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Tini a Tangaroa

Survey of New Zealand sea lion prey at the Auckland Islands and Stewart Snares Shelf

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The main breeding population of New Zealand (NZ) sea lions (*Otariidae*: *Phocarctos hookeri*) at the Auckland Islands has declined by about 50% since the late-1990s. This population displays numerous indicators of nutritional stress, but the precise mechanisms of this stress (e.g., essential prey species and changes in their availability to NZ sea lions) remain poorly understood. This precludes a meaningful assessment of the effects of environmental change or indirect fishery effects on NZ sea lion populations.

In 2016 a survey was undertaken to describe the spatial and bathymetric distribution of NZ sea lion prey species in habitat foraged by lactating female NZ sea lions at the Auckland Islands and Stewart Island—a small, but growing population. A demersal trawl survey around the Auckland Islands (50–500 m depth) found a limited diversity of prey species present shallower than 200 m depth. This is a plausible explanation for the extreme deep diving of the Auckland Islands New Zealand sea lion population, one of the deepest diving of all otariid populations globally.

Many of the key prey species of NZ sea lions were vulnerable to standard trawl gear, whilst the benthic camera surveys conducted were effective in determining the relative abundance of smaller-bodied prey species e.g., opalfish (*Hemerocoetes* spp.), oblique banded-rattail spp. (*Coelorinchus aspercephalus*) and small red cod. Southern arrow squid (*Nototodarus sloanii*) were the only key prey species captured in abundance at less than 200 m and should be highly available to sea lions. Red cod (*Pseudophycis bachus*), potentially the main benthic finfish prey, had greatest catch density in survey trawls at 200–400 m depth, although smaller individuals were observed by the camera survey shallower than 200 m. Observer records from commercial fishing trawls indicate that yellow octopus (*Enteroctopus zealandicus*), a nutritionally high value prey species, are present from 100–700 m and partially overlap with the distribution of deep "benthic" diving NZ sea lions (dives most concentrated between 75–200 m). A trial potting study for yellow octopus, potentially the main benthic cephalopod prey, was unsuccessful in describing their bathymetric distribution.

Hoki (*Macruronus novaezelandiae*), potentially the main prey of mesopelagic foraging NZ sea lions, and southern blue whiting (*Micromesistius australis*) had the greatest biomass estimates of all species in the Auckland Islands trawl survey and were abundant over seafloor greater than 300 m depth. However, both hoki and southern blue whiting undergo diurnal vertical migrations and may be predated by "mesopelagic" diving NZ sea lions in midwater at shallower depths. An analysis of historical survey trawls at the Auckland Islands indicated that hoki abundance shallower than 500 m depth (where they would be available to NZ sea lions) was very low throughout the period 2000–2009, although it increased after 2009. Southern blue whiting rarely appeared in trawl survey catches there before 2000, but have since become a major constituent of the Auckland Islands slope ecosystem.

On the Stewart Snares shelf, a much greater abundance of potential prey species was captured in survey trawls shallower than 200 m, including barracouta (*Thyrsites atun*), jack mackerel spp. (*Trachurus* spp.) and blue cod (*Parapercis colias*). The relative abundance of these species and of slope prey (e.g., hoki and ling – *Genypterus blacodes*) suggest that the Stewart Snares region provides an optimal trophic habitat for the continued growth of this population of sea lions.

With sufficient stations at 300–500 m depth, the Sub-Antarctic trawl survey could provide a fishery-independent means of monitoring prey availability to mesopelagic foraging NZ sea lions. Observed commercial trawl catch-effort records may also provide the information requirements for monitoring prey that are rarely captured by surveys, such as yellow octopus. Time series of prey abundance can then be related to the demographic histories of benthic- versus mesopelagic-foraging sea lions to determine the population consequences of changing prey availability—a prerequisite for understanding climate and indirect fishery effects on NZ sea lions.

1. INTRODUCTION

1.1 Background

The New Zealand (NZ) sea lion (*Otariidae*: *Phocarctos hookeri*) breeds exclusively around NZ with about 98% of annual pup production at the Auckland Islands and Campbell Island in the Sub-Antarctic region. It is thought that NZ sea lions once bred much more widely and that genetically distinct breeding populations on the mainland and at Chatham Islands were eradicated shortly after the arrival of the first human settlers to NZ in the C13th (Collins et al. 2014a, Collins et al. 2014b, MacDiarmid et al. 2016, Rawlence et al. 2016). The remaining Sub-Antarctic populations were then rapidly depleted by commercial sealing operations after 1806, which became uneconomical by 1826 due to low population size (Childerhouse & Gales 1998). Commercial sealing for NZ sea lions was prohibited by law in New Zealand in 1893 and the species is still considered to be in the process of recovering its ancient breeding range and population size (Childerhouse & Gales 1998, Collins et al. 2014a).

The main breeding population at the Auckland Islands has declined by about 50% since the late-1990s (Figure 1), triggering the development of a Threat Management Plan (TMP) for the species (DOC/MPI 2016). The TMP risk assessment identified bacterial infection-related mortality of pups as a key driver of population change at the Auckland Islands (Roberts & Doonan 2016), but this population also displays numerous indicators of nutritional stress (Augé 2010, Roberts & Doonan, 2014). Nutritional stress has been identified as a primary cause of population decline in other pinnipeds, e.g., Steller sea lions, California sea lions and other marine predators (Trites & Donnelly 2003, Cavole et al. 2016). With respect to NZ sea lions, we have a poor grasp of the precise mechanisms of nutritional stress (e.g., changes in the availability of prey species relative to foraging NZ sea lions) and of how this affects key vital rates (e.g., pup/adult survival and natality). This precludes a thorough assessment of the potential climate or indirect fishery effects on NZ sea lion populations (Roberts & Doonan 2016).

The main prey of the Auckland Islands population include a mixture of species targeted by commercial fisheries (e.g., southern arrow squid – *Nototodarus sloanii*, hoki – *Macruronus novaezelandiae*, red cod – *Pseudophycis bachus* and ling – *Genypterus blacodes*), fishery by-catch species (e.g., rattail spp. – family *Macrouridae*) and species that do not regularly appear in fisheries captures (e.g., yellow octopus – *Enteroctopus zealandicus*) (Childerhouse et al. 2001, Meynier et al. 2009, Stewart-Sinclair 2013) (Table 1). However, the identity of the main species limiting foraging efficiency, and therefore population productivity, is not known.

Lactating female NZ sea lions are thought to be particularly susceptible to food limitation due to the additional energetic burden of reproduction, constraints on foraging range imposed by nursing requirements, and strong individual foraging site fidelity (Chilvers 2008). Biotelemetry studies deploying satellite tags attached to lactating females have identified two discrete foraging strategies at the Auckland Islands: "benthic foragers" that predominantly feed on seafloor areas at 50–200 m depth; and "mesopelagic foragers" that forage in midwater between 0–500 m depth over slopes and at the shelf edge (Figure 2 and Appendix 1) (Chilvers & Wilkinson 2009, Gales & Mattlin 1997, Meynier et al. 2014). These two foraging groups also differ in terms of dive energetics, blubber fatty acid composition and blood serum/whisker stable isotope composition (both indicative of contrasting diet, though not resolved to species level) and somatic condition – benthic foragers being ~10 kg lighter for a given length (Chilvers 2017a, Chilvers & Wilkinson 2009, Gales & Mattlin 1997, Meynier et al. 2014). The relatively poor condition of benthic foragers is thought to be a consequence of inefficient foraging for low energy density prey (Meynier et al. 2014). Air-breathing benthic foraging predators tend to operate close to their physiological limits and, as a consequence, are thought to be particularly susceptible to factors that alter the availability of their benthic prey (Costa et al. 2006).

Previous demersal trawl surveys of the NZ Sub-Antarctic have indicated that the prey mix available to benthic and mesopelagic foragers is likely to be quite different; e.g., hoki are infrequently captured shallower than 300 m depth and few southern arrow squid are captured deeper than this (Bagley et al. 2013). However, the Sub-Antarctic trawl survey had no stations shallower than 300 m since 1991 and there were fewer than 10 stations shallower than 500 m (i.e. overlapping with the foraging of NZ sea lions at the Auckland Islands) in any one year (Table 2). Also, some key prey species e.g., yellow octopus appear to have low vulnerability to trawl survey gear. As such, the distributions of key NZ sea lion prey species have not been well-described around the Auckland Islands, particularly in relation to the foraging of NZ sea lions. This lack of information constrains our ability to:

- Identify the prey species that limit population growth;
- Monitor changes in prey availability of relevance to individual foraging efficiency; and
- Predict how climate or commercial fisheries might affect NZ sea lion populations through alteration of local prey availability.

Furthermore, we know little about the relative prey resources available to smaller populations recolonising Stewart Island and the Otago Peninsula on the NZ mainland, which tend to be shallow-diving and appear to have a lower energetic cost of foraging (Augé et al. 2011a, Chilvers 2015). Even without a deep understanding of predator-prey interactions, the comparison of the prey resources available to different populations will provide context for assessing:

- The extent to which prey depletion may limit larger populations;
- The future growth prospects of smaller populations; and
- The extent to which prey resources might constrain the recolonisation of the NZ sea lion's pre-historic breeding range.

1.2 New Zealand sea lion prey survey

The overarching goal of the prey survey was to determine the potential mechanisms of nutritional stress in breeding female NZ sea lions. The survey was designed to describe the bathymetric and spatial distribution of known NZ sea lion prey species around the Auckland Islands and Stewart Island. This survey was centred on the foraging areas and depths used by lactating female NZ sea lions, as determined by previous foraging studies (Chilvers & Wilkinson 2009, Meynier et al. 2014) and sub-divided into areas used by benthic versus mesopelagic foraging individuals. The survey had four science objectives deploying different gear types:

1. Undertake a demersal trawl survey of the Auckland Islands and Stewart/Snares shelf to determine the spatial/bathymetric distribution and abundance of the main prey species of NZ sea lions in the areas used by benthic and mesopelagic foraging lactating females;
2. Deploy underwater cameras to visually survey seafloor habitat and NZ sea lion prey species over a representative subsample of habitat types, as identified from the acoustic swath habitat characterisation;
3. Conduct a potting feasibility study to determine the distribution, abundance and biology of yellow octopus (*Enteroctopus zealandicus*); and
4. Conduct a benthic habitat characterisation based on acoustic swath mapping of the seafloor in the area immediately surrounding demersal trawl stations.

Thus a number of complementary survey gear types were used to describe not just the distribution of NZ sea lion prey, but to characterise the seawater and seafloor habitat across the foraged range of breeding female NZ sea lions.

This survey provides a resource for understanding interactions between NZ sea lions and their prey. The survey was intended to complement studies centred on NZ sea lion breeding rookeries that seek to understand the relationships between the nutritional status and demographic rates of individuals favouring a particular foraging strategy. These studies provide observations at different points in the chain between prey availability and the demographic processes that drive population change in NZ sea lions. Together they provide some of the information requirements for future risk assessments to account for the effects of prey availability on NZ sea lion populations.

2. METHODS

2.1 Demersal trawl survey

Survey design

The survey area was based on the spatial and bathymetric distribution of foraging by lactating female NZ sea lions at the Auckland Islands (Meynier et al. 2014) and Stewart Island (Chilvers 2015) (Chilvers pers. comm.). The Auckland Islands survey area of 50–500 m depth was divided into 7 strata: A1 (50–150 m); A2, A3 and A4 (all 150–250 m); and A5, A6 and A7 (all 250–500 m) (Figure 3). Auckland Islands survey strata were designed to minimise the coefficient of variation (CV) associated with biomass estimates of key prey and high biomass species as well as to partition depths and areas used by benthic or mesopelagic foraging individuals (Figure 2 and Appendix 1). The Stewart Snares Shelf area of 30–400 m was sub-divided into 9 strata: S2 and S3 (30–100 m); S5a, S5b, S6a, S6b, S10a and S11 (100–200 m); and S13 (200–400 m), based on survey strata used in the Southland demersal trawl surveys of middle depth and inshore species in 1993–1996 (TAN9301, TAN9402, TAN9502 and TAN9604) (Hurst & Bagley 1997). The total survey area (of all strata) at the Auckland Islands (20 187 km^2) was approximately 20% greater than that of Stewart Snares (16 931 km^2) (Table 3).

The trawl station allocation by stratum was determined from simulations based on catch rates from all demersal trawl surveys in the years 1979–2011, using the ‘allocate’ procedure of Bull et al. (2000) as modified by Francis (2006). For the Auckland Islands, the tow allocation was optimised for key NZ sea lion prey species: hoki (expected CV given this tow allocation = 25%), ling (15%), southern arrow squid (37%), red cod (110%), hake (*Merluccius australis*, 30%), barracouta (*Thyrsites atun*, 47%), oblique-banded rattail (*Coelorinchus aspercephalus*, 11%) and warty squid (*Onykia ingens*, 25%). At the Stewart-Snares, the station allocation used in previous surveys were used to apportion the 30 planned stations to survey strata S2, S5a, S6, S10a, S11 and S13 (Figure 4), which was optimised for the known NZ sea lion prey species from limited diet studies of this region (Lalas & Webster 2014, Lalas et al. 2014) and the main species in terms of biomass from previous Southland surveys (Hurst & Bagley 1997): rough skate (*Raja nasuta*; expected CV = 18%), redbait (*Emmelichthys nitidus*; 66%), red cod (61%), blue cod (*Parapercis colias*; 33%), spiny dogfish (*Squalus acanthias*; 24%), barracouta (28%), hoki (25%), Chilean jack mackerel (*Trachurus murphyi*; 44%), and silver warehou (*Seriolella punctata*; 40%).

Vessel and gear specifications

NIWA’s *R.V. Tangaroa* is a purpose-built, research stern trawler of 70 m overall length, a beam of 14 m, 3000 kW (4000 hp) of power, and a gross tonnage of 2282 t. The bottom trawl deployed in this study was the same as that used on previous surveys of middle depth species by *Tangaroa*. The net is an eight-seam hoki bottom trawl with 100 m sweeps, 50 m bridles, 12 m backstrops, 58.8 m groundrope, 45 m headline, and 60 mm codend mesh – see Hurst & Bagley (1994) for net plan and rigging details. All trawls were fitted with an upward facing Sea Lion Exclusion Device (SLED). The design of SLEDs and their placement in trawl nets follow the industry standard adopted for commercial trawls in SQU 6T. The trawl doors were Super Vee type with an area of 6.1 m^2. Measurements of doorspread (from a Scanmar 400 system) and headline height (from a Furuno net monitor) were recorded every 5 minutes during each tow and average values calculated.

Trawling procedure

Trawling followed the standardised procedures described by Hurst et al. (1992). Station positions were selected randomly before the voyage using the RandomStation Generation Program (Version 1.6) developed at NIWA, Wellington. Biomass tows were carried out during daylight hours, with all trawling between 0555 h and 1808 h NZST. At each station the trawl was towed for 3 n. miles at a speed over the ground of 3.5 knots. Towing speed and gear configuration were maintained as constant as possible during the survey, following the guidelines given by Hurst et al. (1992).

Catch and biological sampling

Trawl data were entered in real time using the electronic data capture system on-board the *Tangaroa* and were error-checked at sea. All species were weighed using motion-compensated scales on every successful trawl station. Biological sampling followed standardised procedures outlined by Hurst et al. (1992), specifically:

- A random sample of up to 200 fish of each species were measured.
- A subsample of up to 20 fish from the random sample of key NZ sea lion prey species were measured, weighed, sexed, and reproductive stage was recorded.
- Samples of key NZ sea lion prey species were collected and frozen for subsequent isotopic and dietary analyses.

Estimation of biomass and length frequencies

Doorspread relative biomass was estimated by the swept area method of Francis (1981), Francis (1989) using the formulae in Vignaux (1994) as implemented in NIWA custom software SurvCalc (Francis 2009). The biomass and associated CV were calculated by stratum for key NZ sea lion prey species and other abundant species.

The catchability coefficient (an estimate of the proportion of fish in the path of the net which is caught) is the product of vulnerability, vertical availability, and areal availability. These factors were set at 1 for the analysis, the assumptions being that fish were randomly distributed over the bottom, that no fish were present above the height of the headline, and that all fish within the path of the trawl doors were caught. Population scaled length frequencies were calculated for the key species with SurvCalc, using length-weight data from this survey. Only data from stations where the gear performance was satisfactory (codes 1 or 2) were included for estimating biomass and calculating length frequencies.

2.2 Underwater camera survey

Camera deployment

NIWA’s Deep Towed Imaging System (DTIS) (Hill 2009) was used to quantify prey species densities and characterise benthic habitat at demersal trawl survey stations at night (see Figure 3 and Figure 5). There was insufficient time to deploy cameras at all stations, although there was at least one deployment in each of the Auckland Islands demersal trawl survey strata (ranging from 92–485 m bottom depth, taking the mean depth along each deployment) and across a range of depths on the Stewart Snares shelf (38–292 m) (see Table 3).

Transects were run using DTIS configured with a high-definition digital video camera angled forward at 45° from vertical, and a digital single lens reflex camera angled vertically downwards. Still images were taken automatically at 15 s intervals throughout all transects. During transects, DTIS was ‘flown’ at a target altitude of 2–3 m above the seabed for about 1 hour bottom time (about 1 nautical mile). The seabed position of DTIS was monitored by an acoustic ultra-short baseline (USBL) transponder system (Simrad HPR). The seabed distance of each transect was measured using the R package “argosfilter” (Freitas 2012). Pairs of parallel red lasers at 0.2 m spacing projected into the field of each camera enabled accurate scaling of prey species.

Image post-processing

The full seabed duration of each video transect was reviewed post-voyage by a single analyst. All finfish, cephalopods, crustaceans and other invertebrates (all organisms larger than about 5 cm) and bottom type observations were recorded as counts and then standardised to numbers per linear kilometre of transect. Expert taxonomists were consulted for species/taxon identification and the higher resolution DTIS still images were referred to for confirmation of identities in the video. For some taxa, coarse-level labels, such as ‘Sponge spp.’ (MPI code “ONG”), were assigned where identification from video was uncertain.

2.3 Octopus potting feasibility study

A habitat trap pot study was conducted to assess the feasibility of capturing yellow octopus (*Enteroctopus zealandicus*) and to determine fishery-independent estimates of bathymetric distribution within the Auckland Islands survey area. The pot design, gear configuration and deployment was based on an approach found to give good catch rate (1–5 individuals per 10 pot units) of *Macroctopus maorum* octopus caught in in West Australia (FINS 1980) which have a similar maximum size to yellow octopus. Each pot unit comprised 2 PVC tubes (length 750 mm, diameter 150 mm) bolted together, with a concrete bung (depth 40 mm) in the middle of each tube, so that each unit comprised 4 chambers in which octopus could be retained (Figure 6, top-left). Each pot deployment (or “string”) comprised 20 pot units (or 80 chambers) connected to a mother line via branch lines (Figure 6, top-right).

Pots were deployed along a transect at 50° 41’ S to the east of the Auckland Islands (see Figure 5), where confirmed yellow octopus captures around the Auckland Islands are most densely aggregated (Appendix 2). This transect was first mapped with the multibeam echosounder and pot locations selected on the basis of bathymetry. The total pot deployment comprised 4 pot strings (a total of 80 pot units) at 110, 140, 290 and 425 m depth (the shallowest 2 on the shelf, the third on the slope and deepest away from the bottom of the slope), set on 12 February and retrieved 17 February (5 nights soak time) – based on the minimum soak time of 5 days found to give good catch rate for *M. maorum* using the same pot design (FINS 1980).

2.4 Benthic habitat characterisation

The EM302 multibeam swath mapping echosounder on *Tangaroa* was used to swath map areas of the sea floor immediately surrounding all demersal trawl stations. The multibeam echosounder provides high resolution bathymetry and backscatter data of the seafloor. This was used for two purposes: first, to identify trawlable ground at all demersal trawl stations; and second, to characterise benthic habitat. Post-voyage data analyses of backscatter used the IFREMER SonarScope software to produce compensated backscatter images and to identify areas of ‘sameness’ grouped into one of six habitat classes.

2.5 Oceanographic observations

Acoustic data

Acoustic data were collected during trawling and while steaming between trawl stations (both day and night) with multi-frequency (18, 38, 70, 120, and 200 kHz) Simrad EK60 echosounders with hull-mounted transducers. All frequencies were regularly calibrated following standard procedures (Foote et al., 1987). A quantitative analysis was carried out on daytime trawl and night steam recordings using the custom Echo Sounder Package (ESP2) software (McNeill 2001). Estimates of mean acoustic backscatter per square kilometre were integrated throughout the water column in 100 m depth bins.

Hydrology

The oceanographic programme consists of two main components: the collection of underway data in transit; and water column sampling with trawl-mounted Conductivity-Temperature and Depth (CTD) recorder. Underway water sampling was used to provide continuous spatial coverage of surface waters. Water was collected via a seawater intake in the vessel’s hull and processed through a series of inline electronic instruments to measure sea surface temperature, conductivity, fluorescence, and other properties. Water samples were collected and filtered for stable isotope analysis (49 samples) and rapid DNA sequencing (15 samples). All filters were analysed at NIWA Greta Point for carbon and nitrogen isotope values to assess for spatial variation in the marine environment around the Auckland Islands and to relate to stable isotope signatures from NZ sea lion teeth.

The Seabird SM-37 Microcat CTD was mounted on the headline of the net during all 89 bottom and midwater trawls. Data were collected at 5 second intervals throughout the trawl, providing vertical profiles. Surface values were read off the vertical profile at the beginning of each tow at a depth of about 5 m. Bottom values were about 7.0 m above the seabed (i.e., the height of the headline).

3. RESULTS

3.1 Trawl and underwater camera surveys

A total of 47 trawl survey tows were successfully completed in 7 strata at the Auckland Islands and 34 successful tows in 9 strata on the Stewart Snares shelf (Table 3, Figure 3 and Figure 4). Station details are given in Appendix 3. There was an extensive area of hard, rough (‘foul’) seabed northeast of Auckland Island from about 100–200 m depth (Figure 3). Multibeam echosounder data and camera drops with the DTIS camera showed that this consisted of rock plates and sponge which made bottom trawling impossible in parts of strata A1 and A3. The spatial extent of foul ground meant that only 11 of the 21 planned trawls could be achieved in these strata (Table 3).

A total catch of 48.5 t was recorded from all trawl stations across the Auckland Islands and Stewart Snares shelf (Appendix 4). A total of 142 species/taxa were caught, including: 58 teleosts; 16 elasmobranchs; 16 echinoderms; 12 crustaceans; and 7 cephalopods. The remaining biomass was comprised of assorted benthic and pelagic species. The main species in terms of percentage of total biomass were spiny dogfish (21.6%), hoki (16.9%), southern blue whiting (12.1%), and ling (7.9%). The biomass estimates and associated CV for key species in each survey area are given in Table 4 and Table 5. The highest biomass species around the Auckland Islands were (in descending order): southern blue whiting (2210 t, CV = 30%), hoki (1916 t, CV = 26%), southern arrow squid (1792 t, CV = 37%), ling (1350 t, CV = 16%) and dark ghost shark (1345 t, CV = 27%). All other species had an estimated biomass of less than 150 t within the Auckland Islands survey area. The highest biomass species of the Stewart Snares survey area were: spiny dogfish (4287 t, CV = 23%), barracouta (2585 t, CV = 21%), giant stargazer (1253 t, CV = 18%), hoki (701 t, CV = 88%) and southern arrow squid (296 t, CV = 25%) (Table 5). For nearly all species, the biomass CV was close to the expected value.

A total of 31 DTIS deployments were completed: 18 in the Auckland Islands area and 13 at Stewart Snares (Table 3). DTIS station details are given in Appendix 3 and locations are plotted in Figure 5.

Spatial and bathymetric distribution

The spatial distribution of selected species in the Auckland Islands and Stewart Snares survey areas are shown in Figure 7 and Figure 8. Southern arrow squid and smooth red swimming crab had highest trawl catch rates over the shelf region surrounding the Auckland Islands. Hoki, southern blue whiting, and red cod were most abundant over the slope region to the north. Analysis of species’ bathymetric distributions from trawl catch-effort and DTIS camera transects indicated that spatial distribution (and therefore relative distance from NZ sea lion breeding rookeries) was strongly influenced by bathymetry. The bathymetric distribution of selected species’ catch rate in survey trawls and density of observations in DTIS footage is shown in Figure 9 to Figure 14. Hoki and southern blue whiting are both diurnally migrating species and had greatest trawl catch rates in trawls greater than 300 m depth, where NZ sea lions mostly undertake mesopelagic dives (Appendix 1). Benthic-diving NZ sea lions primarily use the shelf between 100–200 m (Appendix 1). Southern arrow squid, smooth red swimming crab and giant spider crab dominated survey trawls at these depths and were frequently observed along DTIS transects at this depth range. Observations of red cod and oblique-banded rattail in DTIS camera transects indicated that they were most abundant shallower than 200 m, although trawl catch rates for both species were greatest at deeper than 200 m – this discrepancy is likely to relate to the differential vulnerability of small and large individuals to observation by DTIS transects compared with the standard hoki trawl gear.

Opalfish (*Hemerocoetes* spp.) could not be resolved to species level by trawling or DTIS and appeared to be distributed across the 50–500 m depth range of the survey, although DTIS camera transects indicated that the opalfish species group density was greatest shallower than 200 m, where they were frequently observed partially buried into sandy sediment and occasionally in large aggregations (Figure 15). Yellow octopus appear to have low vulnerability to observation by DTIS camera transects (only two were observed, see Figure 15) in addition to the survey trawl gear (one captured), although the bathymetric distribution of these observations indicates that they are present from the shelf to the plateau at the bottom of the slope (i.e., across the bathymetric range of the survey and of NZ sea lion foraging at the Auckland Islands) (Figure 9).

At the Stewart Snares area, blue cod, rough skate and ling all had greatest catch rates to the east of Stewart Island, while giant stargazer were most abundant to the west (Figure 8). A number of known NZ sea lion prey species were abundant shallower than 200 m, including blue cod, barracouta, and jack mackerel species, while hoki and ling were most abundant over slope areas greater than 200 m depth (Figure 8, Figure 10 and Figure 13). Barracouta and jack mackerel were caught all around Stewart Island. These species tended to be present in the same trawls and were observed in the same schools in DTIS-footage to the west of Stewart Island at about 5 m from the bottom. The trawl survey indicated that southern arrow squid may be more deeply distributed at Stewart Snares (peak catch rate between 200–300 m depth) relative to the Auckland Islands (Figure 9), although the DTIS survey (in which smaller individuals were observed) indicated that they were most abundant shallower than 200 m. As at the Auckland Islands, the depth distribution of red cod inferred from DTIS camera transects (greatest density shallower than 200 m depth) was shallower than from the trawl survey (greatest catch rate deeper than 200 m).

Length composition

A total of 30 549 individual fish of 62 species were measured (Appendix 4). The length frequency distributions for major prey species of NZ sea lions and selected abundant species are shown in Figure 16, Figure 17 and Figure 18.

The Stewart Snares area catch of hoki almost entirely comprised individuals 39–47 cm length—probably the 2+ cohort. At the Auckland Islands, the population comprised a number of cohorts, with few hoki less than 60 cm total length (few fish younger than age 3). The modal length (69 cm) was close to the mean length of fish found in NZ sea lion stomachs (72 cm) in a study of individuals captured in commercial squid trawls around the Auckland Islands between 1997 and 2006 (Meynier et al. 2009). Few red cod were measured for estimating length composition at the Auckland Islands, although it is likely that at least two cohorts were captured, including fish less than 25 cm (not more than age 1) and fish between 40 and 60 cm (about age 3 and over). The length composition of southern arrow squid at the Auckland Islands (modes at about 20 cm and 30 cm mantle length) was consistent with at least 2 birth months and was similar to specimens in the stomachs of by-caught NZ sea lions, which had a mean mantle length of 23 cm (Meynier 2009). Few individuals larger than 30 cm were observed in the Stewart Snares area, though their length frequency here also had multiple modes at about 10 cm, 15 cm and 25 cm. Catches of southern blue whiting at the Auckland Islands included individuals age 1+ (20–30 cm) and age 5–10 (35–45 cm fish). This length composition indicates that new cohorts are in the process of recruiting to this population. At Stewart Snares the length composition of barracouta was consistent with at least 3 age cohorts: age 1+ (30–40 cm), age 2+ (about 50 cm) and age 3+ (about 60 cm), although fish greater than 80 cm length were also captured.

Temporal biomass

The catch rate of selected NZ sea lion prey species was assessed in Sub-Antarctic trawl survey stations around the Auckland Islands from 1991–2016 (Table 2). Two depth strata were considered: 300–500 m and 500–800 m. This analysis indicated that a period of low hoki biomass occurred around the Auckland Islands from 2001 to 2008 and that this was accentuated at 300–500 m where they would be available to NZ sea lions (Figure 19 and Figure 20). Javelinfish also had a low catch rate in the shallower stratum from 2000 to 2006, though the number of trawl stations at 300–500 m depth was low in any one year. By comparison the trawl survey catch rate of ling, javelinfish (*Lepidorhynchus denticulatus*), hake and oblique-banded rattail at 500–800 m all showed no obvious year trend. The southern blue whiting catch rate in 300–500 m was very low until 2006 but was comparable to that of hoki in all years since 2009 (Figure 20).

