group was determined using motion compensated scales. Aggregate split-weight by group was the primary measure of sea cucumber biomass at the transect level used in the analysis.

For the majority of sea cucumbers collected, individual length (measured dorsally from the anus to the tentacular crown) was also measured to the nearest 5 mm rounded down, before the sea cucumbers were split. However, length is not considered to be a particularly reliable measure of size for sea cucumbers (Sewell 1990) because of the variable amount of fluid that can be held within each animal. Split-weight is a less variable measure of sea cucumber size. Where feasible, in addition to aggregate split-weights, individual split-weights were also determined (to the nearest 1 g rounded down) for all individuals (or a random subsample for very large catches, with unweighed individuals being counted). At some transects it was not practical to determine individual split-weights, but the aggregate split-weight of each size/habitat group per transect was always determined.

In SCC 7A, from one or more transects per day (selected at random from transects conducted in the afternoon), all sea cucumbers were held in cooled seawater in fish bins and processed onshore after the day's diving activities were completed. The aim was to sample about 150 individuals per day, of a wide range in size, to collect data to examine relationships between individual length (to the nearest 5 mm rounded down), displacement volume (to the nearest millilitre, using a measuring cylinder), squeezed wet weight (to nearest 1 g rounded down), split-weight, and dry weight (to be determined later). During the survey, it was decided that measuring volume and whole (green) weight were not very useful, and these measurements were abandoned, but lengths and split-weights were determined, and specimens were retained for later determination of dry weight. To do this, each individual from the sample of sea cucumbers was measured, split and the split-weight determined, and individually bagged and labelled. All bags of individually processed sea cucumber per transect were placed in a large bag labelled with the transect number, and frozen for later processing to obtain dry weight data. In SCC 1B, it was possible to determine individual sea cucumber length and split-weights on board the vessel during the survey. Bagged samples of individually processed sea cucumbers from transects were frozen and taken ashore for later determination of dry weight.

2.4 Stratum area estimation

Stratum areas were estimated using a coastline GIS layer together with transect data recorded during the surveys. The baseline layer representing the New Zealand coastline in this project was the NIWA mean high water spring (MHWS) coastline layer. Station positions were randomly allocated within strata to this coastline layer, but the transects sampled ran perpendicular to the coast from a position in 2 m depth (some distance from MHWS) to either 15 m depth or a maximum distance offshore, whichever was reached first. Using the recorded GPS position of the 2 m depth of each transect, and the transect length sampled, inner and outer polyline layers were generated in GIS to delimit the shallow and deep boundaries for each stratum. The stratum area lying within those boundaries was the area that potentially could have been sampled by transects.

For each transect, the distance from the transect end position in 2 m water depth to the MHWS coastline was calculated in ArcGIS. Boxplots of this distance by survey and stratum (Figure 2) show that transects in the SCC 1B survey were further offshore in stratum 1 (median = 66 m distance) than in stratum 2 (median = 15 m); in the SCC 7A survey, transects were of similar distances offshore (median values ranging from 16 m to 33 m), but with particularly high variability in stratum 1. Within each stratum, the mean distance offshore from the MHWS coastline was calculated and used within ArcGIS to create a buffer on the coastline, to represent the approximate 2 m depth contour from which all transects ran out down the seabed slope; similarly, within each stratum, the mean transect length was calculated and used to create a buffer on the approximate 2 m depth contour, to represent the approximate farthest distance offshore which all transects ran out to. Figure 3 provides an illustrative example map. Using these two new layers to delimit the shallow and deep boundaries of each stratum, the areas of the stratum polygons were calculated in ArcGIS. Stratum areas were used in the scaling up of stratum estimates of sea cucumber numbers and biomass to absolute estimates.

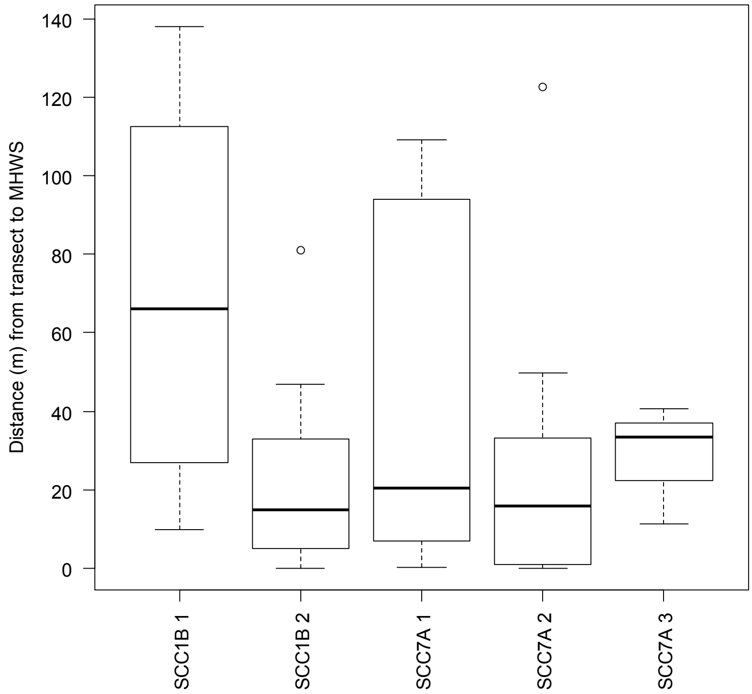


Figure 2: Boxplots of distance from transect end position (in about 2 m depth) to the mean high water spring (MHWS) coastline layer, by survey and stratum. Distances were calculated in ArcGIS.

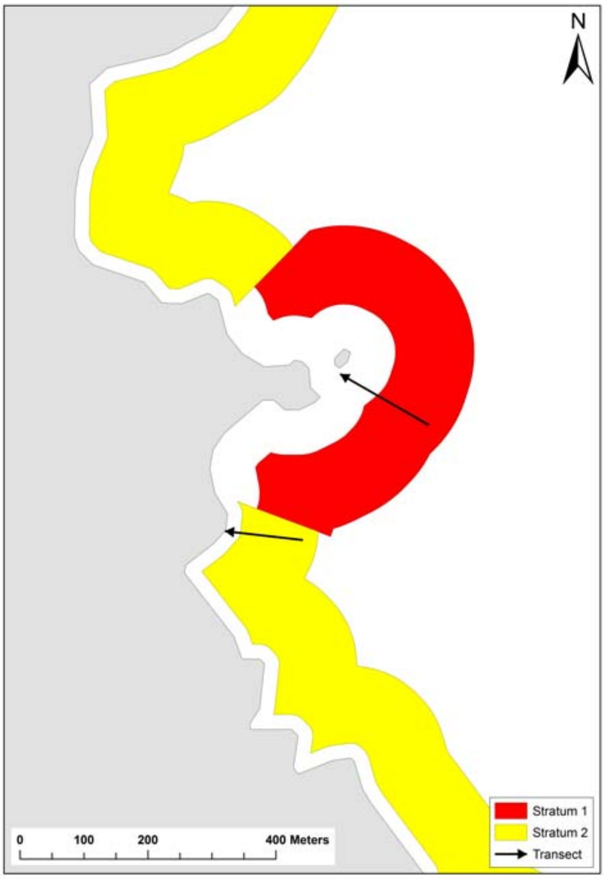


Figure 3: Example map within the SCC 1B survey illustrating differences in the mean distance from transects to the MHWS coastline layer, resulting in stratum 1 being further offshore than stratum 2. Arrows denote the actual positions of transects sampled within the area shown.

