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Tini a Tangaroa

Estimating the abundance of scampi in SCI 6A (Auckland Islands) in 2019

New Zealand Fisheries Assessment Report 2020/13

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

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Photographic and trawl surveys of scampi in SCI 6A were conducted in February and March 2019 from the RV *Kaharoa*. This area was last surveyed in 2016. The photographic survey estimated a scampi burrow abundance of 249 million (CV 10%) over the whole area, continuing the increase observed since the 2013 survey. The photographic estimates of visible scampi and scampi out of burrows also increased from those in 2016. The trawl survey estimate of 711 tonnes (CV 12%) (or 10.4 million individuals, CV 13%) was higher than that in 2016, but the 2013 and 2016 trawl survey estimates were lower than previous estimates. It is unclear how comparable trawl indices before and after 2013 are, due to an unavoidable vessel and gear change. Given that scampi live in burrows and are only available to trawl gear when they emerge on the seabed, trawl survey estimates are likely to be considerable underestimates of the stock biomass or abundance.

Almost 2000 scampi were tagged and released, as part of an investigation into growth, with releases distributed across the fishing grounds. To date, a small number of tagged scampi have been recaptured. A range of additional data were collected during the survey, including visually detected microsporidian infection rates in scampi, CTD profiles, sediment samples, and acoustic seabed measurements, and stomach contents of potential scampi predators. During poor weather, time was spent attempting to tag great white sharks in the vicinity of sea lion colonies, but no sharks were observed.

1. INTRODUCTION

The scampi fishery is based on the species *Metanephrops challengeri*, which is widely distributed around New Zealand (Figure 1). National scampi landings in 2018–19 were 1069 t (limit 1312 t). The landings for scampi in SCI 6A were 257 t in 2018–19 (TACC 306 t) and have been maintained around this level through much of the history of the fishery, but did drop to 100–200 t between 2009/10 and 2014/15. The other major fisheries are SCI 1 (TACC 120 t), SCI 2 (TACC 152 t), SCI 3 (TACC 408 t), and SCI 4A (TACC 120 t). Scampi are taken by light trawl gear, which catches scampi that have emerged from burrows in the bottom sediment. The main fisheries are in waters 300–500 m deep, although the range is slightly deeper in the SCI 6A region (350–550 m). Little is known about the growth rate and maximum age of scampi.

Scampi occupy burrows in muddy substrates and are only available to trawl fisheries when they emerge on the seabed (Bell et al. 2006). Scampi emergence (examined through catch rates, both of European and New Zealand species) has been shown to vary seasonally in relation to moult and reproductive cycles, and over shorter time scales in relation to diel and tidal cycles (Aguzzi et al. 2003, Bell et al. 2006, Tuck et al. 2015b). Uncertainty over trawl catchability associated with these emergence patterns has led to the development of survey approaches based on visual counts of scampi burrows rather than animals (Froglia et al. 1997, Tuck et al. 1997b, Cryer et al. 2003, Smith et al. 2003), although these approaches still face uncertainties over burrow occupancy and population size composition (ICES 2007; Sardà & Aguzzi 2012). Photographic surveying has been used extensively to estimate the abundance of European scampi and has been carried out in New Zealand since 1998. Five previous surveys have been conducted in SCI 6A (2007–09, 2013 and 2016) (Tuck et al. 2007, Tuck et al. 2009a, Tuck et al. 2009b, Tuck et al. 2015a, Tuck et al. 2017). Longer survey series are available for SCI 1 (1998–2018, nine surveys), SCI 2 (2003–18, seven surveys), and SCI 3 (2001–16, six surveys).

These photographic surveys provide two abundance indices: the density of visible scampi (as an index of minimum absolute abundance), and the density of major burrow openings. The index of major burrow openings has been used as an abundance index in recent stock assessments for SCI 1, SCI 2, and SCI 3 (Tuck & Dunn 2012, Tuck 2016). The relationship between scampi and burrows may be different in SCI 6A (Tuck et al. 2007, Tuck & Dunn 2009), and the index of visible scampi was used in the most recent assessment for SCI 6A (Tuck 2017).

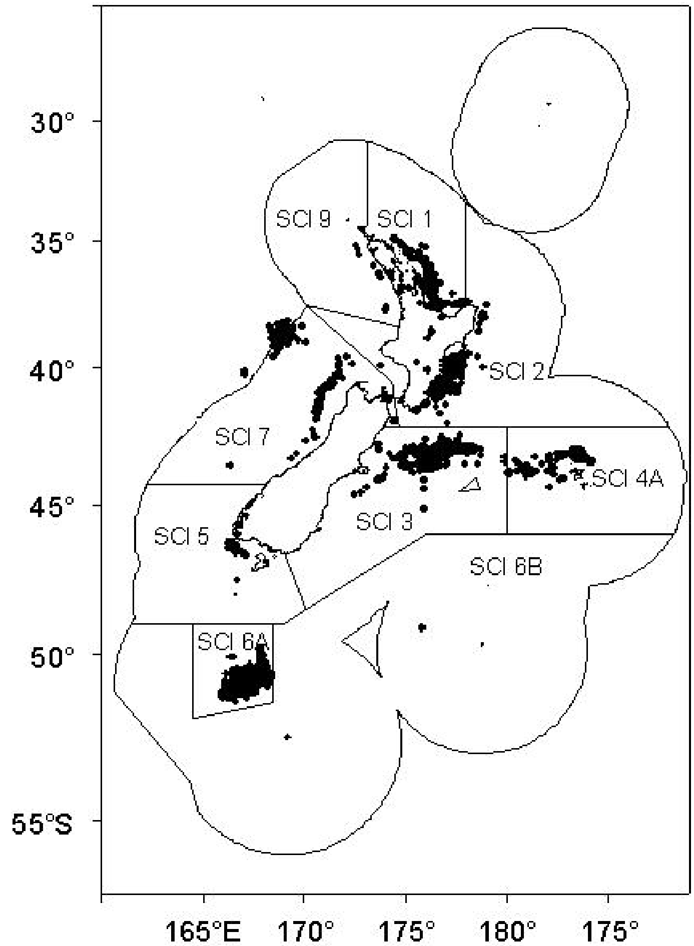

Figure 1: Spatial distribution of the scampi fishery from 1988–89 to 2018–19 (ungroomed data). Each dot shows the mid-point of one or more tows recorded on TCEPR with scampi as the target species.

This report fulfils the final reporting requirement for Fisheries New Zealand research project SCI2018-03.

Overall Objective: To estimate the abundance of scampi (*Metanephrops challengeri*) in SCI 6A.

Objective:
1. To estimate the relative abundance of scampi in SCI 6A using photographic techniques and trawl survey information.
2. To estimate growth of scampi from tagging in SCI 6A.
3. To collect data to underpin the development of assessment and monitoring capabilities for biodiversity and ecosystems.

2. METHODS

A survey design, that followed the design of the 2016 survey, was presented to the Fisheries New Zealand Shellfish (Science) Working Group (SFWG) and submitted to Fisheries New Zealand in early 2019. The survey coverage for both trawl and photographic surveys in SCI 6A has remained consistent over the time series (except for an additional area to the north east that was only surveyed in 2007), but stratification has changed within this overall coverage as improved bathymetric data have become available. The present survey coverage accounts for over 90% of scampi landings from SCI 6A over the history of the fishery, and almost 100% in more recent years. The survey was undertaken from the

NIWA research vessel RV *Kaharoa* in February–March 2019. The initial four surveys of this fishery (2007–09 and 2013) were undertaken from the Sanford Ltd scampi trawler FV *San Tongariro*, but this vessel has not been available since 2013, and subsequent surveys (2016 and 2019) have been undertaken from the RV *Kaharoa*. There should be no effect on the photographic survey component of the work (the photographic data are independent of the platform the system is deployed from), but the trawling component of the survey has been affected by the vessel and trawl change. Net diagrams and other comparisons of the FV *San Tongariro* and RV *Kaharoa* trawl gears (as used on scampi surveys) are provided in Appendix 1.

Following previous survey designs, a random stratified survey was conducted, with stratification on the basis of depth (50 m bands) and general region. Survey coverage and stratum boundaries are shown in Figure 2.

Photo stations were allocated to strata on the basis of burrow abundance data from the 2016 surveys using the *allocate* package (Francis 2006), minimising the CV for a fixed number of stations (40). Random locations for photographic stations were generated within each stratum using the Random Stations package (Doonan & Rasmussen 2012), constrained to keep all stations at least 2 nautical miles apart. The first three random photographic stations from each stratum were taken as trawl stations, with the minimum distance between each trawl station checked, and a station dropped as a trawl station and the next on the list selected if the distance was less than 4 nautical miles. Numbers of stations allocated to each stratum and planned station locations are provided in Table 1 and Figure 3. The predicted CV for the photographic survey was 8.7%.

Table 1: Details of strata and number of stations planned for SCI 6A in 2016.

Stratum	Depth (m)	Area (km^2)	Photo stations	Trawl stations
350	350–400	278	3	3
400N	400–450	789	10	3
400S	400–450	752	3	3
450N	450–500	1 216	10	3
450S	450–500	1 348	8	3
500	500–550	514	6	3

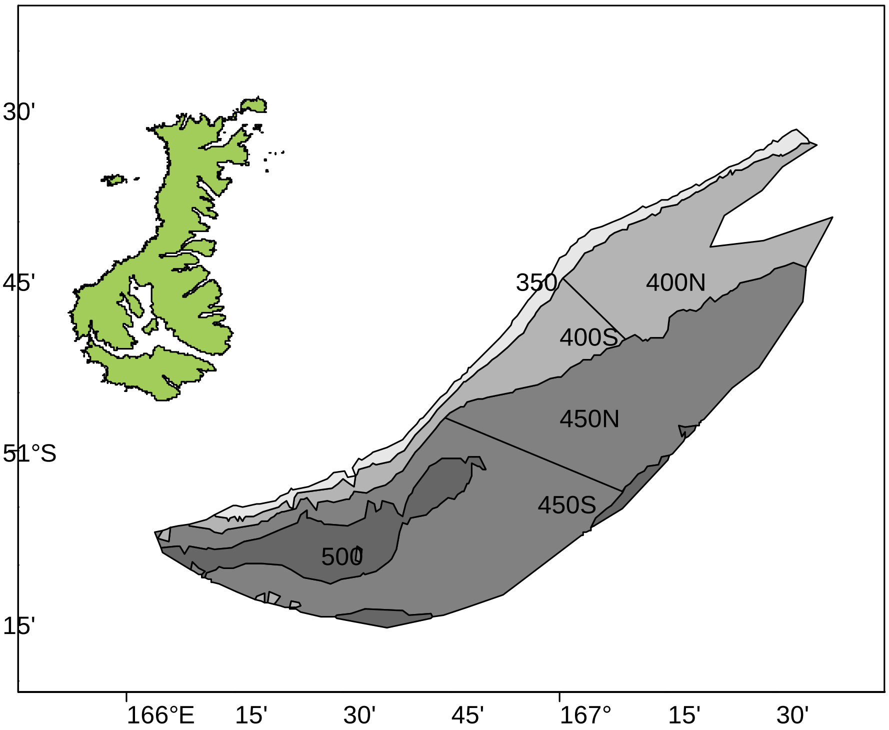

Figure 2: Survey strata for the 2019 photographic survey of SCI 6A.

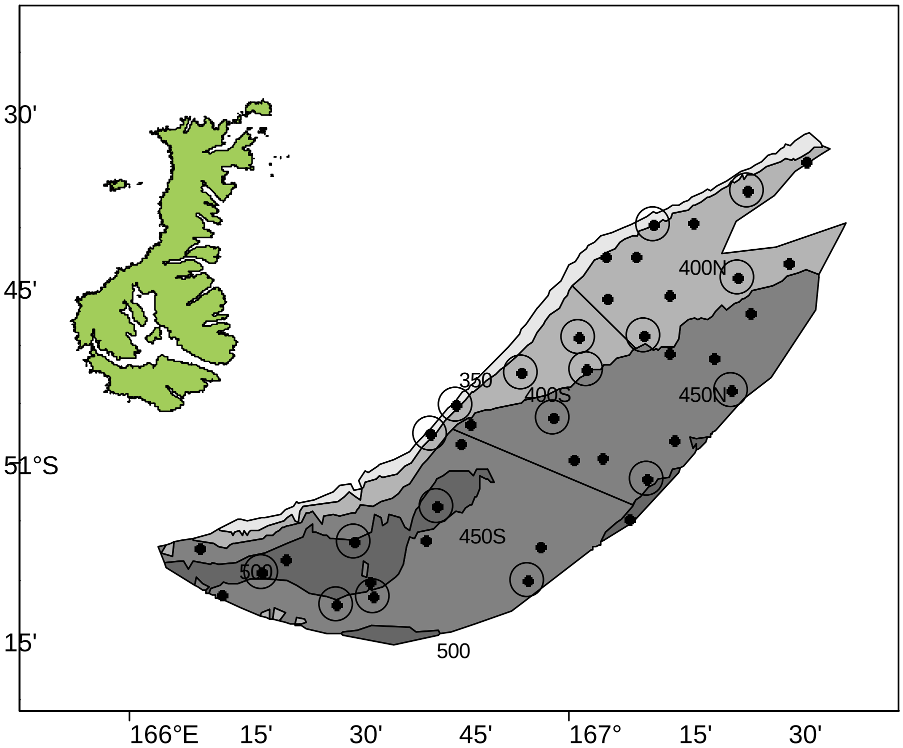

Figure 3: Station locations within each stratum for the 2019 survey in SCI 6A. Camera stations are represented by filled symbols. Trawl stations are represented by open symbols.

2.1 Photographic survey

Photographic sampling was undertaken between 0600 and 1800 NZST to coincide with the period of maximum trawl catchability of scampi. Although the time of day should have no direct effect on the visibility and presence of scampi burrows and their constituent openings, sampling at a time when the greatest number of scampi are likely to be out of their burrows also provides a useful scampi abundance index, which has two further advantages. First, a larger number of individuals can be measured for a photographic length frequency distribution, and, second, the presence of scampi at or near burrow openings is an excellent aid to the identification of certain burrow types as belonging to scampi.

NIWA's deepwater digital camera system (ScampiCam) was used, with an automatic flash exposure providing almost instantaneous triggering and exposure. Images were stored on 1 GB "flash" cards in the camera, so that images could be saved in raw format. After the completion of each station, the images were downloaded from the camera via USB cable (avoiding the need to open the camera housing after each station), and the images were saved to the hard drive of a dedicated PC, and backed up to a portable hard drive.

The camera was triggered using a combination of a time-delay switch and a micro ranger, as its cage was held at a critical height off the seafloor (2–4 m) using a modified Furuno CN22 acoustic headline monitor displaying distance off-bottom in "real time" on the bridge. The micro ranger triggered the camera to take a picture in the critical altitude range, and the timer triggered the camera to also take a picture, once the time limit was reached. The target was to expose roughly 40 frames per station as the ship drifted, using a time delay sufficient to ensure that there was no overlap between adjacent photographs. Visibility was good at most sites, but at some stations a substantial swell hindered the maintenance of the critical altitude off the bottom, and the camera deployment duration was extended to allow for images lost to over and under exposure. Also, when visibility was poor, some stations were repeated later in the trip. Almost all of the photographs in the critical area were of good or excellent quality.

Image selection and scoring
Images were examined and scored using a standardised protocol (Cryer et al. 2002) applied by a team of six trained readers. For each image, the main criteria for usability were the ability to discern fine seabed detail and the visibility of more than 50% of the frame (free from disturbed sediment, poor flash coverage, or other features). If these criteria were met, the image was "adopted" and "initiated" (Cryer et al. 2002). The percentage of the frame within which the seabed is clearly and sharply visible was estimated and marked using polygons in NICAMS (NIWA Image Capture and Manipulation System, developed using the ImageJ software). The criteria used by readers to judge whether or not a burrow should be scored were, of necessity, partially subjective, because readers could not be certain that any particular burrow belonged to a *M. challengeri* and was currently inhabited unless the individual was photographed in the burrow. However, after viewing large numbers of scampi associated with burrows, NIWA has developed a set of descriptors that guide the decisions (Cryer et al. 2002). NIWA defined "major" and "minor" burrow openings, respectively, as the type of opening at which scampi are usually observed and the "rear" openings associated with most burrows. Based on examination of a large number of images of scampi associated with burrows, "major" and "minor" openings each have their own characteristics and should be scored separately (Figure 4). Each opening (whether major or minor) was classed as "highly characteristic" or "probable", based on the extent to which each is characteristic of burrows observed to be used by New Zealand scampi. Scores are saved in a database within the NICAMS system, for later compilation into an ACCESS database containing all scampi image data. Within NICAMS, features counted by each reader are individually identifiable within each image, providing an audit trail. An investigation into mud burrowing megafauna in scampi grounds concluded that it is unlikely that other species present would generate burrows that would be confused with those generated by scampi (Tuck & Spong 2013). Burrows and holes which could conceivably be used by scampi, but which were not thought to be "characteristic" were not counted. The counts of burrow openings may, therefore, be conservative. Many ICES stock assessments of European *Nephrops norvegicus* are conducted using relative abundance indices based on counts of "burrow systems" (rather

than burrow openings) (Tuck et al. 1994, Tuck et al. 1997b). Burrow openings rather than assumed burrows were counted because burrows are relatively large compared with the quadrat (photograph) size and accepting all burrows totally or partly within each photograph is positively biased by edge effects (Marrs et al. 1996, Marrs et al. 1998).