Benthic habitat

DTIS camera transects were used to describe the benthic substrate and associated invertebrate communities. These indicated that shallow stations (less than 200 m) around the Auckland Islands were largely comprised of exposed bedrock, cobbles, gravel or sandy sediment, indicative of strong currents near to the seafloor (Figure 21). The dominance of shallow benthic fauna by filter-feeding sponge species (*Porifera* spp.) (Figure 14) is also indicative of a shelf habitat formed by strong currents. Bedrock and coarser grains gave way to sandy sediment with increasing depth over slopes and the surrounding Campbell Plateau, although even at deeper stations (greater than 300 m depth) muddy sediments were not prevalent, as they were in the Stewart Snares (Figure 21).

Midwater observations

Two midwater trawls (stations 55 and 72; Figure 3) were carried out at night at locations used by mesopelagic foraging NZ sea lions at the Auckland Islands (Figure 2). Midwater trawls used the demersal trawl net ‘flown’ above the seabed with the objective of sampling layers away from the bottom, although catches from these trawls were very small (fewer than 10 individuals) and were deemed unsuitable for estimating the species composition of potential midwater NZ sea lion prey. Throughout the survey, midwater observations of teleost species, southern arrow squid, salps, and krill were made using the DTIS deployed in midwater, though these were not of sufficient quality for species identification.

3.2 Octopus potting study

Four pot lines were re-visited after 5 nights of soak-time (Figure 5). The deepest pot line was recovered in the position it was set, but no octopus of any species were caught. The line set on the slope (station 16) was not located and may have been shifted by strong currents. The two pot lines set on the shelf (stations 14 and 15) were both recovered, but most pot units had been broken off the backbone line. No yellow octopus were retrieved by the potting study. However, the spatial and bathymetric distribution of this species was described by an additional analysis of observer-reported commercial trawl catch-effort data, summarised in Appendix 2.

3.3 Benthic habitat characterisation

Multibeam acoustic bathymetry and backscatter data are consistent with an area of hard, rough seabed northeast of Auckland Island from 100–200 m depth. Camera drops with the DTIS show that this consists of bedrock plates covered with sponges (Figure 14, Figure 21 and Figure 22). Multibeam data at deeper stations suggested softer sediment habitat with sand waves and ripples, confirmed by the DTIS transects (Figure 21). Substrate in the Stewart-Snares area generally consisted of sand and muddy sediment, but there were extensive bedrock reefs towards the southern limit of the survey area (Figure 4 and Figure 21). The diversity of benthic habitat types across the survey area was confirmed by the spatial classification of swath data (Figure 23 and Figure 24). This identified a relatively homogenous habitat in stratum A7 (250–500 m deep) (e.g., Station 12 of Figure 23), which was confirmed by DTIS footage to be dominated by sand and mud sediments. Shelf (e.g., Stations 26 and 36 of Figure 23) and shelf edge sites (e.g., Station 44 of Figure 23) were characterised by a more spatially heterogeneous habitat.

3.4 Oceanographic observations

Acoustic data provided information on the vertical distribution of prey species through the water column, where total backscatter includes all reflecting objects in the water column, i.e., NZ sea lion prey species and/or mesopelagic species such as myctophids. These data were consistent with densest backscatter at water depths greater than 200 m and over slope regions with a depth range of 200–400 m (Figure 25).

The water column was weakly stratified at the Auckland Islands with surface temperatures ranging between 9.8 and 11.4 °C and bottom temperatures between 7.1 and 10.3 °C. In the Stewart-Snares area surface temperatures ranged between 12.0 and 15.9 °C and bottom temperatures between 7.7 and 14.9 °C. The isotopic composition of seawater filtrate showed considerable spatial variation (Figure 26 and Figure 27).

4. DISCUSSION

4.1 Benthic & mesopelagic prey

This survey described the spatial and bathymetric distribution of the main prey species of benthic and mesopelagic-foraging NZ sea lions. The main benthic and mesopelagic prey (Table 6) were identified from their bathymetric distribution relative to that of the dives of each foraging group (Appendix 1) and using prior information about the habitat preference of respective prey species.

Benthic prey – Auckland Islands

The trawl survey of the Auckland Islands estimated southern arrow squid to have the greatest biomass of the known prey species within the 75–200 m depth range mainly used by benthic foragers; the two species with greater overall biomass—southern blue whiting and hoki—were not captured shallower than 250 m (Table 4). This was consistent with the DTIS-camera survey, which found that southern arrow squid had greatest density (*n*/km) at 150–200 m depth (Figure 9).

Southern arrow squid were described as a mesopelagic prey of NZ sea lions by Meynier et al. (2014). At the Auckland Islands, southern arrow squid are targeted by bottom trawls and midwater gear, although both gear types are typically flown close to the bottom (Richard Wells, ResourceWise, personal communication). A trawl survey of southern arrow squid at the Auckland Islands in 1981 found that demersal trawl catch rates in strata less than 200 m depth were greater at night ($\bar{x}$ = 393 kg per 30 minute trawl, 8 stations) than during daytime ($\bar{x}$ = 50 kg per 30 minute trawl) across the same 8 stations (Kawahara & Tokusa 1981). This is inconsistent with southern arrow squid being a prey of mesopelagic divers at the Auckland Islands, as was inferred by Meynier et al. (2014) from blubber fatty acid analysis. However, this pattern could also be explained by changes in catchability during day versus night trawls, e.g. associated with light avoidance, though at Stewart Snares strata the same survey consistently obtained smaller biomass estimates at the night ($\bar{x}$ = 12 kg per 30 minute trawl) than during daytime ($\bar{x}$ = 48 kg per 30 minute trawl) across 20 stations (Kawahara & Tokusa 1981). This is consistent with southern arrow squid being a demersal prey for NZ sea lions at the Auckland Islands and a midwater prey on the Stewart Snares shelf.

NZ sea lion foraging was almost exclusively benthic in winter (July-September) (Appendix 1, Figure A1-3), when fishery catch rate data indicate that southern arrow squid are scarce around the Auckland Islands (Hurst et al. 2012). The DTIS camera survey found that red cod, oblique-banded rattail and opalfish were all most abundant at 100–200 m depth (Figure 9 and Figure 11). According to previous studies, opalfish are the most numerous prey (23–50% *N* across all studies) (Childerhouse et al. 2001, Stewart-Sinclair 2013, Meynier et al. 2009). Opalfish are therefore the most frequent prey interaction, although they only form a low percentage of NZ sea lion diet mass (5% *M*) due to their small individual size ($\bar{x}$ = 20 g) (Meynier et al. 2009).

Red cod are likely to be the main benthic teleost prey in terms of mass contribution (see Table 1), although smaller individuals (abundant in DTIS transects at 100–200 m) would be more available to benthic foragers than larger individuals (peak trawl survey catch rate at 200–400 m depth) (Figure 9). Similarly, observer records of commercial trawl catch-effort indicate that yellow octopus occur from 100–700 m depth, but will have low availability to benthic foragers deeper than 200 m (Appendix 2, Figure A2-3). Yellow octopus predated by NZ sea lions tend to be large (mean mass = 1.8 kg) (Meynier et al. 2009). Yellow octopus will be the main cephalopod prey in winter months when southern arrow squid catch rate is low around the Auckland Islands and appear to be of at least equal importance relative to southern arrow squid in the summer (Table 1) (Meynier et al. 2009, Childerhouse et al. 2001). As such, the year-round foraging efficiency of benthic foragers will be strongly influenced by the relative abundance of yellow octopus.

The diet composition of benthic- and mesopelagic-foraging NZ sea lions at the Auckland Islands was previously inferred from the differential blubber fatty acid composition of lactating females (Meynier et al. 2014). This identified scampi (*Metanephrops challengeri*) as being of particular importance to benthic foragers (27% *M*), though, to date, no single published dietary study based on remains (i.e., from stomach contents or remains in scats and regurgitates) has reported scampi to be present in the diet of NZ sea lions (Meynier et al. 2009, Childerhouse et al. 2001, Stewart-Sinclair 2013). Furthermore, the bathymetric distribution of benthic dives, which is concentrated between 75–200 m, is much shallower than the 350–550 m depth range where scampi are abundant around the Auckland Islands. Meynier et al. (2014) also identified hoki as a major prey of benthic foragers (16% *M*), though this prey survey confirmed that they are not present shallower than 200 m. Therefore, scampi and hoki are not plausible prey for benthic-foraging females at the Auckland Islands.

Benthic prey – Stewart Snares

Limited diet studies at Stewart Island (males and females) and Snares Island (mostly males) indicate that a mixture of demersal (e.g., blue cod, red cod, wrasse and rough skate) and pelagic (e.g., redbait) species are predated, with strong location effects, e.g., wrasse (*Labridae*) dominated prey remains in scat samples inside Port Pegasus and redbait dominated other sites around Stewart Island (Lalas et al. 2014, Lalas & Webster 2014). A biotelemetry study of lactating females at Stewart Island indicated that dives are moderately deep (mean dive depth is about 60 m at Stewart Islands, compared with about 20 m at the Otago Peninsula and about 130 m at the Auckland Islands), although widespread (65% kernel range of foraging at Stewart is 440 km^2, compared with 47 km^2 at the Otago Peninsula and 687 km^2 at the Auckland Islands) (Chilvers 2017b). However, there is currently no information as to whether a particular foraging strategy is favoured by females at Stewart Island or associated bathymetric ranges, so the distribution of known benthic prey across the entire survey area is described here.

The shallowest survey station (66 m depth, station 121 in stratum S3) was most likely too deep to observe wrasse, which are most abundant over shallow rocky reefs fringing the coast. Where abundant, wrasse would provide a highly available food source for NZ sea lions, requiring minimal energetic cost. Blue cod were moderately abundant immediately to the south of Stewart Island (Figure 8) and were regularly observed along shallow DTIS transects (Figure 13), resting exposed on the seabed. Rough skate had greatest catch rate over the shelf edge and upper slope (100–300 m depth, Figure 8 and Figure 13), although individuals were also observed at stations shallower than 100 m depth. A number of other demersal species including tarakihi and hapuku were abundant shallower than 200 m, but have not yet been identified in NZ sea lion diet (Figure 13).

Mesopelagic prey

Hoki and southern blue whiting had the greatest survey trawl biomass estimate of all species across the Auckland Islands survey area and both were abundant over seafloor deeper than 300 m. Both of these species undertake diel migrations up through the water column and can be predated shallower than 300 m by mesopelagic foraging NZ sea lions, which ranged from 0–500 m depth at the Auckland Islands (Appendix 1, Figure A1-3). Both hoki and southern blue whiting were most abundant over the north-east slope (Figure 7), only partially overlapping with the spatial distribution of five mesopelagic foraging sea lions tracked by Meynier et al. (2014) (Figure 2), although this sample size was probably too small to adequately represent the spatial distribution of this foraging group. Meynier et al. (2014) identified a mesopelagic-foraging hotspot over a slope region to the north-west of the Auckland Islands and relatively close to the main breeding rookeries (Figure 2), but this location was not sampled by the prey survey.

At Stewart Snares, only two individual redbait were captured by the trawl survey and were either patchily distributed, not very abundant at the time of the survey or had low vulnerability to capture by the trawl. Barracouta and jack mackerel—major prey of Otago Peninsula NZ sea lions (Augé et al. 2011b)—were both observed in abundance in all areas surrounding Stewart Island (Figure 8) shallower than 150 m depth, though were estimated to be minor prey species of sea lions from limited sampling at Snares Island (Lalas & Webster 2014). More diet studies may be required (e.g., at other haul out sites and months) to adequately represent the diet of the Stewart and Snares Islands populations. Southern arrow squid and juvenile hoki were also abundant along south-east slopes of the Stewart Snares Shelf and appear to provide potential food resources for the Stewart Island population that have yet to be exploited.

4.2 Habitat quality

The Auckland Islands population of NZ sea lions is one the deepest diving sea lion or fur seal populations globally (Chilvers et al. 2006). In contrast females at the Otago Peninsula mostly forage for shallow-distributed species such as jack mackerel and barracouta at less than 30 m depth (Augé et al. 2011a, Augé et al. 2011b). Otago females tend to have better body condition and commence breeding at a younger age relative to the Auckland Islands population (Augé 2010, Roberts & Doonan 2016). This has led to a hypothesis that the shelf and slope areas surrounding the Auckland Island comprise sub-optimal habitat for NZ sea lions, situated at the southern limits of their historical breeding range (Collins et al. 2014a, Collins et al. 2014b, Augé 2010). Biotelemetry studies have found that benthic-foraging females at the Auckland Islands undertake a large proportion of anaerobic dives and are about 10 kg lighter than mesopelagic foragers, suggesting that the Auckland Islands shelf may be of particularly poor habitat quality (Meynier et al. 2014).

The prey survey found a low diversity and abundance of large-bodied NZ prey species over the deep shelf region (75–200 m) where benthic foraging is most concentrated. Of the main prey at the Auckland Islands only southern arrow squid had a high biomass and, so, should be relatively available to benthic-foraging NZ sea lions, though diet studies indicate that southern arrow squid comprise not more than 20% of their diet by mass (see Table 1) (Meynier et al. 2009, Childerhouse et al. 2001, Stewart-Sinclair 2013). A number of other known benthic prey occur at 75–200 m, including: yellow octopus, small red cod, opalfish spp. and oblique-banded rattail – all of which have low vulnerability to the survey trawl. The relatively poor condition of benthic foragers suggests that one or more of these prey species has reduced in abundance. However, demographic rates (e.g., survival, natality and successful rearing of a pup) may be a better measure of a forager’s success than their relative size and condition, which could be an adaptation to a particular mode of feeding rather than just a consequence.

The 12 n. mile marine mammal sanctuary around the Auckland Islands precluded survey effort shallower than 90 m depth. A coastal dive survey in 1986 to 25 m depth found dense macroalgal beds, although finfish were low in abundance and dominated by juveniles of two species only: small-scaled cod (*Paranotonethia microlepidota*) and Maori chief (*Paranotothenia angustata*) (Kingsford et al. 1989, Schiel 1990). These were most abundant at a site close to the Sandy Bay breeding rookery on Enderby Island at Auckland Islands, although diet studies indicate that small-scaled cod are only a minor prey species for this population (Meynier et al. 2009, Childerhouse et al. 2001). The relative lack of benthic dives shallower than 75 m (Appendix 1, Figure A1-3) indicates that the low abundance of prey continues to this depth.

Schiel (1990) hypothesised that the low diversity of littoral species could be driven by barriers to dispersal of biota, low water temperature or predation by NZ sea lions, shags and penguins. Predator depletion of littoral prey around the Auckland Islands was first suggested by Chilton (1909) in 1907, who concluded that “It is doubtless the presence of seals that has driven these fishes [small-scaled cod] to such secluded habitat”. The population of NZ sea lions is thought to have grown substantially since the early-1900s (Childerhouse & Gales 1998) exacerbating intra-specific competition for littoral resources. Extreme sea conditions may also be a factor. The proliferation of bedrock across the shelf (Figure 21) is consistent with strong currents near the bottom or exposure to rough sea conditions, which may also depress the availability of prey in the littoral zone and contribute to the relatively deep, energetically-expensive diving of NZ sea lions over the shelf.

It is likely that a prey species’ relative density will be more important to the foraging success of an individual sea lion than wider area biomass, that the survey was designed to produce for the Auckland Islands and Stewart-Snares area. Inferring a prey species’ relative density from survey biomass estimates within the Auckland Islands and Stewart Snares survey areas is complicated by differences in respective survey area (20 187 km^2 at the Auckland Islands and 16 931 km^2 at Stewart Snares) and survey depth (100–500 m at the Auckland Islands and 30–400 m at Stewart Snares) (Table 3). This means that the relative density of deeper distributed prey such as hoki and ling will be under-represented at Stewart

Snares relative to the Auckland Islands. However, the densities of each prey species at depth (inferred from trawls and DTIS transects; Figure 9 to Figure 14) allow a comparison of the relative availability of prey species to NZ sea lions foraging in each respective area.

A greater number of potential prey species was observed in abundance on the Stewart Snares shelf, including known prey species of the Stewart Island and Otago Peninsula populations, e.g., rough skate, blue cod, barracouta and jack mackerel. The Stewart Island breeding population is small (fewer than 40 pups born each year; DOC unpublished data) and there should be minimal intra-specific competition for food resources. Prey aggregating over the slopes – e.g., southern arrow squid, ling and juvenile hoki – are located further away from Stewart Island but appear to be within range of lactating females (based on Auckland Islands foraging data) and should provide additional resources for the sustained growth of the Stewart Island population.

4.3 Temporal availability

Nutritional stress was identified by the NZ sea lion Threat Management Plan as a driver of the decline at the Auckland Islands, although the precise mechanisms (i.e., essential prey species and stressors of their availability) and associated population consequences are poorly understood. A common approach to identifying key prey species is to relate time series of local prey abundance or their occurrence in predator diet with annual demographic/biological observations of the predator population (Roberts & Doonan 2014, Stewart-Sinclair 2013). Long time-series of annual demographic rates including pupping rate, adult survival and pup survival (to age 1) were estimated by the risk assessment informing the NZ sea lion TMP (Roberts & Doonan 2016). This found that the approximately 50% decline in pup production at the Auckland Islands since the late-1990s (Figure 1) was explained by the combination of low first year survival since 1994, low adult survival since 2000, and occasional years of low pupping rate, with particularly poor demographic rates from 2005–2009 (Roberts & Doonan 2016, Roberts et al. 2014).

A long-term dietary study of NZ sea lions at the Auckland Islands found evidence for a declining trend between 1995–2013 in the contribution of yellow octopus and an increase in other demersal species identified in the prey survey – southern arrow squid, red cod, oblique-banded rattail and opalfish spp. (Stewart-Sinclair 2013). This could be explained by a decline in yellow octopus causing benthic foragers to prey switch to other demersal prey identified in this NZ sea lion prey survey (Section 4.1) (Table 6), though larger sample sizes than were available to Stewart-Sinclair (2013) may have been required to identify specific years of high and low prey availability.

The analysis of trawl survey catch rate around the Auckland Islands since 1990 indicated that long-term temporal shifts in the availability of hoki, southern blue whiting and javelinfish have occurred (Figure 19 and Figure 20), all of which are mesopelagic prey species. The Sub-Antarctic trawl survey series indicates that hoki abundance was relatively high from 1991–1993, reduced sometime prior to 2000, then was particularly low from 2003–2006, before increasing again (Bagley et al. 2013). The same basic trend was observed in trawl survey catch rate around the Auckland Islands at 500–800 m depth (where hoki are most abundant, though inaccessible to NZ sea lions), except that catch rate declined after peaking in 2009. At 200–500 m depth, the catch rate of hoki was consistently very low in all years from 2000–2009 (Figure 19), indicating that an adverse shift in bathymetric distribution occurred on top of the decline in abundance, though the number of stations in each year was low. During this time (encompassing the 2005–2009 period of very poor NZ sea lion demographic rates) it is likely that hoki abundance was particularly low over the slopes, where they would normally be available to NZ sea lions feeding in midwater.

There was no obvious trend in the time series of trawl survey catch rates of other prey species, except southern blue whiting, which were rarely captured prior to 2006, but have become one of the more abundant species since in this region (Figure 20). Southern blue whiting were not previously identified as a major prey species of NZ sea lions (Childerhouse et al. 2001, Meynier 2009) when historical surveys indicate they were not locally abundant, although their increased occurrence in NZ sea lion scats at the Auckland Islands since 2010 (Stewart-Sinclair, personal communication) suggests that their importance to NZ sea lions has grown as the abundance of southern blue whiting has increased around the Auckland Islands.

Standardised catch-per-unit-effort indices of southern arrow squid were estimated from commercial trawl catch records for the period 1990–2008 and this found evidence for a period of high abundance around the Auckland Islands from 2004–2008 (Hurst et al. 2012). High southern arrow squid abundance during a period of very poor NZ sea lion demographic rates is not consistent with squid abundance being the principal driver of population change in NZ sea lions at the Auckland Islands. Observer records from this fishery indicate that yellow octopus are caught—MPI species code EZE, though OCT is often erroneously used—the code for *Macroctopus maorum*, a similar-sized octopus that does not occur around the Auckland Islands (O'Shea 1999) (OCP is the generic species code for octopus spp.). Observer records were used to describe the distribution of yellow octopus around the Auckland Islands, although the issue of species code mis-specification may currently prevent the use of fishery data to monitor their relative abundance through time. Changes in their prevalence in dietary samples provide another means of monitoring their predation by NZ sea lions, which should relate to abundance, though greater sample sizes of both scats *and* regurgitates may be required, since most large octopus beaks will be expelled within the regurgitated fraction (regurgitates have not been routinely collected since 2003).

4.1 Limitations of this study

This survey provides a single-year snapshot of NZ sea lion prey species across the known foraging distribution of lactating females breeding at the Auckland Islands and Stewart Island. The primary goal of the survey was to describe the spatial and bathymetric distribution of the main NZ sea lion prey species relative to the foraging of lactating females in order to identify potential mechanisms of nutritional stress. Multi-year studies are required to assess for temporal variation in the availability of key prey species (the most likely explanation for adverse demographic rates in NZ sea lions) and, while comparison is possible with previous Sub-Antarctic trawl surveys there has tended to be limited survey effort around the Auckland Islands shallower than 500 m depth where NZ sea lions forage, making comparison difficult. In addition, the use of a SLED in the prey survey may have affected the size-based selectivity of certain species, e.g., elasmobranch spp. (Wakefield et al. 2017), potentially affecting the comparability of outputs between the prey survey and previous Sub-Antarctic groundfish surveys.

With the exception of midwater measurement of acoustic backscatter, the survey was concentrated on seafloor habitat within the bottom few metres of the water column, such that purely pelagic species would be poorly-represented. However, nearly all of the main prey species of NZ sea lions, including some diurnally-migrating species such as hoki which feed in midwater, appeared to have high vulnerability to the standard Sub-Antarctic groundfish trawl. Nearly all species for which high biomass estimates were obtained in the Auckland Islands area are known to be predated by NZ sea lions. Notable exceptions, including spiny dogfish, ghost shark spp. and giant spider crab, are either adorned with large spines or possess tough exoskeletons that may effectively deter predation by NZ sea lions. The respective size distribution of the main prey species in the catch was similar to that of corresponding prey in NZ sea lion dietary studies (Meynier et al. 2009, Childerhouse et al. 2001). The DTIS camera survey provided a complementary description of the distribution of small-bodied prey, e.g., opalfish and small red cod, which have low vulnerability to the survey trawl, but were observed in abundance in DTIS images.

In order to determine the true biomass from the survey estimate it would be necessary to account for species- catchability. No attempt was made to do that in the prey survey analysis, so caution should be exercised when directly comparing species biomass estimates. Species with low vulnerability to trawl gear (including known NZ sea lion prey species, such as yellow octopus) may still have been relatively abundant despite low abundance estimates from the trawl survey. Likewise, avoidance behaviour will affect the relative vulnerability of different species to observation by DTIS camera transects.

The survey was restricted from the Marine Mammal Sanctuary around the Auckland Islands (extending 12 n miles from the coast), which includes the shelf area shallower than 90 m depth. Biotelemetry studies indicate that there is limited NZ sea lion foraging shallower than 75 m depth (see Appendix 1). Previous studies provide information as to the composition and abundance of potential prey within the littoral zone (0–75 m) and these are discussed below.

5. CONCLUSIONS

Nutritional stress is a strong candidate cause of the decline of breeder numbers at the Auckland Islands (Roberts & Doonan 2016) and of exceptionally high pup mortality at Campbell Island in recent years (62% of pup deaths provisionally attributed to starvation in the latest census year, 2015) (Childerhouse et al. 2015). Together, these populations comprise about 98% of the New Zealand sealion breeding population (Roberts & Doonan 2016, Childerhouse et al. 2016, Childerhouse et al. 2015). Our poor understanding of how changes in prey availability affect NZ sea lion demographics currently precludes a meaningful quantitative assessment of climate- or fishery-effects on demographic rates and population size (Roberts & Doonan 2016).

In order to address key knowledge gaps relating factors that affect prey availability to the demographic processes that drive population change in NZ sea lions, future research in the following three areas would be required: (1) monitoring prey availability; (2) monitoring NZ sea lions; and (3) managing prey availability. These are expanded on below.

5.1 Monitoring prey availability

Many of the key prey species of NZ sea lions are vulnerable to capture by the standard groundfish survey trawl, and the complementary benthic camera survey was effective in determining the relative abundance of most of the remaining prey that have low vulnerability to the trawl gear. A repeat of the prey survey would allow an assessment of variation in benthic prey abundance shallower than 200 m (the Sub-Antarctic trawl survey is deeper than this). Where cost prevents this, the Sub-Antarctic survey could be modified to include additional stations at 300–500 m depth around the Auckland Islands.

Observer-reported fishery catch-effort records provide another promising means for monitoring temporal shifts in the abundance and distribution of key NZ sea lion prey (Hurst et al. 2012), although these are constrained to the main fishery areas, which only partially overlap with NZ sea lion foraging around the Auckland Islands (Chilvers & Wilkinson, 2009). With improvements in observer identification in octopus species and, given consistent observer coverage of squid trawls at the Auckland Islands, observer catch records could also be used to monitor coarse changes in the abundance of yellow octopus. Scat and regurgitate sampling is another cost-effective means for monitoring shifts in the importance of yellow octopus and other prey in NZ sea lion diet, though larger sample sizes may be required to identify individual year-effects.

5.2 Monitoring NZ sea lions

The Auckland Islands population comprises a mixture of individuals adopting contrasting foraging strategies (Figure A1-2 of Appendix 1). Each foraging strategy will respond differently to shifts in the available prey community through time. As such, our efforts to relate trends in NZ sea lion demographic rates to changes in prey abundance is obscured by our current inability to bulk-identify individuals that predominantly forage in the benthic zone (which should respond to changes in yellow octopus, southern arrow squid, red cod and other benthic prey) or the mesopelagic zone (which will respond more to changes in hoki and southern blue whiting). Depth of foraging data are currently used to characterise individual foraging strategy, although deployment of biotelemetry gear is costly, precluding the collection of sufficient mark-recapture sample size for estimating demographic rates.

Other, cheaper means for assessing foraging type (e.g., isotope/chemistry/fatty acid-based indicators from whiskers or blubber samples) could be developed, e.g. building on the research of Chilvers (2017a), to characterise the foraging of a larger number of individuals. The isotopic analysis of seawater filtrate suggested strong spatial variation in nutrient cycling across the survey area (Figure 26 and Figure 27). This was important to document as it aids in the interpretation of the stable isotope values measured in NZ sea lion teeth (MPI project SEA201404) and bodily tissues. The spatial variability observed at the base of the food web suggests that stable isotope analysis could help distinguish different foraging strategies (e.g., benthic versus meso-pelagic foragers) when more individuals are examined.

The summer diet of NZ sea lions has been well-studied, although the outputs are spread across journal articles, student theses and reports, and the current lack of a cross-population overview may be a hindrance to conservation management. A review of dietary studies that focussed on producing relevant outputs could be useful for making monitoring and management decisions. Any such review should also account for biases associated with the methodology, season of data collection, probable demographic grouping and location of foraging.

There are currently no published studies of the winter diet of the Auckland Islands population. The prey composition available to lactating female NZ sea lions in winter is likely to be quite different from the summer diet, given the relative lack of mesopelagic foraging at this time of year (Figure A1-2 of Appendix 1). In winter the pups will be larger and the energetic burden of lactation will be greater. A winter diet study would allow the identification of key prey at a critical stage of the breeding cycle.

5.3 Prey availability

The diet of NZ sea lions varies by region, though nearly all populations (Campbell Island is a possible exception) have at least one important prey species (at least 10 % of diet mass in a dietary study) that is either targeted by commercial fisheries or is taken as by-catch.

Listed from north to south these are thought to be:
- Otago Peninsula – jack mackerel spp., barracouta, southern arrow squid;
- Stewart Island – rough skate, redbait; and
- Auckland Islands – hoki, southern arrow squid, red cod and ling.