2.5 Biomass estimation

Coastline length method

Preliminary biomass estimates were generated at the time of the surveys using a method based on the 'shoreline length' method applied previously for estimating sea cucumber biomass in British Columbia, Canada (Campagna & Hand 2004). Transect aggregate split-weight data by size group were analysed, using the transect as the sampling unit for analysis. For each stratum, the mean biomass density (kg split-weight per transect) and its associated variance were calculated using standard parametric methods, giving each transect an equal weighting. Stratum biomass was calculated by multiplying the stratum mean biomass density by the estimated length of the coastline within the stratum. Total biomass was calculated as the sum of the stratum biomasses.

Issues with this preliminary approach include the invalid assumption that all transects have equal weighting (clearly some transects were longer, and covered different areas of habitat, than others) and the sensitivity of the estimated biomass to the estimated coastline length (the resolution at which the coastline is measured affects the estimated biomass).

To address these issues, a 'stratum area' method was developed as the preferred estimation method.

Stratum area method

This approach estimated biomass density by habitat type for each stratum, and scaled the densities to estimated habitat areas within the overall stratum area (rather than scaling densities to the stratum coastline length). Stratum areas were estimated using the method described in section 2.4. Uncertainty was incorporated by bootstrapping (resampling with replacement) transects within strata, using 1000 iterations. Each iteration involved the following process. For each stratum, the proportion of the total transect area sampled that was on reef or sediment habitat was multiplied by the stratum area, to give the estimated habitat areas (km^2 on reef or sediment) (see Table 2). For each size group of interest (juvenile, commercial, or total), mean biomass density (kg split-weight per transect) and its variance were calculated by habitat type (reef/sediment) within the stratum. Stratum biomass was calculated by multiplying the mean density on reef and sediment by the corresponding estimated habitat areas, and the resulting biomass estimates by habitat type were summed to give the stratum biomass. Total biomass was calculated as the sum of the stratum biomasses. This process was repeated for 1000 iterations, producing a set of 1000 estimates of biomass.

Habitat map approach

Additionally, for the SCC 1B location, a slightly revised version of the stratum area method described above was used to estimate sea cucumber biomass in which habitat areas were derived from a subtidal habitat map instead of from the transect data. The original habitat map (Figure 4) was produced in 2015 from satellite imagery (J. Walker, Auckland Council, unpublished data), and provides a way of investigating how sensitive the biomass estimates are to the method of estimating habitat area. In our analysis, the map's habitat categories were assessed and pooled into three simpler categories: 'reef', 'sediment', and 'excluded'. The 'excluded' category comprised the areas of intertidal and terrestrial habitat (a total of 0.629 km^2), and in our habitat map approach this area was excluded from the overall survey area. The resulting 'revised' version of the habitat map (Figure 5) was used to estimate the areas on reef and sediment (see Table 2) for use in estimating biomass.

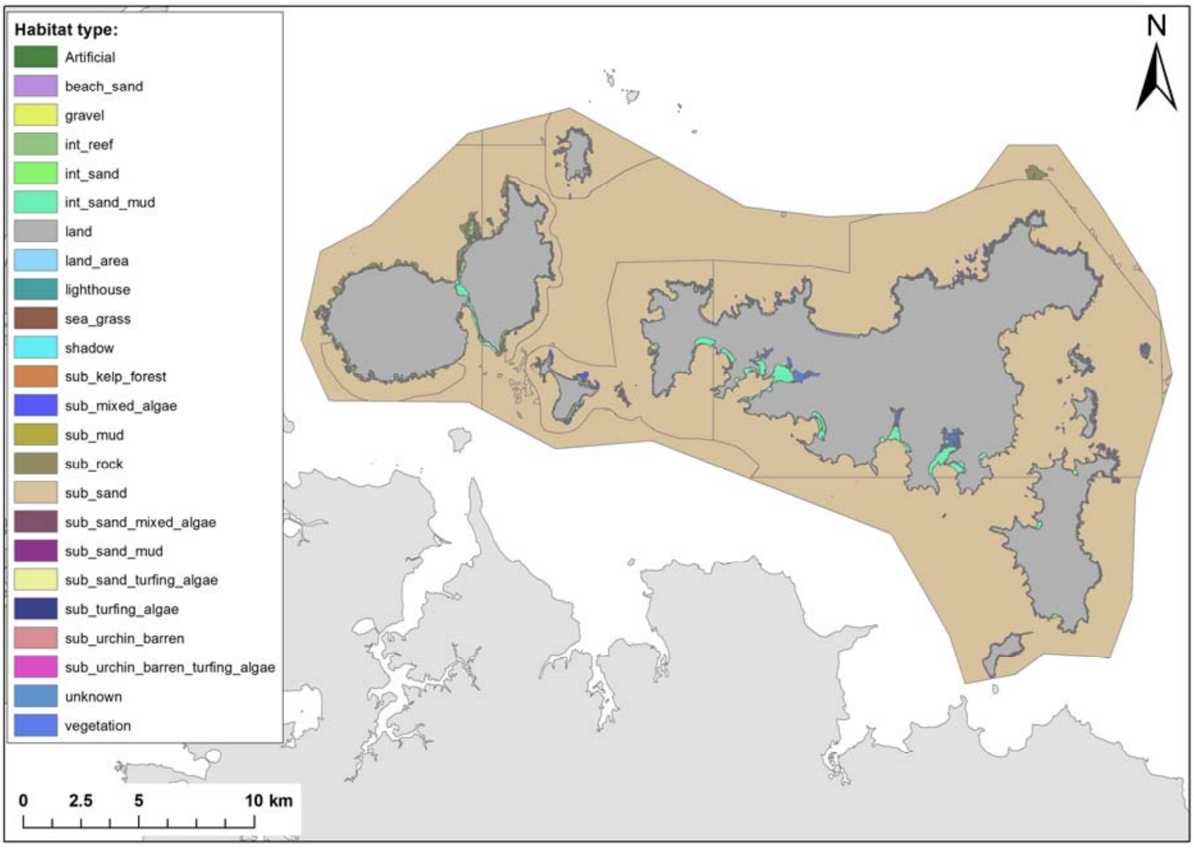


Figure 4: Habitat map for coastal areas at and around Waiheke Island, produced from an analysis of satellite imagery (Map provided by J. Walker, Auckland Council, unpublished data).