Once the images from any particular stratum or survey have been scored by three readers, any images for which the greatest difference between readers in the counts of major openings (combined for "highly characteristic" and "probable") is more than 1 are re-examined by all readers (who may or may not change their score, in the light of observations from other readers). All images where there is any difference between readers on the count of visible scampi (even a difference of interpretation as to whether a scampi is "in" or "out" of a burrow) were also re-examined by all readers. During the second reading process, each reader had access to the score and annotated files of all other readers and, after re-assessing their own interpretation against the original image, were encouraged to compare their readings with the interpretations of other readers. Thus, the re-reading process is a means of maintaining consistency among readers as well as refining the counts for a given image.

Reader and year calibration

To enable comparison of the 2019 survey data with previous surveys, a reference set of SCI 6A images collected in 2007, 2008, 2009, 2013, and 2016 was re-read in 2019 (at the same time as the 2019 survey images), with each image in each reference set being read by all six readers, following the standard image scoring and re-reading procedure.

Calibration across years and between readers was conducted in a single analysis, rather than the two stage process implemented previously (Tuck et al. 2009a). All the image count data (including reference set counts) were combined into a single dataset. Interaction terms were created for *reader_year* (combination of reader and the year in which the image was read), *stratum_year* (combination of survey stratum and year the image was recorded in), and *station_year* (combination of station number and survey year). Burrow and scampi count data from individual images were aggregated at the station (or appropriate combination of reference set images) level and examined within a generalised linear mixed modelling (GLMM) framework. To exclude a possible image size effect (burrows perhaps being more or less likely to be accepted as the number of pixels making up their image decreases), the approach adopted has been that images with a very small (less than 2 m^2) or very large (more than 16 m^2) readable area have been excluded.

Following presentation of the most recent survey results (Tuck et al. 2019), the SFWG proposed an alternative approach to estimate abundance indices from the photographic survey data, and both the original (Method 1) and this alternative (Method 2) approach have been applied.

<u>Calibration method 1</u>

In the original approach (implemented in Tuck et al. 2019 and previously) station level burrow (and scampi) count data were examined within a GLMM framework with *stratum_year*, *reader_year*, and *readable_area* (offset) as explanatory variables, and *station_year* as random effects, and a negative binomial or Poisson error distribution (determined by examination of diagnostics). The significance of terms was tested by sequentially dropping terms from a full model. Canonical indices of the *reader_year* terms were estimated from the final model and used (without their associated uncertainty) to generate correction factors, which were applied to the original current and historical reads, which were then used to estimate density (as below: Data analysis).

<u>Calibration method 2</u>

In the alternative approach, the GLMM developed within Method 1 was simply used to predict burrow counts (given actual *readable_area*) for each station within each survey for a *reader_year* combination for which the Method 1 approach estimated an average correction factor (DP_2009). Predicted burrow counts were used with readable area to estimate burrow density.

Data analysis
For any given stratum, the mean density of openings and its associated variance were estimated using standard parametric methods, giving each station an equal weighting. The total number of openings in each stratum was estimated by multiplying the mean density by the estimated area of the stratum. The overall mean density of openings in the survey area was estimated as the weighted average mean density, and the variance for this overall mean was derived using the formula for strata of unequal sizes (Snedecor & Cochran 1989):

For the overall mean, $\bar{x}_{(y)} = \sum W_i . \bar{x}_i$

and its variance, $s^2{}_{(y)} = \sum W_i{}^2 . S_i{}^2 . (1 - \phi_i) / n_i$

where $s^2{}_{(y)}$ is the variance of the overall mean density, $\bar{x}_{(y)}$, of burrow openings in the surveyed area, W_i is the relative size of stratum i, and S_i^2 and n_i are the sample variance and the number of samples respectively from that stratum. The finite correction term, $(1 - \phi_i)$, was set to unity because all sampling fractions were less than 0.01.

Separate indices were calculated for major and minor openings, for all visible scampi, and for scampi "out" of their burrows (i.e., walking free on the sediment surface). The minor sensitivity of the indices to the reader "bias" identified for SCI 1 (Cryer et al. 2002) was investigated using the two approaches described above, and a "corrected" density index for major burrow openings is also provided.

For Method 1, confidence in the estimates was examined through a bootstrapping procedure, resampling stations (with replacement) within strata, selecting one reader (from three) for each station. For Method 2, confidence in the estimates was examined through bootstrapping stations within strata.

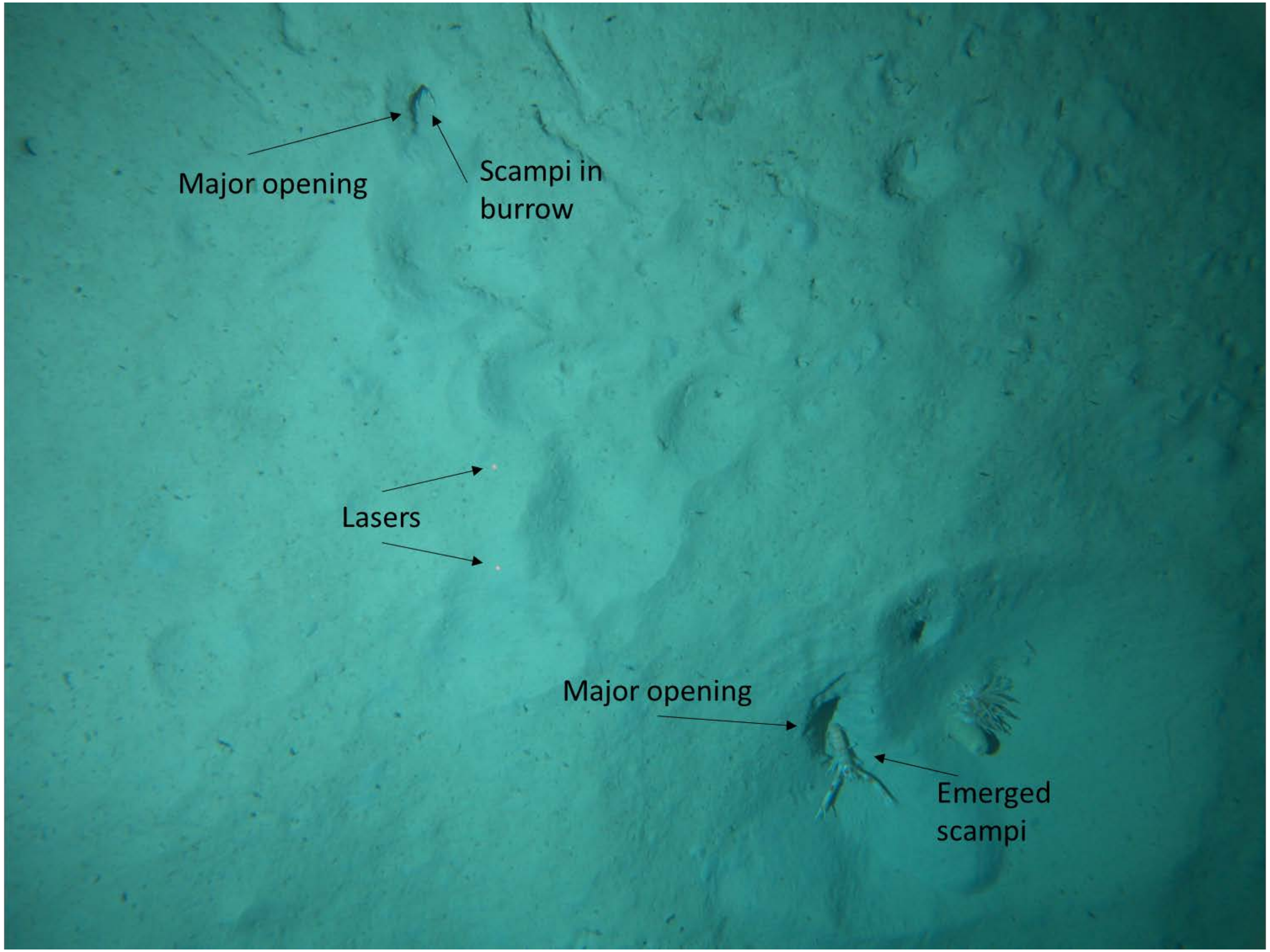

Figure 4: Example image from March 2019 survey in SCI 6A showing laser scaling dots, characteristic scampi burrows, and scampi.

2.2 Trawl survey

Trawl survey sampling was undertaken between 0600 and 1800 NZST, during the second half of the voyage, after the photographic survey had been completed. The first three random photographic stations allocated to each stratum were reselected as trawl stations. Trawl sampling was conducted with the RV *Kaharoa* scampi trawl, as with previous scampi surveys from this vessel in SCI 6A in 2016 and in all other QMAs.

Trawl survey catch rates were estimated on the basis of distance towed and a wingspread swept width of 25 m and raised to stratum area to estimate total biomass and abundance.

Scampi tagging

The second objective of the voyage was to tag and release scampi to investigate growth. When time allowed, all scampi caught during each tow that were considered to be in good health were tagged and released. All scampi were rapidly sorted from the catch and stored in darkened non-draining bins of well aerated seawater. Any animals with carapace punctures were excluded, and, for tagged animals, any damaged or missing limbs were recorded. Animals were tagged between the carapace and cuticle of the first abdominal segment through the musculature of the abdomen with sequentially numbered streamer tags (Hallprint type 4S, Figure 5), Hallprint T-bar tags, or both. The streamer tags have been used successfully in previous scampi studies (Cryer & Stotter 1997, Cryer & Stotter 1999, Tuck & Dunn 2012), although tag return data suggest that some tag loss may be occurring following moulting, and a T-bar tag approach was therefore also used for this survey. Previous tagging investigations from recent surveys in this fishery have had good recoveries. The next scheduled research sampling in SCI 6A is planned for 2022, and so it is anticipated that recoveries will be from commercial fishing activity. Tag mortality has been examined previously in this fishery (Tuck et al. 2015a), but at the request of Fisheries New Zealand and the Shellfish (Science) Working Group, no tag mortality component was included in this survey, because it was considered very unlikely that tag recapture data would be used to estimate stock size for this fishery.

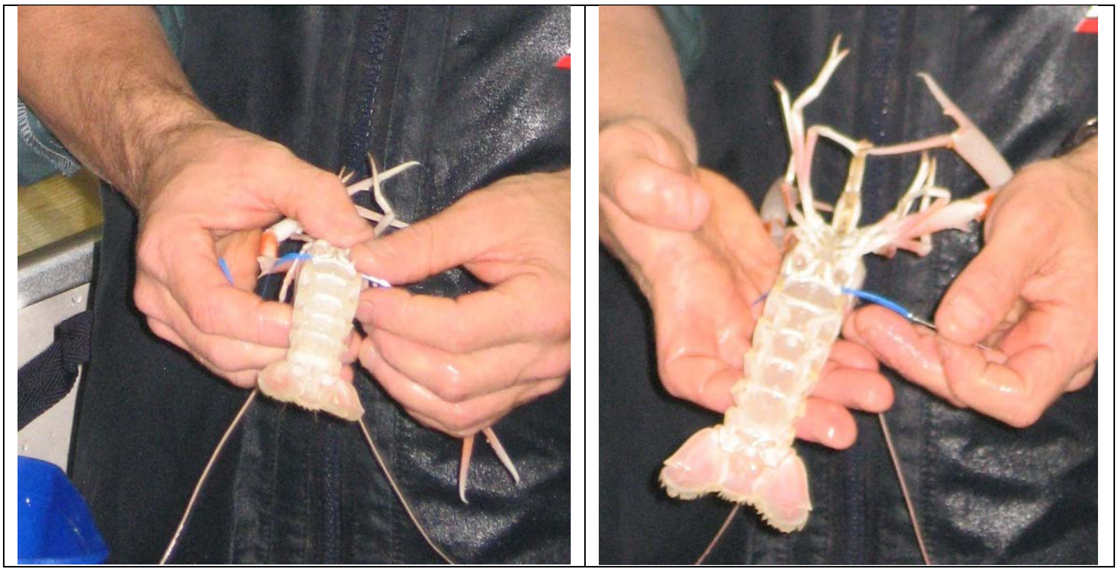

Figure 5: Photographs showing location of streamer tags in scampi.

2.3 Other data

In addition to the main survey objectives, a range of other tasks were undertaken during the voyage as opportunity arose, to meet the third objective of collecting data to underpin the development of assessment and monitoring capabilities for biodiversity and ecosystems.

Microsporidian infection of scampi
From samples of scampi collected from SCI 6A during the 2007 and 2008 surveys, a new microsporidian parasite was identified and described (Stentiford et al. 2010). Infected lobsters displayed an unusual external appearance (Figure 6) and were lethargic. Histology was used to demonstrate replacement of skeletal and other muscles by the parasite, and infection at visually detectable levels is considered fatal. Low levels of infection were reported during these first observations (Tuck et al. 2009a), but recent reports from some components of the fishing industry suggest infection rates may have increased.

All scampi measured during the survey were examined and categorised as infected or non-infected on the basis of Figure 6.

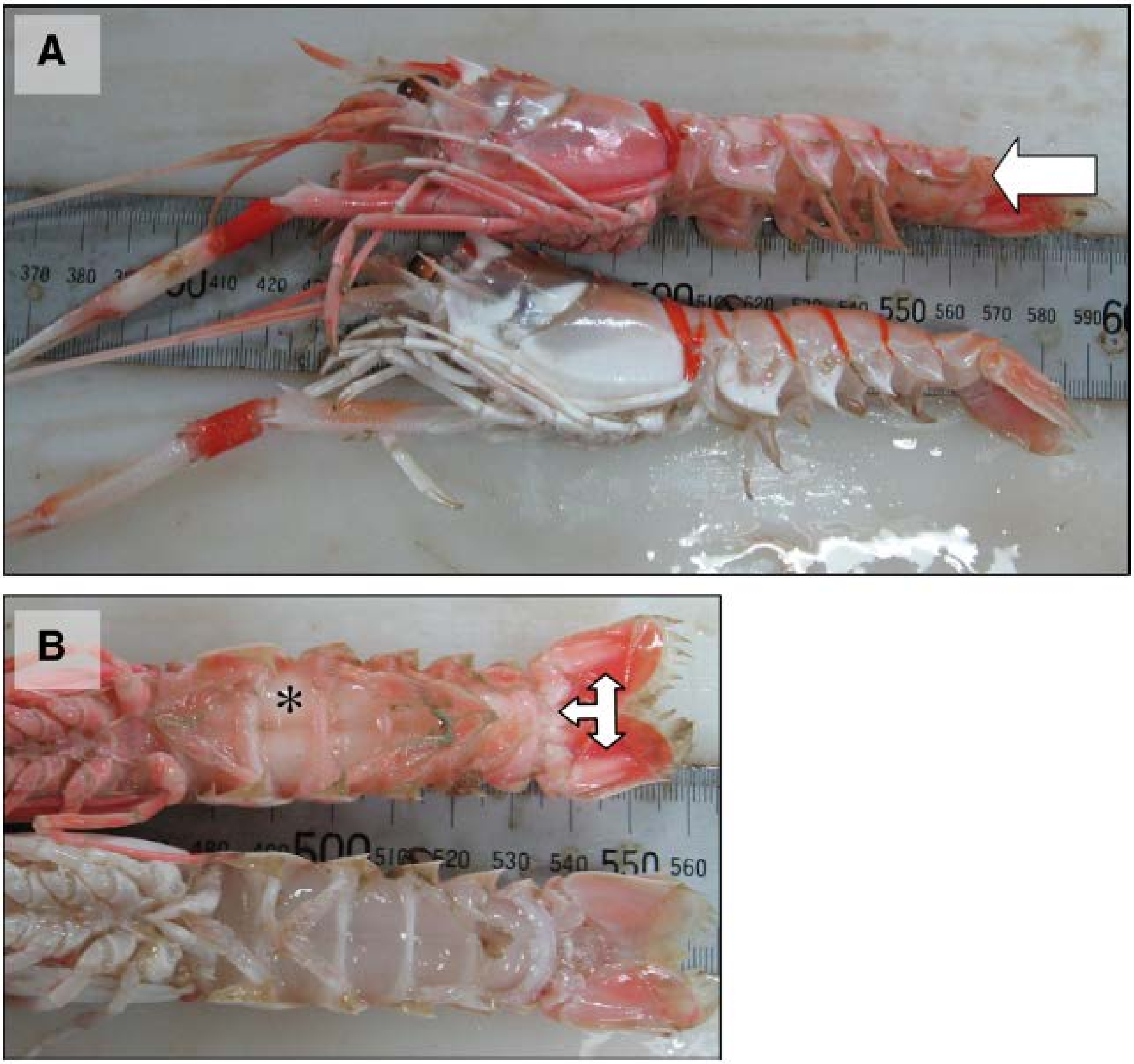

Figure 6: ***Myospora metanephrops*** **infected and non-infected** ***Metanephrops challengeri*** **(scampi). (A) Infected scampi (arrow) appears differentially pigmented with increased opacity in all body sections relative to non-infected scampi. (B) Infection is most apparent in major flexor muscles (asterisk) and telson muscles (arrow) of infected scampi compared to non-infected scampi (source Stentiford et al. 2010).**

CTD profiles
A Sea-Bird CTD (conductivity, temperature, depth) instrument was attached to the camera system, and CTD profiles were recorded from all photographic stations.