A review of the potential indirect effects of fishing on the Auckland Islands population concluded that there was no reliable evidence for resource competition, but this review was strongly focussed on the southern arrow squid trawl fishery at the Auckland Islands (Bowen 2012). The relatively high abundance of southern arrow squid around the Auckland Islands during a period of very poor NZ sea lion demographic rates indicates that this prey species is unlikely to have limited the productivity of NZ sea lions. The hoki biomass series from the Sub-Antarctic groundfish survey includes periods of high biomass (1991–1993) and low biomass (2003–2006) that coincided with periods of good and bad NZ sea lion demographic rates, respectively. The duration and extent of the low biomass period appears to have been accentuated shallower than 500 m where hoki would be available to NZ sea lions. As such, hoki is a stronger candidate for a limiting prey species and for a negative indirect effect of fishing or climate on the NZ sea lion population. Note that yellow octopus also appear to be an important prey, but fluctuations in this species are unlikely to be driven directly by commercial fisheries.

Habitat degradation, such as through increased sedimentation rate, is an additional anthropogenic threat that may be of more relevance to the mainland population (e.g., Otago coast and Stewart Island). NIWA is leading an ongoing study (MBIE project CO1X1618) of habitat quality effects on juvenile growth and survival of coastal species, which should provide insights with respect to the effects of habitat degradation on coastal predators.

There are also likely to be strong climate effects on the recruitment and relative availability of key NZ sea lion prey (Hurst et al. 2012, Beentjes & Renwick 2000) that cannot be controlled for by fisheries management. This means that populations will tend to fluctuate even in the absence of human-effects. Understanding climate effects on prey will provide valuable context for monitoring and managing anthropogenic effects and will improve predictions of future prey availability and NZ sea lion productivity.

5.4 Summary

Monitoring and managing prey availability:

- In order to identify specific prey species limiting the productivity of NZ sea lions, trawl survey and commercial catch-effort data could be analysed to assess for changes in the distribution/abundance of prey species (focussing on hoki, red cod, southern arrow squid and yellow octopus) that would affect their availability to NZ sea lions. Time-series of NZ sea lion demographic rates can be used to identify marker years when changes are likely to have occurred.

- Improved observer identification of octopus species would facilitate a more robust assessment of yellow octopus distribution and, potentially, changes in relative abundance through time. It is also recommended that observers collect whole samples of yellow octopus to allow assessments of basic life history and diet.
- Future Sub-Antarctic trawl surveys could conduct additional tows at 300–500 m depth around the Auckland Islands, to extend the index of relative prey availability to NZ sea lions (Figure 19).
- A previous review concluded that there was limited potential for an indirect effect of fishing on NZ sea lions at the Auckland Islands, but this review was focussed on the southern arrow squid fishery. Future assessments of potential indirect fishery or climate effects on the Auckland Islands NZ sea lion population would potentially benefit if more consideration was given to the hoki/hake/ling fishery.

Monitoring NZ sea lions:

- A review of studies relating the diet and nutrition of NZ sea lions, collating an extensive but fragmented literature into a format that will be most useful for making the information more readily accessible.
- Most of our dietary information for NZ sea lions comes from the summer period around pupping, although winter diet may be even more important given that the energetic costs of lactation are increased and the diversity of preferred prey is likely to be reduced. Dietary studies conducted in winter months, initially based on hard part remains/DNA from scats and regurgitates would address this knowledge gap.
- The Auckland Islands population comprises individuals with a mixture of foraging strategies that are likely to respond differently to a change in the prey mix. Analysis of tissue chemistry (e.g., isotopic composition, concentration of heavy metals) is a relatively cheap means for the bulk-identification of foraging type of a sufficiently large sample, so that changes in demographic rates of a foraging type can be related to the availability of relevant prey species.

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8. TABLES AND FIGURES

Table 1: **Summary of the main prey of NZ sea lions at the Auckland Islands in terms of percent mass (%M).The mean mass of prey from Meynier et al. (2009) and Roberts & Lalas (2015) was used to derive mass of prey from total numbers reported by Childerhouse et al. (2001) and Stewart-Sinclair (2013).**

Years, sampling method & reference	**Main prey (all >10 %*M*) and %*M***
1997–2006 stomach contents of individuals captured in commercial trawls around the Auckland Islands (Meynier et al., 2009)	Partially digested specimens: 1. Yellow octopus, 28% 2. Southern arrow squid, 18% 3. Hoki, 16%
1995–1997, scats & regurgitates collected at the Auckland Islands (Childerhouse et al., 2001)	Scats: 1. Hoki, 45% 2. Yellow octopus, 14% Regurgitates: 1. Yellow octopus, 73% 2. Hoki, 23%
2000–2013, scats & regurgitates collected at the Auckland Islands (Stewart-Sinclair, 2013)	Scats: 1. Red cod, 21% 2. Hoki, 17% 3. Yellow octopus, 13% 4. Ling, 12% Regurgitates: 1. Yellow octopus, 87% 2. Southern arrow squid, 11%

Table 2: Summary of demersal groundfish survey stations around the Auckland Islands (bounded by 51.25 ºS - 49.25 ºS and 165.5 ºE - 168.5 ºE) by survey year and depth stratum. Only bottom trawls with a gear performance code of "1" or "2" were included.

			Stations	
Survey	**Year**	**Month**	**300–500 m**	**500–800 m**
TAN9105	1991	Dec	7	6
TAN9204/TAN9211	1992	Apr/Dec	9	10
TAN9310	1993	Dec	3	9
TAN9605	1996	Apr	4	9
TAN9805	1998	Apr	3	5
TAN0012	2000	Dec	1	12
TAN0118	2001	Dec	5	8
TAN0219	2002	Dec	3	5
TAN0317	2003	Nov/Dec	2	6
TAN0414	2004	Dec	1	7
TAN0515	2005	Dec	1	9
TAN0617	2006	Dec	3	12
TAN0714	2007	Dec	4	5
TAN0813	2008	Dec	5	1
TAN0911	2009	Dec	2	7
TAN1117	2011	Dec	2	7
TAN1215	2012	Dec	2	6
TAN1412	2014	Dec	2	9
TAN1602	2016	Feb	30	1

Table 3: Summary of demersal trawl stations planned/completed and DTIS transects by survey stratum.

Stratum	**Stratum area (km^2)**	**Depth (m)**	**Number of trawl stations planned**	**Number of trawl stations completed**	**Number of DTIS transects**
Auckland Islands					
A1	5 569	50–150	12	6	4
A2	2 951	150–250	5	5	1
A3	1 777	150–250	9	5	3
A4	1 036	150–250	3	3	1
A5	1 115	250–500	7	6	1
A6	2 328	250–500	12	11	4
A7	5 411	250–500	12	11	4
Total	20 187		60	47	18
Stewart-Snares					
S2	2 111	30–100	3	4	6
S3	985	30–100	0	3	2
S5a	3 707	100–200	4	4	0
S5b	1 409	100–200	4	4	1
S6a	3 350	100–200	4	4	0
S6b	1 221	100–200	4	4	1
S10a	2 188	100–200	4	4	1
S11	1 506	100–200	3	3	1
S13	454	200–400	4	4	1
Total	16 931	30–400	30	34	13

Table 4: Biomass estimates and associated coefficient of variation (CV) of key NZ sea lion prey and other selected species at the Auckland Islands. Also biomass estimates by stratum.

Species		Stratum							Auckland Islands survey area	
		A1	A2	A3	A4	A5	A6	A7		
Common name	**Genus species**	**50–150 m**			**150–250 m**			**250–500 m**	**Biomass (t)**	**CV (%)**
Southern blue whiting	*Micromesistius australis*	0	0	0	0	369	1 390	450	2 210	29.8
Hoki	*Macruronus novaezelandiae*	0	0	0	0	155	980	781	1 916	26.4
Southern arrow squid	*Nototodarus sloanii*	180	1 257	72	229	27	18	10	1 792	36.7
Ling	*Genypterus blacodes*	0	0	0	0	299	409	642	1 350	15.8
Dark ghost shark	*Hydrolagus novaezealandiae*	0	25	67	0	206	605	441	1 345	26.6
Spiny dogfish	*Squalus acanthias*	0	0	65	1	18	522	374	980	19.1
Javelinfish	*Lepidorhynchus denticulatus*	0	0	0	0	136	187	169	492	26.3
Oblique-banded rattail	*Coelorinchus aspercephalus*	1	1	2	6	129	201	121	461	13.2
Smooth red swimming crab	*Nectocarcinus bennetti*	148	208	2	41	0	0	0	398	35.2
Hake	*Merluccius australis*	0	0	0	0	11	71	60	143	22.3
Giant spider crab	*Jacquinota edwardsii*	56	13	11	44	5	4	0	134	23.6
Silver warehou	*Seriolella punctata*	0	24	2	4	0	14	17	60	46.1
Rough skate	*Raja nasuta*	1	8	22	2	4	13	10	60	26.7
Red cod	*Pseudophycis bachus*	5	0	4	0	19	14	10	53	30.2
Giant stargazer	*Kathetostoma giganteum*	0	0	0	0	0	0	0	50	20.1
Warty squid	*Onykia ingens*	0	0	0	0	4	6	3	13	35.6
Scampi	*Metanephrops challengeri*	0	0	0	0	0	0	5	5	14.8
Barracouta	*Thysites atun*	0	3	0	0	0	0	0	3	100
Yellow octopus	*Enteroctopus zealandicus*	0	0	0	0	0	0	2	2	96.6
Jack mackerel spp.	*Thrachurus* spp.	0	0	0	0	0	0	0	0	0
Blue cod	*Parapercis colias*	0	0	0	0	0	0	0	0	0
Redbait	*Emmelichthys nitidus*	0	0	0	0	0	0	0	0	0
Sea perch	*Helicolenus barathrI*	0	0	0	0	0	0	0	0	0
Hapuku	*Polyprion oxygeneios*	0	0	0	0	0	0	0	0	0

Table 5: Biomass estimates and associated coefficient of variation (CV) of key NZ sea lion prey and other selected species at Stewart Snares. Also biomass estimates by stratum.

Species										Stratum	Stewart Snares survey area	
		S2	S3	S5a	S5b	S6a	S6b	S10a	S11	S13		
Common name	**Genus species**		**30–100 m**						**100–200 m**	**200–400 m**	**Biomass (t)**	**CV (%)**
Spiny dogfish	*Squalus acanthias*	764	117	823	162	548	12	200	565	1 095	4 287	23.4
Barracouta	*Thysites atun*	199	35	728	4	632	26	197	764	0	2 585	21.2
Giant stargazer	*Kathetostoma giganteum*	122	86	158	30	25	39	57	729	5	1 253	18.2
Hoki	*Macruronus novaezelandiae*	0	0	0	0	0	0	0	0	701	701	88.2
Southern arrow squid	*Nototodarus sloanii*	7	5	24	6	37	12	57	47	101	296	25.4
Rough skate	*Raja nasuta*	9	0	25	23	103	13	33	0	34	240	15.8
Hapuku	*Polyprion oxygeneios*	70	8	26	7	50	8	51	11	0	230	19.8
Ling	*Genypterus blacodes*	4	0	25	13	0	0	0	2	110	154	21
Blue cod	*Parapercis colias*	21	0	1	12	43	6	30	0	0	113	24.8
Silver warehou	*Seriolella punctata*	0	0	18	4	15	0	32	8	10	87	44
Oblique-banded rattail	*Coelorinchus aspercephalus*	0	0	0	0	0	0	0	0	65	65	58.1
Sea perch	*Helicolenus barathrI*	0	0	0	14	37	6	5	0	0	62	44.6
Dark ghost shark	*Hydrolagus novaezealandiae*	0	0	0	0	0	0	0	0	41	41	71.1
Greenback jack mackerel	*Thrachurus declivis*	0	0	5	0	2	0	4	19	0	30	44.8
Chilean jack mackerel	*Thrachurus murphii*	0	1	7	0	5	0	3	13	0	29	34.4
Javelinfish	*Lepidorhynchus denticulatus*	0	0	0	0	0	0	0	0	8	8	63.7
Redbait	*Emmelichthys nitidus*	0	0	0	0	2	0	0	0	0	3	88.3
Red cod	*Pseudophycis bachus*	0	0	0	0	0	0	0	0	1	1	58.8
Southern blue whiting	*Micromesistius australis*	0	0	0	0	0	0	0	0	1	1	100
Yellow octopus	*Enteroctopus zealandicus*	0	0	0	0	0	0	0	0	0	0	0
Giant spider crab	*Jacquinota edwardsii*	0	0	0	0	0	0	0	0	0	0	100
Hake	*Merluccius australis*	0	0	0	0	0	0	0	0	0	0	0
Warty squid	*Onykia ingens*	0	0	0	0	0	0	0	0	0	0	0
Smooth red swimming crab	*Nectocarcinus bennetti*	0	0	0	0	0	0	0	0	0	0	0
Scampi	*Metanephrops challengeri*	0	0	0	0	0	0	0	0	0	0	0

Table 6: Main benthic and mesopelagic NZ sea lion prey in the Stewart Snares and Auckland Islands areas.

Breeding population	Main prey species	
	Benthic (demersal prey)	Mesopelagic (pelagic prey)
Stewart/Snares Islands	Wrasse spp.	Redbait
	Rough skate	Barracouta*
		Jack mackerel spp.*
		Southern arrow squid*
		Hoki*
Auckland Islands	Yellow octopus	Hoki
	Southern arrow squid	Southern blue whiting
	Red cod	
	Ling	

*abundant/species eaten by NZ sea lions not yet recorded in the diet of that population

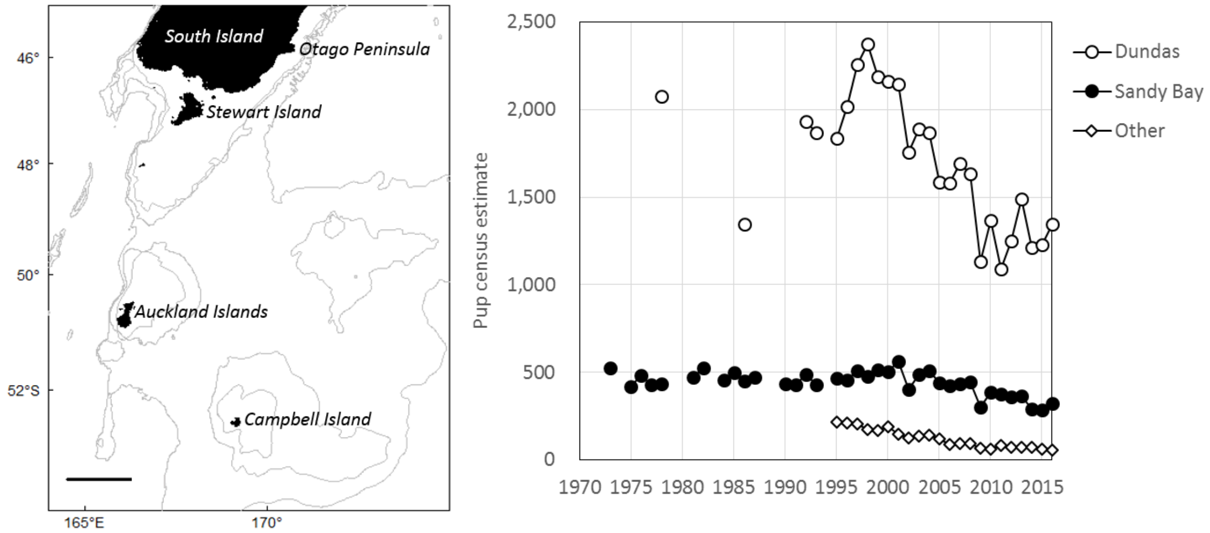

Figure 1: Location of known New Zealand sea lion breeding rookeries (left) and annual pup census estimates at the Auckland Islands since 1973 (right). Pup census estimates reported by Childerhouse et al. (2016), Childerhouse & Gales (1998). Major breeding colonies at Enderby and Dundas are located at the Auckland Islands.

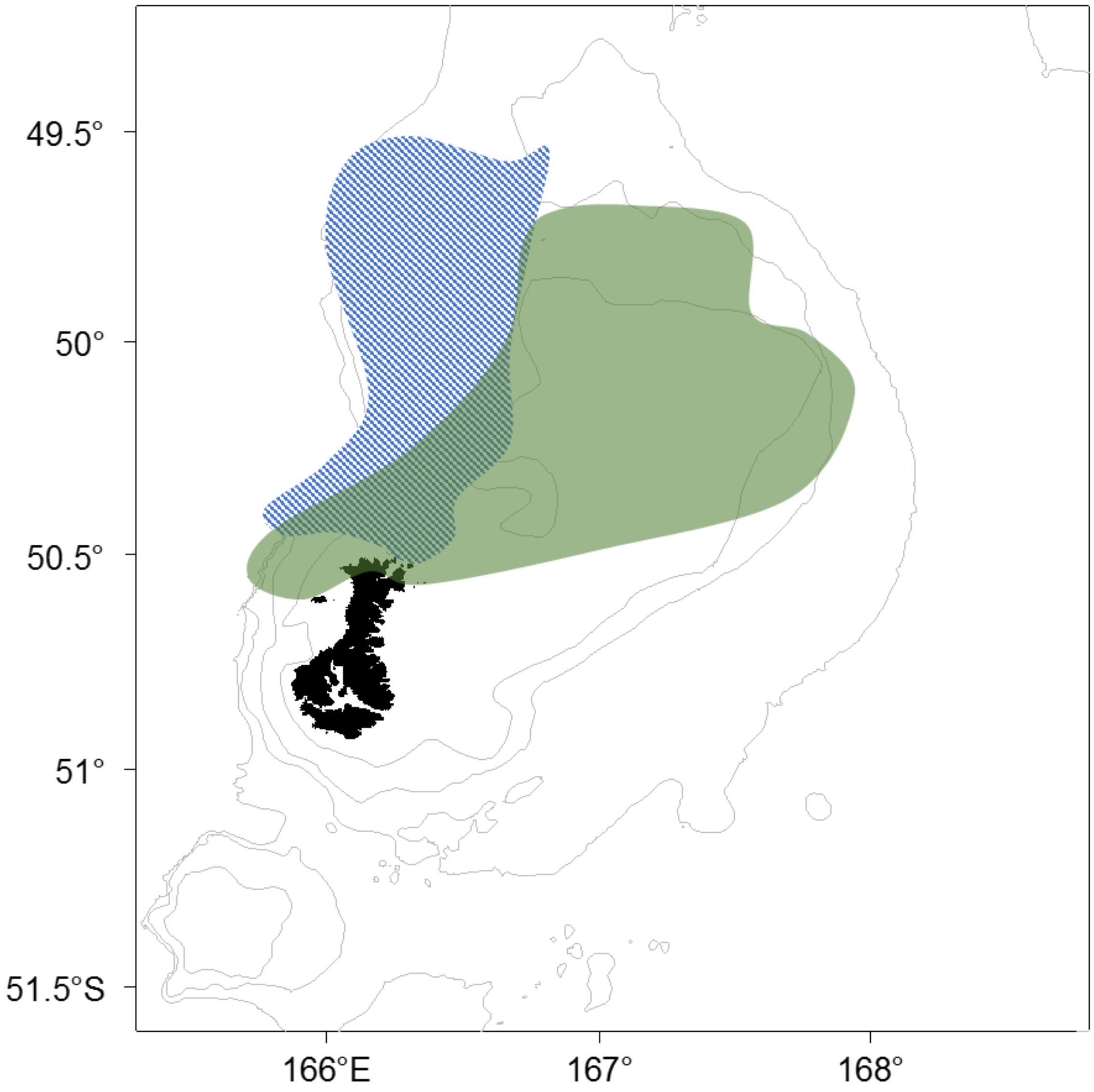

Figure 2: The foraging distributions of lactating female NZ sea lions at the Auckland Islands grouped by foraging strategy – mesopelagic (blue cross-hatched) and benthic foraging (green) individuals; Figure modified from Meynier et al. (2014). Grey lines are the 150 m, 250 m, 500 m and 750 m depth contours.

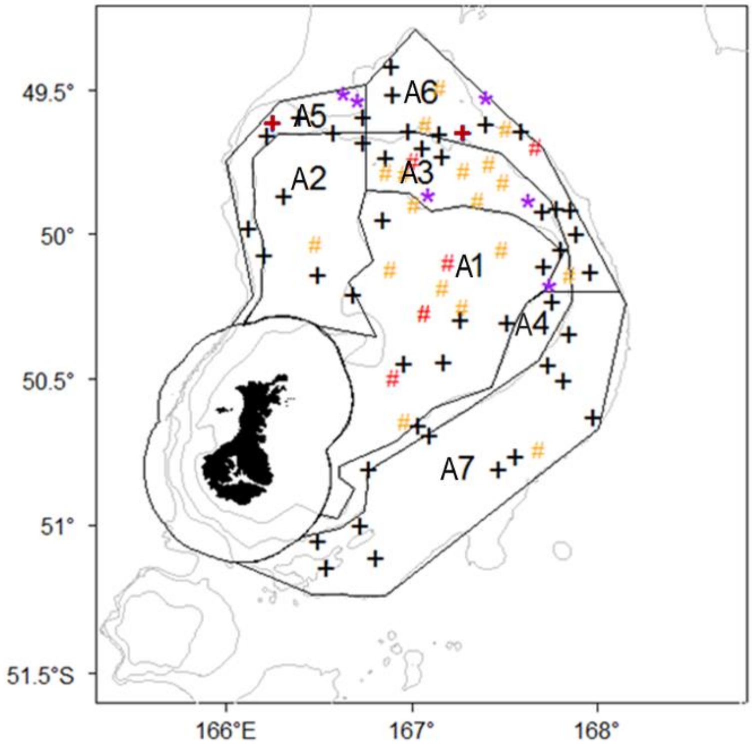

Figure 3: **Location of all trawl stations at Auckland Islands. Symbols represent: completed bottom trawl (+); completed bottom or midwater trawl (+); bottom trawl attempted but stopped early when stuck to bottom (#); bottom surveyed with multibeam and not deemed trawlable (#); location wrong depth for stratum (★).**

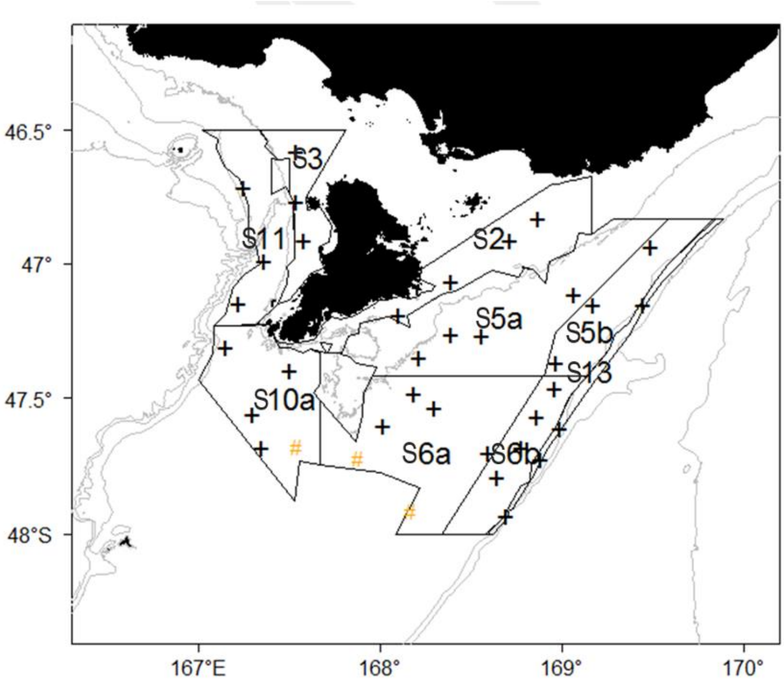

Figure 4: Location of all trawl stations at Stewart-Snares. Symbols show: completed bottom trawl (+); area surveyed with multibeam and not deemed trawlable or known rough area (#).

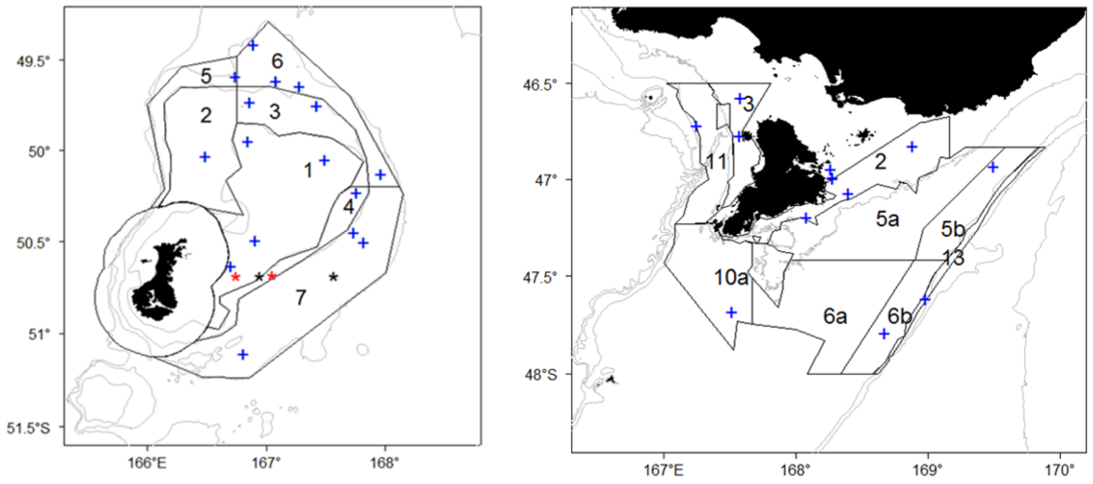

Figure 5: Location of DTIS deployments (+). Left panel also shows octopus pot deployments where some pots were retrieved (✱); and where all pots were lost (✱).

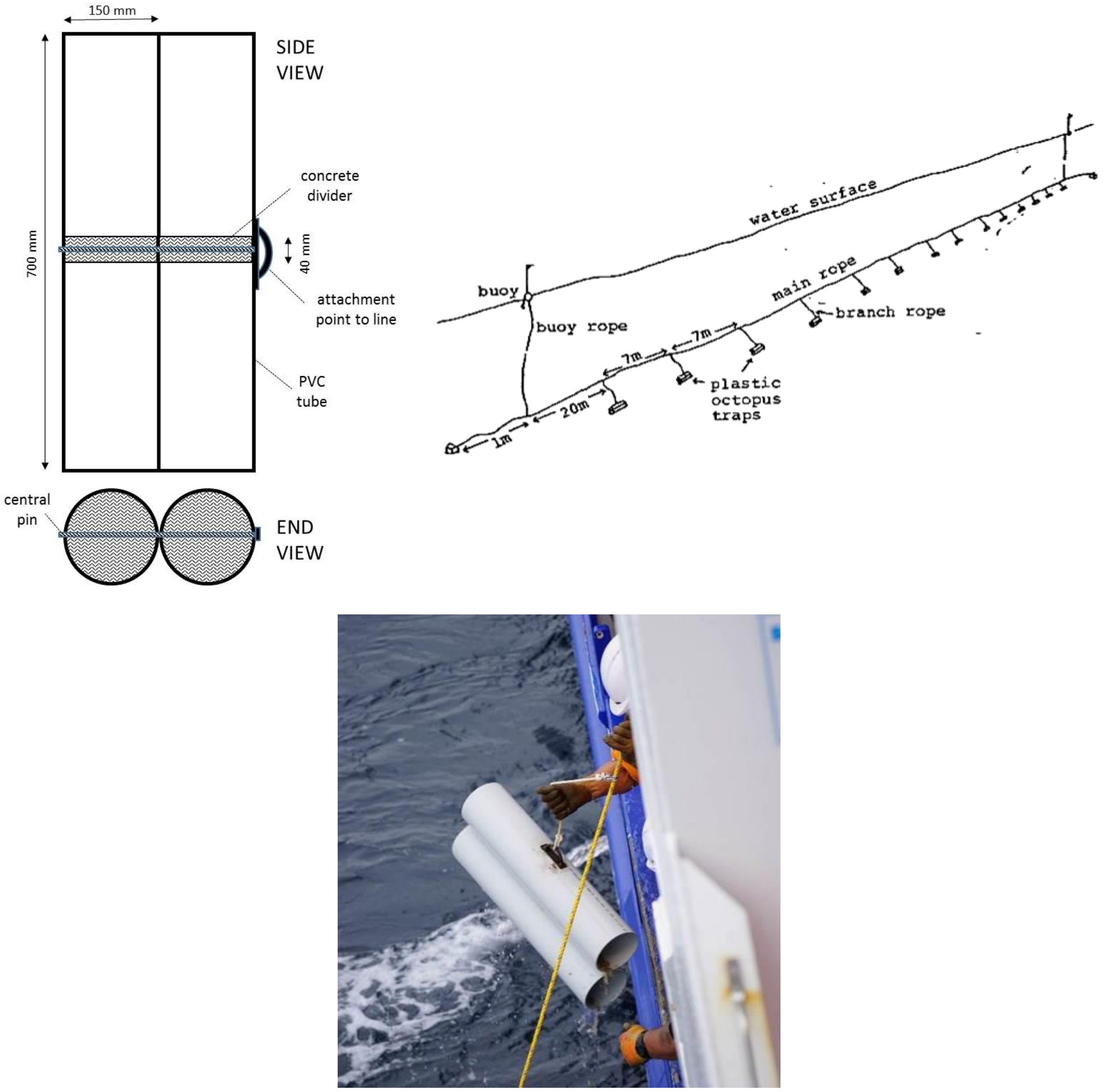

Figure 6: PVC octopus pot design (top-left), configuration along the mother line (top-right, taken from FINS 1980) and photograph of pot unit being retrieved during the survey (bottom).