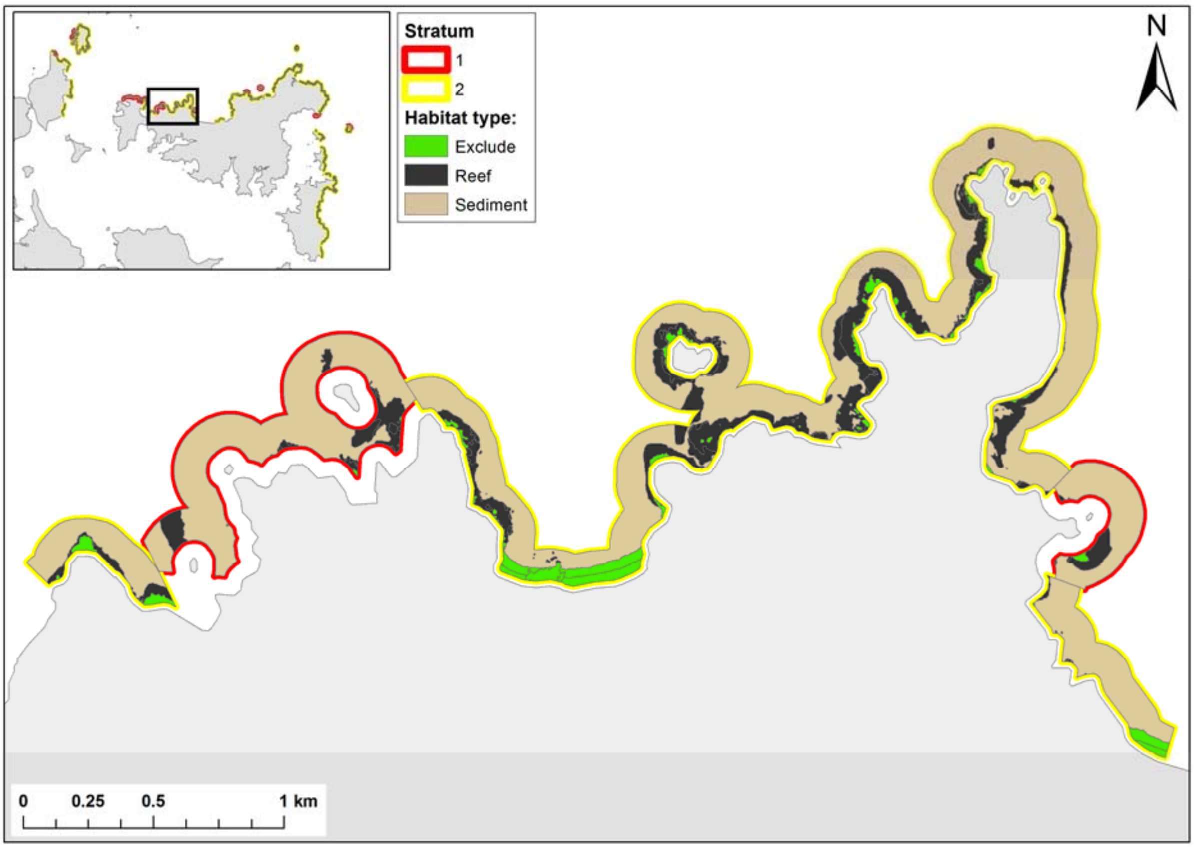


Figure 5: Top: The revised version of the satellite imagery-derived habitat map with original habitat categories pooled into three simpler categories: 'reef', 'sediment', and 'excluded', and the extent constrained to include only the surveyed area. Bottom: Large-scale zoom of the same map shown as an example of reef, sediment, and 'excluded' areas.

3. RESULTS

3.1 Survey details

The SCC 7A survey was conducted from 14 to 16 January 2014. Twenty transects in three strata in Queen Charlotte Sound were sampled. One additional transect was sampled but was excluded from the analysis: that transect was chosen by the commercial fisher assisting with the survey to represent a typical site where commercial harvesting occurs.

The SCC 1B survey was conducted from 8 to 10 December 2014. Fifteen transects in two strata at Waiheke Island were sampled.

Stratum and transect details for the surveys are shown in Table 1.

Table 1: Stratum and transect details. Coastline lengths and stratum areas were estimated using ArcGIS.

Stock	Stratum	MHWS coastline length (km)	Stratum area (km^2)	Transects (*n*)	Mean distance to MHWS (m)	Mean transect length (m)	Mean minimum depth (m)	Mean maximum depth (m)
SCC 7A	1	41.265	3.449	8	44	90	2.0	12.1
	2	56.826	3.598	9	27	66	1.7	14.8
	3	10.585	0.942	3	28	100	1.5	11.9
	Total	108.676	7.988	20	–	–	–	–
SCC 1B	1	9.974	1.475	7	70	123	2.3	13.2
	2	67.658	8.065	8	23	121	2.3	9.9
	Total	77.632	9.540	15	–	–	–	–

Table 2: Estimated areas of habitat types (rocky reef or soft sediment) within the areas surveyed in SCC 7A and SCC 1B. For both stocks, areas estimated from the transect habitat data were scaled to stratum areas. Additionally for SCC 1B, areas were also estimated using a habitat map produced from satellite imagery (J. Walker, Auckland Council, unpublished data). Note that none of these area estimates were derived using bootstrapping. In the analysis using the habitat map approach, the area comprising intertidal and terrestrial habitat categories (a total of 0.629 km^2) was excluded from the overall survey extent.

Stock	Stratum	Habitat	Area (km^2) from transect data	Area (km^2) from map data
SCC 7A	1	reef	0.096	–
		sediment	3.353	–
	2	reef	1.494	–
		sediment	2.104	–
	3	reef	0.204	–
		sediment	0.738	–
	Total	reef	1.794	–
		sediment	6.195	–
	Total	reef and sediment	7.988	–
SCC 1B	1	reef	0.913	0.200
		sediment	0.562	1.256
		excluded	0.000	0.020
	2	reef	2.224	2.721
		sediment	5.841	4.736
		excluded	0.000	0.609
	Total	reef	3.138	2.920
		sediment	6.403	5.992
		excluded	0.000	0.629
	Total	reef and sediment	9.540	8.912

3.2 Distribution

Sea cucumber densities for the transect areas sampled in the two stocks are shown in Figure 6. In the SCC 7A survey, densities were higher in strata 2 and 3 (outer Queen Charlotte Sound and Tory Channel, respectively) than in stratum 1 (inner Queen Charlotte Sound). In the SCC 1B survey, as predicted, densities were higher in stratum 1 than in stratum 2.