Acoustic seabed measurements and sediment sampling
Existing seabed sediment data have recently been collated for New Zealand (Bostock et al. 2018a; Bostock et al. 2018b), but sample coverage in some scampi grounds is sparse. Deployment of gear to sample sediment in 300–500 m water depth is time consuming, and although relationships between scampi density and sediment parameters are likely to be informative (Tuck et al. 1997a), collection of sediment data has not been an objective of previous surveys.

In recent years NIWA has started to collect sediment samples when time allows using a small (Clamshell) grab (0.01 m^2 footprint, Figure 7), without disruption of survey activities (e.g., at the end of the working day when insufficient time allows completion of another station). This practice was continued, to augment the existing data available. In addition, throughout the survey, data from the vessel's scientific Simrad ES60 38-kHz echo sounder were recorded. Analysis of the acoustic data is beyond the scope of this project, but the longer term aim is to explore the relationships between sediment particle size, acoustic seabed hardness (or other acoustic measures derived from the echo sounder data, potentially along the lines of the RoxAnn approach (e.g., Greenstreet et al. 1997)), and scampi density.

Figure 7: Clamshell grab used to collect sediment samples during the survey.

Predation on scampi
Recent ecosystem modelling applications on the Chatham Rise (McGregor et al. 2019) suggest that predation pressure on scampi may have varied considerably over time, and understanding this may help understand observed population fluctuations. There are limited data on scampi predators, and so where possible the stomachs of a variety of fish species caught during research trawling were examined, to quantify the incidence of scampi (scampi presence and size in relation to fish species and size), and the

proportion of stomach contents that scampi makes up. Specific sampling protocols followed those developed for stomach sampling on the Chatham Rise and Sub-Antarctic surveys (Darren Stevens, *pers. comm.*), and data were recorded within the *biological_table* of the *trawl* database. The analysis of stomach samples was time consuming and not possible during normal survey operations because of the number of scientific staff and the time required for working up the catch and scampi tagging data. Fish were therefore stored on ice for later analysis during weather down-time when at anchor.

Ecosystem role of great white sharks
There are known interactions between the Sub-Antarctic squid trawl fishery and New Zealand sea lions, *Phocarctos hookeri*, (Roberts 2019), but the overall effects of these interactions on the sea lion population, and the proportion of total mortality they account for, are unclear. Predation mortality by great white sharks, *Carcharodon carcharias*, could be large and important in the population dynamics of sea lions. The aim of this task was to determine the seasonal presence and abundance of great white sharks at the main sea lion colonies at the Auckland Islands.

During the survey voyage, there were a number of periods when the weather was too poor to work. During this 'weather-down-time', the presence of great white sharks near the Auckland Islands' largest sea lion colonies at Enderby Island and Dundas Island, and within Carnley Harbour was investigated. Berley was used to attempt to attract sharks to the vessel, with the aim to estimate their size with stereo-video cameras and tag them with acoustic tags to determine how long the sharks spend close to those sea lion colonies. Acoustic receivers on moorings were taken on the voyage to deploy if sharks were successfully tagged, to record the sharks' presence over the next 1–2 years. The costs associated with the applications for approvals and mooring deployment were covered by internal NIWA Fisheries Centre funding.

3. RESULTS

The voyage was completed successfully between 8 February and 19 March 2019. All but one photographic station and trawl station were completed, despite very poor weather during some parts of the voyage, with thirteen days being lost.

3.1 Photographic survey

Visibility was very good, but large swells throughout the survey meant that it was difficult to maintain the camera at a consistent altitude above the seabed. This meant that at some stations the target of 40 images per station was not met, despite running longer transects, because some images were taken too high above the seabed to be considered useable. This has consistently been a problem for surveys in SCI 6A. Over the whole survey, a total area of 6549 m^2 of seabed was viewed (acceptable quality images), with an average of 34.4 images per station, an average seabed area viewed by each image of 5.67 m^2, providing an average area viewed of 195.05 m^2 at each station. Previous surveys in SCI 6A have had an average viewed area per station of 207–315 m^2. The slightly reduced overall area per station in the current survey was a result of a slightly smaller average image area, through maintaining the camera at a closer altitude above the seabed. One photographic station was not completed; survey details are given in Table 2.

Table 2: Details of strata and number of photo stations completed for SCI 6A survey in 2019.

			Photo stations	
Stratum	Depth (m)	Area (km^2)	Planned	Completed
350	350–400	278	3	3
400N	400–450	789	10	9
400S	400–450	752	3	3
450N	450–500	1 216	10	10
450S	450–500	1 348	8	8
500	500–550	514	6	6
Total		4 897	40	39

For the GLMM of major burrow openings a Poisson error distribution provided the best fit to the data, and a model testing the null hypotheses that there were no *stratum_year* or *reader_year* differences between burrow counts over time, detected highly significant effects (both considered as factors) (Table 3). Diagnostic plots for the model are shown in Figure 8.

Table 3: Analysis of deviance for a generalised linear mixed model relating the count of major burrow openings to *reader_year*, *stratum_year*, and *readable area* (offset) for SCI 6A.

	Df	Sum sq	Mean Sq	F value
reader_year	35	302.63	8.6465	8.6465
stratum_year	29	404.41	13.9450	13.9450

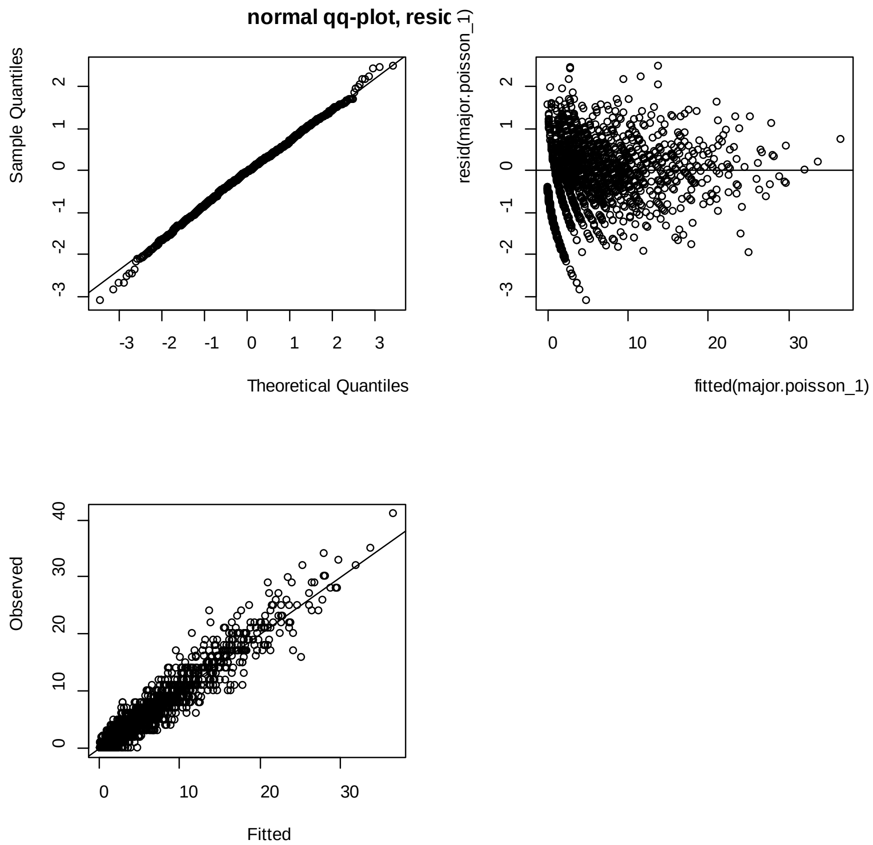

Figure 8: Diagnostic plots for generalised linear mixed effects model examining *reader_year* effects on counts of major burrow openings.

For analysis using Method 1, canonical indices of the *reader_year* terms are presented in

Table 4 and plotted in Figure 9. These were calculated from the GLMM indices and covariance matrix (Francis 1999).

The correction factor (

Table 4) for each *reader_year* (C_i) is defined as follows

$$C_i = \frac{\bar{c}}{c_i}$$

where c_i is the index of the *i*th *reader_year*, and $\bar{c}$ is the average of the *reader_year* indices. These correction factors were applied to the individual counts when estimating overall abundance.

Table 4: Canonical indices (and variance, CV, and upper and lower 95% CI) and correction factor for *reader_year* terms from a generalised linear mixed model relating the count of major burrow openings to *reader_year*, *stratum_year*, and *readable area* (offset) for SCI 6A.

reader_year	Index	Variance	CV	Upper 95%	Lower 95%	Correction factor
AM_2013	2.189001	0.074186	0.124427	2.733742	1.644259	0.483662
AM_2016	0.935084	0.015365	0.132562	1.182998	0.687170	1.132236
AM_2019	1.403886	0.041320	0.144794	1.810433	0.997339	0.754147
BH_2007	0.547575	0.004710	0.125337	0.684838	0.410311	1.933501
BH_2008	0.847045	0.010662	0.121904	1.053562	0.640529	1.249917
BH_2009	0.797531	0.008925	0.118453	0.986471	0.608591	1.327518
DP_2007	0.418892	0.003494	0.141108	0.537110	0.300674	2.527469
DP_2008	1.132260	0.017310	0.116200	1.395397	0.869122	0.935065
DP_2009	1.011967	0.013914	0.116561	1.247878	0.776055	1.046216
DP_2013	1.724263	0.047243	0.126056	2.158971	1.289556	0.614022
DP_2016	1.119755	0.021086	0.129681	1.410177	0.829332	0.945507
DP_2019	1.384542	0.040595	0.145522	1.787504	0.981579	0.764683
HA_2007	0.676452	0.006710	0.121093	0.840279	0.512625	1.565132
HA_2008	1.085778	0.016342	0.117735	1.341448	0.830109	0.975094
HA_2009	1.168259	0.018248	0.115628	1.438427	0.898091	0.906251
HA_2013	1.377377	0.031551	0.128960	1.732631	1.022123	0.768661
HA_2016	0.798088	0.011950	0.136973	1.016721	0.579454	1.326592
HA_2019	1.162197	0.029888	0.148753	1.507957	0.816437	0.910978
IT_2007	0.792116	0.008721	0.117892	0.978885	0.605347	1.336593
IT_2008	1.169815	0.018527	0.116357	1.442046	0.897584	0.905046
IT_2009	0.854492	0.010216	0.118287	1.056642	0.652341	1.239025
IT_2013	1.478231	0.036206	0.128721	1.858791	1.097671	0.716218
IT_2016	0.842242	0.012672	0.133656	1.067382	0.617101	1.257046
IT_2019	1.303433	0.036292	0.146155	1.684440	0.922426	0.812267
JD_2007	0.544724	0.004595	0.124441	0.680296	0.409153	1.943618
JD_2008	1.216986	0.020005	0.116220	1.499863	0.934108	0.869966
JD_2009	0.734666	0.007878	0.120812	0.912179	0.557153	1.441113
JD_2019	0.773083	0.014237	0.154344	1.011725	0.534441	1.369499
MS_2007	0.660946	0.006761	0.124410	0.825402	0.496490	1.601850
MS_2008	1.006261	0.014094	0.117981	1.243700	0.768822	1.052149
MS_2009	1.071511	0.015549	0.116374	1.320902	0.822120	0.988078
MS_2013	1.636213	0.043480	0.127439	2.053250	1.219177	0.647065
MS_2016	1.009040	0.017106	0.129618	1.270619	0.747462	1.049251
MS_2019	1.343352	0.038010	0.145130	1.733274	0.953430	0.788130
NR_2013	1.108029	0.021856	0.133424	1.403705	0.812353	0.955513
NR_2016	0.789414	0.011322	0.134788	1.002220	0.576607	1.341168

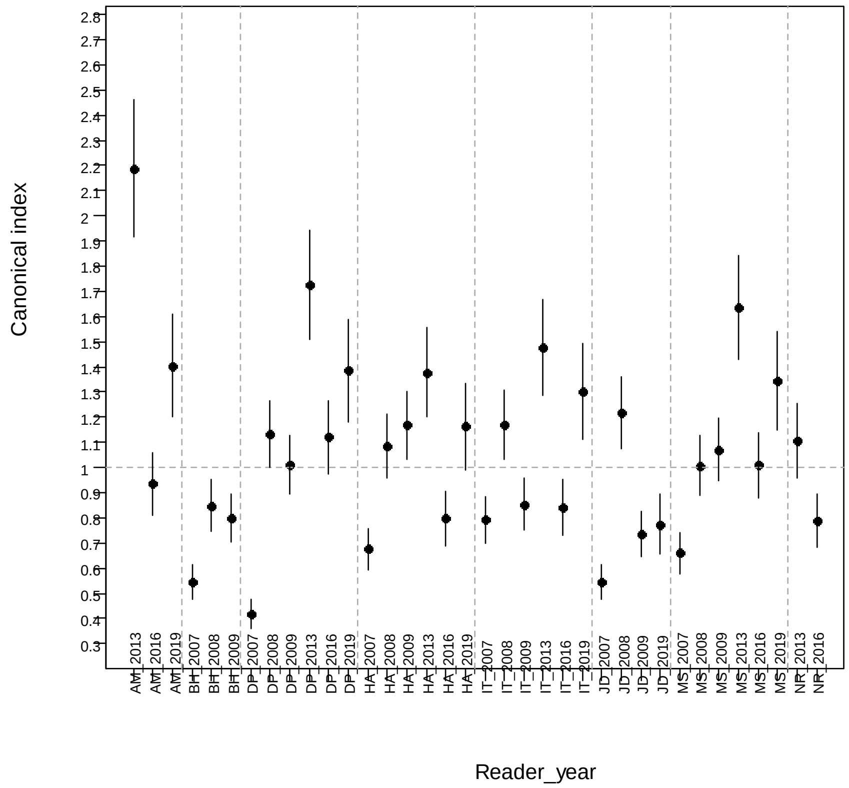

Figure 9: Canonical indices (and CV) for *reader_year* terms from a generalised linear mixed model relating the count of major burrow openings to *reader_year*, *stratum_year*, and *readable area* (offset) for SCI 6A.

For visible scampi, a Poisson error distribution provided the best fit to the data; *reader_year* effects were not retained in the final model (Table 5, diagnostic plots in Figure 10), supporting NIWA's previously assumed (but untested) view that identification and counting of scampi is far less subjective than that of burrow openings.

Table 5: Analysis of deviance for a generalised linear mixed model relating the count of visible scampi to *stratum_year* and *readable area* (offset) for SCI 6A.