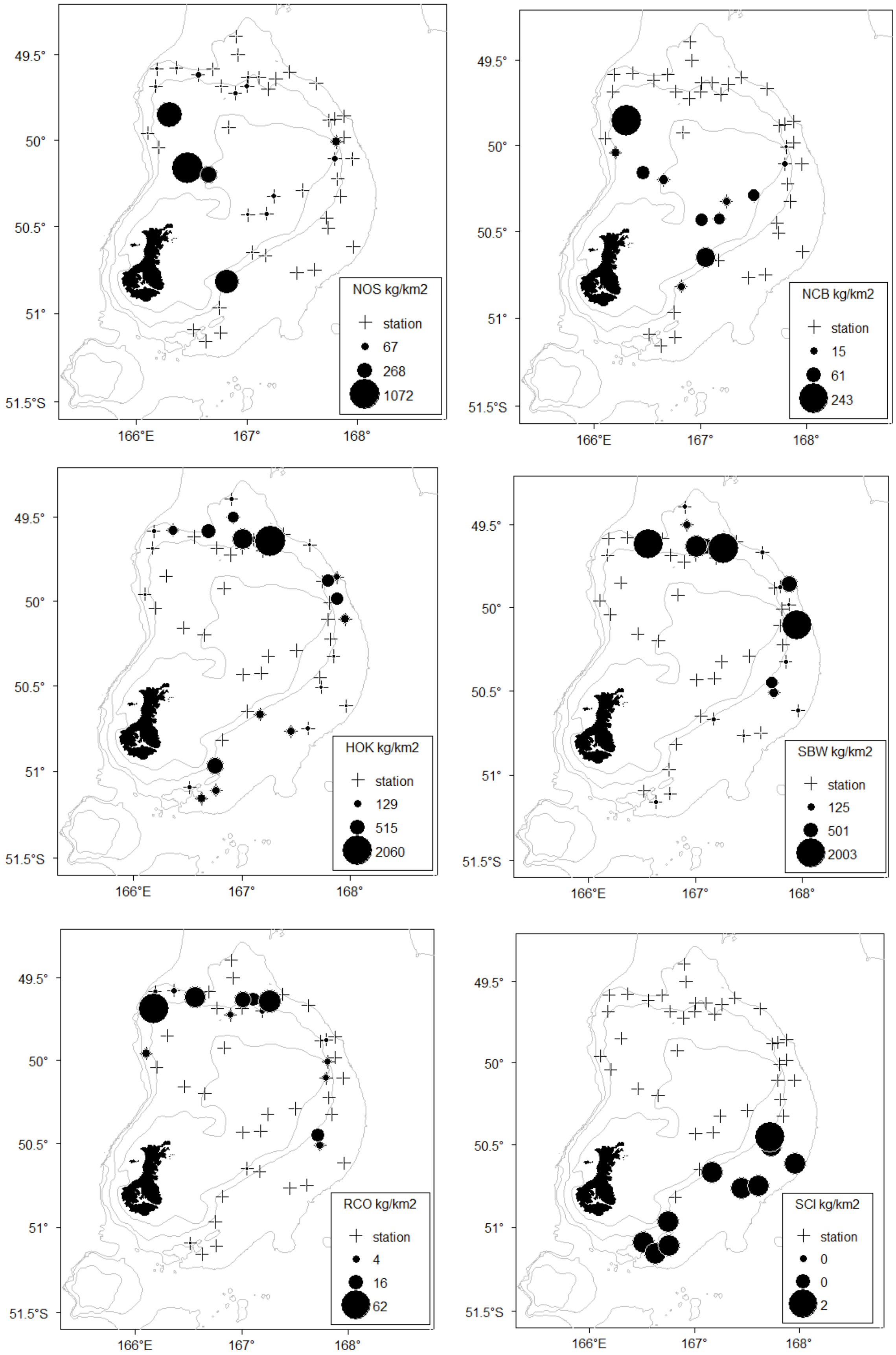

Figure 7: Species catch density by bottom trawl station of selected species in the Auckland Islands survey area. Crosses show the location of tows with zero catch for a species. Species codes are: NOS, southern arrow squid (*Nototodarus sloanii*); NCB, smooth red swimming crab (*Nectocarcinus bennetti*); HOK, hoki (*Macruronus novaezelandiae*); SBW, southern blue whiting (*Micromesistius australis*); RCO, red cod (*Pseudophycis bachus*); and SCI, scampi (*Metanephrops challengeri*).

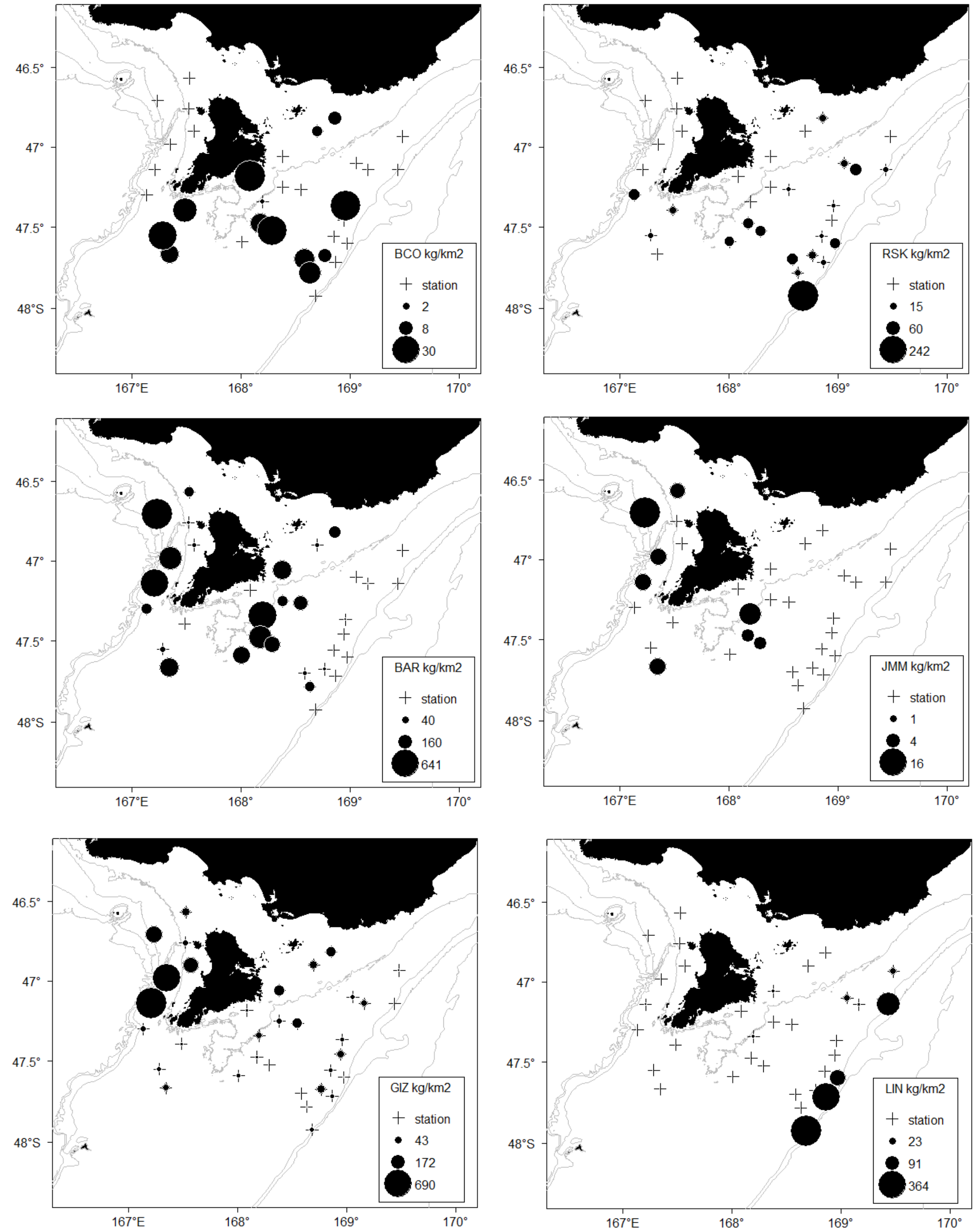

Figure 8: Species catch density by bottom trawl station of selected species in the Stewart-Snares survey area. Crosses show the location of tows with zero catch for a species. Species codes are: BCO, blue cod (*Parapercis colias*); RSK, rough skate (*Raja nasuta*); BAR, barracouta (*Thyrsites atun*); JMM, Chilean jack mackerel (*Trachurus murphyi*); GIZ, giant star gazer (*Kathetostoma giganteum*); and LIN, ling (*Genypterus blacodes*).

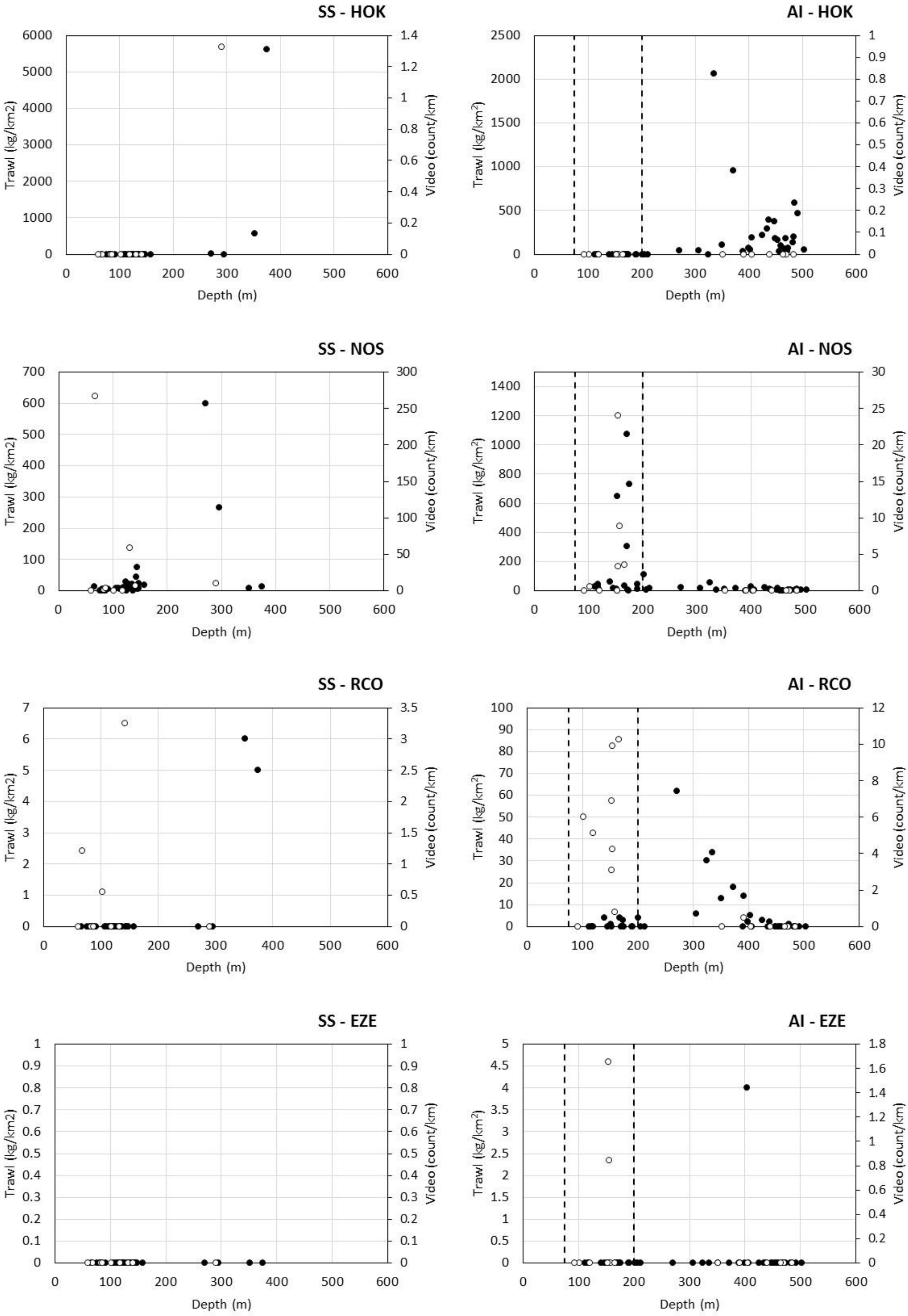

Figure 9: Bathymetric distribution of selected finfish and cephalopod species (the main prey of NZ sea lions at the Auckland Islands) catch rate in demersal trawls (black circles) and density of observations in DTIS camera footage (open circles) at Stewart Snares (SS) and the Auckland Islands (AI): HOK, hoki (*Macruronus novaezelandiae*); NOS, southern arrow squid (*Nototodarus sloanii*); RCO, red cod (*Pseudophychis bachus*); and EZE, yellow octopus (*Enteroctopus zealandicus*). Dashed lines demarcate the 75–200 m depth zone where benthic foraging is most-concentrated.

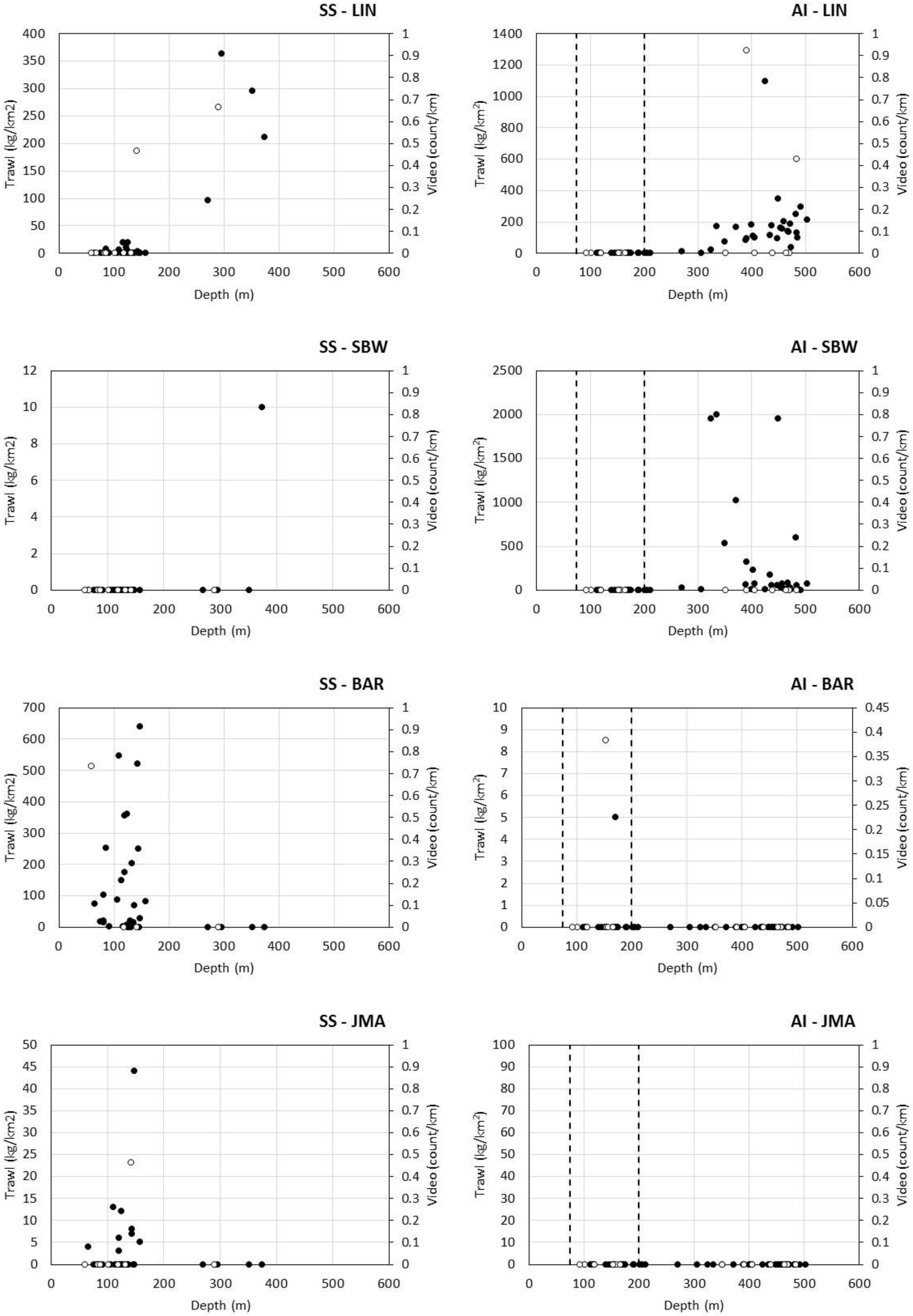

Figure 10: Bathymetric distribution of selected finfish species catch rate in demersal trawls (black circles) and density of observations in DTIS camera footage (open circles) at Stewart Snares (SS) and the Auckland Islands (AI): LIN, ling (*Genypterus blacodes*); SBW, southern blue whiting (*Micromesistius australis*); BAR, barracouta (*Thyrsites atun*); and JMA, jack mackerel spp. (*Trachurus* spp.). Dashed lines demarcate the 75–200 m depth zone where benthic foraging is most-concentrated.

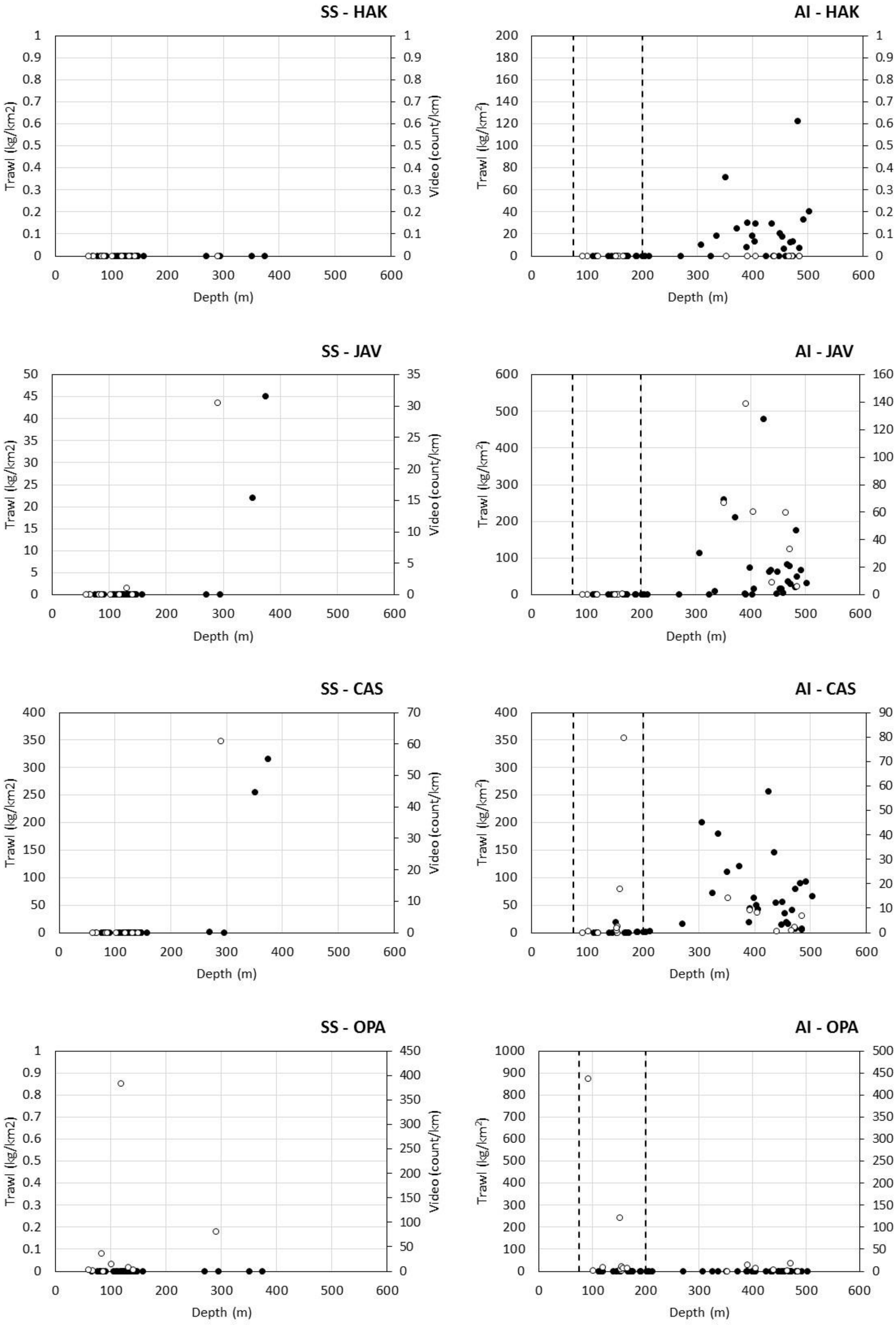

Figure 11: Bathymetric distribution of selected finfish species catch rate in demersal trawls (black circles) and density of observations in DTIS camera footage (open circles) at Stewart Snares (SS) and the Auckland Islands (AI): HAK, hake (*Merluccius australis*); JAV, javelinfish (*Lepidorhynchus denticulatus*); CAS, oblique-banded rattail (*Ceolorinchus aspercephalus*); and OPA, opalfish spp.. Dashed lines demarcate the 75–200 m depth zone where benthic foraging is most-concentrated.

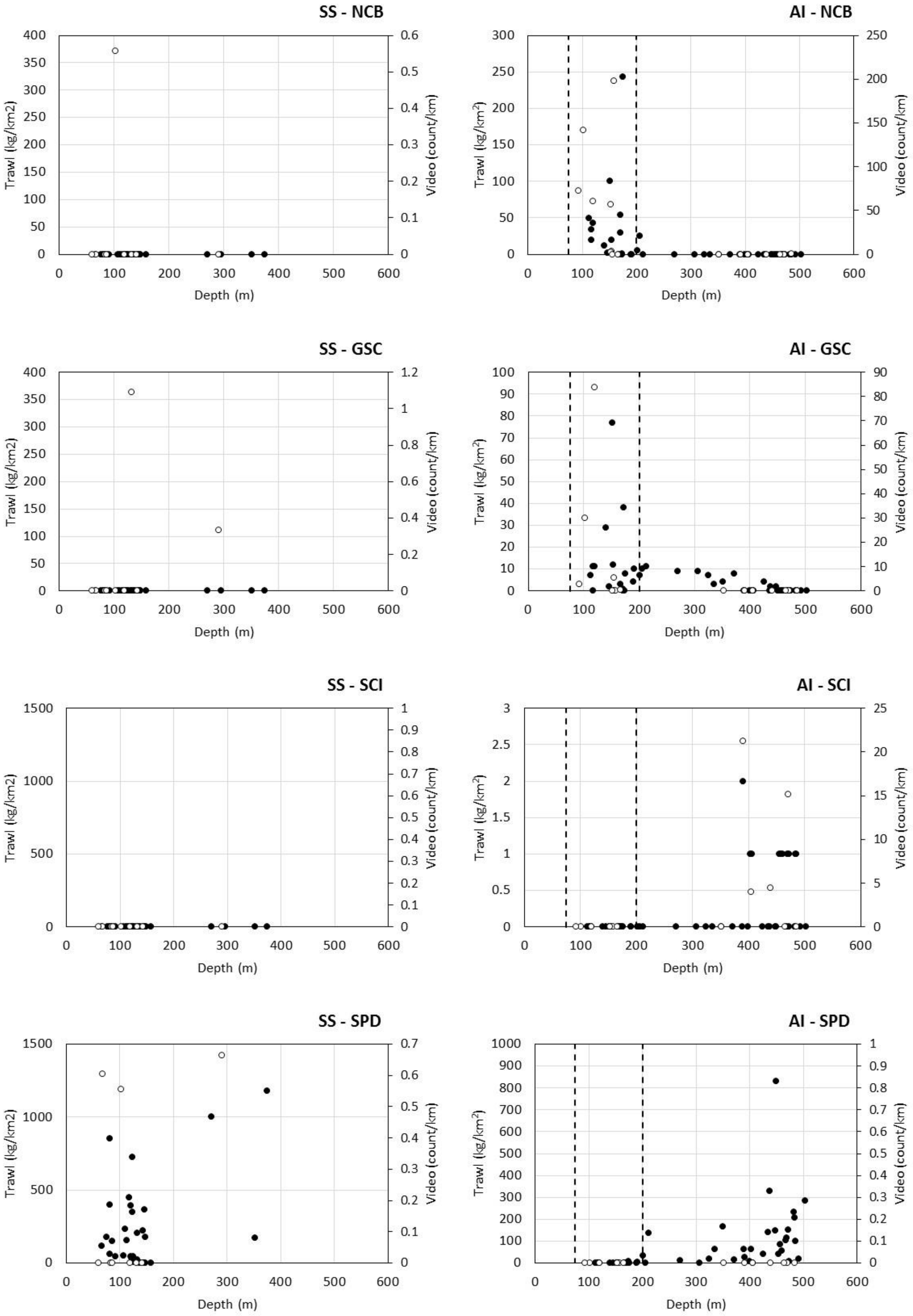

Figure 12: Bathymetric distribution of selected crustacean and finfish species catch rate in demersal trawls (black circles) and density of observations in DTIS camera footage (open circles) at Stewart Snares (SS) and the Auckland Islands (AI): NCB, smooth red swimming crab (*Nectocarcinus bennetti*); GSC, giant spider crab (*Jacquinotia edwardsii*); SCI scampi (*Metanephrops challengeri*) ; and SPD, spiny dogfish (*Squalus acanthias*). Dashed lines demarcate the 75–200 m depth zone where benthic foraging is most-concentrated.

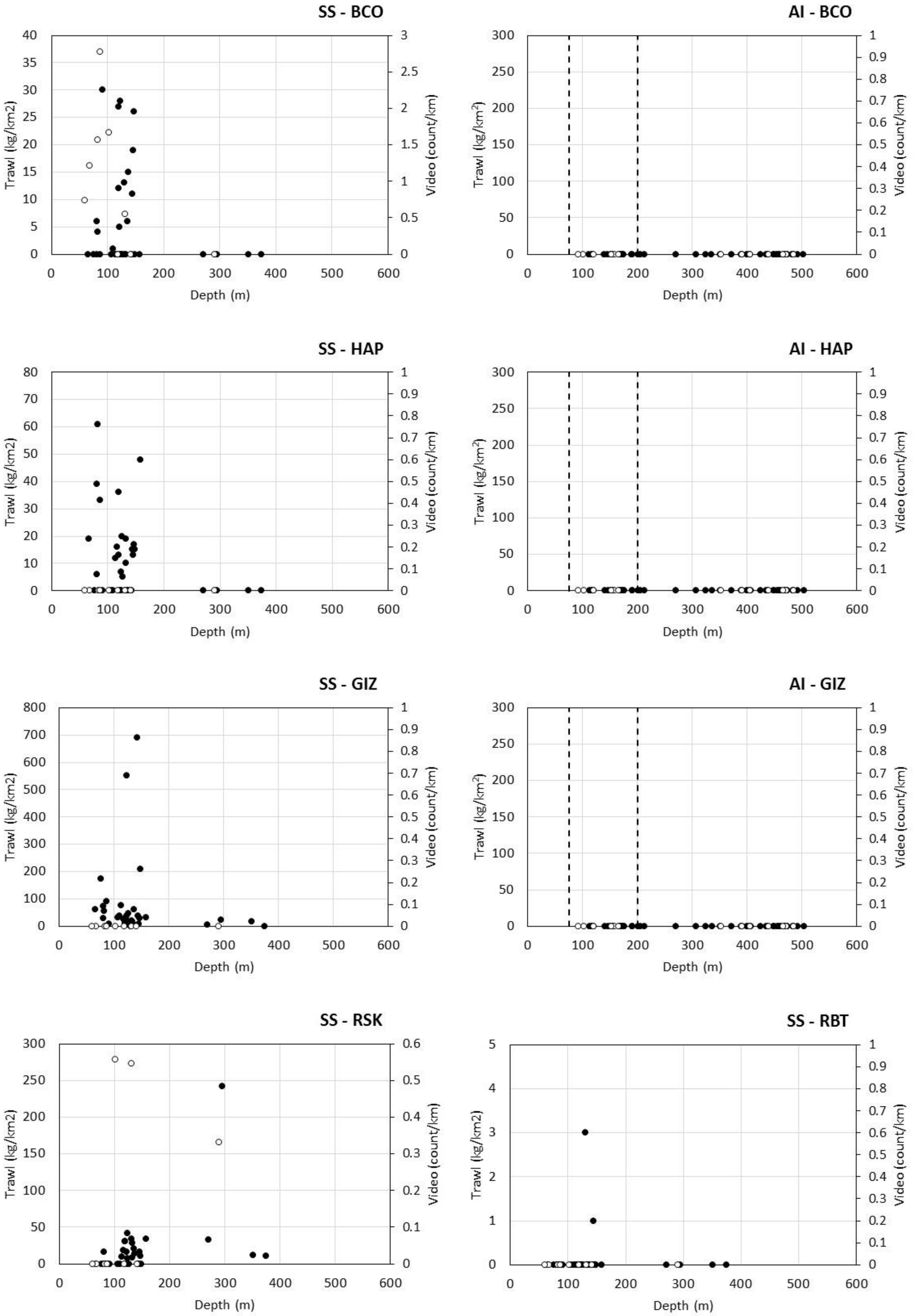

Figure 13: Bathymetric distribution of selected finfish species catch rate in demersal trawls (black circles) and density of observations in DTIS camera footage (open circles) at Stewart Snares (SS) and the Auckland Islands (AI): BCO, blue cod (*Parapercis colias*); HAP, hapuku (*Polyprion oxygeneios*); GIZ giant stargazer (*Kathetostoma giganteum*); RSK, rough skate (*Raja nasuta*); and RBT redbait (*Emmelichthys nitidus*). Dashed lines demarcate the 75–200 m depth zone where benthic foraging is most-concentrated.