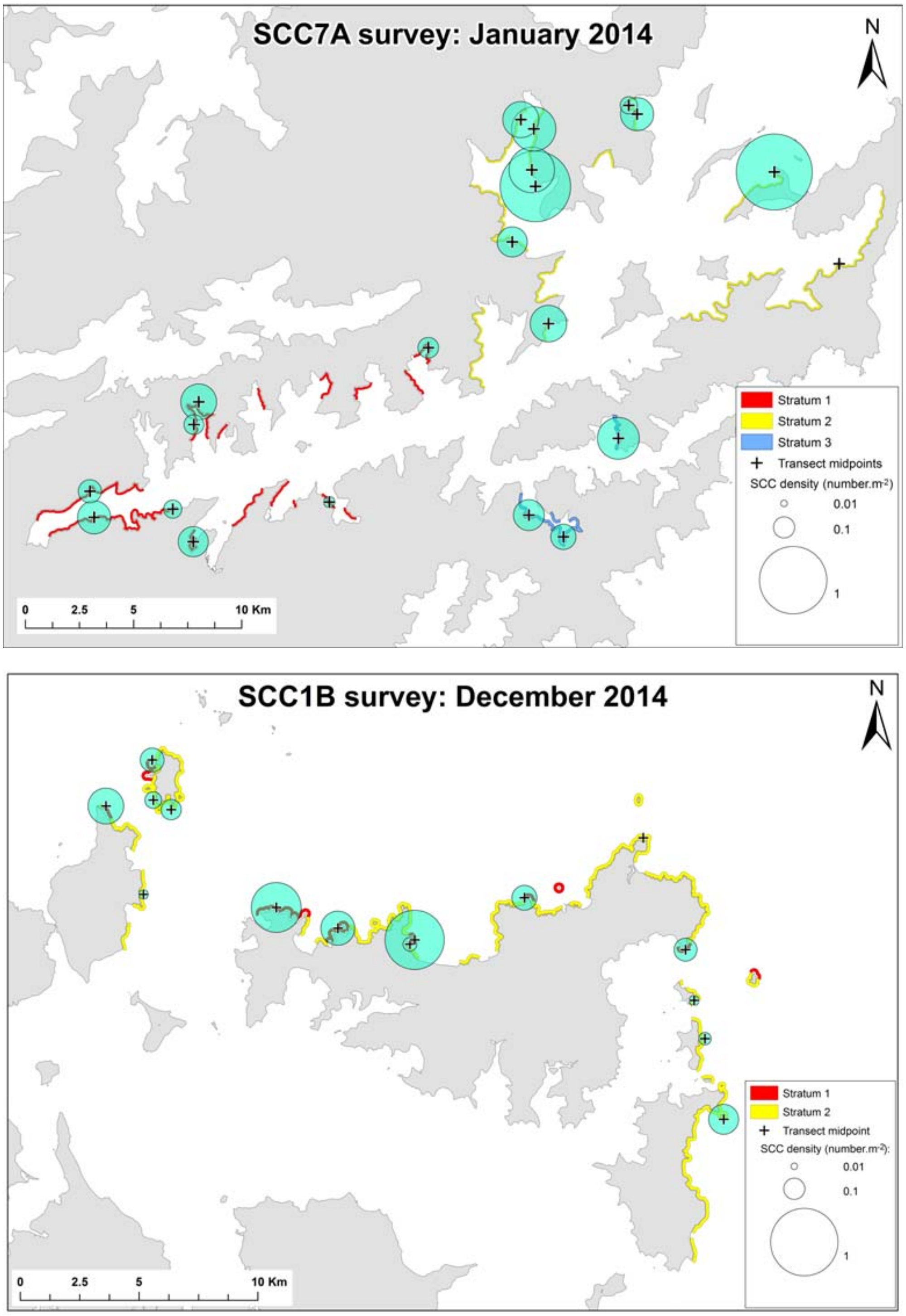


Figure 6: Density (number.m^{-2}) of sea cucumbers from dive transect surveys in Queen Charlotte Sound (SCC 7A) in January 2014 (top) and at Waiheke Island (SCC 1B) in December 2014 (bottom). Transects were perpendicular to the shore, in 2 m to 15 m depth. Circle area is proportional to density.

Transect profiles in the SCC 7A survey were generally steeper than in the SCC 1B survey, in which some transects extended further than the nominal 100 m transect length (Figure 7). Sea cucumber densities were highly variable and although there was no clear pattern with depth, densities were generally higher on reef than on sediment habitat, and reef habitat was generally in the shallower depths (Figure 8). In both surveys, the proportion of the total transect area sampled was lower on reef than on sediment habitat.

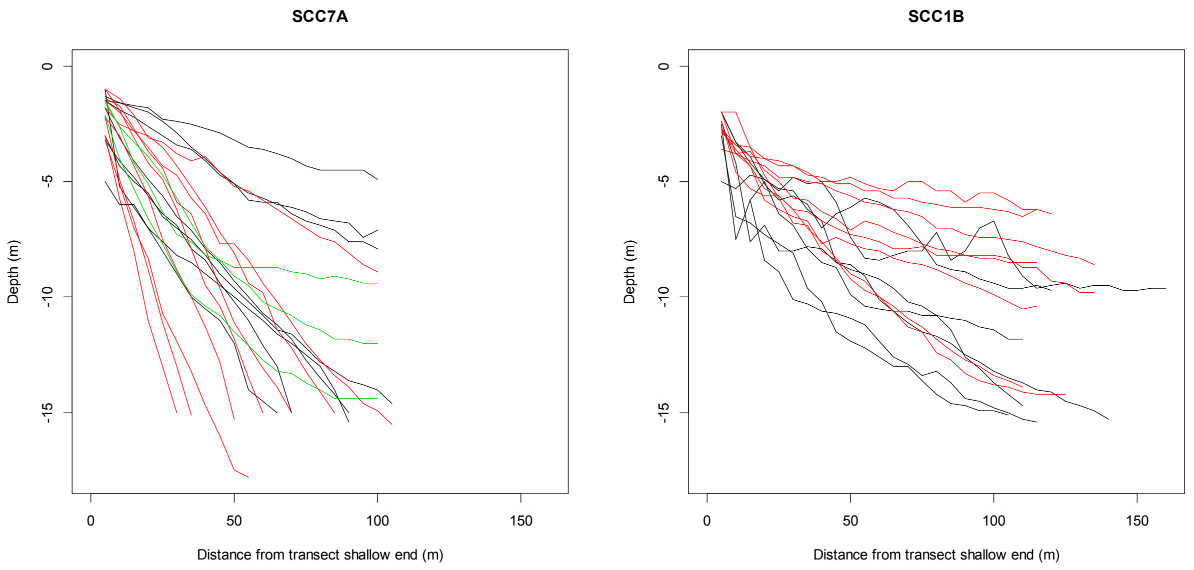


Figure 7: Dive transect depth profiles with distance from the shallow end of the transect. Transects coloured by stratum (1 = black, 2 = red, 3 = green).