	Df	Sum sq	Mean Sq	F value
Stratum_year	29	152.54	5.26	5.26

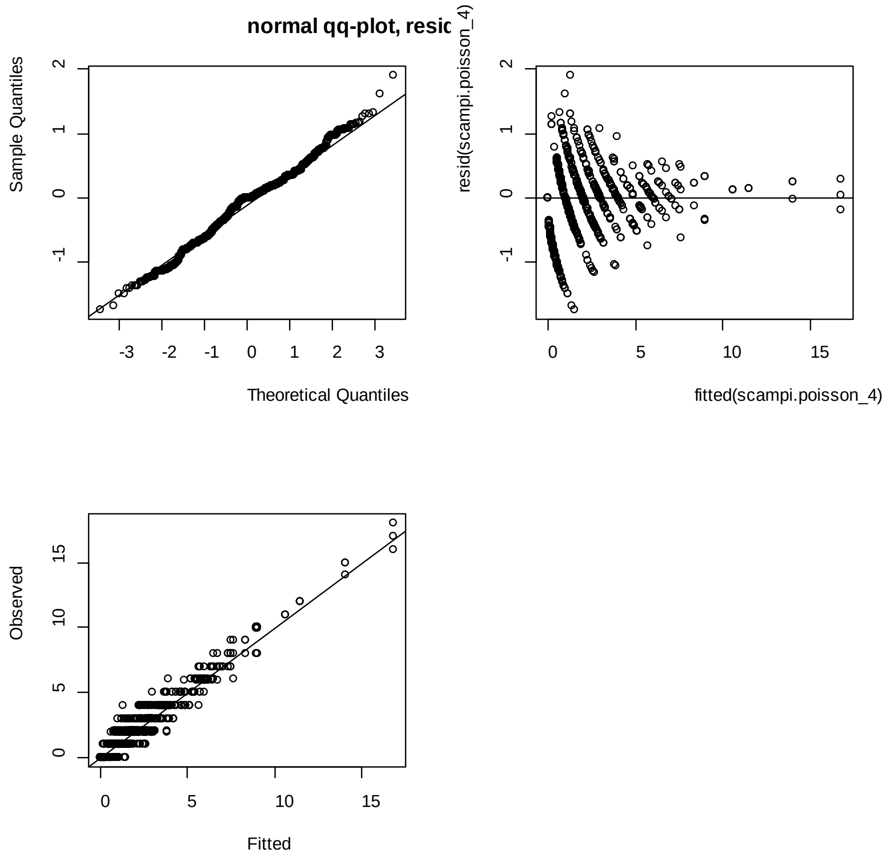

Figure 10: Diagnostic plots for generalised linear mixed effects model examining effects on counts of visible scampi.

The locations of photographic stations and relative burrow densities are shown in Figure 11. The uncorrected burrow density estimates at the station level varied from 0–0.15 m^{-2}, and reader correction factors slightly reduced these. Densities of all scampi, and scampi out of their burrows, ranged from 0 to 0.044 (Figure 12) and 0.022 m^{-2}, respectively. Scaling the densities to the combined area of the strata (4897 km^2) leads to abundance estimates of 249 million burrows or, assuming 100% occupancy, a maximum abundance estimate of the same number of animals (Table 6). Analysis of all SCI 6A surveys (with and without *reader_year* corrections) are presented in Appendix 2.

Overall, the corrected density of major scampi burrow openings was estimated to be 0.05 m^{-2}. The density was lowest in the shallower (350–400 m) stratum, and highest in the northern stratum in the 450–500 m depth range. The CVs from the bootstrapped estimates (bootstrapping of the *reader_year* corrected estimates, resampling stations with replacement within strata, and selecting one of the three readers for each station) were very similar to those of the fishery estimates (Table 6).

The estimated mean density of all visible scampi was 0.016 m^{-2}, with the lowest density observed in the shallowest stratum. Scaling the observed annual density of visible scampi by the area in each stratum leads to a minimum abundance estimate of 76 million animals for the surveyed area (Table 7). Counting animals out of burrows and walking free on the surface reduced this estimate to 38 million animals (Table 8). The CVs for visible scampi and scampi out of burrows from the bootstrapped estimates were comparable with those of the original estimates.

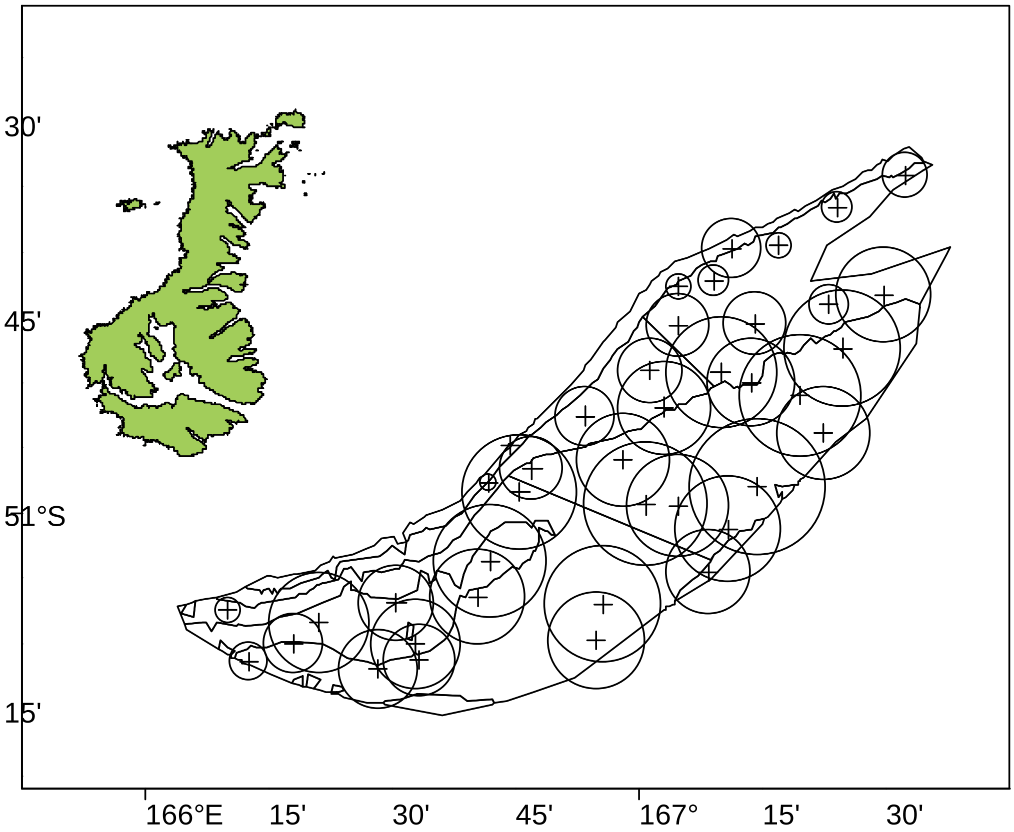

Figure 11: Station locations for the 2019 photographic survey of SCI 6A (area of symbol represents relative burrow density). Largest circle represents 0.15 burrows m^{-2} (uncorrected for *reader_year*).

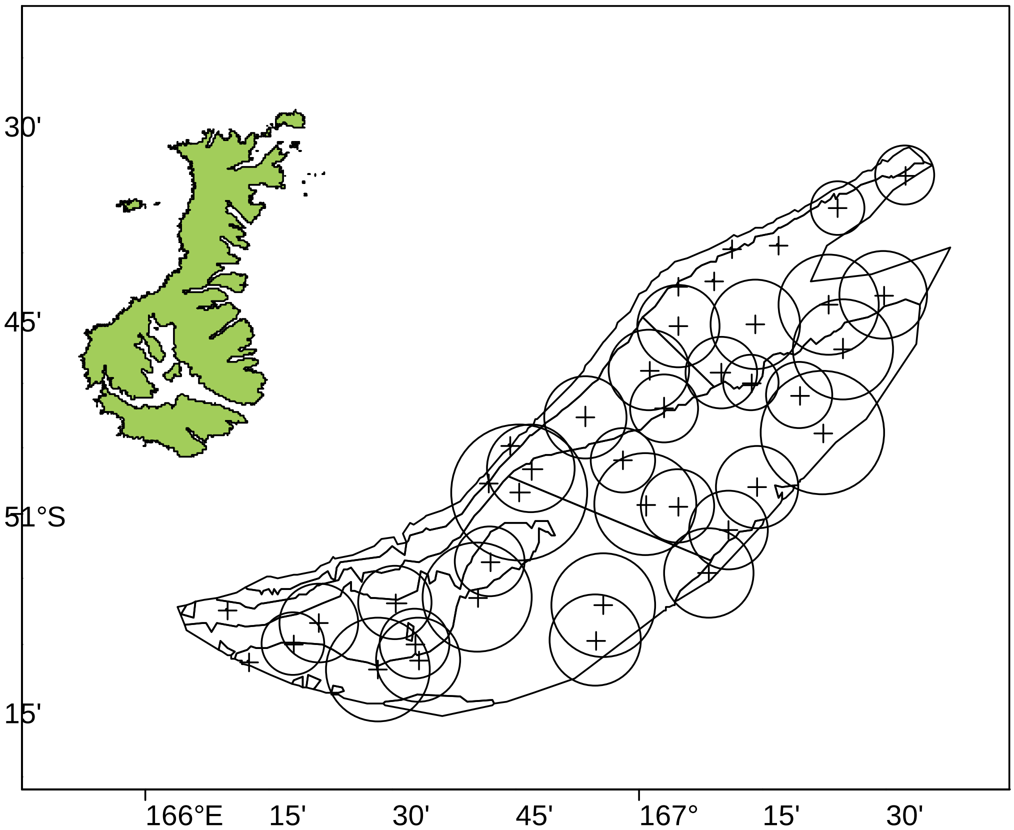

Figure 12: Station locations for the 2019 photographic survey of SCI 6A (area of symbol represents relative visible scampi density). Largest circle represents 0.044 visible scampi m^{-2}.

Table 6: Estimates of the density and abundance of major burrow openings from the SCI 6A survey for 2019, by stratum. Counts by each reader have been scaled by correction factors for *reader_year* (Method 1). Fishery estimates of density and abundance represent the combined stratum estimates. Bootstrap estimates of density and abundance (for the whole survey) based on median of 1000 sets of resampling stations within strata and reader within station.

	Stratum							
Major burrows	350	400N	400S	450N	450S	500	Fishery	Bootstrap
Area (km^2)	278	789	752	1 216	1 348	514	4 897	
Stations	3	9	3	11	8	6	40	
Mean density (m^{-2})	0.0097	0.0222	0.0405	0.0804	0.0526	0.0583	0.0509	
CV	0.88	0.46	0.30	0.13	0.21	0.16	0.10	0.09
Abundance (millions)	2.70	17.51	30.44	97.81	70.97	29.96	249.39	251.06

Table 7: Estimates of the density and abundance of visible scampi from the SCI 6A survey for 2019, by stratum. Fishery estimates of density and abundance represent the combined stratum estimates. Bootstrap estimates of density and abundance (for the whole survey) are based on median of 1000 sets of resampling stations within strata and reader within station.

	Stratum							
Visible scampi	350	400N	400S	450N	450S	500	Fishery	Bootstrap
Area (km^2)	278	789	752	1 216	1 348	514	4 897	
Stations	3	9	3	11	8	6	40	
Mean density (.m^{-2})	0.0000	0.0093	0.0154	0.0171	0.0219	0.0137	0.0156	
CV		0.32	0.13	0.19	0.26	0.16	0.12	0.11
Abundance (millions)	0.00	7.31	11.59	20.76	29.58	7.04	76.28	76.21

Table 8: Estimates of the density and abundance of scampi out of burrows from the SCI 6A survey for 2019, by stratum. Scampi "out" were defined as those for which the telson was not obscured by the burrow. Fishery estimates of density and abundance represent the combined stratum estimates. Bootstrap estimates of density and abundance (for the whole survey) are based on median of 1000 sets of resampling stations within strata and reader within station.

	Stratum							
Scampi out	350	400N	400S	450N	450S	500	Fishery	Bootstrap
Area (km^2)	278	789	752	1 216	1 348	514	4 897	
Stations	3	9	3	11	8	6	40	
Mean density (.m^{-2})	0.0000	0.0056	0.0109	0.0064	0.0110	0.0055	0.0077	
CV		0.33	0.32	0.31	0.29	0.57	0.16	0.14
Abundance (millions)	0.00	4.41	8.19	7.76	14.78	2.81	37.94	38.06

The trend in abundance in major burrow openings is shown in Figure 13. The calibration to account for *reader_year* effects considerably increased the estimated abundance in 2007 and reduced the estimate to a lesser extent in 2013, but does not change the overall pattern in the data. The estimated abundance of major burrow openings shows a slight increase between 2013 and 2016, and a further increase to 2019, having declined considerably between 2009 and 2013. The Method 2 estimation of burrow density and abundance provided a very similar trend to the Method 1 index, with the overall magnitude of abundance shifting depending on the *reader_year* selected for predictions. The indices of scampi abundance (visible scampi and scampi out of burrows) are presented in Figure 14. These show a steady decline between 2007 and 2009, a further slight decline by 2013, and an increase between 2013 and 2019. Estimates of scampi out of burrows are lower but show a similar pattern.

Overall survey mean densities for the current and previous surveys in SCI 6A are provided in Table 9. The count of visible scampi as a percentage of burrows (which could be considered a minimum estimate of occupancy) was 31% in 2019 (mean of 27% for survey series). The range observed is slightly higher than that from other SCI survey series (Tuck et al. 2013, Tuck et al. 2016). The proportion of scampi seen out of their burrows (scampi out as a proportion of all visible scampi) was 50% in 2019 (mean of 60% for survey series), which is considerably higher than other surveys in SCI 1, SCI 2, and SCI 3 (which average about 20%, Tuck et al. 2013, Tuck et al. 2016). It has been hypothesised that the seabed sediment in SCI 6A is not cohesive enough to maintain large burrows, and large scampi are often observed in narrow trenches (possibly collapsed burrows), which may explain the increased proportion of animals being categorised as "out".

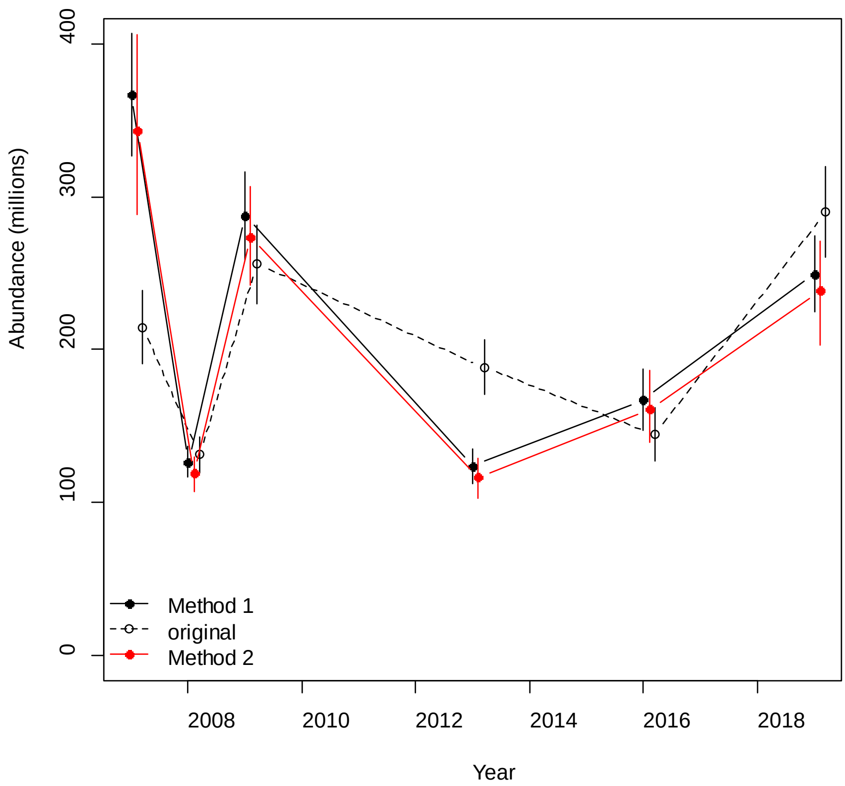

Figure 13: Estimated abundance of scampi major burrow openings (± CV) for SCI 6A. Original index represents counts uncorrected for *reader_year*.

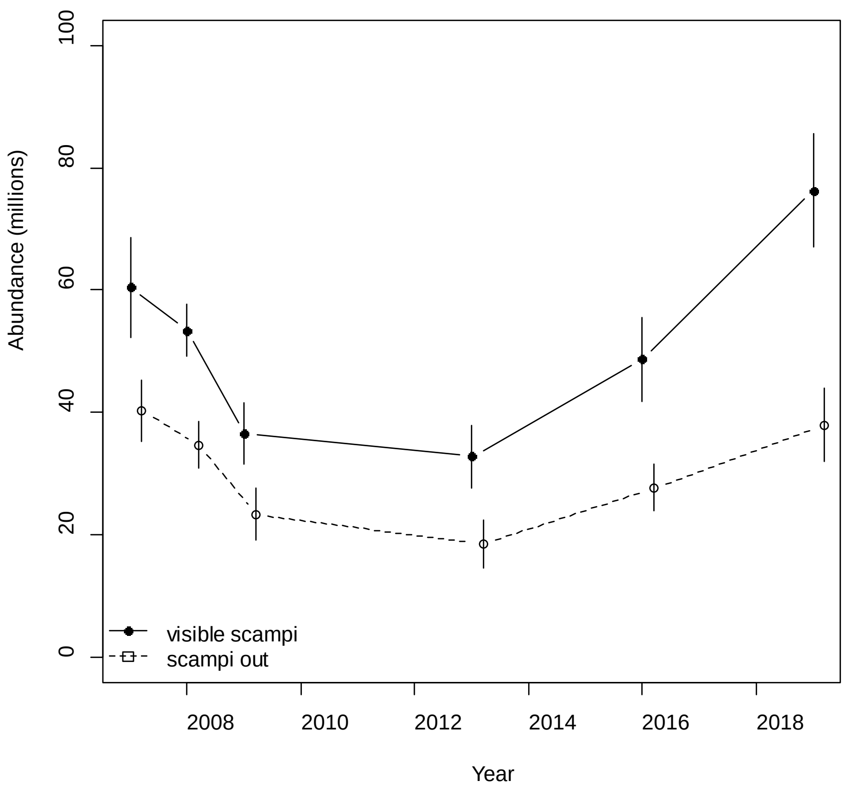

Figure 14: Estimated abundance of all visible scampi and those seen outside of a burrow (± CV) for SCI 6A.