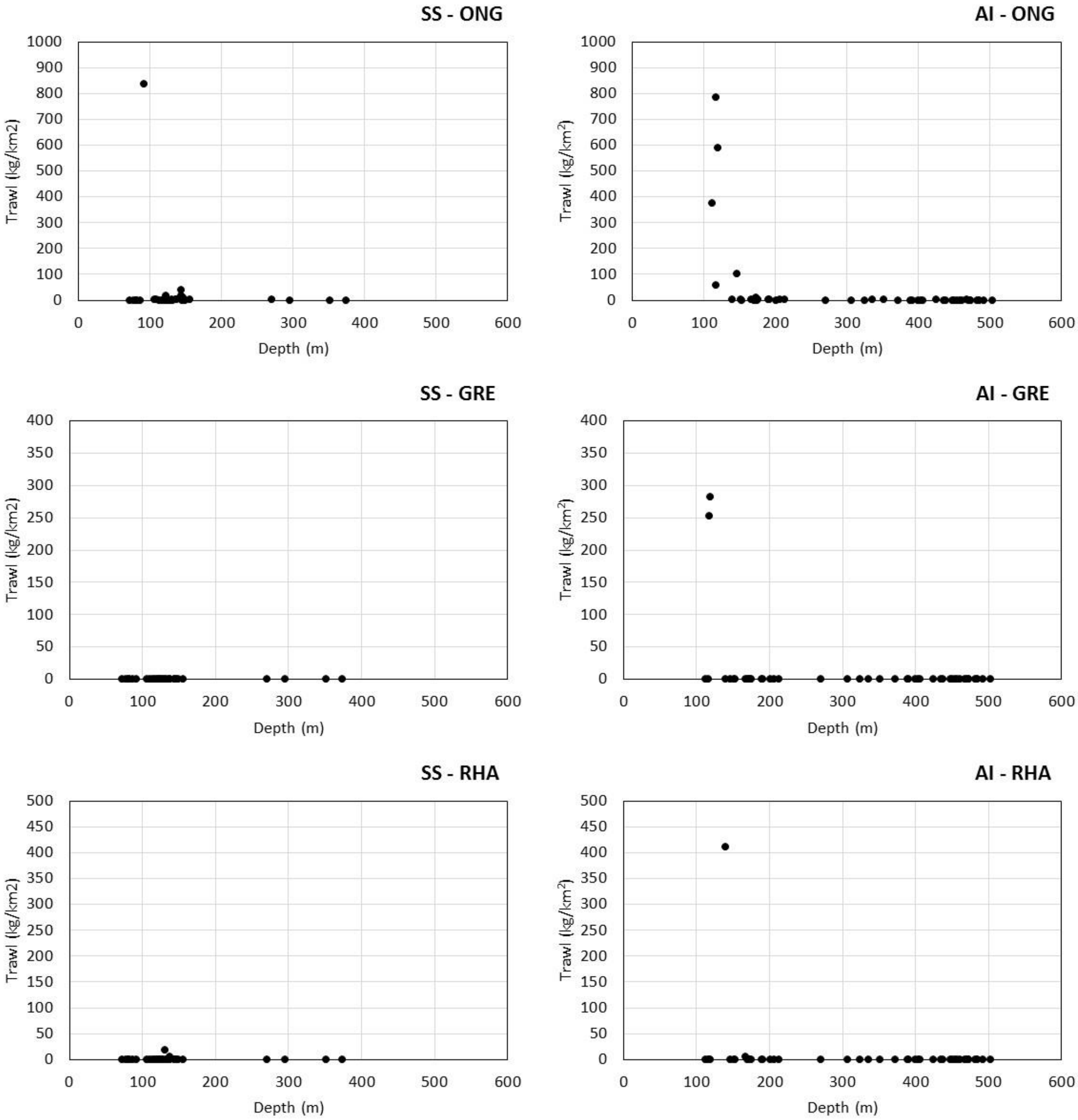

Figure 14: Bathymetric distribution of catch rate of sessile benthic invertebrate taxa in demersal trawls at Stewart Snares (SS) and the Auckland Islands (AI). Only taxa for which more than 50 kg were captured are shown (all sponges): ONG, *Porifera* spp.; GRE, *Geodia regina* (curling stone sponge); RHA, *Rhabdastrella* sp. (Pink ice egg sponge).

Figure 15: Sample photos from DTIS (Deep-Towed Imaging System) transects at the Auckland Islands indicating yellow octopus (*Enteroctopus zealandicus*) (left) and opalfish (*Hemerocoetes* sp.) (right).

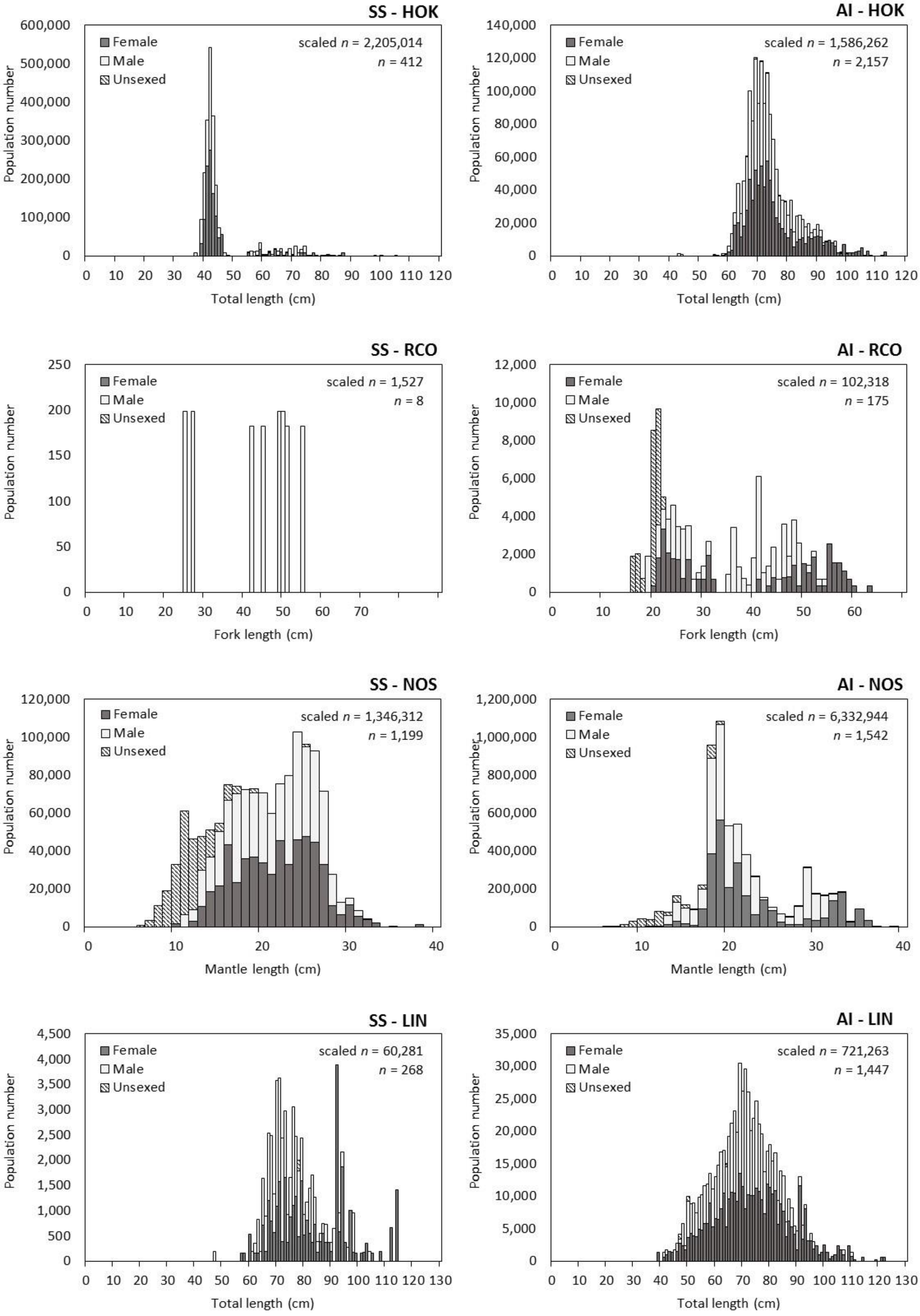

Figure 16: Length frequency distributions of major NZ sea lion prey species – hoki (HOK; *Macruronus noveazelandiae*), red cod (RCO; *Pseudophycis bachus*), southern arrow squid (NOS; *Nototodarus sloanii*) and ling (LIN; *Genypterus blacodes*) – at the Stewart Snares shelf (SS) and Auckland Islands (AI) in 2016 (scaled *n* = estimated total population in survey area; *n* = number of fish measured).

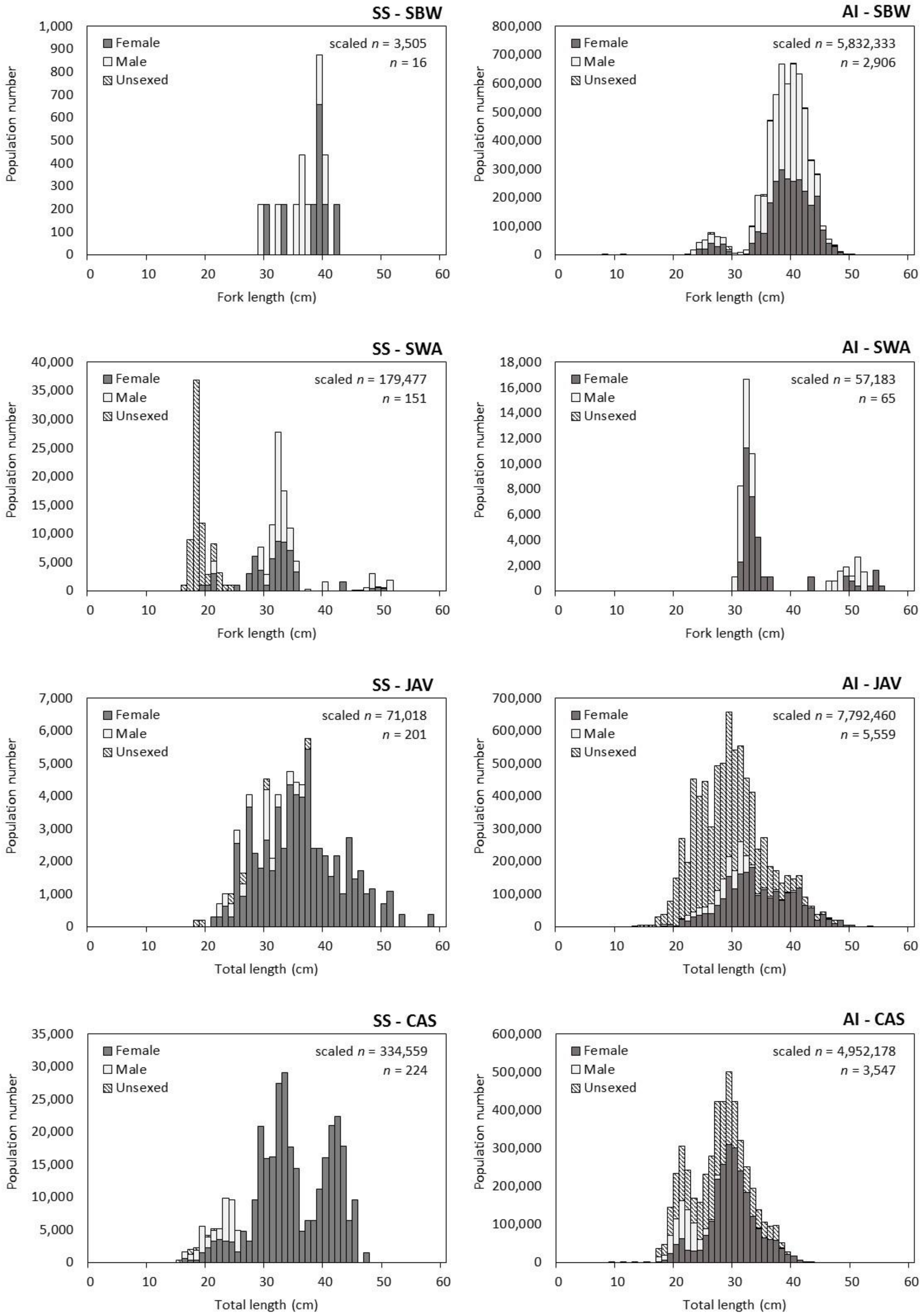

Figure 17: Length frequency distributions of minor NZ sea lion prey species – southern blue whiting (SBW; *Micromesistius australis*), silver warehou (SWA; *Seriolella punctata*), javelinfish (JAV; *Lepidorhynchus denticulatus*) and oblique-banded rattail (CAS; *Coelorinchus aspercephalus*) – at the Stewart Snares shelf (SS) and Auckland Islands (AI) in 2016 (scaled *n* = estimated total population in survey area; *n* = number of fish measured).

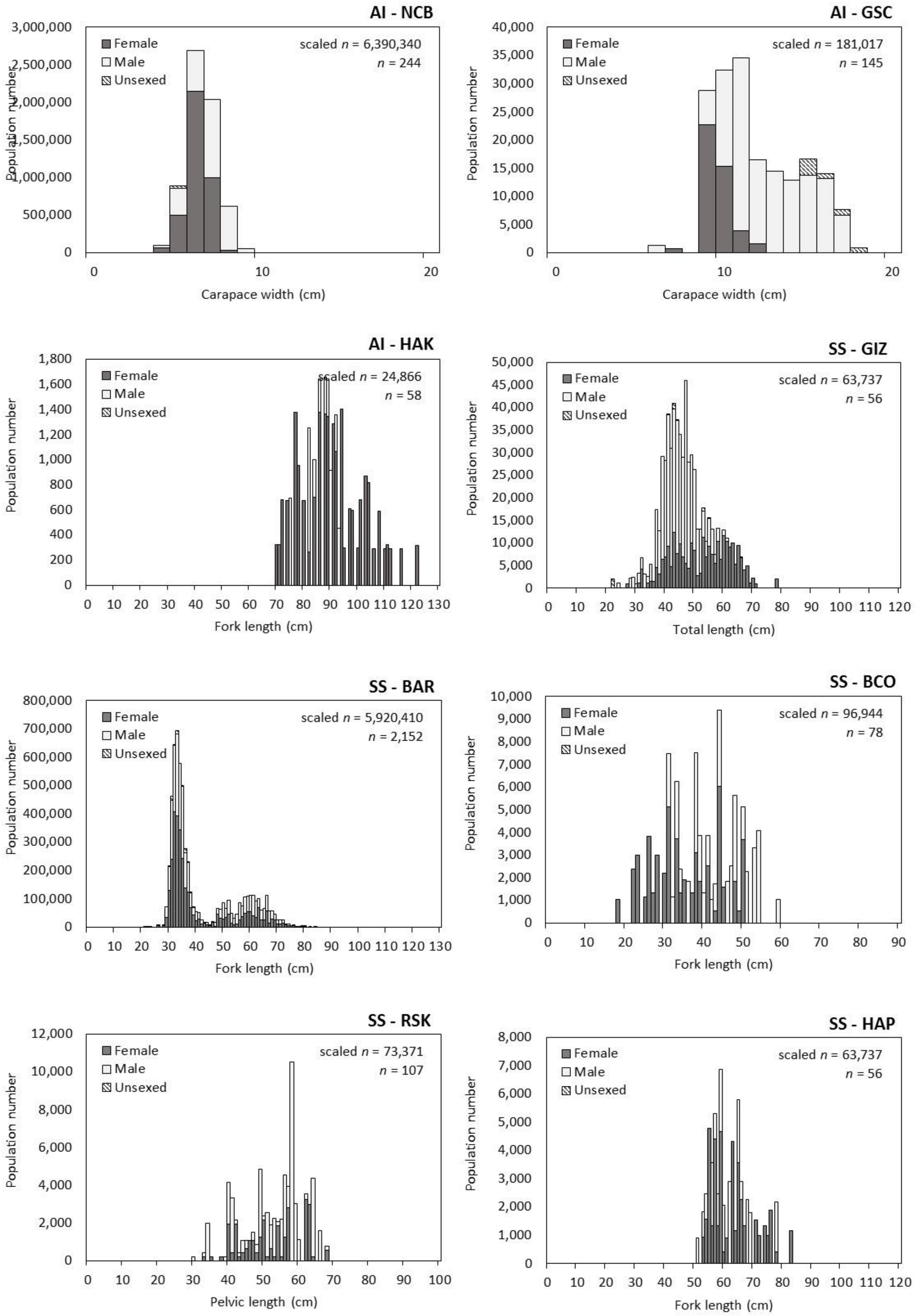

Figure 18: Length frequency distributions of minor NZ sea lion prey species – smooth red swimming crab (NCB; *Nectocarcinus bennetti*), hake (HAK; *Merluccius australis*), barracouta (BAR; *Thyrsites atun*) and rough skate (RSK; *Raja nasuta*) – at the Stewart Snares shelf (SS) and Auckland Islands (AI) in 2016 (scaled *n* = estimated total population in survey area; *n* = number of fish measured).

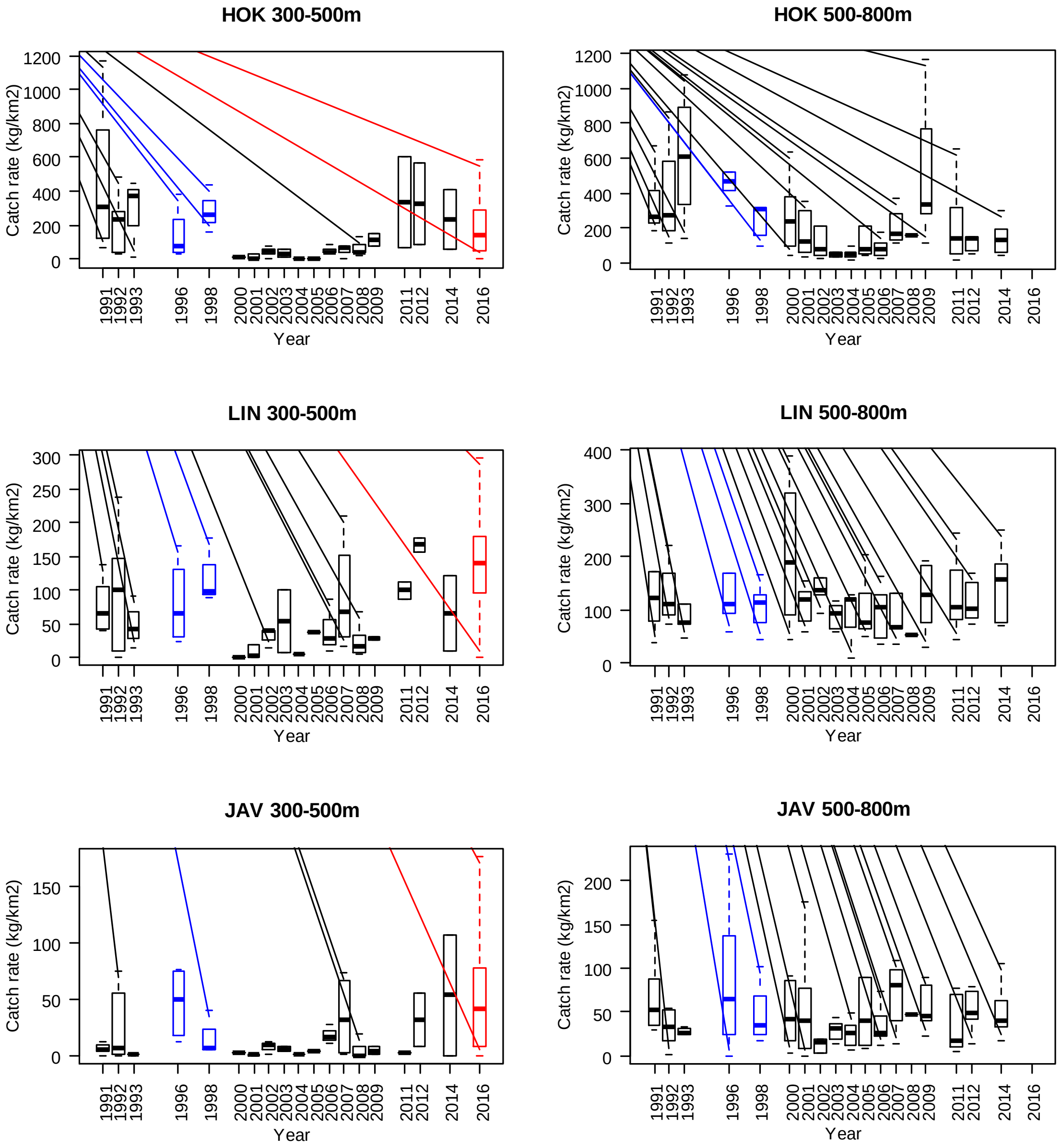

Figure 19: Catch rate of hoki (*Macruronus novaezelandiae*), ling (*Genypterus blacodes*) and javelinfish (*Lepidorhynchus denticulatus*) in demersal hoki survey trawls around the Auckland Islands at 300–500m depth (left) and 500–800m (right) by survey station and year. Auckland Islands area bounded by 51.25–49.25 ºS and 165.5–168.5 ºE; only bottom trawls with a gear performance code of "1" or "2" were included. Summer surveys (Nov/Dec) in black; late-Autumn surveys (April) in blue; and the TAN1602, early-Autumn survey (Feb) in red. Bold lines and boxes are the median and lower and upper quantiles, respectively; whiskers extend to the most extreme data point that is not more than 1.5*interquartile range from the box (outliers are not shown).

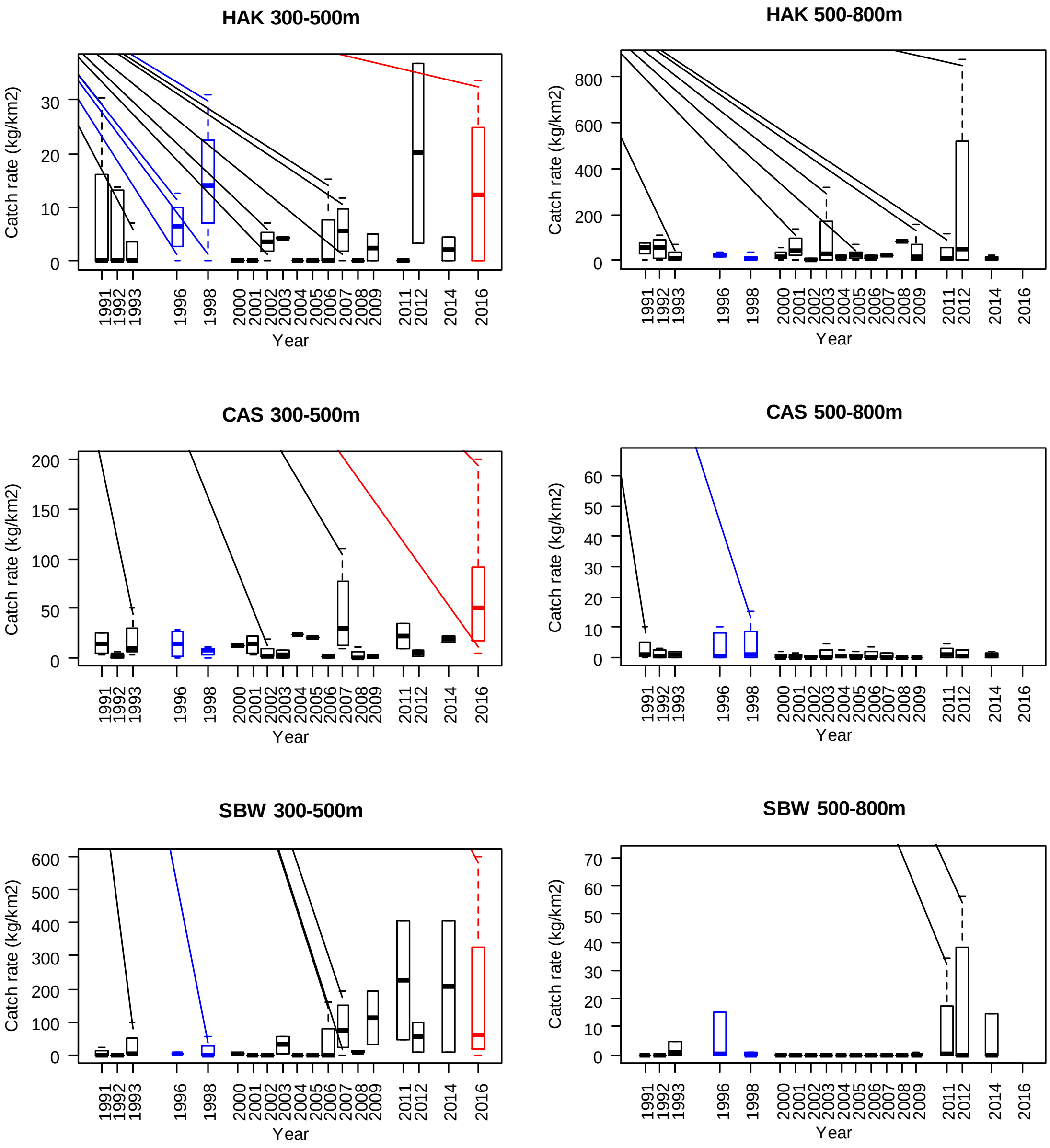

Figure 20: Catch rate of hake (*Merluccius australis*), oblique-banded rattail (*Coelorinchus aspercephalus*) and southern blue whiting (*Micromesistius australis*) in demersal hoki survey trawls around the Auckland Islands at 300–500m depth (left) and 500–800m (right) by survey station and year. Auckland Islands area bounded by 51.25–49.25 °S and 165.5–168.5 °E; only bottom trawls with a gear performance code of "1" or "2" were included. Summer surveys (Nov/Dec) in black; late-Autumn surveys (April) in blue; and the TAN1602, early-Autumn survey (Feb) in red. Bold lines and boxes are the median and lower and upper quantiles, respectively; whiskers extend to the most extreme data point that is not more than 1.5*interquartile range from the box (outliers are not shown).

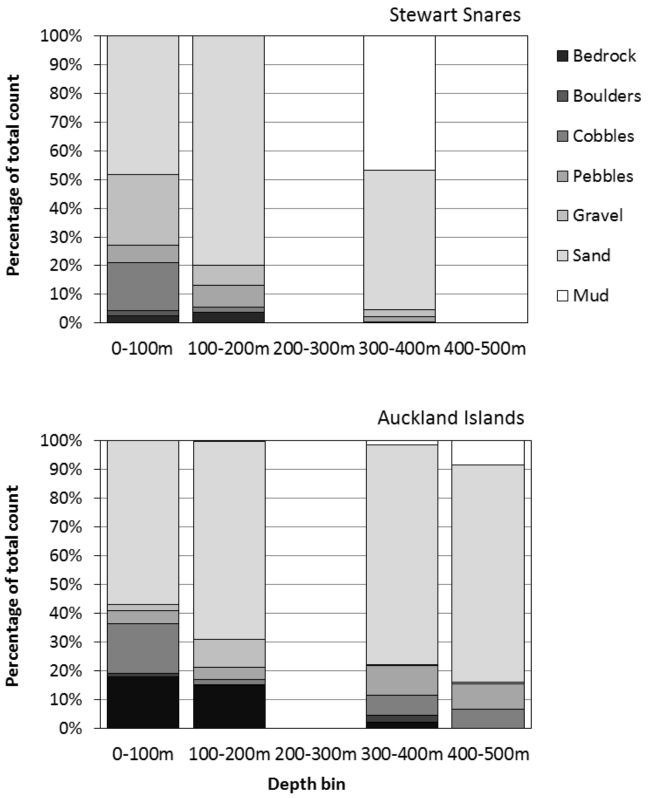

Figure 21: Bottom type composition by depth stratum at the Stewart Snares Shelf (top) and Auckland Islands (bottom) survey areas, determined from DTIS camera footage. Bottom type presented in terms of percentage of total number of times each type was specified by the video analyst across stations within a 100 m depth band.