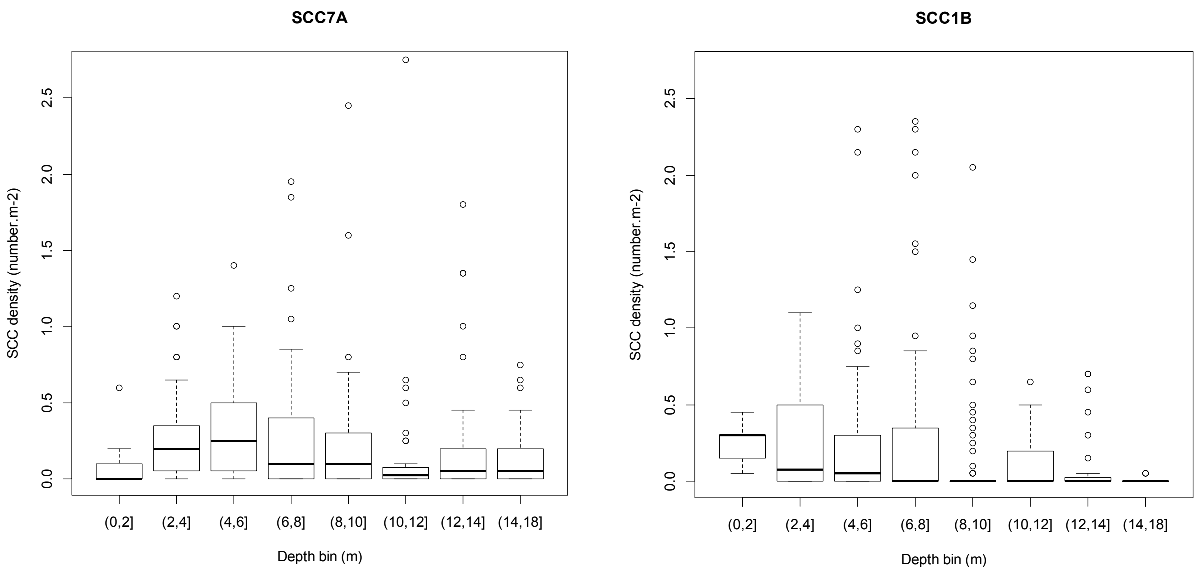


Figure 8: Distribution of sea cucumber density (number.m^{-2}) with depth.

3.3 Size frequency

Sea cucumbers sampled on the SCC 7A survey ranged from 4 g to 240 g split-weight. The primary modal size of commercial size sea cucumbers was about 75 split-weight, and small ('juvenile') sea cucumbers had a primary mode at just under 50 g (Figure 9).

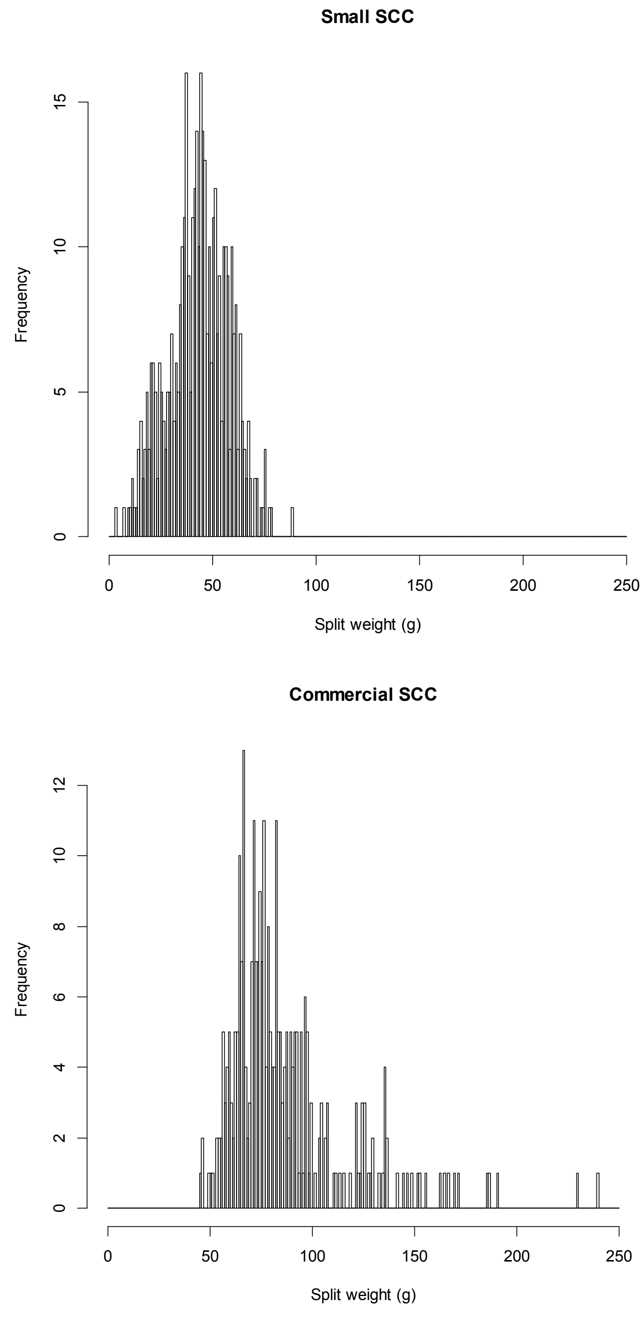


Figure 9: Frequency distribution of sea cucumber split-weight (g) by size as categorised by a SCC 7A commercial sea cucumber diver: small (top) and commercial (bottom).

3.4 Fisher selectivity

In the SCC 7A survey, a local commercial sea cucumber fisher assisted with the survey, and as part of the sampling procedure he categorised the sea cucumbers collected from each transect as either commercial size or 'juvenile'. The individual split-weight data from this survey were examined using a standard logistic selectivity curve, and the L50, the weight at which 50% of individuals were retained (regarded as commercial size) by the fisher, was 63 g split-weight (Figure 10).

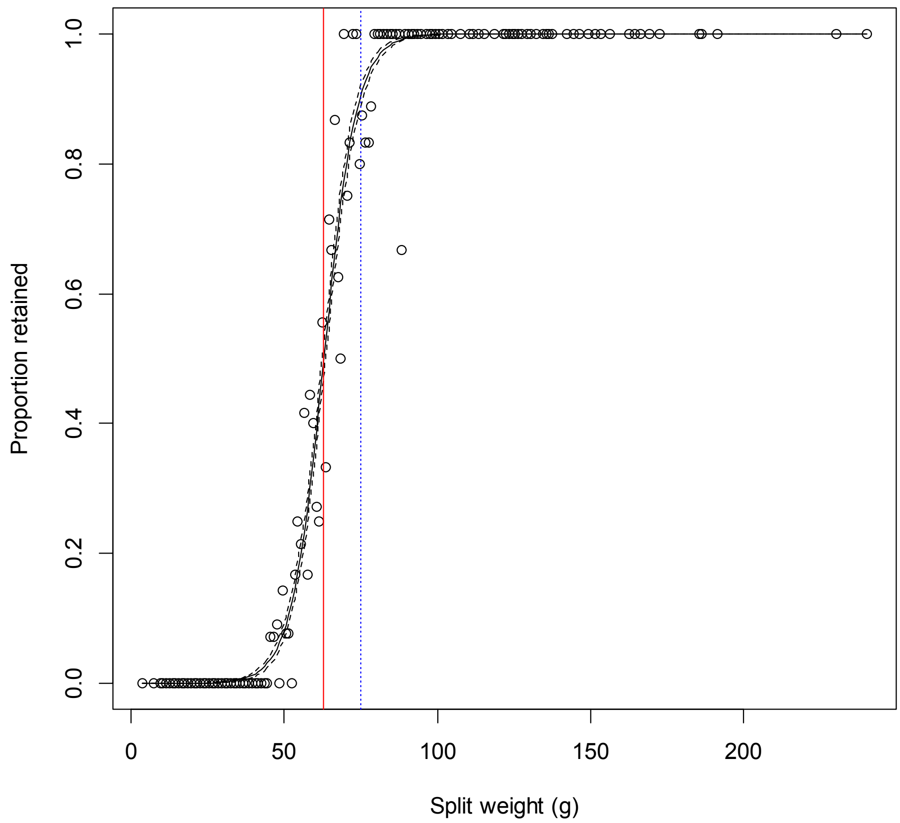


Figure 10: SCC 7A fisher selectivity of sea cucumbers regarded as commercial size. L50 = 63 g split-weight (solid vertical line). The dotted vertical line represents a knife edge selectivity of 75 g split-weight applied when determining aggregate weights in the field on the SCC 1B survey.