Table 9: Overall survey mean densities (m^{-2}) of major burrow openings (corrected using Method 1), visible scampi and scampi out of burrows, for the series of SCI 6A surveys.

Year	Major opening	Visible scampi	Scampi "out"	Scampi as proportion of openings	Proportion of visible scampi “out”
2007	0.0624	0.0123	0.0082	0.20	0.67
2008	0.0259	0.0109	0.0071	0.42	0.65
2009	0.0587	0.0075	0.0048	0.13	0.64
2013	0.0253	0.0067	0.0038	0.26	0.56
2016	0.0341	0.0099	0.0057	0.29	0.57
2019	0.0509	0.0156	0.0077	0.31	0.50

3.2 Trawl survey

The locations of trawl survey stations and relative scampi catch rates are shown in Figure 15. Biomass estimates are provided by stratum for the 2019 survey in Table 10 and are compared with previous surveys estimated over the same stratum (but with a different vessel) in Table 12 and Figure 16. Equivalent abundance estimates (i.e., by number) are provided for the 2019 survey in Table 11 and are compared with previous surveys in Table 13 and Figure 17.

Table 10: Trawl survey biomass estimates (tonnes) by stratum for SCI 6A. Mean values are expressed as kilograms per nautical mile (using the *Kaharoa* scampi trawl gear).

	Stratum						Total
	350	400N	400S	450N	450S	500	
Area (km^2)	278	789	752	1 216	1 348	514	4 897
No. stations	3	3	3	3	3	3	18
Mean (kg nmi^{-1})	6.44	3.97	4.08	7.21	10.36	5.08	6.72
CV	0.24	0.34	0.72	0.30	0.10	0.05	0.12
Biomass (tonnes)	38.64	67.71	66.27	209.95	271.97	56.37	710.91

Table 11: Trawl survey estimates (abundance) by stratum for SCI 6A. Mean values are expressed as numbers per nautical mile (using the *Kaharoa* scampi trawl gear).

	Stratum						Total
	350	400N	400S	450N	450S	500	
Area (km^2)	278	789	752	1 216	1 348	514	4 897
No. stations	3	3	3	3	3	3	18
Mean (No. nmi^{-1})	85.4	74.4	55.1	109.2	150.6	82.3	101.4
CV	0.27	0.43	0.69	0.38	0.07	0.04	0.13
Abundance (millions)	0.5	0.9	0.9	3.2	4.0	0.9	10.4

The overall raised trawl survey estimate was 711 tonnes (12% CV) (Table 10), or 10.7 million individuals (14% CV) (Table 11). Given that scampi live in burrows and are only available to trawl gear when emerged on the seabed, this is likely to be (as with all the trawl surveys) a considerable underestimate of the stock biomass. Trends in biomass (Table 12, Figure 16) and abundance (Table 13, Figure 17) show a similar pattern, with the 2019 estimate showing a slight (but not significant) increase on the 2016 estimate and a marked decrease in the biomass and abundance estimate between 2013 and 2016 (when the survey vessel and trawl gear changed).

Table 12: Time series of raised trawl survey scampi stock estimates (tonnes) by survey and stratum for SCI 6A.

	Stratum							Total
Year	350	400 all	400N	400S	450N	450S	500	
2007	52.4	327.5			248.5	435.4	73.4	1 137.2
2008	100.7	277.3			493.0	236.2	121.9	1 229.2
2009	34.0		137.1	154.3	317.2	60.0	119.0	821.6
2013	38.9		215.6	319.8	247.4	311.2	125.0	1 257.9
2016	37.0		97.6	58.1	231.6	134.8	34.6	593.8
2019	38.6		67.7	66.3	209.9	272.0	56.4	710.9

Table 13: Time series of raised trawl survey scampi stock estimates (millions) by survey and stratum for SCI 6A.

	Stratum							Total
Year	350	400 all	400N	400S	450N	450S	500	
2007	0.3	3.9			3.4	5.6	1.2	14.4
2008	1.2	3.5			6.9	3.4	1.9	16.9
2009	0.4		1.5	1.8	4.0	0.7	1.5	9.9
2013	0.5		2.3	2.4	3.4	4.4	1.1	14.1
2016	0.4		1.3	0.8	3.3	2.0	0.5	8.2
2019	0.5		0.9	0.9	3.2	4.0	0.9	10.4

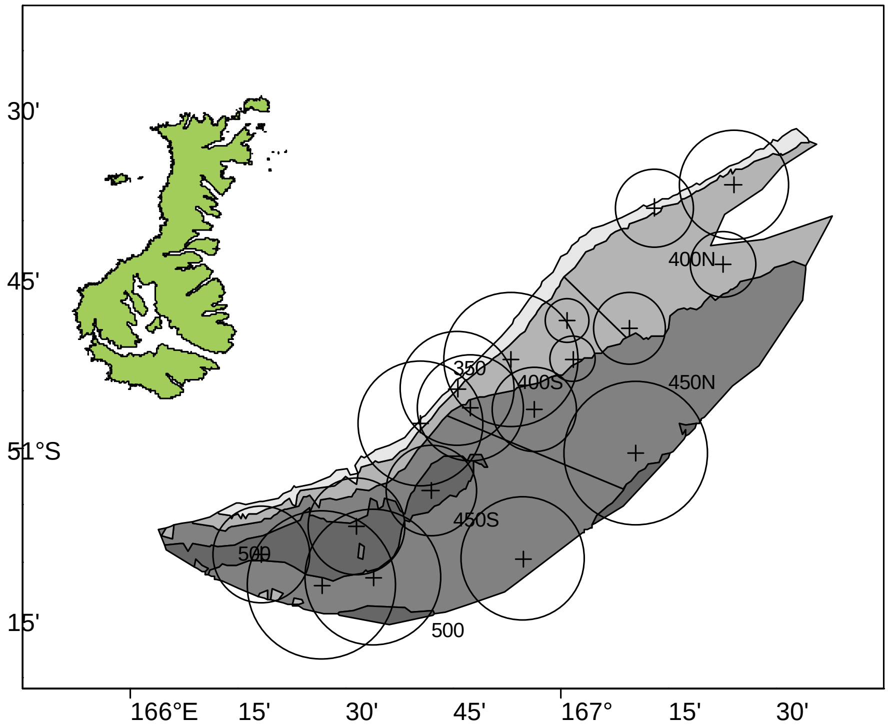

Figure 15: Trawl station locations for the 2019 photographic survey of SCI 6A (area of symbol represents relative scampi catch rate). Largest circle represents 12.2 kg nmi^{-1}.

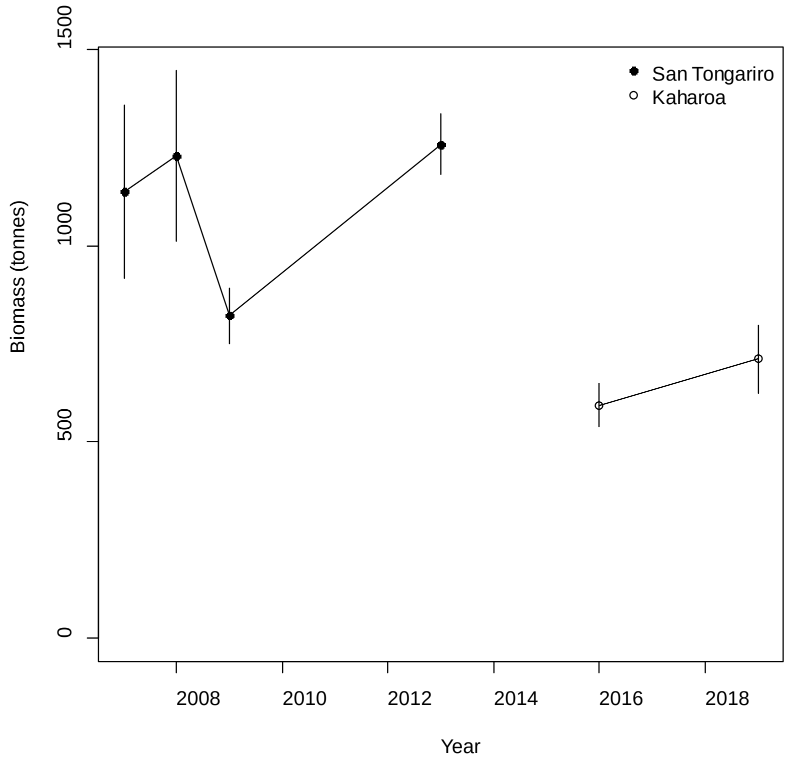

Figure 16: Plot of time series of trawl survey biomass estimates (± CV) for SCI 6A.

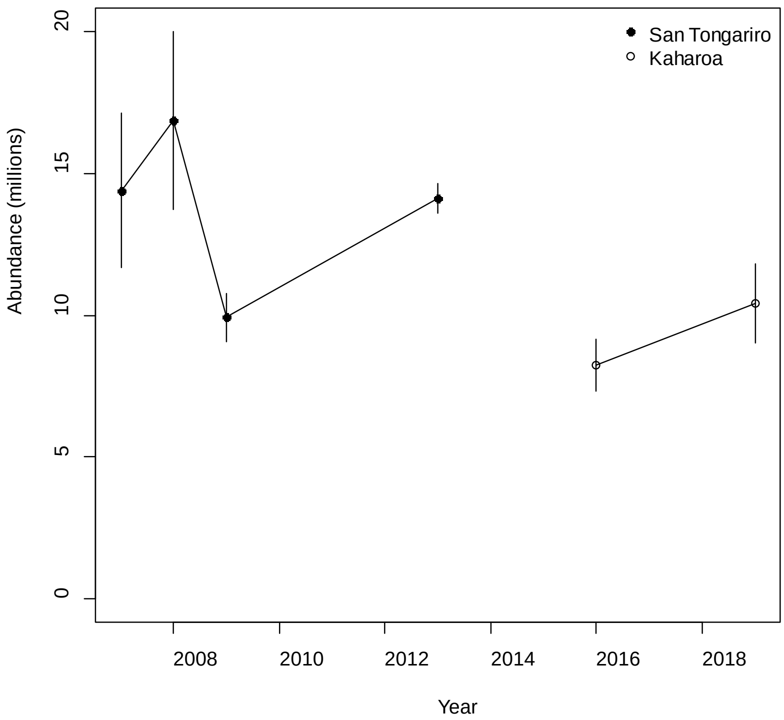

Figure 17: Plot of time series of trawl survey abundance estimates (± CV) for SCI 6A.

Although it is anticipated that changing the survey vessel may change trawl survey catchability there is no reason to expect the camera survey catchability to be platform dependent. Comparison of the photographic and trawl survey abundance estimates available up to 2017 were used to provide preliminary estimates of the relative catchability of the *San Tongariro* (2007–09, 2013) and *Kaharoa* (2016) scampi trawl gear (Tuck 2017), suggesting that the *San Tongariro* caught almost twice as much as the *Kaharoa*. Expanding this analysis to include the most recent survey does not change the overall pattern (Figure 18).

The ratio of the regression slopes (trawl survey density as a function of visible scampi density) for the two vessels was examined by resampling with replacement from the original data for each vessel, estimating the slope of the linear fit forced through the origin for each vessel, and estimating the ratio of the slopes (*Kaharoa* / *San Tongariro*). The distribution of the ratio from 1000 iterations had a median of 0.42 (95% CI of 0.31–0.56) and appears well represented by a log-normal distribution with mean of 0.42 and CV of 0.15 (Figure 19). This could be used as a q-ratio prior in future stock assessments using the SCI 6A trawl survey series.

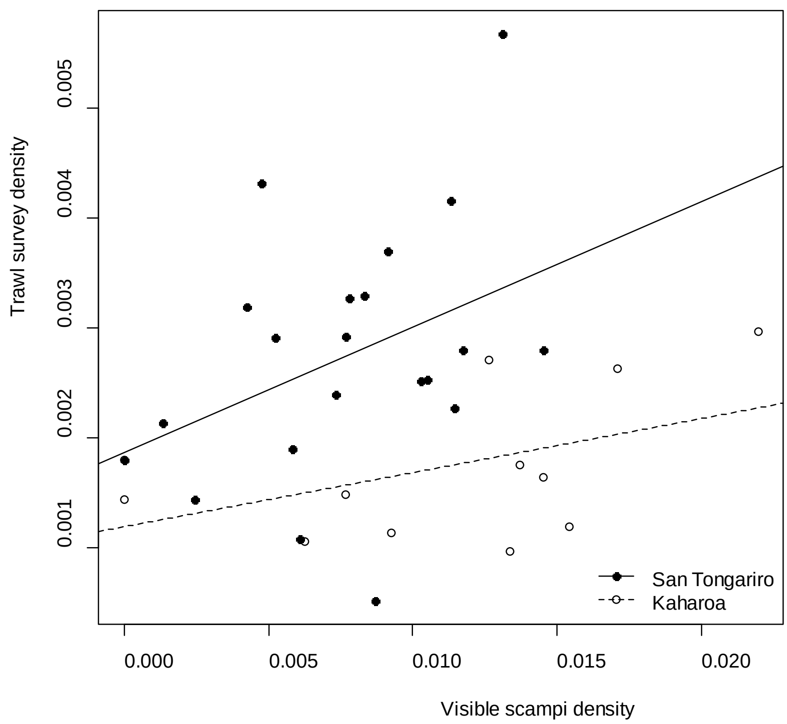

Figure 18: Plot of stratum level trawl survey scampi densities against photo survey scampi densities and best fit linear regression by vessel.

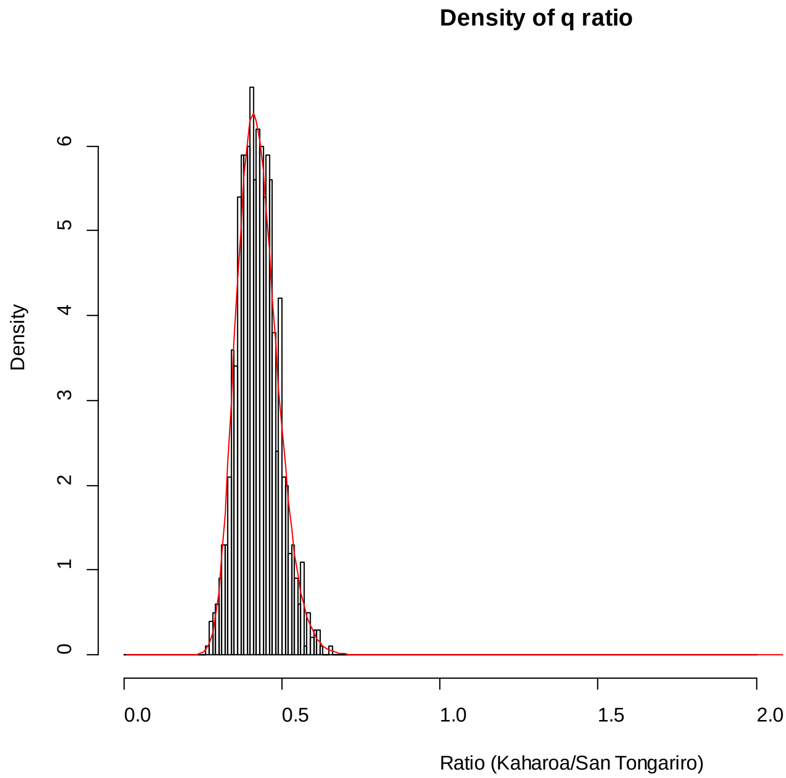

Figure 19: The distribution of the q-ratio (ratio between q values estimated for the two vessels for potential use as a prior). The red line represents the estimated log-normal distribution for the q-ratio prior, with mean of 0.42, and CV of 0.15.

Over the whole SCI 6A trawl survey, 334 kg of scampi were caught, accounting for about 6% of the total catch (5491 kg). Scampi were the fifth most abundant species. By weight, the most dominant species in the catches were javelinfish (35.8%), hoki (10.7%), ling (7.0%), ghost sharks (6.1%), and scampi (6.0%). Within commercial fishing activities, scampi forms a greater proportion of the total catch because bycatch mitigation approaches reduce finfish catches.