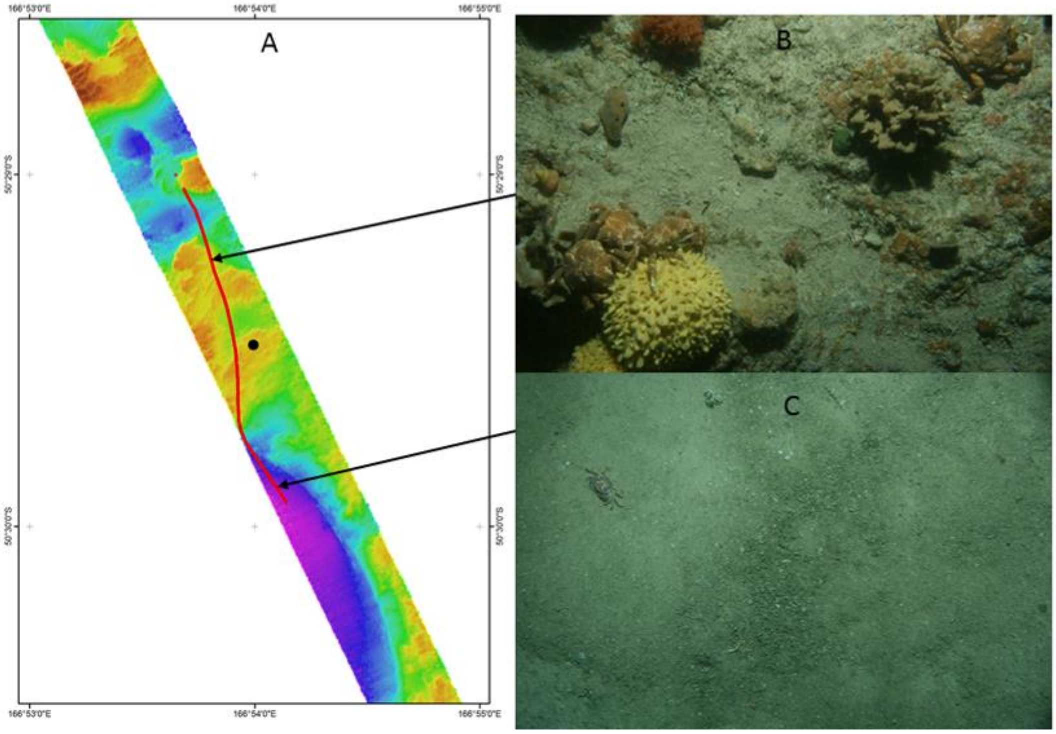

Figure 22: Multibeam and DTIS images from site 1.7 in stratum 1 at the Auckland Islands. Panel A shows depth profile of the seafloor from multibeam swath data, black dot marks the random location for this site, depths range 98–107 m, the red line shows the vessel path during the DTIS deployment. Panel B shows DTIS image over a low bedrock outcrop covered in sponges from the location indicated along the DTIS transect. Panel C shows DTIS image of a soft substrate at location indicated, comprising rubble and shell hash overlaying a sandy and muddy sediment.

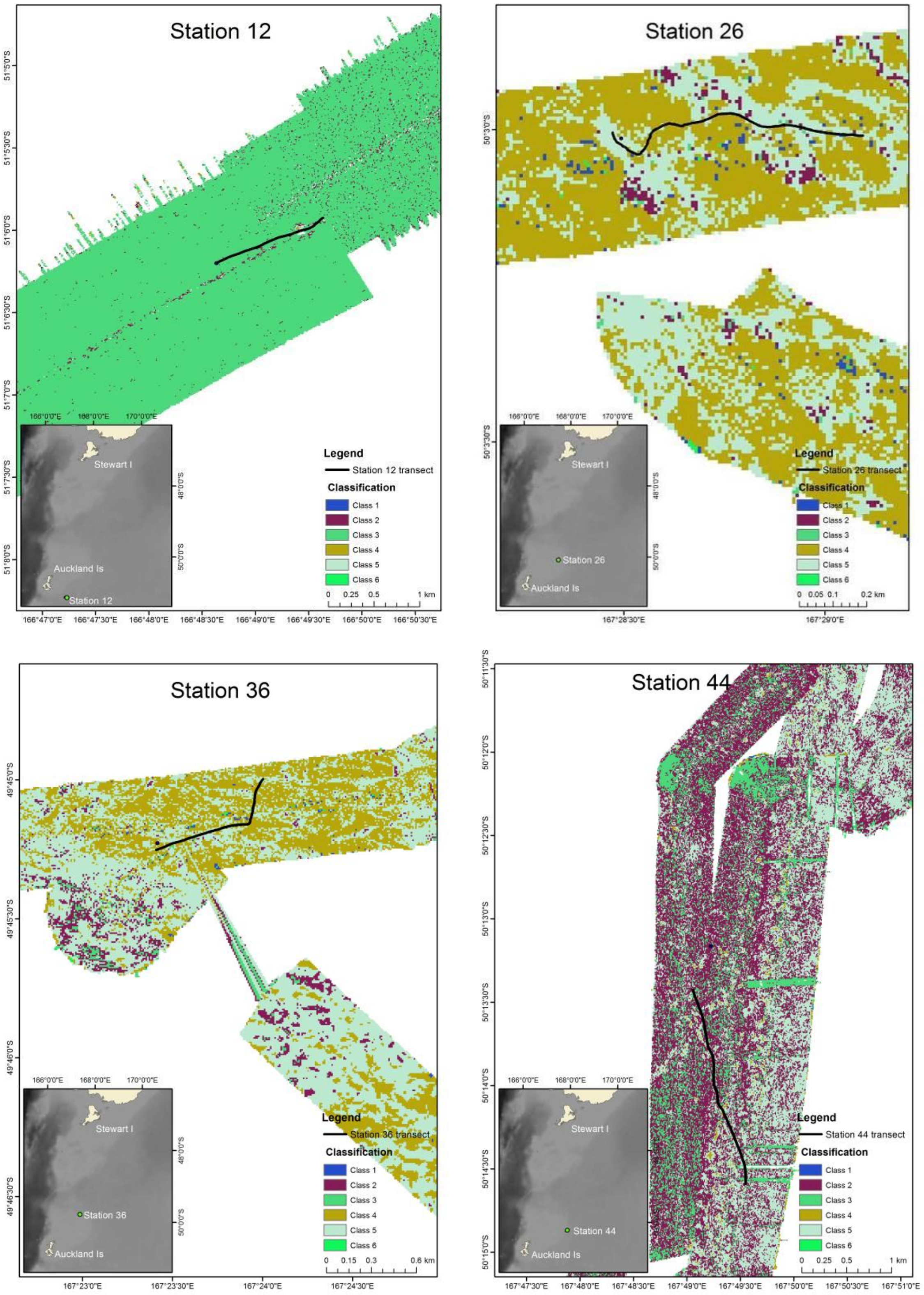

Figure 23: Spatial plots of habitat type determined by benthic classification using swath data for stations 12 (stratum A7, 470 m start depth), 26 (A1, 118 m), 36 (A3, 161 m) and 44 (A4, 174 m) at the Auckland Islands. Black lines show the paths of the DTIS transects.

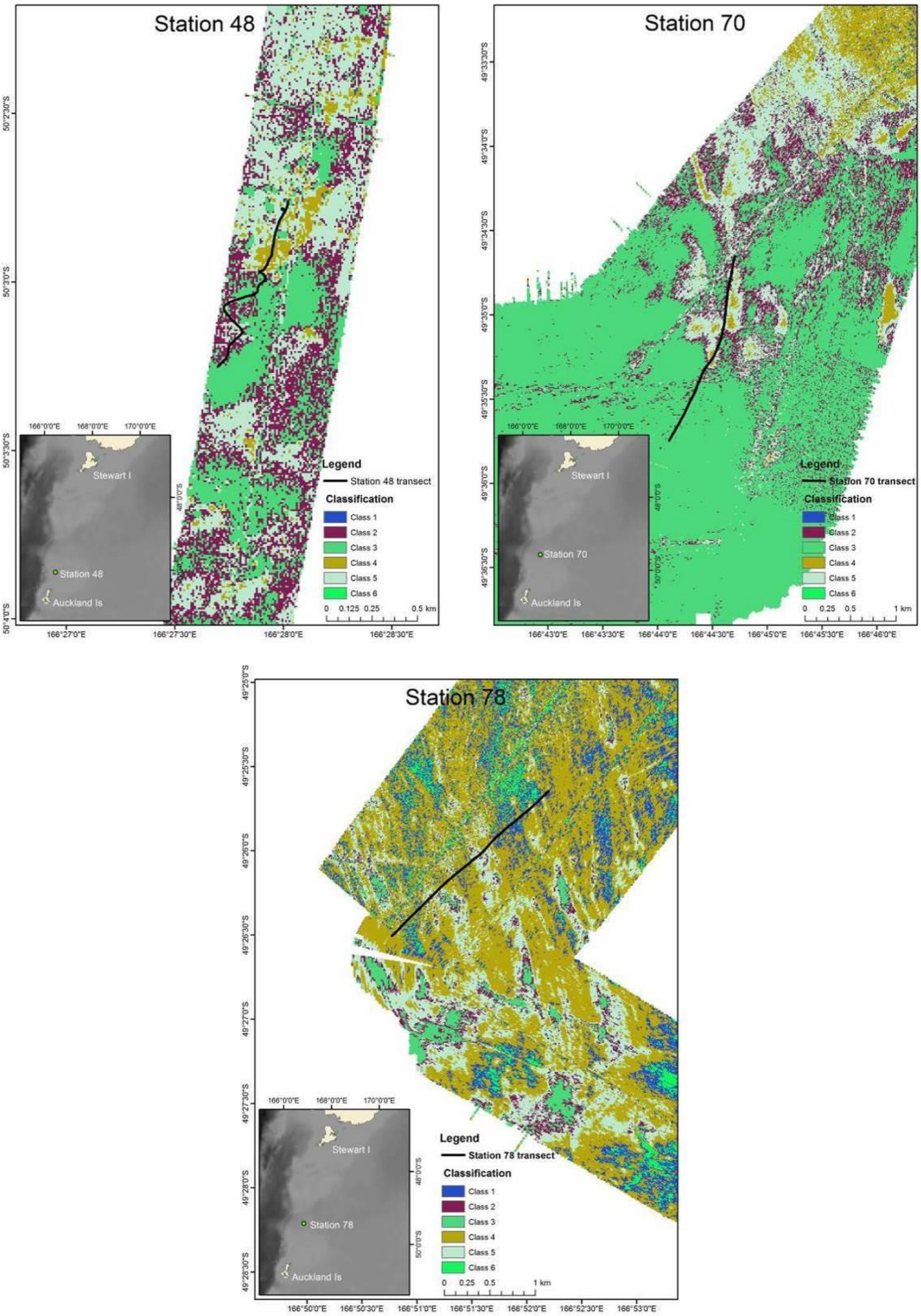

Figure 24: Spatial plots of habitat type determined by benthic classification using swath data for stations 48 (stratum A2, 169 m start depth), 70 (A5, 494 m), and 78 (A6, 469 m) at the Auckland Islands. Black lines show the paths of the DTIS transects.

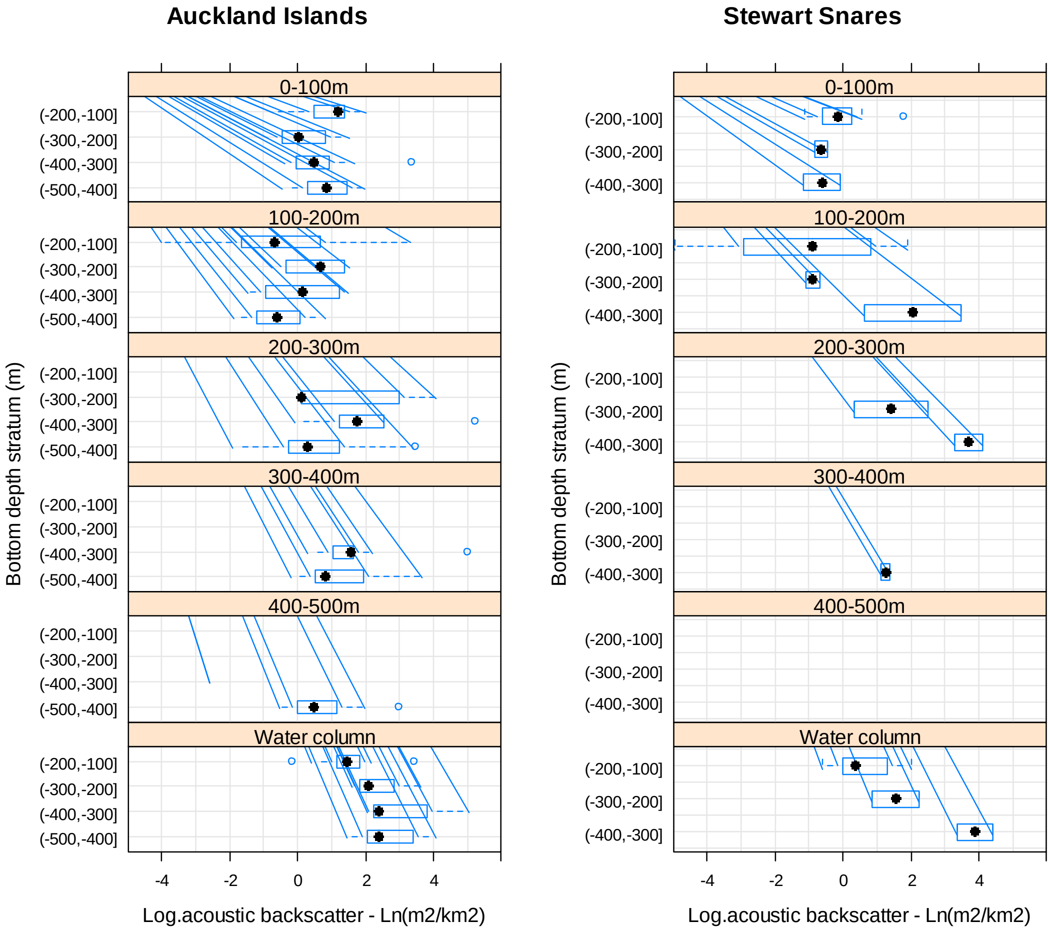

Figure 25: Distribution of acoustic backscatter density (m^2/km^2, x-axis) by bottom depth at location of measurement (y-axis) and depth in the water column from 0–100 m (top panels) to 400–500 m and through the entire water column (bottom panels). Each panel shows the log of total backscatter within a water column depth stratum (e.g., 100–200 m below the surface) disaggregated by total water column (or bottom) depth. The bottom panels show total backscatter across all water column depth strata.

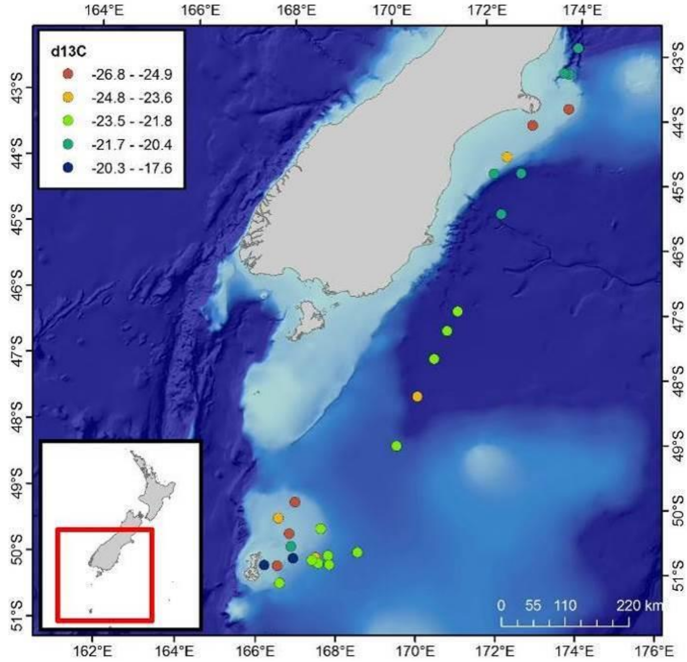

Figure 26: The carbon isotope values of particulate organic matter (POM) collected from the surface waters. Interestingly, the two higher values (less negative) sampled near the Auckland Islands correspond to samples collected during or just after storms with high winds and swells. That suggests injection of nutrients from deeper waters into the mixed layer, and corresponding increased growth rates in phytoplankton.

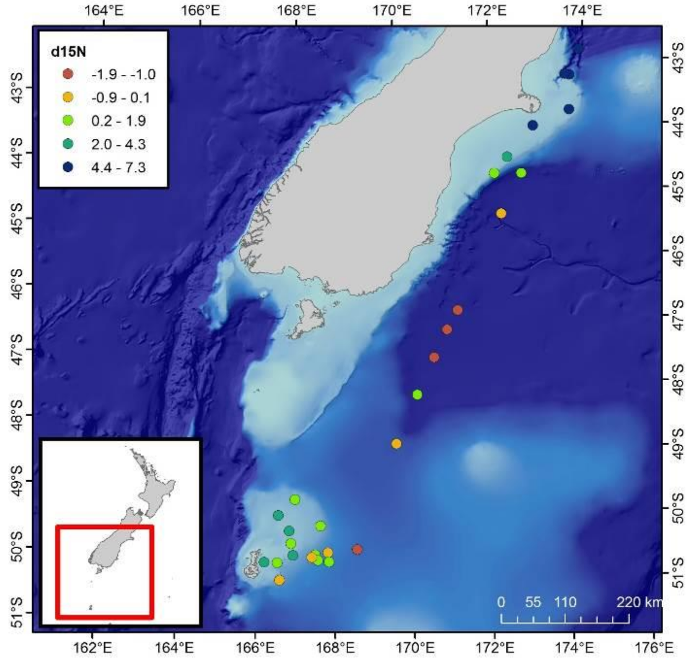

Figure 27: The nitrogen isotope values of particulate organic matter (POM) collected from the surface waters. Higher values indicate areas where nitrate and other nitrogen sources are key to primary production, whereas lower values can demonstrate areas where nutrients are limited and where nitrogen fixation could be important.

APPENDIX 1 NZ SEA LION FORAGING CHARACTERISATION

Background

The New Zealand sea lion prey survey was designed to maximise the precision of biomass estimates of key prey species using the standard demersal survey trawl, based on previous survey catch-effort. The Auckland Islands survey area was divided into 7 strata across 3 depth strata – 50–150 m, 150–250 m and 250–500 m. The survey was also designed to obtain a good spatial and bathymetric coverage of survey effort across the known foraging distribution of lactating female New Zealand sea lions. Previous foraging studies at the Auckland Islands (e.g., Chilvers & Wilkinson 2009) have concluded that lactating females conform to one of two foraging strategies:

- **Benthic** – characterised by dive bouts consisting of dives with a consistent depth; and

- **Mesopelagic** – characterised by dive bouts of dives with a variable depth.

Previous studies of individuals in 2000–2004 have concluded that benthic foragers primarily dive between 100 and 200 m depth so benthic dives mostly occur on the Auckland Islands shelf; whereas mesopelagic foragers are capable of dives in excess of 400 m and tend to use slope areas to the north and north-west of the Auckland Islands (Chilvers & Wilkinson 2009, Meynier et al. 2014).

In order to identify the probable prey species of each foraging group it is necessary to relate the bathymetric distribution of prey species inferred from the survey to the bathymetric distribution of foragers to a user-defined resolution. Unfortunately the data from foraging studies of lactating females in the years 2000–onward (used in the studies cited above) were not made available to the prey survey analysis. However, time depth recorder (TDR) records were obtained for lactating females in the summers of 1995–1997 and winters of 1996 and 1997. These dive records were explored to determine:

- The bathymetric depth distribution of *dives* by foraging type (as opposed to all dives by *individuals* ascribed to each foraging type); and
- The proportion of dives by each individual conforming to each foraging type.

The key outputs and then summarised and recommendations made with respect to the prey survey analysis.

Method

Dive data were obtained from 46 summer deployments (Jan–Feb of 1995, 1996 and 1997) and 8 winter deployments (July–September of 1996 and 1997). Methods of NZ sea lion capture and gear deployment and dive data post-processing are detailed in Chilvers et al. (2013).

In this analysis, benthic dives were defined as dives with a recorded depth within 10 m of the previous dive and for which there was at least 1 minute of bottom time (defined as the time an individual spent at depths exceeding 85 % of the maximum depth for that dive). All dives not meeting both these criteria were categorised as mesopelagic dives.

Results and Discussion

The distribution of dives with respect to calculated bottom time had a bimodal distribution, with peaks at 0.0–0.5 minutes and 2.5–3.0 minutes and a minimum of 1.0–1.5 between these peaks. The location of this minimum suggests that 1 minute cut-off for delineating mesopelagic and benthic dives is appropriate (i.e., true benthic dives will have a calculated bottom time longer than this). Approximately two-thirds of dives were to a depth within 10 m of the previous dive – all dives within 10 m of the previous dive depth were assumed to be benthic dives where they also had a bottom time of greater than 1 minute (Figure A1-1).

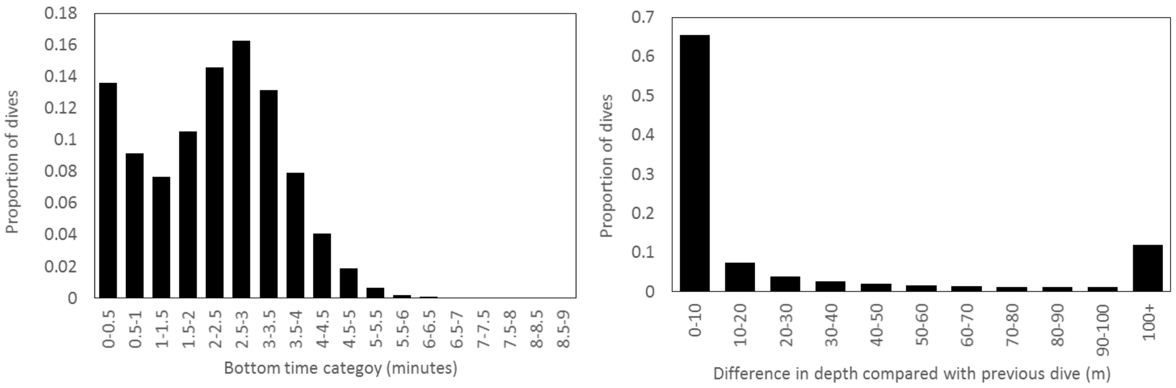

Figure A1-1: Distribution of New Zealand sea lion dives with respect to bottom time (left) and difference in depth with respect to the previous dive (right).

Individual NZ sea lions have previously been attributed a foraging type based on the percentage of dives within 50 m of the mean dive depth for a dive bout (Chilvers & Wilkinson 2009). They found that 10 out of 18 individuals undertook predominantly benthic dives (ranging from 68–88%), while the remaining 8 individuals undertook a much smaller percentage of benthic dives (range of 23–38%) and, so, were categorised as mesopelagic. The clear separation of proportion of benthic dives has justified the discrete categorisation of individuals as either benthic or mesopelagic.

We applied a slightly different methodology (described above) to an earlier dataset (Jan–Feb of 1995–1997 instead of 2000–2004) and found no evidence for a clear separation of individuals with respect to the proportion of benthic dives in summer. Slightly more than half of individuals (27 out of 46) undertook more than 62% mesopelagic dives and would have been described as mesopelagic divers by Chilvers & Wilkinson (2009). However, only 6 out of 46 individuals undertook more than 68% benthic dives and the remaining 13 individuals were distributed somewhere between these two extremes and could be described has having a ‘hybrid’ foraging strategy (Figure A1-2).

With respect to the prey survey, we want to identify the bathymetric range foraged by benthic versus mesopelagic dives. However, because relatively few individuals almost exclusively undertake benthic or mesopelagic foraging (and an approximately even proportion of benthic and mesopelagic dives for some) it is not appropriate to use the bathymetric distribution of dives by *individuals* in each group, as reported by Chilvers & Wilkinson (2009).

The bathymetric distribution of benthic dives (ignoring individual NZ sea lion foraging category) was much narrower with 75% of benthic dives occurring between 100–200 m depth, compared with 55% of dives by *individuals* classified as benthic foragers (Chilvers & Wilkinson 2009). Their analysis found that more than 30% of dives by benthic foraging individuals were greater than 200 m depth, though we found that only 7% of benthic dives were greater than this depth (Figure A1-3; Tables A1-1 and A1-2). The depth band from 75–200 m contained 85% and 94% of benthic dives in Summer and Winter, respectively, and can be used to identify the key prey when adopting this mode of foraging (i.e., key benthic prey species that are abundant across this depth range).

Mesopelagic dives comprised 22% of dives in Winter compared with 61% in Summer, which may indicate that mesopelagic foraging individuals in Summer switch to benthic foraging in Winter, although the sample size of individuals is small in Winter (N = 8). The majority (83%) of Summer dives deeper than 200 m were classified as mesopelagic, compared with 48% in Winter. Only 2% of dives in Winter were deeper than 200 m regardless of foraging category and relatively few were shallower than 100 m (Figure A1-3; Tables A1-1 and A1-2).

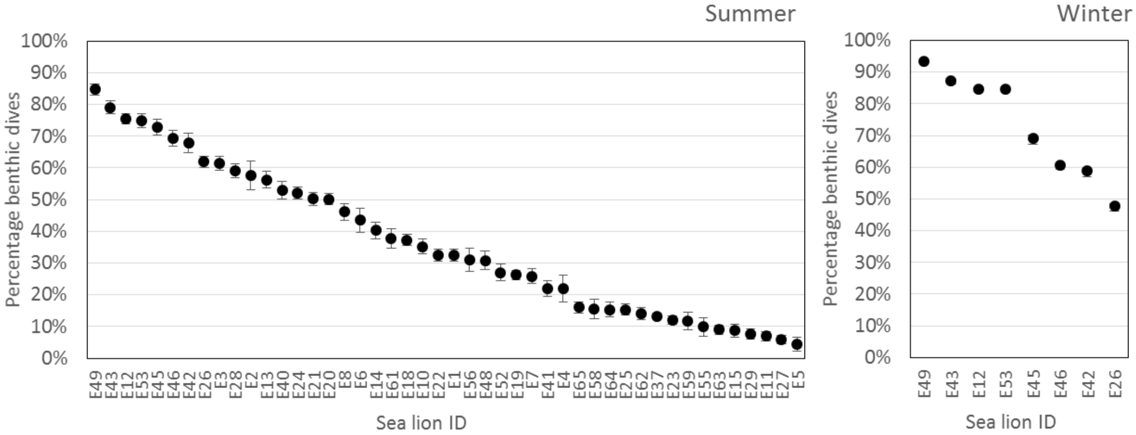

Figure A1-2: Percentage of dives categorised as benthic for instrumented lactating female New Zealand sea lions in the Summers of 1995, 1996 and 1997 (left) and Winters of 1996 and 1997 (right).