For the SCC 1B survey, a local commercial fisher could not assist with the survey. At the time of the survey, the L50 had not been determined, and examination of the size structure of the commercial and juvenile individuals from the SCC 7A survey suggested a 90% selectivity at about 75 g split-weight. In the SCC 1B survey, individuals were classified as commercial size if they were 75 g or greater. Aggregate weights by size/habitat group were determined during the survey using this 75 g knife-edge selectivity.

In the data analysis for SCC 1B, using the individual sea cucumber split-weight data for each transect, each individual was re-categorised as commercial size (63 g or more) or 'juvenile'. The individual split-weights in each size category were summed and used as the 'new' aggregate weight data for estimating SCC 1B survey biomass.

3.5 Biomass estimates

Preliminary estimates

Preliminary basic estimates of sea cucumber biomass (see Table 3, Appendix 1) were produced using the 'shoreline length' estimation method. In the SCC 7A survey, in which the sea cucumbers were categorised as 'commercial' or 'small' by a commercial sea cucumber fisher, the commercial biomass was 93 t (CV = 0.22). In the SCC 1B survey, in which sea cucumbers were categorised in the field as 'commercial' or 'small' using an arbitrary knife-edge selectivity of 75 g split-weight to represent commercial size, the commercial biomass was 32 t (CV = 0.34). Later analysis using the stratum area method estimated the SCC 1B surveyed biomass using a knife-edge selectivity of L50 = 63 g. Note that one station (station 7 in stratum 1) in the SCC 1B survey, where sea cucumbers were particularly abundant (n = 494 collected, 41 kg aggregate split-weight), had a large influence on the estimated biomass and its CV.

Final estimates

Using the 'stratum area' method of estimation, commercial sea cucumber biomass (t split-weight) estimates for the surveyed areas were similar to those produced using the shoreline length method. However, using the habitat map approach the estimated biomass in the surveyed area within SCC 1B was about half the size of the biomass estimated using the stratum area method. Distributions of the estimated biomass within the surveyed areas in SCC 7A (Figure 11) and SCC 1B (Figure 12) were approximately normal. The final estimates with associated uncertainty are summarised as follows:

SCC 7A stratum area method	88 t (median value, 95%CI = 58–115 t; mean = 88 t, CV = 0.17)
SCC 1B stratum area method	38 t (median value, 95%CI = 22–59 t; mean = 39 t, CV = 0.26)
SCC 1B habitat map approach	18 t (median value, 95%CI = 11– 26 t; mean = 18 t, CV = 0.22)

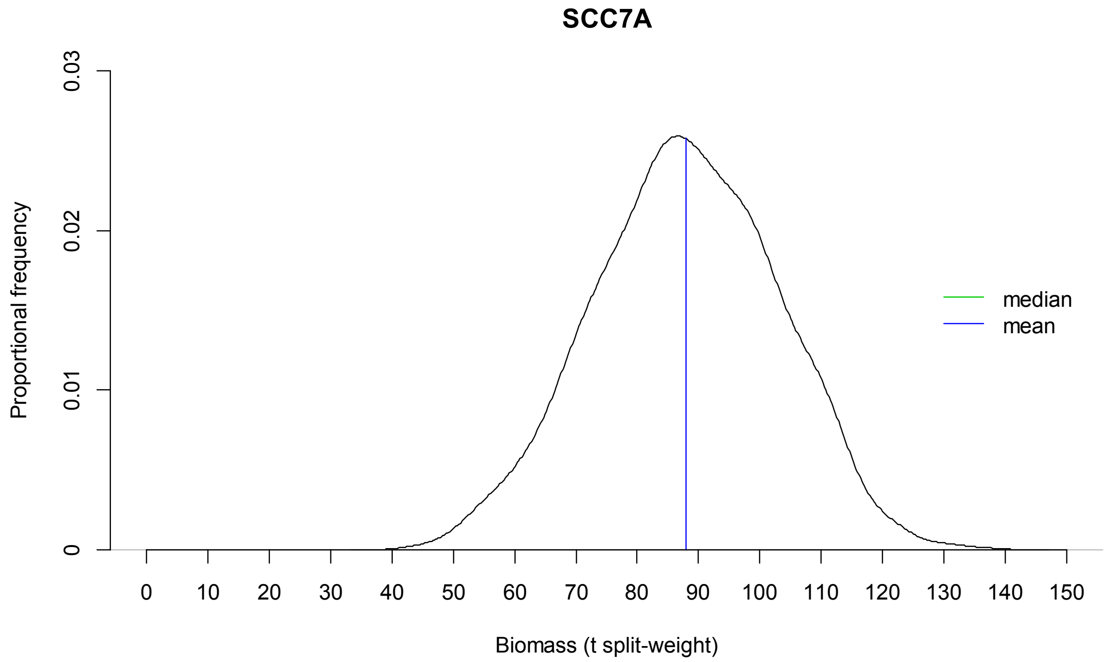
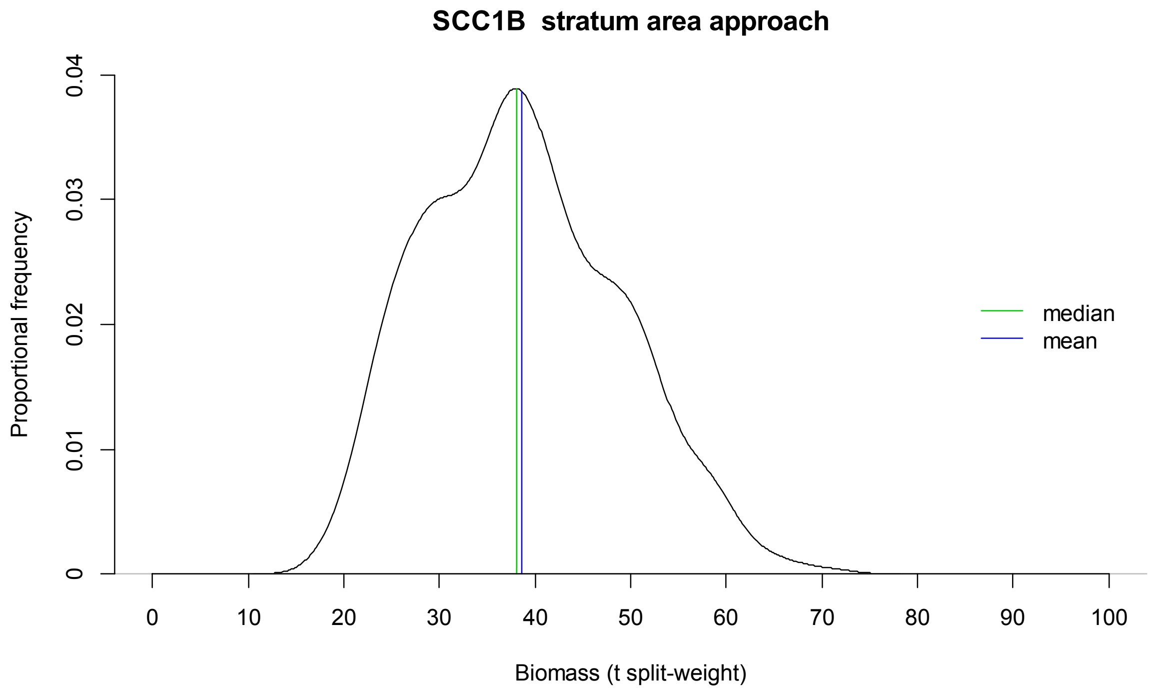