3.3 Tagging

Undamaged active scampi were tagged from each trawl catch and released to investigate growth. The next scheduled research sampling in SCI 6A will be in 2022, and it is anticipated that all recoveries will come from commercial fishing activity. During the trawling component of the survey, almost 2000 scampi were tagged with streamer tags and then released. The length distributions of the tagged scampi are presented in Figure 20. Tagging did not target specific size ranges, and the length distribution of tagged animals reflects the size distribution of suitable animals from the catches (Figure 21). The dominance of females in catches and tag releases was consistent with previous surveys in SCI 6A at this time of year (Tuck et al. 2015a) because males moult at this time of year in burrows, reducing their availability to trawl gear. The tagged scampi were released at 23 separate locations (Figure 22). No scampi were released while the vessel was fishing, and no recaptures were made by the RV *Kaharoa* during the survey. Tagging mortality was not investigated during this voyage (following recommendations of the Shellfish (Science) Working Group), but when examined previously, short-term (up to seven days) survival has been estimated at 88% in SCI 6A (Tuck et al. 2015a) and, 76% in SCI 2 (Tuck et al. 2013) the difference assumed to be related to higher release mortality caused by warmer surface water temperatures in SCI 2.

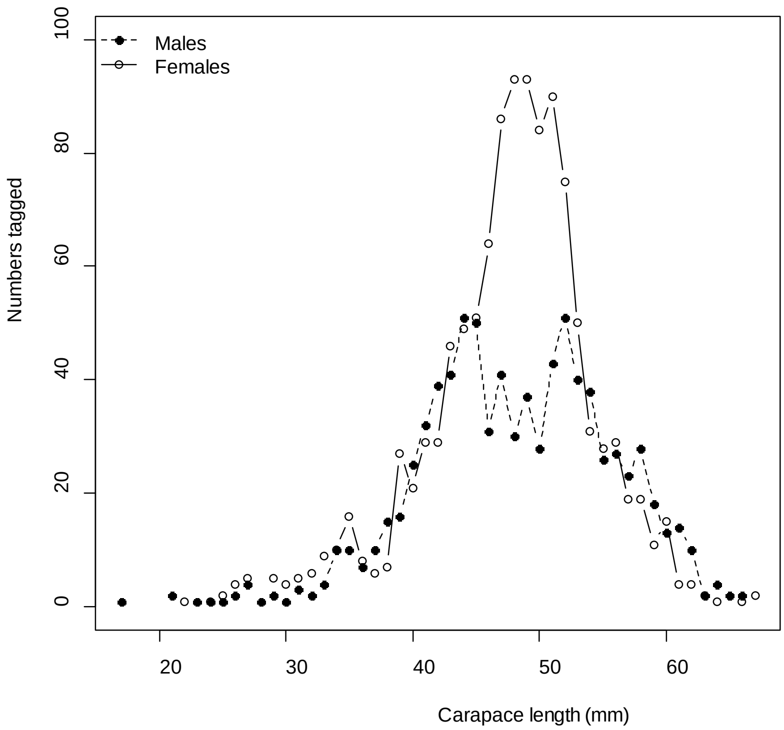

Figure 20: Length distribution of scampi tagged and released in SCI 6A during the 2019 survey voyage.

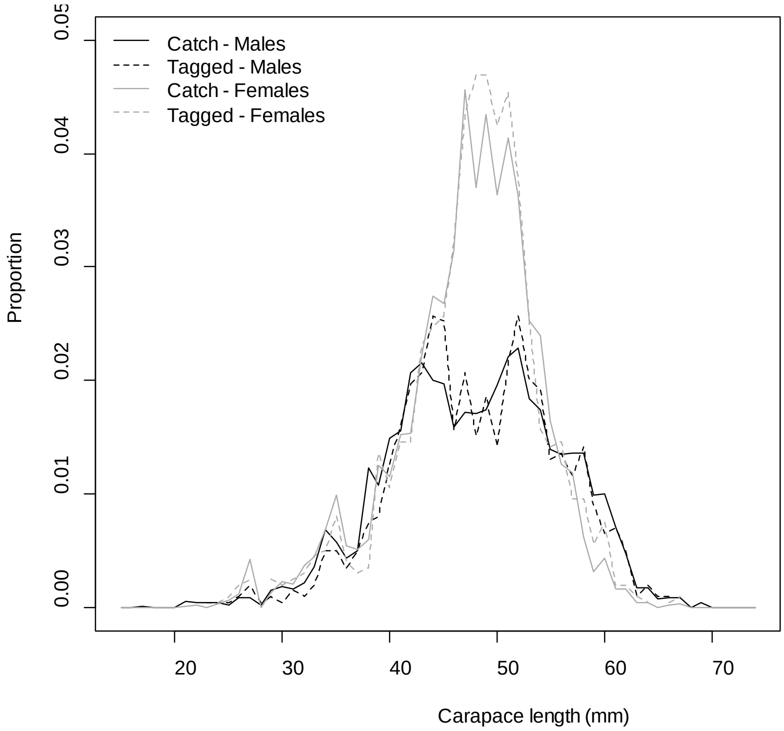

Figure 21: Proportion at length by sex in the scampi survey catches and tagged sample during the 2019 survey voyage.

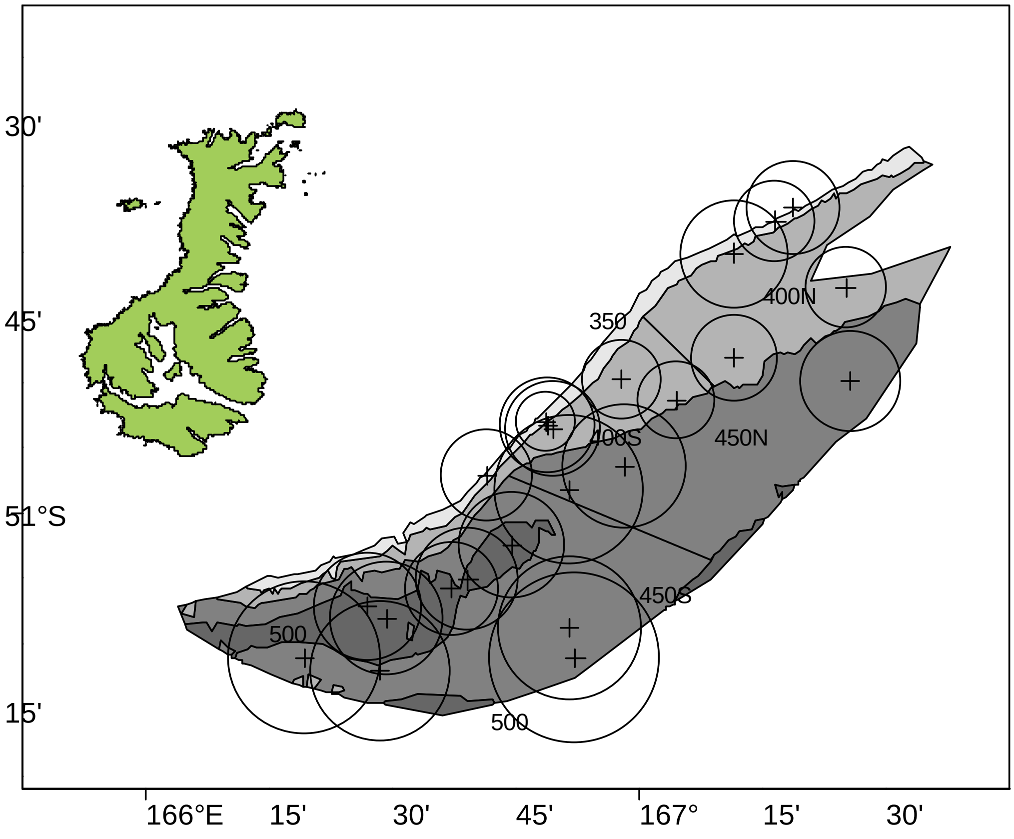

Figure 22: Map showing distribution of 2019 scampi release locations in SCI 6A and relative numbers released at each location. Largest circles represent 205 animals. The smallest release batch was 25 animals, and the average release batch was 86 animals.

To date (October 2019) only 3 recoveries have been reported to NIWA from the 2019 tagging in SCI 6A. Tag recovery rates from SCI 6A have generally been higher than from other scampi fisheries where tagging has been undertaken. The same tagging approach is used in all areas, and it is unclear why recovery rates are so different, although the colder surface waters in SCI 6A may contribute to increased survival.

3.4 Other sampling

Microsporidian infection of scampi
All measured scampi were examined for visual signs of microsporidian infection on the basis of diagnostic features identified in Figure 6. Estimated infection rates ranged from 2% to 33% at the individual station level and were 9.3% overall (Table 14). These rates appear higher than had previously been estimated, although previous surveys have not routinely examined large numbers of animals.

During the scampi survey in SCI 3 (September 2019, within Fisheries New Zealand project SCI2019-01), NIWA had the opportunity to compare identification rates between recorders and identified that the infection diagnosis from the SCI 6A survey was more focused on the pinkish carapace colouration, rather than the increased opacity of the flesh. Carapace colouration can vary with moult stage and NIWA considers the opacity of the abdomen flesh and telson muscles to be the best visual diagnostic (see Figure 6B), and therefore the estimates provided in Table 14 probably overestimate infection.

Table 14: Details of scampi examined and visually detected with signs of microsporidian infection. These are considered to overestimate infection (see above).

Station	Stratum	Scampi examined	Not infected	Infected	% Infected
19	500	230	216	14	6.1
21	450S	486	464	22	4.5
23	450S	478	398	80	16.7
25	400N	214	186	28	13.1
53	400S	48	47	1	2.1
54	400S	395	384	11	2.8
56	350	88	81	7	8.0
57	350	348	328	20	5.7
58	350	299	280	19	6.4
59	450N	113	105	8	7.1
60	450N	242	234	8	3.3
61	500	246	216	30	12.2
62	500	265	218	47	17.7
63	400S	53	49	4	7.5
65	400N	132	121	11	8.3
67	400N	121	111	10	8.3
69	350	101	67	34	33.7
71	450N	571	521	50	8.8
72	450S	391	349	42	10.7
Total		4821	4375	446	9.3

CTD profiles
CTD profiles were collected from every photographic station. Data were downloaded at sea and have been provided to the MPI *ctd* database manager.

Acoustic seabed measurements and sediment sampling
Data from the vessel's ES60 scientific echo sounder (set at a range to observe the double echo of the seabed) were recorded throughout the voyage (Figure 23), except during periods when finer resolution detail of the seabed was required (e.g., running trawl lines overnight in advance of fishing). These data have been indexed in ESP3 and will be analysed in the future once more data have been collected.

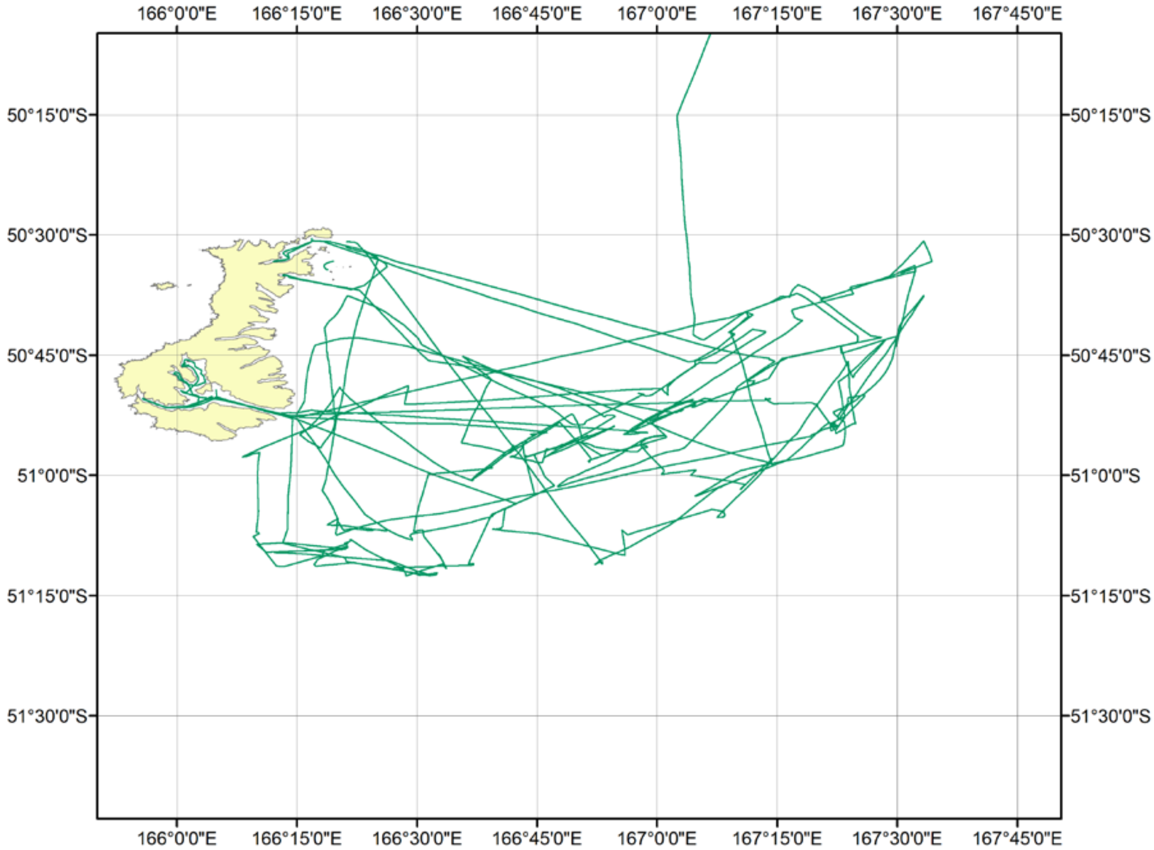

Figure 23: Vessel track data for which acoustic data were recorded during the survey.

Predation on scampi
Fish samples from trawl catches were held on ice for further analysis during periods of poor weather when the vessel was at anchor. A total of 619 individual fish were examined, across 18 species caught in the SCI 6A survey. Of the 619 stomachs examined, 317 were classed as empty or regurgitated (Table 15). Of the remaining 302 stomachs, scampi remains (sometimes from more than one individual) were identified from 16 fish stomachs (excluding very fresh material considered to have been consumed in the trawl). The species identified as scampi predators were GSP, HCO, LIN, SCO, SPD and SSK.

Stomach sampling was opportunistic, but across the survey the size range of sampled fish by species reflected the size range of fish caught reasonably well (Figure 24), although not necessarily the length distribution, particularly for the more abundant species (LIN and SPD). Where a broad size range of fish was available and sampled, scampi were generally found in larger fish.

Scampi remains detected in fish stomachs were in a range of digested states, and it was rare to find an intact carapace to measure. Various measurements of components available were used to estimate the carapace length (CL) of the original scampi prey, to examine the relationship between predator and prey. This has not been possible yet for all scampi remains, and a number of new relationships for body parts and carapace length will need to be developed over future surveys for this approach to be comprehensive. This assumes that the presence of a scampi claw reflects the whole animal being eaten, and not just the claw being eaten and the animal escaping.

Table 15: Summary of stomach contents analysis conducted during SCI 6A survey.

Species	Common name	Empty / regurgitated	Not empty	Containing scampi	Total	% of not empty stomachs containing scampi
GIZ	Stargazer	0	5		5	
GSH	Ghost shark	46	22		68	
GSP	Pale ghost shark	13	32	2	45	6.25
HAK	Hake	11	20		31	
HCO	Hairy conger	5	22	2	27	9.09
HOK	Hoki	53	72		125	
LCH	Longnose spookfish	5	2		7	
LDO	Lookdown dory	3	4		7	
LIN	Ling	97	24	4	121	16.67
PLS	Plunket’s shark	0	1		1	
RCO	Red cod	5	19		24	
RSK	Rough skate	3	11		14	
SBW	Southern blue whiting	21	4		25	
SCO	Swollenhead conger	3	17	2	20	11.76
SPD	Spiny dogfish	52	22	2	74	9.09
SSK	Smooth skate	0	10	4	10	40
SWA	Silver warehou	0	5		5	
WWA	White warehou	0	10		10	
Total		317	302	16	619	

A plot of scampi prey CL against fish predator length for the data available to date is provided in Figure 25. Most samples were available for ling, and for this species prey length increased with predator length. For other predator species, the number of samples was low and no relationship was apparent. Scampi smaller than 20 mm CL are very rarely observed in trawl catches, and it is thought that individuals smaller than this very rarely emerge from burrows. It is interesting to note that two very small scampi (10–11 mm CL) were found within a swollenhead conger stomach. This predator would be narrow enough to swim into a scampi burrow.