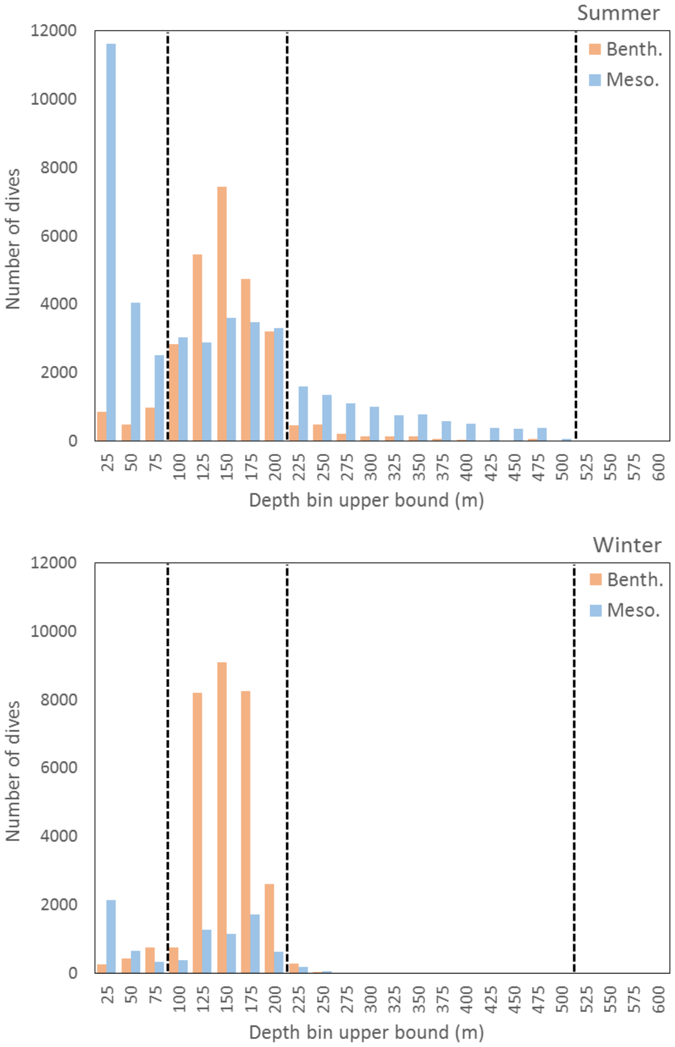

Figure A1-3: Bathymetric distribution of benthic and mesopelagic dives by lactating female New Zealand sea lions at the Auckland Islands in Summer 1994/95, 1995/96 and 1996/97 (top) and Winter 1994/95 and 1995/96 (bottom). Benthic dives were defined as those within 10 m depth of the previous dive and greater than 1 minute bottom time; dashed lines delineate depth bands 0–75 m (mostly shallow mesopelagic dives), 75–200 m (mostly benthic dives), 200–500 m (mostly deep mesopelagic dives) and 500+ (very small percentage of dives for either foraging type).

Table A1-1: The distribution of benthic/mesopelagic dives with respect to depth band in Summer

Depth band (m)	Total dives		Percentage dives by type		Percentage dives by depth band	
	Benthic	Mesopelagic	Benthic	Mesopelagic	Benthic	Mesopelagic
0–75	2 323	18 192	8.3%	41.8%	11.3%	88.7%
75–200	23 668	16 322	85.0%	37.5%	59.2%	40.8%
200–500	1 866	8 950	6.7%	20.6%	17.3%	82.7%
500+	1	39	< 0.1%	< 0.1%	2.5%	97.5%
Total	27 858 (39.0%)	43 503 (61.0%)				

Table A1-2: The distribution of benthic/mesopelagic dives with respect to depth band in Winter

Depth band (m)	Total dives		Percentage dives by type		Percentage dives by depth band	
	Benthic	Mesopelagic	Benthic	Mesopelagic	Benthic	Mesopelagic
0–75	1 477	3 147	4.8%	36.3%	31.9%	68.1%
75–200	28 937	5 185	94.0%	59.7%	84.8%	15.2%
200–500	373	347	1.2%	4.0%	51.8%	48.2%
500+	0	0	0.0%	0.0%	-	-
Total	30 787 (78.0%)	8 679 (22.0%)				

Conclusions

The main conclusions with respect to the prey survey are as follows:

- While there are individuals that can be considered mostly benthic or mesopelagic, a large proportion of individuals undertake almost an even mixture of the dive types and can be considered hybrid foragers (a new category). This will be a key consideration for future studies relating foraging category to demographic processes.

- **The depth band from 75–200 m** comprised 85% of benthic dives in Summer and 94% in Winter and **can be used to identify the key benthic prey species**.

- The majority (83%) of Summer dives deeper than 200 m were classified as mesopelagic. Therefore, **daytime demersal trawls deeper than 200 m can be used to identify key prey species of mesopelagic foragers**. A large percentage (79%) of mesopelagic dives are shallower than this and cannot be related to prey species based on their bathymetric distribution. However, the spatial distribution of mesopelagic foragers in Meynier et al. (2014) indicates that a large proportion of dives shallower than 200 m are over slopes greater than 200 m bottom depth to the North and Northwest of the Auckland Islands.

- Benthic prey captured at trawl stations deeper than 200 m could be predated during deep benthic dives (though these are infrequent), or on dives that reach the bottom but were classified as mesopelagic because they were more than 10 m deeper or shallower than the previous dive or the bottom time was less than 1 minute.

- Mesopelagic foragers may switch to benthic foraging in Winter. This being the case, the prey of benthic foragers will be of particular importance to a lactating female NZ sea lion’s annual energy budget.

References

Chilvers, B.L.; Wilkinson, I. (2009). Diverse foraging strategies in lactating New Zealand sea lions. *Marine Ecology Progress Series 378*: 299–308.

Chilvers, B.L.; Childerhouse, S.J.; Gales, N.J. (2013). Winter foraging behaviour of lactating New Zealand sea lions (*Phocarctos hookeri*). *New Zealand Journal of Marine and Freshwater Research 47:* 125–138.

Meynier, L.; Morel, P.C.H.; Chilvers, B.L.; Mackenzie, D.D.S.; Duignan, P.J. (2014). Foraging diversity in lactating New Zealand sea lions: insights from qualitative and quantitative fatty acid analysis. *Canadian Journal of Fisheries and Aquatic Sciences 71*: 984–991.

APPENDIX 2 DISTRIBUTION OF YELLOW OCTOPUS

Background

Yellow octopus (*Enteroctopus zealandicus*) are the main cephalopod prey of New Zealand sea lions at the Auckland Islands and Campbell Island (Childerhouse et al. 2001, Meynier et al. 2009, Roberts & Lalas 2015). There is a need to better understand their biology and distribution in relation to New Zealand sea lion foraging. The current basic understanding of yellow octopus' biology and distribution was summarised by O'Shea (1999) and was based on fewer than 100 specimens positively identified as yellow octopus, including specimens:

- Captured from Cook Strait in the north to Campbell Island in the south (Figure A2-1, left);
- Southernmost specimens from littoral to 530 m depth; Northernmost specimens mostly from 300–522 m
- Up to 27.2 cm mantle length

The New Zealand sea lion habitat survey of the Auckland Islands and Stewart-Snares Shelf (TAN1602) conducted an octopus potting feasibility study to the east of the Auckland Islands. The study was unsuccessful in capturing a single specimen. Here, we analyse observer catch-effort data from the main commercial trawl fisheries in order to determine the spatial/bathymetric distribution of yellow octopus around the Auckland Islands. This can then be related to the foraging patterns characteristic of mesopelagic versus benthic foraging New Zealand sea lions (See Appendix 1).

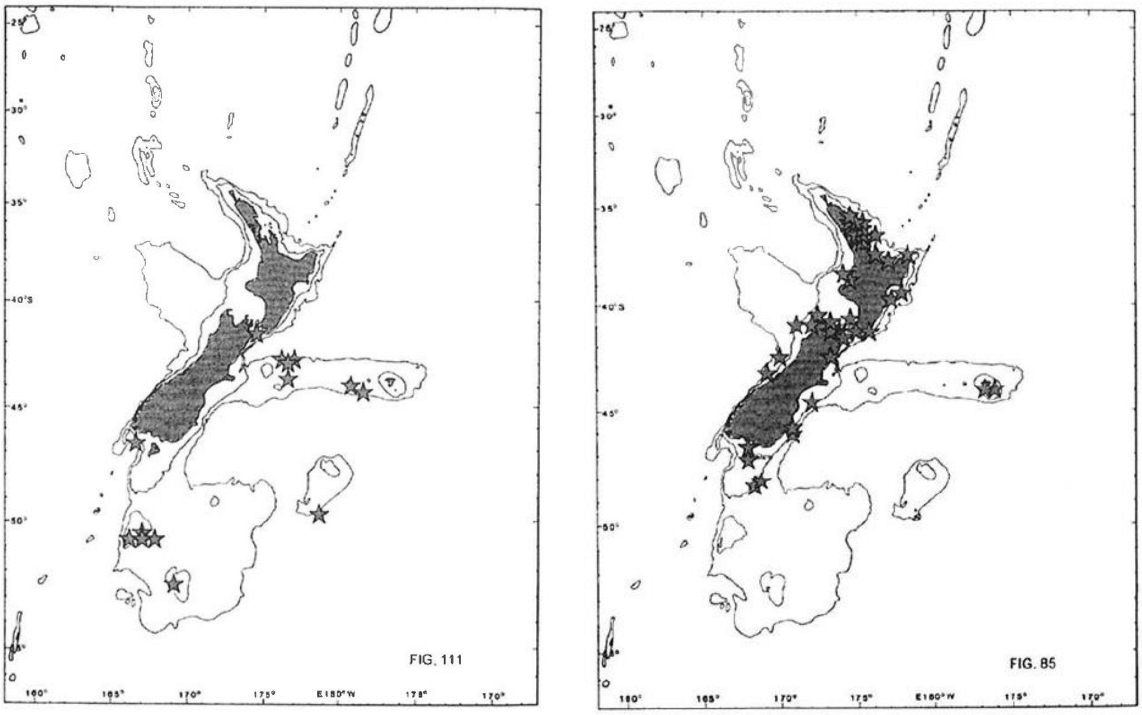

Figure A2-1. The recognised distribution of yellow octopus (*Enteroctopus zealandicus*; left) and common octopus (*Macroctopus maorum*; right); figure taken from O'Shea (1999).

Method

Observer reported commercial trawl catch records were considered for the 3 MPI species codes that yellow octopus catches could have been recorded under: “EZE” (yellow octopus - *Enteroctopus zealandicus*), “OCT” (common octopus; *Macroctopus maorum*) and; “OCP” (unidentified octopus spp.; *Octopoda*). Catch rate in terms of kilograms per hour of trawl effort (derived from the recorded start and end of fishing) was calculated for 50 m depth bins ranging from 50–700 m with 700 m+ the deepest depth bin. “Species” catch rate was only reported for fishery target/depth bins for which there was at least 100 hours of trawl effort.

Results and discussion

The total observer-reported captures of yellow octopus (EZE) in commercial trawls around the Auckland Islands in the fishing years 1986/87 to 2015/16 was 4681 kg, although all of this was since 2005/06 and it is likely that this species was not specifically recorded by observers in years prior to this. Observer-reported captures of common octopus (OCT) around the Auckland Islands exceeded those of yellow octopus in all years, though this species is not thought to occur this far south (Figure A2-1) and these are considered to mainly comprise misidentified yellow octopus – the only other New Zealand octopus species capable of attaining the large size (greater than 1 kg) of common octopus (*M. maorum*).

Table A2-1. Observed catch of *Enteroctopus zealandicus* (EZE), individuals identified as common octopus (OCT) (assumed to comprise a large proportion of EZE) and unidentified octopus spp. (OCP) in commercial trawls at the Auckland Islands by target species and fishing year. HHL = target hoki/hake/ling.

Fishing year	Observed catch (kg) by target species												All observed tows
	EZE				OCT				OCP				
	SQU	SCI	HHL	Other	SQU	SCI	HHL	Other	SQU	SCI	HHL	Other	
1986/87	0	-	0	0	66	-	35	121	0	-	0	0	222
1987/88	0	-	0	0	4	-	49	1 229	0	-	0	0	1 282
1988/89	0	-	0	0	259	-	109	603	0	-	0	0	971
1989/90	0	-	0	0	43	-	43	54	0	-	3	1	140
1990/91	0	0	0	0	36	118	407	74	0	0	27	7	635
1991/92	0	0	0	0	22	97	209	52	0	17	74	20	380
1992/93	0	0	0	0	449	197	214	805	0	0	0	0	1 665
1993/94	0	0	0	0	1 790	648	131	124	0	0	0	0	2 693
1994/95	0	0	0	0	110	630	89	150	0	0	0	0	979
1995/96	0	0	0	0	64	514	218	2	0	0	0	0	798
1996/97	0	0	0	0	431	115	47	167	0	0	0	0	760
1997/98	0	0	0	0	48	238	292	58	0	0	41	0	636
1998/99	0	0	0	0	3 124	270	701	107	0	12	0	0	4 202
1999/00	0	0	0	0	149	372	1 976	413	0	0	10	0	2 910
2000/01	0	0	0	0	457	108	702	406	0	0	35	0	1 673
2001/02	0	0	0	0	382	1 017	1 671	117	0	0	0	0	3 187
2002/03	0	0	0	0	596	89	462	148	0	0	0	0	1 295
2003/04	0	0	0	0	114	5 363	154	248	0	542	0	0	5 879
2004/05	0	0	0	0	1 195	4	188	234	0	2	0	2	1 621
2005/06	51	68	8	0	846	9	149	264	0	0	4	9	1 395
2006/07	21	6	0	0	998	159	75	150	0	0	4	3	1 409
2007/08	12	37	37	3	282	205	148	303	2	0	0	4	1 027
2008/09	23	0	32	7	1 017	156	58	354	0	38	0	4	1 647
2009/10	79	54	36	10	188	134	467	95	0	0	1	3	1 063
2010/11	265	56	78	28	1 629	420	208	349	9	0	6	11	3 033
2011/12	103	338	29	8	1 493	477	65	335	0	0	0	2	2 848
2012/13	963	26	112	73	1 985	66	660	489	24	0	4	1	4 374
2013/14	1 372	35	46	125	3 839	15	588	2 130	0	0	0	0	8 150
2014/15	390	21	67	62	2 265	132	753	1 317	10	0	0	0	5 007
2015/16	0	-	0	0	0	-	8	154	0	-	0	0	162
All	3 279	641	445	316	23 881	11 553	10 876	11 052	45	611	209	67	62 043

Low observed catches and the restricted spatial coverage of observed effort in hoki/hake/ling and scampi trawl fisheries meant that these could not be used to determine the spatial distribution of yellow octopus catch rate (observed kg/hour) around the Auckland Islands. For bottom trawls targeting southern arrow squid, the spatial distribution of yellow octopus (EZE) catch rate was similar to that of OCT (suspected to include misidentified EZE) – these appear to be most abundant along the north-eastern shelf break to the east of the Auckland Islands, though were also present in shallow regions immediately to the east of the main breeding rookeries (Figure A2-2).

The total observed catch was too low to infer the bathymetric distribution of yellow octopus, although the bathymetric range of bottom trawls on which they were captured (97 m to 688 m) suggests that they are present on the shelf, the slopes and the deeper Campbell Plateau to the east of the slope. The maximum depth reported by fisheries observers around the Auckland Islands is greater than the species' maximum depth of 530 m in O'Shea (1999) (Figure A2-3).

The catch rate of OCT in bottom trawls targeting southern arrow squid increased with increasing depth up to the approximately 350 m maximum depth of observed fishing effort. Catch rate of EZE and OCT were reduced in trawls targeting scampi and hoki/hake/ling, which were distributed deeper than squid trawls. However gear and operations are different in these fisheries, so abundance effects on variable catch rate of yellow octopus will most likely be confounded with fishing gear/operational factors (Figure A2-3).

Conclusions

Yellow octopus are likely to be one of the main prey of benthic-foraging NZ sea lions at the Auckland Islands. Benthic dives are concentrated between 75–200 m depth (See Appendix 1) where the catch rate of yellow octopus (EZE) in bottom trawls targeting southern arrow squid were relatively high, although the catch rate of OCT (which are likely to be misidentified EZE) was greatest in trawls from 250 m to 350 m indicating that a large proportion of yellow octopus will have low availability to foraging NZ sea lions.

The ecology and lifecycle of yellow octopus is extremely poorly described. Of particular relevance to NZ sea lion foraging efficiency, the extent to which changes in spatial and/or depth distribution occur is not known and probably cannot be determined from existing commercial fishery/survey data. Improvements in observer species identification of octopus species may improve our understanding of this species' distribution within the fished area. Also, the collection of yellow octopus specimens by fishery observers will allow us to better describe their biology, including: diet, longevity and recruitment variability.

Reference

Childerhouse, S.; Dix, B.; Gayles, N. (2001). Diet of New Zealand sea lions (*Phocarctos hookeri*) at the Auckland Islands. *Wildlife Research 28*: 291–298.

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Roberts, J.; Lalas, C. (2015). Diet of New Zealand sea lions (*Phocarctos hookeri*) at their southern breeding limits. *Polar Biology 38*: 1483–1491.

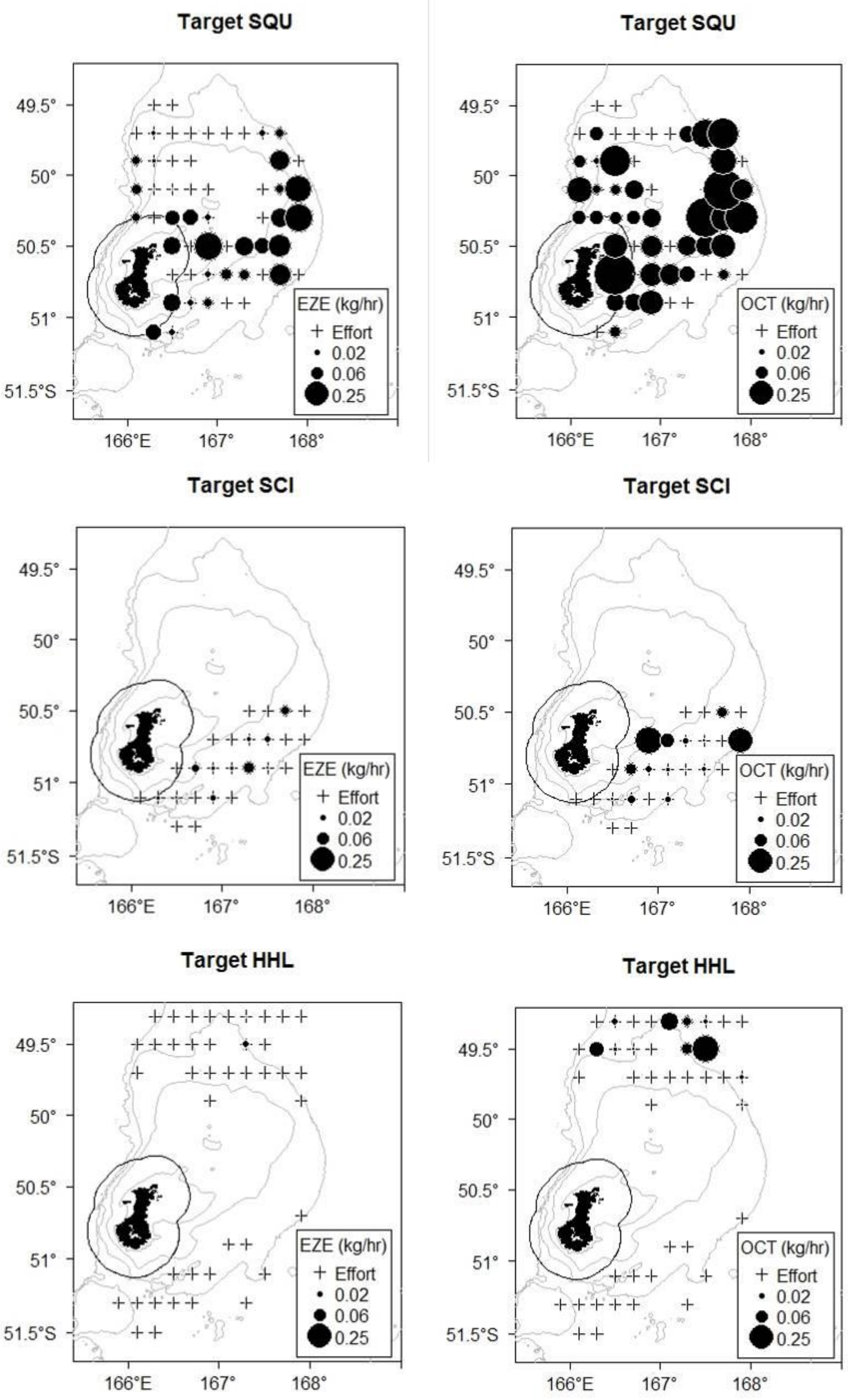

Figure A2-2. Observer-reported spatial catch rate of *Enteroctopus zealandicus* (EZE) and common octopus (OCT; likely to comprise a large proportion of misidentified EZE) in bottom trawls targeting southern arrow squid (SQU), scampi (SCI) and hoki/hake/ling (HHL) at the Auckland Islands from 2005/06 to 2014/15.

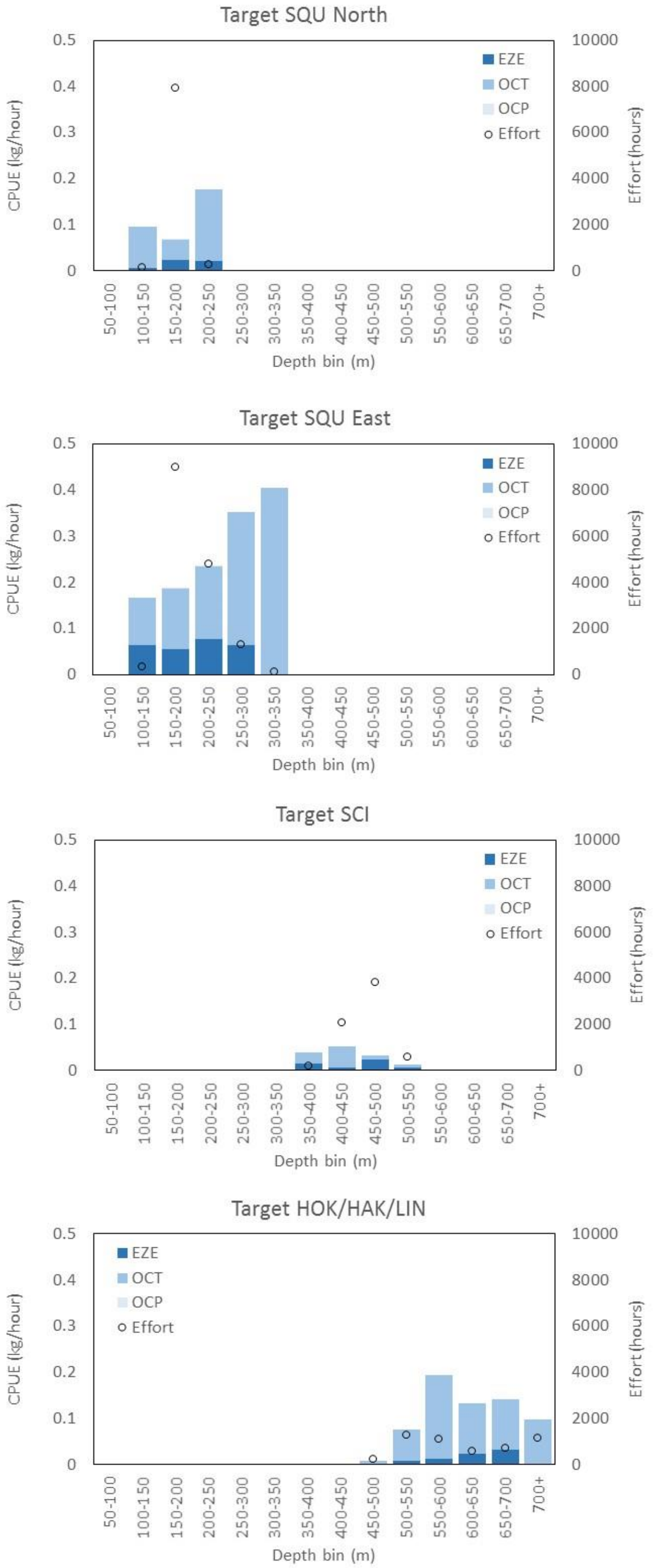

Figure A2-3. Observer-reported catch rate of *Enteroctopus zealandicus* (EZE), common octopus (OCT; likely to comprise a large proportion of misidentified EZE) and unidentified octopus spp. (OCP) and effort (trawl hours) by depth bin in bottom trawls targeting southern arrow squid (SQU), scampi (SCI) and hoki/hake/ling at the Auckland Islands from 2005/06 to 2014/15; "North" corresponds with the area bounded by latitudes 50.4ºS to 49.5ºS and longitudes 165ºE and 167ºE; "East" is all fishing outside of this area.

APPENDIX 3 STATION DETAILS

Table A3-1: Basic description of all prey survey stations. Gear code: BT, demersal trawl; DTIS, deep tow imaging system; POT, octopus pots, MWT, midwater trawl; CAL, acoustic calibration. * indicates bottom trawls that were unsuitable for abundance estimation due to poor gear performance.

Station	Date	Start time (NZST)	Gear	Stratum	Start latitude (decimal)	Start longitude (decimal)	Start depth (m)	Distance towed (n. mile)
1	8-Feb-16	1206	BT	A7	-50.6308	167.9323	441	2.99
2	8-Feb-16	1514	BT	A7	-50.5045	167.7785	400	2.99
3	8-Feb-16	1804	BT	A7	-50.4423	167.7605	392	3.01
4	9-Feb-16	0627	BT	A4	-50.6697	167.0312	153	2.96
5	9-Feb-16	0847	BT	A7	-50.6938	167.1495	407	2.97
6	9-Feb-16	1153	BT	A7	-50.7788	167.4173	451	2.98
7	11-Feb-16	0555	BT	A4	-50.8008	166.8488	151	2.53
8	11-Feb-16	0849	BT	A7	-50.9913	166.7282	490	3.00
9	11-Feb-16	1239	BT	A7	-51.0788	166.5090	450	2.94
10	11-Feb-16	1525	BT	A7	-51.1810	166.5975	486	3.01
11	11-Feb-16	1750	BT	A7	-51.1082	166.8032	470	3.00
12	11-Feb-16	2007	DTIS	A7	-51.0982	166.8255	470	0.69
13	12-Feb-16	0148	DTIS	A7	-50.6927	167.7095	350	0.72
14	12-Feb-16	0834	POT		-50.6832	166.7495	107	
15	12-Feb-16	1001	POT		-50.6822	166.9533	139	
16	12-Feb-16	1230	POT		-50.6825	167.0430	291	
17	12-Feb-16	1347	POT		-50.6832	167.5380	425	
18	12-Feb-16	1617	BT	A7	-50.7597	167.5812	460	2.98
19	12-Feb-16	2140	DTIS	A1	-50.4842	166.8950	110	0.94
20	13-Feb-16	0628	BT	A7	-50.3552	167.8408	386	3.00
21	13-Feb-16	0910	BT	A1	-50.2800	167.5302	121	3.00
22	13-Feb-16	1125	BT	A1	-50.3528	167.2472	118	2.57
23	13-Feb-16	1321	BT	A1	-50.4332	167.2250	117	3.00
24	13-Feb-16	1509	BT	A1	-50.4480	167.0613	111	3.01
25*	13-Feb-16	1726	BT	A1	-50.5040	166.9133	101	1.39
26	14-Feb-16	0247	DTIS	A1	-50.0498	167.4847	118	0.42
27	14-Feb-16	0617	BT	A1	-50.1135	167.7720	131	2.00
28	14-Feb-16	0905	BT	A4	-50.2032	167.8317	168	3.02
29*	14-Feb-16	1320	BT	A1	-50.0947	167.1885	126	1.84
30*	14-Feb-16	1626	BT	A1	-50.2617	167.0828	121	0.90
31*	14-Feb-16	1802	BT	A1	-50.2602	167.0572	126	0.70
32	15-Feb-16	0958	BT	A3	-49.7152	167.2293	169	2.38
33*	15-Feb-16	1518	BT	A6	-49.7197	167.6600	474	1.53
34	15-Feb-16	1808	BT	A6	-49.6523	167.6027	502	2.99
35	15-Feb-16	2142	DTIS	A3	-49.7477	167.4023	162	0.30
36	15-Feb-16	2244	DTIS	A3	-49.7497	167.3983	161	0.47
37	16-Feb-16	0611	BT	A3	-49.9990	167.8087	194	3.00
38	16-Feb-16	0833	BT	A6	-50.1428	167.9698	450	3.00
39	16-Feb-16	1041	BT	A6	-50.0138	167.8920	450	2.05
40	16-Feb-16	1253	BT	A6	-49.8973	167.8962	482	3.06
41	16-Feb-16	1454	BT	A6	-49.8617	167.7908	444	2.98
42	16-Feb-16	1715	BT	A3	-49.9158	167.7715	233	3.00
43	16-Feb-16	2033	DTIS	A6	-50.1375	167.9557	446	1.05
44	16-Feb-16	2320	DTIS	A4	-50.2417	167.8250	174	0.88
45	17-Feb-16	0225	DTIS	A7	-50.4527	167.7523	404	1.01
46	17-Feb-16	0510	DTIS	A7	-50.5237	167.7492	400	0.68
47	17-Feb-16	1821	CAL		-50.7447	166.6807	112	
48	18-Feb-16	0256	DTIS	A2	-50.0538	166.4615	169	0.52
49	18-Feb-16	0631	BT	A2	-49.8378	166.3093	178	2.51
50	18-Feb-16	0906	BT	A5	-49.9875	166.1152	309	3.00