Figure 11: Distribution of the estimated split-weight biomass of commercial sized sea cucumbers in the area surveyed in SCC 7A in January 2014. Commercial sized sea cucumbers are those weighing 63 g or more. The results of a non-parametric resampling with replacement approach to estimating biomass (1000 bootstraps) are shown in tonnes split-weight. Note that the vertical line denoting the estimated mean weight (87.9 t) obscures that of the median weight (87.8 t).



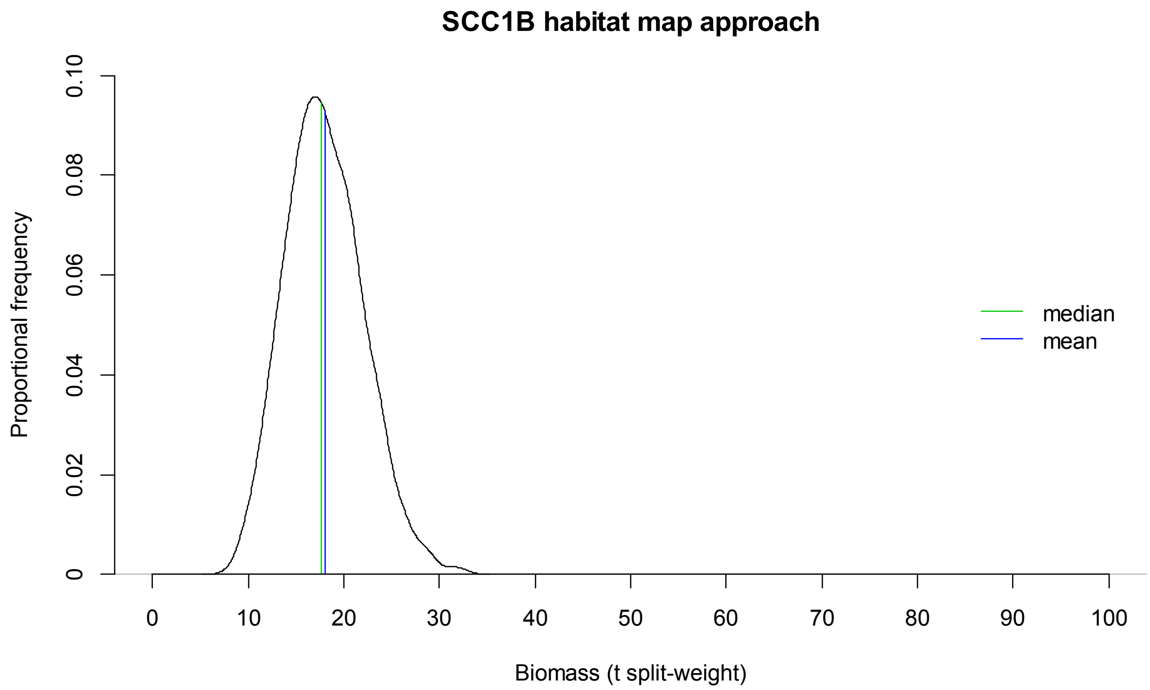


Figure 12: Distributions of the estimated split-weight biomass of commercial sized sea cucumbers in the area surveyed in SCC 1B in December 2014, using the standard stratum area approach (top plot) and the habitat map approach (bottom plot) to estimating habitat areas. Commercial sized sea cucumbers are those weighing 63 g or more. The results of a non-parametric resampling with replacement approach to estimating biomass (1000 bootstraps) are shown in tonnes split-weight.

4. DISCUSSION

Through discussions with commercial sea cucumber fishers, we identified and surveyed shallow water sea cucumber populations in two key fishery areas that support commercial harvesting by breath-hold diving. Fishers reported that these areas appear to offer good potential of providing increased fishing opportunity, but that current catch limits prevent fishery development. The stratum area method of biomass estimation generated commercial size sea cucumber biomass estimates of 88 t (95%CI = 58–115 t) in SCC 7A and 38 t (95%CI = 22–59 t) in SCC 1B within the areas surveyed. These estimates may be conservative because the transect searches may not account for cryptic sea cucumbers hidden from the divers (e.g., in inaccessible reef cracks and crevices). The surveys did not account for sea cucumbers in waters deeper than 15 m, which could be available to fishers using UBA, and clearly the areas surveyed represent only small proportions of the overall SCC stock areas, the level at which catch limits are set. The Total Allowable Commercial Catches (TACCs) for SCC are currently 5 t in SCC 7A and 2 t in SCC 1B. In each stock, theoretically, if all of the TACC is caught from within the surveyed areas, catches at the level of the TACC would equate to exploitation rates of 6% in SCC 7A and 5% in SCC 1B. Given the large size of the SCC stock areas, it was not possible to estimate the biomass at the stock-wide level within this project.

Using a habitat map approach to estimation suggested that commercial biomass in the SCC 1B surveyed area was about half the size of that generated using the stratum area method. It appears that the spatial resolution at which the habitat map was able to be produced may be too coarse to accurately characterise the subtidal habitat types in the area surveyed, and this may be particularly problematic for the deeper reef areas surveyed, which appear to hold higher densities of sea cucumbers than shallower areas. The habitat map used here was only preliminary in nature, and the methodology for accurately mapping subtidal habitats using satellite imagery in New Zealand is still in the early stages of development. Given that we directly sampled reef and sediment habitats using divers during the surveys, and consider our sampling to provide representative and unbiased estimates of the overall population of reef/sediment habitats within the areas surveyed, we recommend that the stratum area method applied here is the most appropriate method available for estimating sea cucumber biomass.

On the basis of the biomass estimates provided by the present study, sustainable harvest (yield) estimates could be generated using methods appropriate for sea cucumbers or similar sedentary species. Yield estimation will also require estimates of biological parameters relating to natural mortality, growth and maturity, depending on the approach considered most appropriate to estimate sustainable harvest. Currently there is little information in the New Zealand literature to guide appropriate estimates of these parameters for *A. mollis* (see review by Zamora & Jeffs 2013). Natural mortality in the wild is a key unknown parameter, but if no appropriate value can be found in the literature, sensitivity to a likely range of estimates could be examined. Aquaculture studies may provide some guidance, and it has been suggested that sea cucumbers live for about five years (Stenton-Dozey, NIWA, pers. comm.). An emphasis on spatial considerations in the method of assessment will be necessary given the likely strong spatial structure inherent in *A. mollis* populations, and the concentration of the fisheries on dense aggregations which may form the most important component of the spawning biomass. Drawing on assessment frameworks used for other species of sea cucumber overseas (e.g. Duprey et al. 2010) will be beneficial.