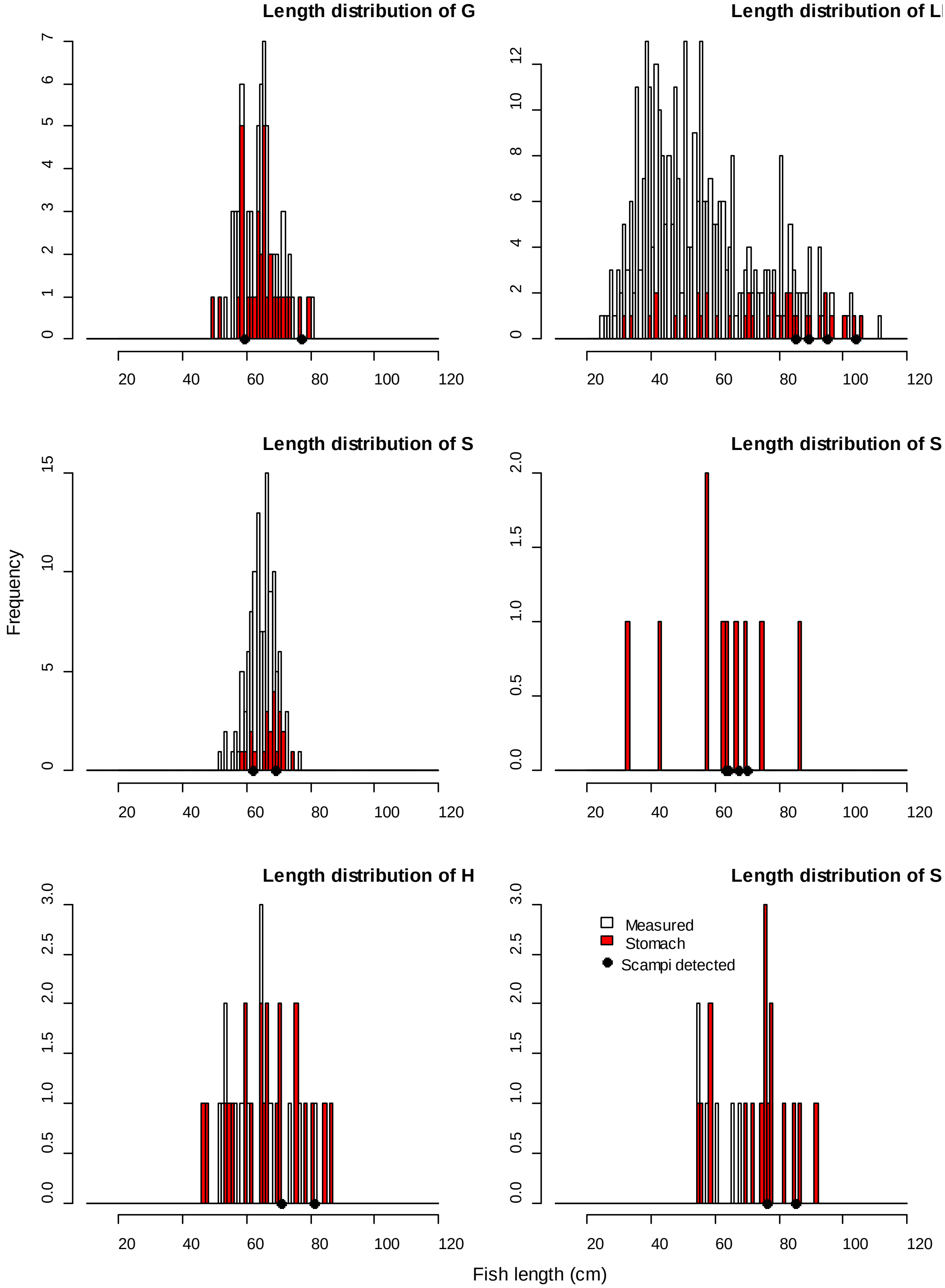

Figure 24: Length frequency distribution of measured fish for species identified as scampi predators (Table 15), and individuals for which stomachs were examined. The lengths of individuals containing scampi remains are identified by filled symbols.

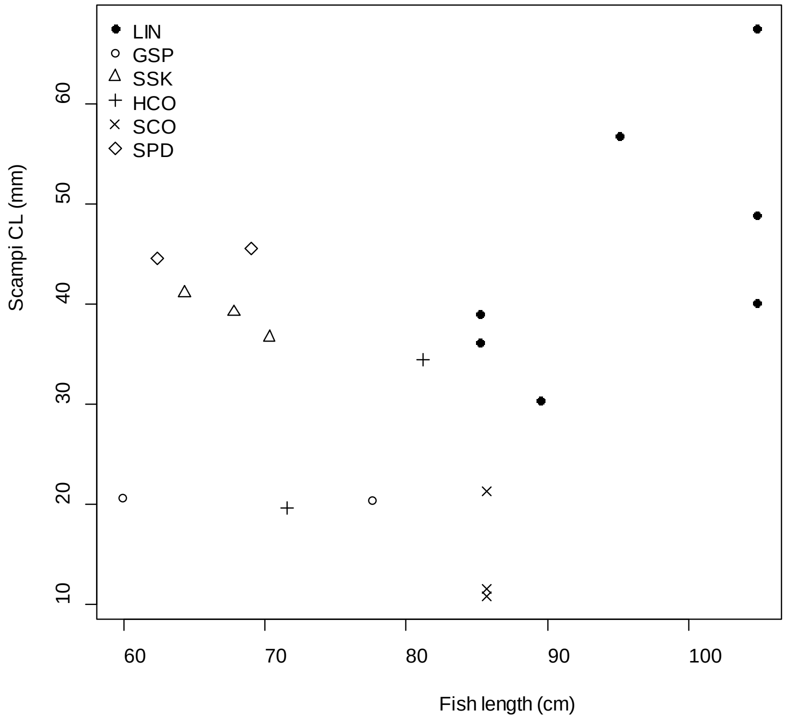

Figure 25: Plot of estimated scampi CL against fish predator length. It has not been possible to estimate the size of all scampi prey yet (see text above).

Ecosystem role of great white sharks
Fish berley was sourced from trawl bycatch after the first trawl stations (to avoid the risk of introducing new material to the region, a Department of Conservation requirement for the work). Over 13 days (or part days), a total of 87.5 hours was spent looking for great white sharks, across 4 locations (Figure 26). These activities were conducted during poor weather conditions (unsuitable for survey work), and so observation conditions were not ideal, but wearing polarised sunglasses allowed a good view through the glare on the water surface.

Throughout the observation period no sharks were seen, and there was no evidence (from behaviour of other species) that sharks were in the vicinity of the vessel.

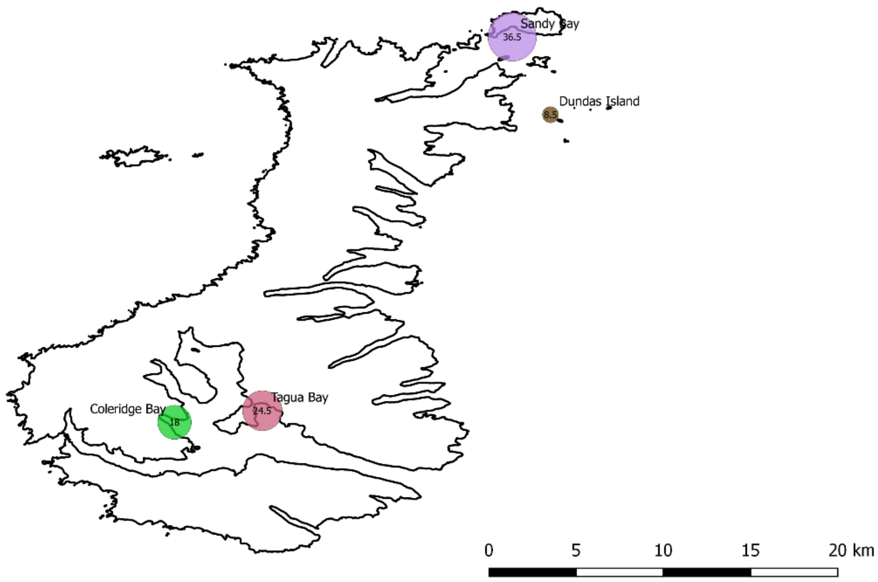

Figure 26: The NIWA 2019 scampi survey to the Auckland Islands sampled for great white sharks (*Carcharodon carcharias*) at four locations. The size of the circles is representative of the number of hours spent observing at each site, and the number of hours is included within the circles.

4. CONCLUSIONS

A photographic and trawl survey of scampi in SCI 6A was conducted in February and March 2019, replicating the coverage of previous surveys in the region. The photographic survey estimated a scampi burrow abundance of 249 million over the whole area, continuing the increase observed since the 2013 survey. The indices of emerged and visible scampi also show an increase since the 2013 survey. The trawl survey estimated a biomass of 711 tonnes. This represents an increase from the 2016 estimate. There was a forced vessel change for this survey after 2013, and, by comparing the relationship between visible scampi and trawl catches across surveys, the current survey catchability (with *Kaharoa*) is estimated at 0.42 (with 15% CV) of survey catchability with the *San Tongariro*. Given that scampi live in burrows and are only available to trawl gear when they emerge on the seabed, trawl survey estimates are likely to be considerable underestimates of the stock biomass.

Almost 2000 scampi were tagged and released as part of an investigation into growth, and, to date, three scampi have subsequently been recaptured by fishers. These will be incorporated into the existing tag recapture dataset for this stock and used to estimate growth rates within the stock assessment model.

A range of additional data was collected during the survey, including visually detected microsporidian infection rates in scampi, CTD profiles, sediment samples, acoustic seabed measurements, and stomach contents of potential scampi predators. Microsporidian infection rates were recorded as 9.3% across the whole survey, but comparison of detection rates on a more recent survey suggest that these figures may be an overestimate. Six species were identified as predators of scampi. As might be expected, larger predators were able to consume larger scampi, but there were also some differences between predator species. Very small scampi were observed in swollenhead conger stomachs, which may have been predated upon within the burrow. During poor weather, time (87.5 hours across 13 days) was spent attempting to tag great white sharks in the vicinity of sea lion colonies, but no sharks were observed.

5. ACKNOWLEDGEMENTS

This work would not have been possible without the advice and cooperation of the skipper and the crew of the RV *Kaharoa*. Derrick Parkinson led the voyage. We thank the EPA and the NIWA Activity Notifications team for their help in complying with the requirements of the Exclusive Economic Zone and Continental Shelf Regulations 2013, in relation to returning tagged scampi to the sea. Scampi tag recoveries have been made and reported to NIWA by the fishing industry. The voyage was funded within project SCI2018-03. This report was reviewed by Bruce Hartill.

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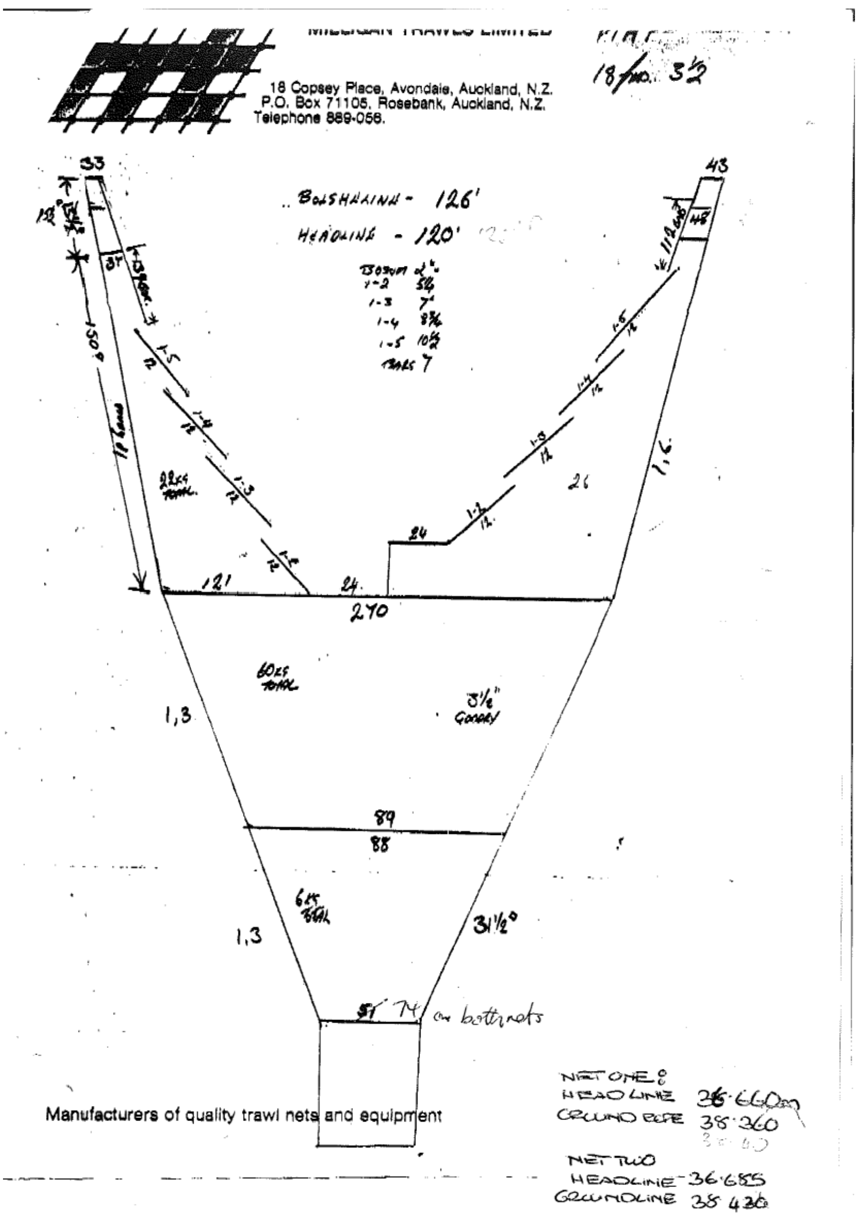
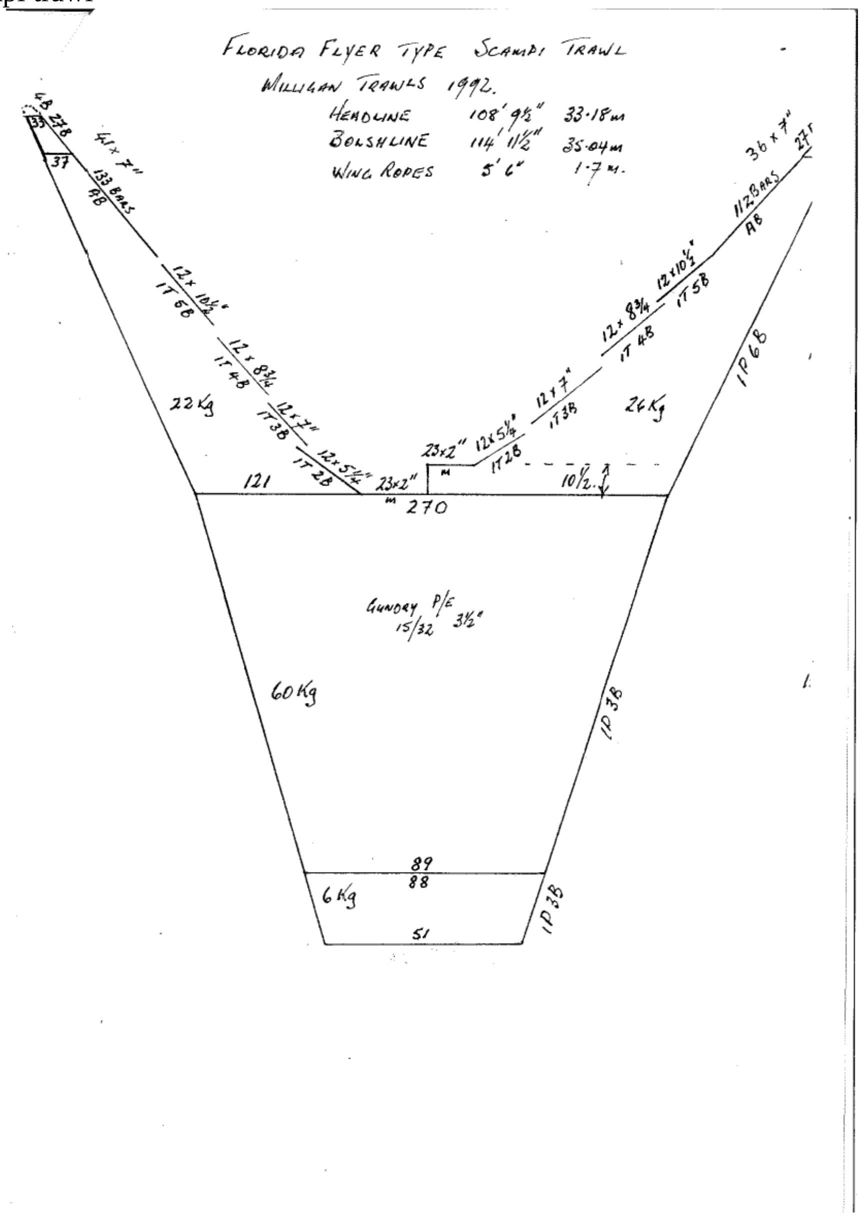
APPENDIX 1: DETAILS OF SURVEY TRAWL GEARS