Station	Date	Time	Gear	Stratum	Start latitude (decimal)	Start longitude (decimal)	Start depth (m)	Distance towed (n. mile)
51	18-Feb-16	1151	BT	A2	-50.0780	166.2022	204	3.05
52	18-Feb-16	1423	BT	A2	-50.1750	166.4325	173	3.00
53	18-Feb-16	1608	BT	A2	-50.1987	166.6177	171	2.98
54	18-Feb-16	2158	DTIS	A3	-49.7127	166.8372	167	0.89
55	19-Feb-16	0438	MWT	A5	-49.5855	166.1843	390	2.21
56	19-Feb-16	0602	BT	A5	-49.5703	166.2242	410	3.02
57	19-Feb-16	0806	BT	A5	-49.6708	166.2085	268	2.99
58	19-Feb-16	1049	BT	A5	-49.6278	166.5255	321	3.02
59	19-Feb-16	1236	BT	A2	-49.6760	166.7385	200	3.01
60	19-Feb-16	1424	BT	A3	-49.7033	166.9020	182	3.04
61	19-Feb-16	1643	BT	A1	-49.9143	166.8407	147	3.00
62	19-Feb-16	1833	DTIS	A1	-49.9583	166.8458	141	1.21
63	20–Feb-16	0240	DTIS	A6	-49.6055	167.1037	371	1.48
64	20-Feb-16	0557	BT	A6	-49.6452	167.1572	342	2.99
65	20-Feb-16	0744	BT	A3	-49.6988	167.0443	192	3.01
66*	20-Feb-16	0924	BT	A3	-49.7425	166.9682	153	0.86
67	21-Feb-16	1812	DTIS	A1	-50.6213	166.6983	101	1.28
68	22-Feb-16	1344	BT	A5	-49.5912	166.3973	425	2.41
69	22-Feb-16	1659	BT	A5	-49.5902	166.7340	488	3.01
70	22-Feb-16	1942	DTIS	A5	-49.5770	166.7435	494	1.17
71	23-Feb-16	0153	DTIS	A6	-49.6415	167.2813	322	0.50
72	23-Feb-16	0313	MWT	A6	-49.6340	167.2758	338	1.84
73	23-Feb-16	0636	BT	A6	-49.6303	167.4132	454	3.00
74	23-Feb-16	0856	BT	A6	-49.6503	167.2313	326	3.01
75	23-Feb-16	1212	BT	A6	-49.6492	166.9843	373	2.11
76	23-Feb-16	1431	BT	A6	-49.5027	166.9543	418	2.76
77	23-Feb-16	1720	BT	A6	-49.3860	166.9180	466	2.12
78	23-Feb-16	1855	DTIS	A6	-49.4267	166.8678	469	1.27
79	24-Feb-16	0716	BT	S13	-47.9130	168.7100	303	3.02
80	24-Feb-16	1250	BT	S6A	-47.7003	168.6173	129	2.15
81	24-Feb-16	1438	BT	S6B	-47.7900	168.6780	138	2.98
82	24-Feb-16	1740	BT	S6B	-47.6828	168.8050	136	2.27
83	25-Feb-16	0617	BT	S13	-47.7447	168.8588	354	2.95
84	25-Feb-16	0801	BT	S13	-47.6230	168.9697	276	2.02
85	25-Feb-16	1010	BT	S6B	-47.5893	168.8423	133	2.98
86	25-Feb-16	1146	BT	S6B	-47.4838	168.9302	126	3.02
87	25-Feb-16	1325	BT	S5B	-47.3882	168.9432	124	3.00
88	25-Feb-16	1814	DTIS	S13	-47.6028	168.9807	161	1.50
89	25-Feb-16	2135	DTIS	S6B	-47.7888	168.6780	138	0.86
90	26-Feb-16	0634	BT	S13	-47.1712	169.4277	382	2.99
91	26-Feb-16	959	BT	S5B	-41.2462	169.0382	122	2.03
92	26-Feb-16	1129	BT	S5A	-47.1303	169.0380	117	3.06
93	26-Feb-16	1320	BT	S5B	-47.1648	169.1423	123	2.95
94	26-Feb-16	1616	BT	S5B	-46.9185	169.5167	125	2.99
95	26-Feb-16	1753	DTIS	S5B	-46.9283	169.4960	124	0.48
96	27-Feb-16	0025	DTIS	S2	-47.0643	168.3893	86	0.63
97	27-Feb-16	0406	DTIS	S2	-46.8163	168.8780	81	0.83
98	27-Feb-16	0609	BT	S2	-46.8297	168.9045	83	3.01
99	27-Feb-16	0843	BT	S2	-46.9223	168.7400	84	2.96
100	27-Feb-16	1214	BT	S2	-47.0453	168.3853	81	2.67

Station	Date	Time	Gear	Stratum	Start latitude (decimal)	Start longitude (decimal)	Start depth (m)	Distance towed (n. mile)
101	27-Feb-16	2327	DTIS	S2	-47.1865	168.0867	91	1.11
102	28-Feb-16	0609	BT	S5A	-47.2702	168.5930	114	3.01
103	28-Feb-16	0801	BT	S5A	-47.2487	168.4187	107	2.99
104	28-Feb-16	1052	BT	S2	-47.2013	168.1313	92	3.01
105	29-Feb-16	0102	DTIS	S2	-46.9838	168.2778	48	0.69
106	29-Feb-16	2058	DTIS	S2	-46.9388	168.2620	48	0.74
107	29-Feb-16	2300	DTIS	S2	-46.9873	168.2750	50	1.01
108	1-Mar-16	0619	BT	S5A	-47.3375	168.2477	110	3.03
109	1-Mar-16	1020	BT	S6A	-47.4567	168.1917	120	3.01
110	1-Mar-16	1255	BT	S6A	-47.5105	168.3078	120	2.98
111	1-Mar-16	1609	BT	S6A	-47.5818	168.0413	133	2.99
112	2-Mar-16	0436	DTIS	S10A	-47.6753	167.5130	133	0.57
113	2-Mar-16	0623	BT	S10A	-47.6617	167.3350	144	2.33
114	2-Mar-16	0844	BT	S10A	-47.5362	167.3128	147	3.01
115	2-Mar-16	1129	BT	S10A	-47.4083	167.4655	146	3.03
116	2-Mar-16	1433	BT	S10A	-47.3317	167.1315	158	3.00
117	2-Mar-16	1658	BT	S11	-47.1245	167.2368	143	2.99
118	2-Mar-16	2217	DTIS	S3	-46.7645	167.5655	73	0.88
119	3-Mar-16	0133	DTIS	S11	-46.7092	167.2447	145	1.15
120	3-Mar-16	0435	DTIS	S3	-46.5713	167.5842	65	0.72
121	3-Mar-16	0618	BT	S3	-46.5728	167.5697	66	3.00
122	3-Mar-16	1033	BT	S3	-46.7910	167.5322	81	2.68
123	3-Mar-16	1230	BT	S3	-46.8925	167.5747	76	2.11
124	3-Mar-16	1427	BT	S11	-46.9695	167.3747	124	2.99
125	4-Mar-16	0625	BT	S11	-46.6920	167.2330	148	3.03

APPENDIX 4 SPECIES LIST AND BIOLOGICAL SAMPLING

Table A4-1: List of species captured by trawl survey gear and biological samples collected.

Code	**Scientific name**	**Common name**	**Catch weight (kg)**	**Number measured**	**Number of samples**
ACS	Actinostolidae	Deepsea anemone	14.6	0	2
AER	*Aeneator recens*	*Aeneator recens*	0.1	0	0
ANT	Anthozoa	Anemones	6.0	0	1
API	*Alertichthys blacki*	Alert pigfish	0.1	0	0
ASC	Ascidiacea	Sea squirt	3.5	0	3
ASR		Asteroid (starfish)	0.1	0	1
AWI	*Alcithoe wilsonae*	*Alcithoe wilsonae*	0.1	0	0
BAR	*Thyrsites atun*	Barracouta	1 924.8	2 154	120
BBE	*Centriscops humerosus*	Banded bellowsfish	18.3	69	0
BCO	*Parapercis colias*	Blue cod	97.0	78	48
BER	*Typhlonarke* spp.	Numbfish	0.1	1	1
BGZ	*Kathetostoma binigrasella*	Banded stargazer	50.7	18	0
BIV	Bivalvia	Bivalves unidentified	0.1	0	1
BOC	*Bolocera* spp.	Deepsea anemone	0.1	0	0
BTA	*Brochiraja asperula*	Smooth deepsea skate	0.6	0	0
CAR	*Cephaloscyllium isabellum*	Carpet shark	168.2	71	62
CAS	*Coelorinchus aspercephalus*	Oblique banded rattail	1 603.5	3 793	192
CBO	*Coelorinchus bollonsi*	Bollons rattail	19.3	18	0
CCX	*Coelorinchus parvifasciatus*	Small banded rattail	0.1	0	0
CFA	*Coelorinchus fasciatus*	Banded rattail	7.2	73	0
CJA	*Crossaster multispinus*	Sun star	0.4	0	0
COF	*Flabellum* spp.	Flabellum coral	0.4	0	0
COL	*Coelorinchus oliverianus*	Olivers rattail	0.2	1	0
COU		Coral (unspecified)	0.1	0	0
COZ	Bryozoa (Phylum)	Bryozoan	15.0	0	0
CRB		Crab	0.1	0	2
CRM	*Callyspongia cf ramosa*	Airy finger sponge	18.5	0	1
CRU		Crustacea	0.1	0	6
CSQ	*Centrophorus squamosus*	Leafscale gulper shark	13.9	1	5
DCO	*Notophycis marginata*	Dwarf cod	0.5	0	0
DCS	*Bythaelurus dawsoni*	Dawson's catshark	0.1	0	0
DDI	*Desmophyllum dianthus*	*Desmophyllum dianthus*	0.1	0	0
DMG	*Dipsacaster magnificus*	*Dipsacaster magnificus*	0.3	0	0
DPP	*Diplopteraster* sp.	*Diplopteraster* sp.	0.5	0	0
DSP	*Congiopodus coriaceus*	Deepsea pigfish	51.3	340	0
EGC		Egg case	0.1	0	0
ELE	*Callorhinchus milii*	Elephant fish	144.7	53	0
ESO	*Peltorhamphus novaezeelandiae*	N.Z. sole	0.3	1	0
ETB	*Etmopterus baxteri*	Baxter’s lantern dogfish	2.0	0	0
ETL	*Etmopterus lucifer*	Lucifer dogfish	2.4	7	7
EZE	*Enteroctopus zealandicus*	Yellow octopus	2.6	0	2
FHD	*Hoplichthys haswelli*	Deepsea flathead	2.1	0	0
FMA	*Fusitriton magellanicus*	*Fusitriton magellanicus*	0.2	0	0
GAS	Gastropoda	Gastropods	0.7	0	4
GDU	*Goniocorella dumosa*	Bushy hard coral	0.7	0	3
GFL	*Rhombosolea tapirina*	Greenback flounder	9.4	14	0
GIZ	*Kathetostoma giganteum*	Giant stargazer	1 329.4	606	0
GMC	*Leptomithrax garricki*	Garrick's masking crab	0.1	0	1
GON	*Gonorynchus forsteri & G. grey*	Sandfish	5.5	1	0
GPF	*Notolabrus cinctus*	Girdled wrasse	0.3	0	0
GRE	*Geodia regina*	Curling stone sponge	245.5	0	0
GSC	*Jacquinotia edwardsii*	Giant spider crab	155.0	152	92
GSH	*Hydrolagus novaezealandiae*	Ghost shark	3 445.7	1 797	0
GSP	*Hydrolagus bemisi*	Pale ghost shark	751.8	325	2
GUR	*Chelidonichthys kumu*	Gurnard	128.2	205	0
HAK	*Merluccius australis*	Hake	350.6	59	56
HAP	*Polyprion oxygeneios*	Hapuku	194.0	56	2
HCO	*Bassanago hirsutus*	Hairy conger	24.0	16	0
HDF		Feathery hydroids	0.9	0	6
HMP	*Hemerocoetes pauciradiatus*	Short-rayed opalfish	0.1	0	2
HMR	*Hemerocoetes morelandi*	Moreland's opalfish	0.1	0	0

Code	Scientific name	Common name	Catch weight (kg)	Number measured	Number of samples
HMT	Hormathiidae	Deepsea anemone	26.1	0	0
HMU	*Hemerocoetes artus*	Narrow opalfish	0.2	0	2
HOK	*Macruronus novaezelandiae*	Hoki	8 193.7	2 585	142
HOR	*Atrina zelandica*	Horse mussel	0.4	0	0
HTH	Holothurian unidentified	Sea cucumber	4.8	0	3
HTR	*Hippasteria phrygiana*	Trojan starfish	0.2	0	0
HYA	*Hyalascus* sp.	Floppy tubular sponge	1.0	0	0
ISO	Isopoda	Isopod	0.2	0	2
JAV	*Lepidorhynchus denticulatus*	Javelin fish	1 272.2	3 781	130
JFI		Jellyfish	147.4	0	0
JMD	*Trachurus declivis*	Greenback jack mackerel	26.9	21	10
JMM	*Trachurus murphyi*	Slender jack mackerel	23.0	16	11
LBI	*Lissodendoryx bifacialis*	*Lissodendoryx bifacialis*	11.8	0	2
LCH	*Harriotta raleighana*	Long-nosed chimaera	8.3	7	0
LDO	*Cyttus traversi*	Lookdown dory	39.7	73	0
LEA	*Meuschenia scaber*	Leatherjacket	0.4	1	0
LHC	*Leptomithrax longimanus*	Long-handed masking crab	0.1	0	1
LHE	*Lampanyctodes hectoris*	Hector's lanternfish	0.3	0	4
LIN	*Genypterus blacodes*	Ling	3 810.8	1 735	123
LIP	*Liponema* spp.	Deepsea anemone	0.6	0	0
LLC	*Leptomithrax longipes*	Long-legged masking crab	1.2	0	2
LSO	*Pelotretis flavilatus*	Lemon sole	1.7	5	0
LSQ	*Lycoteuthis lorigera*	*Lycoteuthis lorigera*	0.1	0	0
MAN	*Neoachiropsetta milfordi*	Finless flounder	0.7	0	0
MDO	*Zenopsis nebulosa*	Mirror dory	2.4	1	0
MIQ	*Onykia ingens*	Warty squid	32.6	18	18
MMU	*Maurolicus australis*	Pearlside	0.3	0	1
MSL	*Mediaster sladeni*	Starfish	0.1	0	0
NCB	*Nectocarcinus bennetti*	Smooth red swimming crab	324.2	253	73
NMP	*Nemadactylus macropterus*	Tarakihi	138.2	221	5
NOS	*Nototodarus sloanii*	NZ southern arrow squid	2 390.5	2 761	767
NUD	Nudibranchia (Order)	Nudibranchia	0.2	0	2
OCP		Octopod	0.1	0	4
ONG	Porifera (Phylum)	Sponges	1 829.9	0	36
OPH		Ophiuroid (brittle star)	0.2	0	1
OPI	*Opisthoteuthis* spp.	Umbrella octopus	1.3	0	1
PAG	Paguroidea	Pagurid	0.2	0	1
PAM	*Pannychia moseleyi*	*Pannychia moseleyi*	1.2	0	0
PAO	*Pillsburiaster aoteanus*	*Pillsburiaster aoteanus*	0.2	0	0
PHW	*Psammocinia cf hawere*	*Psammocinia cf hawere*	1.0	0	1
PIG	*Congiopodus leucopaecilus*	Pigfish	6.9	4	0
PLS	*Proscymnodon plunketi*	Plunket's shark	11.1	1	2
PMO	*Pseudostichopus mollis*	*Pseudostichopus mollis*	0.5	0	0
POS	*Lamna nasus*	Porbeagle shark	80.0	0	0
PRU	*Pseudechinaster rubens*	*Pseudechinaster rubens*	0.5	0	0
PSI	*Psilaster acuminatus*	Geometric star	0.3	0	0
PYR	*Pyrosoma atlanticum*	*Pyrosoma atlanticum*	190.5	0	76
QSC	*Zygochlamys delicatula*	Queen scallop	0.3	0	2
RBT	*Emmelichthys nitidus*	Redbait	1.6	2	2
RCO	*Pseudophycis bachus*	Red cod	129.2	183	82
RHA	*Rhabdastrella* sp.	Pink ice egg sponge	207.7	0	0
RSK	*Zearaja nasuta*	Rough skate	445.2	157	55
RSO	*Rexea solandri*	Gemfish	15.3	5	0
SAL		Salps	0.2	0	0
SBW	*Micromesistius australis*	Southern blue whiting	5 877.1	2 946	122
SCD	*Notothenia microlepidota*	Smallscaled cod	1.7	2	2
SCG	*Lepidotrigla brachyoptera*	Scaly gurnard	11.3	184	0
SCH	*Galeorhinus galeus*	School shark	179.6	19	1
SCI	*Metanephrops challengeri*	Scampi	6.8	65	44
SCO	*Bassanago bulbiceps*	Swollenhead conger	22.5	20	0
SDM	*Sympagurus dimorphus*	Pagurid	0.3	0	0
SDO	*Cyttus novaezealandiae*	Silver dory	690.7	1 427	10
SEO		Seaweed	0.2	0	0
SMK	*Teratomaia richardsoni*	Spiny masking crab	0.7	0	1
SMO	*Sclerasterias mollis*	Cross-fish	2.4	0	0
SPD	*Squalus acanthias*	Spiny dogfish	10 466.7	2 899	137
SPE	*Helicolenus* spp.	Sea perch	59.1	77	0
SPT	*Spatangus multispinus*	Heart urchin	0.6	0	0
SRB	*Brama australis*	Southern rays bream	43.5	13	0

Code	**Scientific name**	**Common name**	**Catch weight (kg)**	**Number measured**	**Number of samples**
SSI	*Argentina elongata*	Silverside	104.8	800	0
SSK	*Dipturus innominatus*	Smooth skate	314.0	18	1
STU	*Allothunnus fallai*	Slender tuna	46.8	7	7
SUA	*Suberites affinis*	Fleshy club sponge	0.2	0	2
SWA	*Seriolella punctata*	Silver warehou	201.9	216	38
TOP	*Ambophthalmos angustus*	Pale toadfish	11.5	0	0
TRU	*Latris lineata*	Trumpeter	3.1	3	0
TSQ	*Todarodes filippovae*	*Todarodes filippovae*	5.9	0	0
VST	*Neophrynichthys heterospilos*	Variable spotted toadfish	6.5	0	2
WIT	*Arnoglossus scapha*	Witch	9.6	9	0
WWA	*Seriolella caerulea*	White warehou	212.1	105	0
ZOR	*Zoroaster* spp.	Rat-tail star	1.5	0	0
Total			48 477.2	30 549	2 550

APPENDIX 5 ACOUSTIC BACKSCATTER OBSERVERVATIONS

Table A5-1: Calculated acoustic backscatter at survey stations of the demersal trawl survey of the Auckland Islands by depth stratum.

Station											Backscatter (m^2/km^2)		
	Depth	Start Latitude	Start Longitude	0–50	50–100	100–150	150–200	200–250	250–300	300–350	350–400	400–450	450–500
1	453.44	-50.63	167.89	2.85	1.40	0.51	1.53	0.21	0.26	1.09	1.15	0.44	0.15
2	402.73	-50.49	167.82	2.06	2.34	0.12	0.12	0.13	0.32	0.46	0.81	-	-
3	391.29	-50.43	167.79	0.96	0.67	0.22	0.16	0.24	0.35	0.31	4.88	-	-
4	146.23	-50.68	167.02	0.30	0.56	0.69	-	-	-	-	-	-	-
5	400.97	-50.71	167.12	0.39	0.31	0.12	0.18	0.21	0.28	4.44	2.74	-	-
6	451.85	-50.78	167.38	0.26	0.62	0.20	0.10	0.05	0.05	0.89	1.16	0.96	-
7	148.88	-50.79	166.86	0.30	1.60	5.88	-	-	-	-	-	-	-
8	478.42	-51.01	166.70	0.19	1.16	0.26	0.29	0.25	0.18	0.77	1.08	1.02	1.31
9	470.36	-51.06	166.52	0.30	1.29	0.68	0.21	0.19	1.04	0.84	0.85	1.28	1.24
10	484.19	-51.19	166.56	0.35	0.45	0.26	0.60	0.38	0.28	1.06	2.42	0.55	1.19
11	468.46	-51.10	166.83	0.97	1.22	0.38	0.96	0.32	0.24	1.89	0.39	1.00	0.49
18	459.49	-50.76	167.55	1.19	1.13	0.30	0.10	0.20	0.58	0.58	0.24	1.38	0.03
20	389.89	-50.38	167.83	3.08	2.23	0.41	0.45	0.67	1.81	4.36	4.79	-	-
21	112.87	-50.27	167.54	0.19	7.43	0.05	-	-	-	-	-	-	-
22	113.38	-50.36	167.25	0.38	2.42	0.02	-	-	-	-	-	-	-
23	112.05	-50.43	167.24	0.58	3.44	0.03	-	-	-	-	-	-	-
24	112.73	-50.45	167.07	0.67	2.83	0.09	-	-	-	-	-	-	-
25	104.96	-50.51	166.92	0.69	3.06	-	-	-	-	-	-	-	-
27	134.71	-50.11	167.76	1.16	1.60	0.37	-	-	-	-	-	-	-
28	166.53	-50.19	167.83	0.19	1.41	5.84	0.51	-	-	-	-	-	-
29	122.46	-50.09	167.19	0.84	4.97	0.43	-	-	-	-	-	-	-
30	122.79	-50.25	167.11	1.29	3.81	0.19	-	-	-	-	-	-	-
31	125.73	-50.25	167.05	2.91	2.71	0.37	-	-	-	-	-	-	-
32	169.27	-49.72	167.25	0.41	1.33	0.65	0.08	-	-	-	-	-	-
33	459.60	-49.73	167.69	1.82	2.36	0.10	0.05	0.07	0.09	0.26	6.15	18.76	0.86
34	499.97	-49.63	167.58	1.12	1.44	0.31	0.05	0.40	15.73	3.70	3.55	1.72	2.57
37	192.94	-49.99	167.80	0.71	3.18	2.05	2.71	-	-	-	-	-	-
38	440.70	-50.16	167.98	2.11	4.67	0.42	0.12	0.13	2.31	0.96	0.32	1.49	-
39	438.46	-50.04	167.91	4.58	2.77	0.32	0.61	0.63	0.34	0.35	0.83	1.02	-
40	475.94	-49.93	167.92	0.59	3.76	0.69	1.22	0.73	0.14	2.48	4.29	0.52	0.27
41	431.99	-49.84	167.78	5.44	1.01	0.30	0.95	11.15	9.27	9.34	20.18	1.83	-
42	205.87	-49.93	167.78	0.89	3.65	2.44	0.97	0.19	-	-	-	-	-
49	168.07	-49.83	166.31	3.98	1.32	0.75	0.13	-	-	-	-	-	-
50	295.68	-50.01	166.12	0.54	0.39	0.62	0.48	10.29	24.67	-	-	-	-
51	204.80	-50.09	166.20	0.12	0.31	0.50	4.06	-	-	-	-	-	-
52	166.99	-50.18	166.42	0.86	0.60	3.16	0.28	-	-	-	-	-	-
53	165.78	-50.19	166.61	0.80	2.78	27.58	0.30	-	-	-	-	-	-
55	392.50	-49.60	166.15	0.43	1.15	0.62	1.17	1.35	1.03	1.51	3.71	-	-
56	385.27	-49.56	166.25	0.17	0.65	1.48	2.00	1.66	0.65	0.83	1.67	0.07	-
57	260.89	-49.65	166.23	0.67	0.47	0.34	0.13	5.86	0.33	-	-	-	-
58	318.13	-49.63	166.50	0.88	1.67	0.17	0.06	0.18	3.76	2.81	-	-	-
59	182.69	-49.67	166.72	0.14	0.35	0.30	0.06	-	-	-	-	-	-
60	157.21	-49.70	166.91	0.31	1.03	1.22	0.74	-	-	-	-	-	-
61	139.51	-49.91	166.84	1.46	1.86	0.96	-	-	-	-	-	-	-
64	342.79	-49.64	167.19	0.41	1.25	0.68	0.48	0.28	2.72	4.72	0.00	-	-
66	147.77	-49.74	166.95	0.39	0.60	0.51	-	-	-	-	-	-	-
68	418.51	-49.60	166.42	0.21	0.42	0.12	0.05	7.91	8.87	0.93	1.21	1.33	-
69	486.68	-49.59	166.77	1.15	1.32	0.08	0.46	15.62	2.46	0.66	3.49	1.91	1.21
72	340.25	-49.64	167.24	17.08	11.39	3.28	1.21	3.14	4.78	2.46	1.51	-	-
73	471.11	-49.65	167.43	0.96	1.26	0.27	1.98	0.48	0.75	0.80	0.90	2.06	1.19
74	323.26	-49.65	167.21	0.33	0.35	1.24	2.58	27.91	81.58	1.32	-	-	-
75	373.57	-49.65	166.96	0.17	0.78	0.14	0.12	0.15	6.23	####	9.37	-	-
76	429.07	-49.50	166.99	0.78	1.91	0.24	0.23	0.21	0.56	3.06	27.13	7.22	-
77	460.71	-49.37	166.93	0.61	0.74	0.21	0.10	0.77	0.81	4.78	33.50	4.85	0.35

Table A5-2: Calculated acoustic backscatter at survey stations of the demersal trawl survey of the Stewart Snares shelf by depth stratum.

Station				Backscatter (m^2/km^2)									
	Depth	Start Latitude	Start Longitude	0–50	50–100	100–150	150–200	200–250	250–300	300–350	350–400	400–450	450–500
79	293.50	-47.90	168.72	0.23	0.21	0.14	0.19	5.51	3.27	-	-	-	-
80	129.05	-47.70	168.64	0.26	0.14	0.29	-	-	-	-	-	-	-
81	132.41	-47.79	168.69	0.29	0.16	0.87	-	-	-	-	-	-	-
83	353.25	-47.76	168.84	0.13	0.17	0.42	32.31	35.46	12.32	2.65	0.43	-	-
84	266.85	-47.64	168.96	0.21	0.42	0.25	0.27	0.97	0.22	-	-	-	-
85	125.65	-47.60	168.84	0.41	0.34	0.25	-	-	-	-	-	-	-
86	122.96	-47.49	168.92	0.45	0.35	0.28	-	-	-	-	-	-	-
87	118.85	-47.39	168.93	0.20	0.51	0.04	-	-	-	-	-	-	-
90	361.09	-47.19	169.41	0.62	0.32	0.27	1.60	18.23	4.20	2.70	1.27	-	-
91	115.92	-47.25	169.04	0.26	0.58	0.48	-	-	-	-	-	-	-
92	113.24	-47.13	169.03	0.18	0.35	0.01	-	-	-	-	-	-	-
93	118.83	-47.17	169.13	0.22	0.28	0.09	-	-	-	-	-	-	-
94	119.12	-46.91	169.52	0.31	0.23	0.05	-	-	-	-	-	-	-
98	75.79	-46.83	168.91	0.38	0.84	-	-	-	-	-	-	-	-
99	76.01	-46.93	168.75	0.51	0.43	-	-	-	-	-	-	-	-
102	108.41	-47.27	168.60	0.25	1.44	0.03	-	-	-	-	-	-	-
103	101.04	-47.25	168.43	0.28	1.00	-	-	-	-	-	-	-	-
104	86.55	-47.20	168.14	0.93	2.61	-	-	-	-	-	-	-	-
108	103.18	-47.34	168.26	0.45	5.48	-	-	-	-	-	-	-	-
109	112.98	-47.45	168.19	0.12	1.12	0.33	-	-	-	-	-	-	-
110	119.39	-47.50	168.31	0.07	0.70	0.51	-	-	-	-	-	-	-
111	133.81	-47.58	168.05	0.14	0.18	2.36	-	-	-	-	-	-	-
113	138.93	-47.65	167.33	0.58	0.70	1.20	-	-	-	-	-	-	-
114	143.04	-47.53	167.32	0.60	0.68	3.75	-	-	-	-	-	-	-
115	139.54	-47.41	167.45	0.52	1.25	1.89	-	-	-	-	-	-	-
116	152.27	-47.34	167.12	0.69	0.98	2.29	-	-	-	-	-	-	-
117	138.79	-47.12	167.24	0.49	0.46	2.50	-	-	-	-	-	-	-
121	66.18	-46.57	167.58	0.56	0.35	-	-	-	-	-	-	-	-
122	79.31	-46.80	167.53	7.27	27.60	-	-	-	-	-	-	-	-
123	72.07	-46.88	167.58	0.83	38.17	-	-	-	-	-	-	-	-
124	123.16	-46.96	167.38	0.39	0.47	4.07	-	-	-	-	-	-	-
125	142.51	-46.68	167.23	0.45	0.49	6.70	-	-	-	-	-	-	-