In addition to setting appropriate harvest limits, sustainable management requires some form of longer term monitoring, and although both collection of data on stock productivity (growth, reproduction, mortality) and long term monitoring of populations were beyond the scope of this survey project, collaborations developed within the project with the fishing industry and researchers could be used to instigate both fine scale catch and effort recording and longer term biological studies in future.

Once a fishery for a species or stock has been developed, it is important that the stock is monitored, to identify any changes in stock status that may require management action. For relatively sedentary species like sea cucumbers, serial depletion of localised areas can be a major source of management concern, and there is considerable evidence of serial depletion and over exploitation in a number of Pacific Island sea cucumber fisheries (Friedman et al. 2008). It is likely that the New Zealand system of fishery catch and effort reporting at the broad spatial scale of the existing management areas would fail to identify such local scale effects. Liaison between scientists, fishers and MPI is needed to identify cost effective ways for the sea cucumber fishing industry to collect fine scale stock monitoring data. This is likely to be in the form of catch, effort and biological data, collected over scales relevant to the fisher (e.g., bays, inlets), to provide fine scale data without being overly demanding on the fisher's time. Trialling fisher data collection schemes using electronic data loggers is recommended. The recent change that permits UBA harvesting requires the use of an electronic logger, but while there is no such requirement for harvesting by breath-hold diving, trialling data loggers is still recommended. Additional biological information on size composition (or numbers per kg) could also be incorporated into the collection system; such schemes have previously been shown to work well in New Zealand rock lobster fisheries (Starr & Vignaux 1997).

There are a number of potential biological studies that would help to improve the assessment and management of sea cucumber fisheries in New Zealand. Size at maturity and whether it varies spatially could be examined using maturity staging methods previously described for *A. mollis* (Sewell 1992); this would be a useful parameter for estimating spawning stock biomass in different fishery areas. Other projects could examine growth and natural mortality through mark recapture and aquarium studies. Tagging approaches for sea cucumbers have generally not proved particularly successful (Kirshenbaum et al. 2006), but photographic recognition approaches (based on unique markings and colour patterns) appear to have far more potential (Stenton-Dozey, NIWA, pers. comm.). Successful mark recapture approaches would allow examination of growth (probably weight) increments over time, and estimation of mortality. All of these parameters would usefully inform the estimation of sustainable harvest for sea cucumber. Studies on the implications of spatial scale for sea cucumber population dynamics will also be important, and could include investigating spawning dynamics to inform density dependent thresholds below which spawning success may be impaired, or management strategy evaluations to explore best fishing practices to balance utilisation with sustainability.

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6. REFERENCES

Campagna, S.; Hand, C. (2004). Baseline density estimates from sea cucumber (*Parastichopus californicus*) surveys conducted in British Columbia, Canada. *Canadian Science Advisory Secretariat Research Document 2004/65*: 42 p.

Duprey, N.M.T.; Hand, C.M.; Lochead, J.; Hajas, W. (2010). Assessment framework for sea cucumber in British Columbia. *Canadian Science Advisory Secretariat Research Document 2010/105*: 38 p.

Francis, R.I.C.C. (2006). Optimum allocation of stations to strata in trawl surveys. New Zealand Fisheries Assessment Report 2006/23. 50 p.

Friedman, K.; Purcell, S.; Bell, J.; Hair, C. (2008). Sea cucumber fisheries: a manager's toolbox. *ACIAR Monograph No 135*: 32 p.

Kirshenbaum, S.; Feindel, S.; Chen, Y. (2006). A study of tagging methods for the sea cucumber Cucumaria frondosa in the waters off Maine. *Fishery Bulletin 104*: 299-302.

Ministry for Primary Industries (2013). Use of underwater breathing apparatus (UBA) in selected shellfish fisheries. MPI Regulatory Impact Statement. ISBN No: 978-0-478-42032-6 (online). 10 p.

Sewell, M.A. (1990). Aspects of the ecology of *Stichopus mollis* (Echinodermata: Holothuroidea) in north-eastern New Zealand. *New Zealand Journal of Marine and Freshwater Research 24*: 97-103.

Sewell, M.A. (1992). Reproduction of the temperate aspidochirote *Stichopus mollis* (Echinodermata: Holothuroidea) in New Zealand. *Ophelia 32*: 103-121.

Shears, N.T.; Babcock, R. (2007). Quantitative description of mainland New Zealand's shallow subtidal reef communities. Science for Conservation 280. Department of Conservation, Wellington. 126 p.

Starr, P.J.; Vignaux, M. (1997). Comparison of data from voluntary logbook and research catch-sampling programmes in the New Zealand lobster fishery. *Marine Freshwater Research 48*: 1075-1808.

Zamora, L.N.; Jeffs, A.G. (2013). A review of the research on the Australasian sea cucumber, *Australostichopus mollis* (Echinodermata: Holothuroidea) (Hutton 1872), with emphasis on aquaculture. *Journal of Shellfish Research 32*: 613–627.

APPENDIX 1

Preliminary biomass estimates

Table 3. Preliminary basic estimates of sea cucumber biomass (split-weight) from surveys of key fishing locations within SCC 7A and SCC 1B, 2014. Derived using aggregate split-weight data and the 'coastline length' approach to estimation. Note that commercial size in the SCC 7A survey was determined by a local commercial fisher, and analysis showed a selectivity of L50 = 63 g; in the SCC 1B survey, it was not possible for a commercial fisher to categorise sea cucumbers by size, and the commercial size used to determine aggregate weights was 75 g (representing selectivity of about L90).

Stock	SCC Size	Stratum	Coast length (m)	Prop. length	Transects	Mean (kg.transect)	CV	Biomass (t)
SCC 7A	Commercial	1	41265	0.38	8	1.28	0.25	13.153
		2	56826	0.52	9	4.77	0.30	67.812
		3	10585	0.10	3	4.63	0.31	12.252
		Total	108676	1.00	20	3.43	0.22	93.218
	Small	1	41265	0.38	8	1.56	0.31	16.068
		2	56826	0.52	9	2.25	0.72	32.012
		3	10585	0.10	3	1.96	0.31	5.178
		Total	108676	1.00	20	1.96	0.44	53.257
	All	1	41265	0.38	8	2.83	0.22	29.221
		2	56826	0.52	9	7.03	0.32	99.824
		3	10585	0.10	3	6.59	0.31	17.430
		Total	108676	1.00	20	5.39	0.23	146.475
SCC 1B	Commercial	1	9974	0.13	7	8.94	0.48	22.297
		2	67658	0.87	8	0.70	0.33	10.413
		Total	77632	1.00	15	1.76	0.34	32.710
	Small	1	9974	0.13	7	3.76	0.38	9.384
		2	67658	0.87	8	1.38	0.43	20.429
		Total	77632	1.00	15	1.69	0.32	29.813
	All	1	9974	0.13	7	12.71	0.38	31.682
		2	67658	0.87	8	2.08	0.34	30.842
		Total	77632	1.00	15	3.45	0.26	62.523