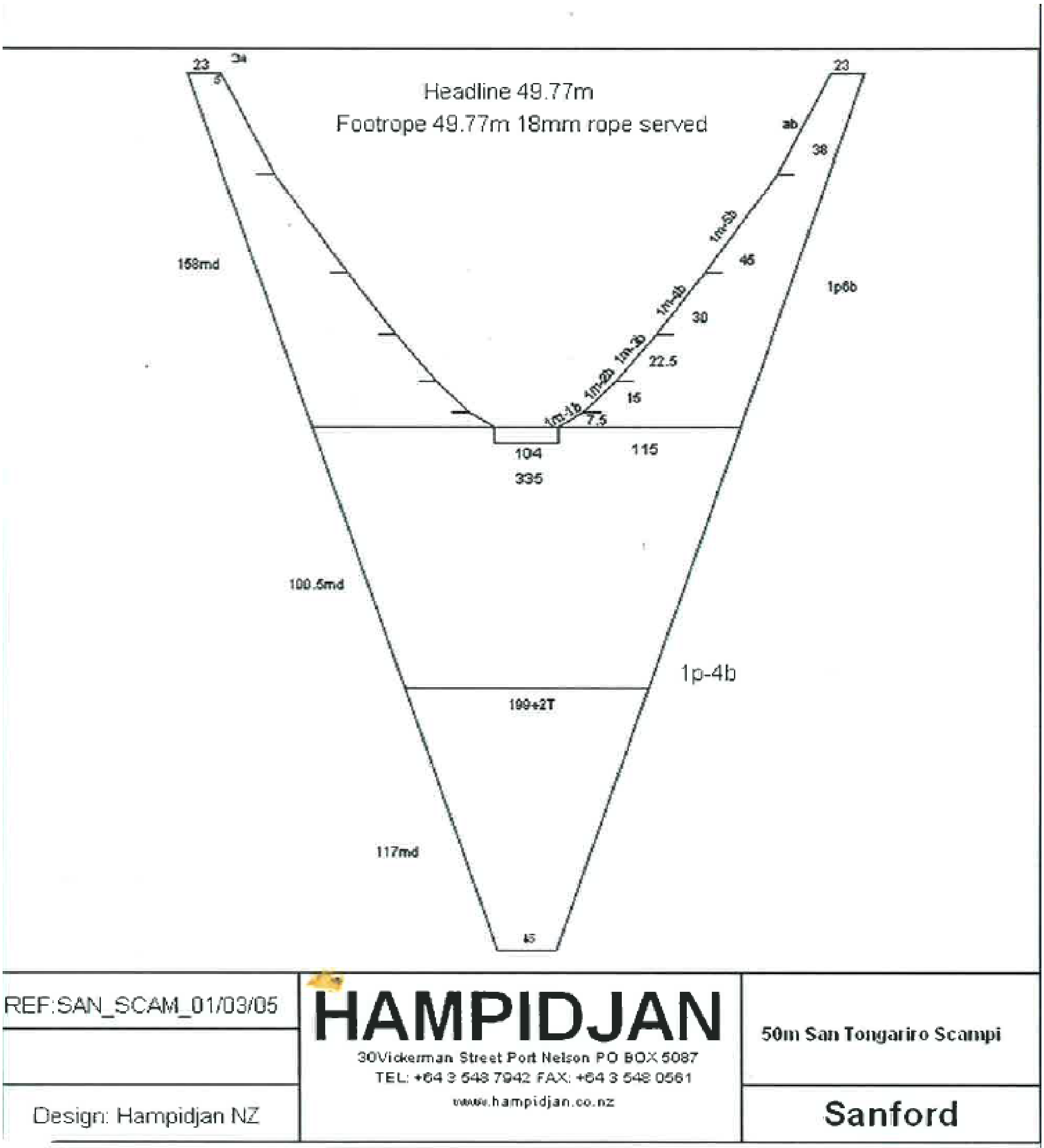
*Kaharoa s*campi trawl



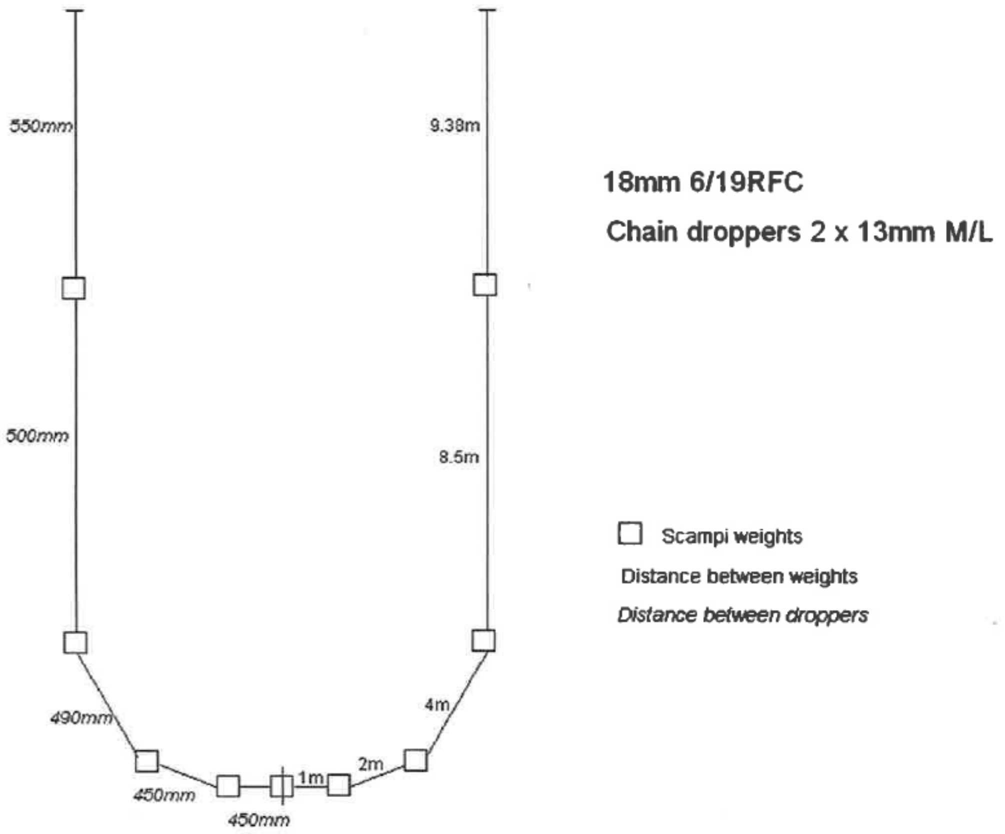
Kaharoa scampi trawl



San Tongariro scampi trawl



San Tongariro Groundrope 49.77m



Gear comparison between *Kaharoa* and *San Tongariro* scampi trawls (as employed during scampi surveys)

Parameter	***Kaharoa***	***San Tongariro***
Groundrope length (m)	35.04	49.77
Headline length (m)	33.18	49.77
Groundrope type	Rubber cookies	Looks like rubber cookies
Groundrope cookie diameter (mm)	65	Reported as served rope on plan but looks like rubber cookies from photographs
Groundrope (extra weights)	No	Yes
Groundrope dropper heights	5 links of 8 mm long link chain. Approx 200 mm. Note: 1 link is in between the rubber cookies	2 x 13 mm medium link chain Approx 100 mm
Groundrope dropper spacings	1 m apart	
Bottom contact	Video shows good contact	Extra weights on groundrope
Warps	Two warps	Single warp
Door type	Bison, Polaris. 1760 x 1200 mm. Code: 070515444	PolyIce Viking Extreme 3.9 m^2
Door weight	~ 300 kg	625 kg
Bridle length	6.5-6.6 m	
Wingspread (measured)	24 m	21 m
Headline height	Approx 1.0 m	1.5-1.8 m
Body of trawl mesh size (mm)	3.5” (88 mm) knot centres. About 80 mm actual opening. Twine is 3 mm twist	120 mm knot centres, 112.8 mm opening
Cod-end mesh size (Inside measurement.	42 mm opening or 48 mm knot centres. 3 mm twist	42 mm opening centres. 3 mm twist

APPENDIX 2: SUMMARY OF PHOTO SURVEY WORKUP

Uncorrected analysis (raw counts, no *reader_year* effect applied)

2007							
Major	350	4001	4002	4502	4501	500	Fishery
Area (sq km)	278	789	752	1 216	1 348	514	4 897
Count (stations)	3	10	3	6	5	5	32
Mean (/sq m)	0.0078	0.0309	0.0338	0.0583	0.0458	0.0584	0.0438
CV	0.56	0.24	0.31	0.18	0.25	0.25	0.11
Millions	2.18	24.42	25.40	70.90	61.80	30.00	214.70
Scampi	350	4001	4002	4502	4501	500	Fishery
Area (sq km)	278	789	752	1 216	1 348	514	4 897
Count (stations)	3	10	3	6	5	5	32
Mean (/sq m)	0.0061	0.0123	0.0086	0.0145	0.0113	0.0189	0.0123
CV	0.52	0.21	0.35	0.14	0.41	0.33	0.14
Millions	1.69	9.67	6.48	17.65	15.25	9.72	60.45
Out	350	4001	4002	4502	4501	500	Fishery
Area (sq km)	278	789	752	1 216	1 348	514	4 897
Count (stations)	3	10	3	6	5	5	32
Mean (/sq m)	0.0061	0.0075	0.0072	0.0105	0.0066	0.0109	0.0082
CV	0.52	0.21	0.46	0.18	0.34	0.29	0.12
Millions	1.69	5.94	5.40	12.79	8.91	5.61	40.34

Uncorrected analysis (raw counts, no *reader_year* effect applied)

2008							
Major	350	4001	4002	4502	4501	500	Fishery
Area (sq km)	278	789	752	1 216	1 348	514	4 897
Count (stations)	4	6	3	9	9	10	41
Mean (/sq m)	0.0033	0.0170	0.0187	0.0376	0.0338	0.0224	0.0268
CV	0.64	0.24	0.46	0.11	0.16	0.16	0.09
Millions	0.91	13.43	14.08	45.71	45.62	11.53	131.28
Scampi	350	4001	4002	4502	4501	500	Fishery
Area (sq km)	278	789	752	1 216	1 348	514	4 897
Count (stations)	4	6	3	9	9	10	41
Mean (/sq m)	0.0047	0.0094	0.0136	0.0131	0.0103	0.0091	0.0109
CV	0.17	0.19	0.10	0.14	0.21	0.21	0.08
Millions	1.32	7.42	10.19	15.94	13.85	4.70	53.42
Out	350	4001	4002	4502	4501	500	Fishery
Area (sq km)	278	789	752	1 216	1 348	514	4 897
Count (stations)	4	6	3	9	9	10	41
Mean (/sq m)	0.0047	0.0068	0.0105	0.0062	0.0065	0.0074	0.0071
CV	0.17	0.26	0.24	0.18	0.30	0.23	0.11
Millions	1.32	5.36	7.92	7.60	8.73	3.80	34.73

Uncorrected analysis (raw counts, no *reader_year* effect applied)

2009							
Major	350	4001	4002	4502	4501	500	Fishery
Area (sq km)	278	789	752	1 216	1 348	514	4 897
Count (stations)	6	6	2	10	14	5	43
Mean (/sq m)	0.0045	0.0275	0.0559	0.0553	0.0664	0.0661	0.0522
CV	0.51	0.17	0.55	0.10	0.10	0.16	0.10
Millions	1.26	21.69	42.05	67.30	89.49	33.96	255.75
Scampi	350	4001	4002	4502	4501	500	Fishery
Area (sq km)	278	789	752	1 216	1 348	514	4 897
Count (stations)	6	6	2	10	14	5	43
Mean (/sq m)	0.0024	0.0058	0.0073	0.0083	0.0087	0.0077	0.0075
CV	1.00	0.37	0.53	0.23	0.20	0.28	0.14
Millions	0.68	4.59	5.52	10.11	11.75	3.93	36.59
Out	350	4001	4002	4502	4501	500	Fishery
Area (sq km)	278	789	752	1 216	1 348	514	4 897
Count (stations)	6	6	2	10	14	5	43
Mean (/sq m)	0.0024	0.0034	0.0073	0.0026	0.0062	0.0057	0.0048
CV	1.00	0.53	0.53	0.34	0.26	0.32	0.18
Millions	0.68	2.67	5.52	3.17	8.36	2.95	23.35

Uncorrected analysis (raw counts, no *reader_year* effect applied)

2013							
Major	350	4001	4002	4502	4501	500	Fishery
Area (sq km)	278	789	752	1 216	1 348	514	4 897
Count (stations)	5	4	6	8	13	4	40
Mean (/sq m)	0.0117	0.0237	0.0266	0.0559	0.0423	0.0417	0.0385
CV	0.56	0.29	0.26	0.17	0.16	0.28	0.09
Millions	3.25	18.67	19.98	68.03	57.08	21.42	188.43
Scampi	350	4001	4002	4502	4501	500	Fishery
Area (sq km)	278	789	752	1 216	1 348	514	4 897
Count (stations)	5	4	6	8	13	4	40
Mean (/sq m)	0.0000	0.0052	0.0042	0.0117	0.0078	0.0013	0.0067
CV		0.50	0.63	0.25	0.23		0.16
Millions	0.00	4.14	3.19	14.28	10.54	0.69	32.83
Out	350	4001	4002	4502	4501	500	Fishery
Area (sq km)	278	789	752	1 216	1 348	514	4 897
Count (stations)	5	4	6	8	13	4	40
Mean (/sq m)	0.0000	0.0036	0.0031	0.0065	0.0038	0.0004	0.0038
CV		0.75	0.65	0.30	0.32		0.21
Millions	0.00	2.84	2.34	7.93	5.11	0.22	18.44

Uncorrected analysis (raw counts, no *reader_year* effect applied)

2016

Major	350	400A	400B	450A	450B	500	Fishery
Area (sq km)	278	789	752	1 216	1 348	514	4 897
Count (stations)	3	5	4	12	13	3	40
Mean (/sq m)	0.0033	0.0399	0.0142	0.0323	0.0298	0.0429	0.0295
CV	0.78	0.39	0.38	0.17	0.16	0.34	0.12
Millions	0.93	31.51	10.65	39.29	40.14	22.04	144.55

Scampi	350	400A	400B	450A	450B	500	Fishery
Area (sq km)	278	789	752	1 216	1 348	514	4 897
Count (stations)	3	5	4	12	13	3	40
Mean (/sq m)	0.0000	0.0145	0.0062	0.0126	0.0077	0.0134	0.0099
CV		0.45	0.25	0.22	0.21	0.17	0.14
Millions	0.00	11.44	4.69	15.37	10.35	6.87	48.72

Out	350	400A	400B	450A	450B	500	Fishery
Area (sq km)	278	789	752	1 216	1 348	514	4 897
Count (stations)	3	5	4	12	13	3	40
Mean (/sq m)	0.0000	0.0032	0.0062	0.0077	0.0039	0.0114	0.0057
CV		0.62	0.25	0.30	0.32	0.07	0.14
Millions	0.00	2.56	4.69	9.32	5.27	5.86	27.70

Uncorrected analysis (raw counts, no *reader_year* effect applied)

2019

Major	350	400N	400S	450N	450S	500	Fishery
Area (sq km)	278	789	752	1 216	1 348	514	4 897
Count (stations)	3	9	3	11	8	6	40
Mean (/sq m)	0.0104	0.0256	0.0482	0.0937	0.0600	0.0699	0.0592
CV	0.87	0.43	0.32	0.14	0.22	0.19	0.10
Millions	2.89	20.16	36.23	113.90	80.89	35.91	289.99

Scampi	350	400N	400S	450N	450S	500	Fishery
Area (sq km)	278	789	752	1 216	1 348	514	4 897
Count (stations)	3	9	3	11	8	6	40
Mean (/sq m)	0.0000	0.0093	0.0154	0.0171	0.0219	0.0137	0.0156
CV		0.32	0.13	0.19	0.26	0.16	0.12
Millions	0.00	7.31	11.59	20.76	29.58	7.04	76.28

Out	350	400N	400S	450N	450S	500	Fishery
Area (sq km)	278	789	752	1 216	1 348	514	4 897
Count (stations)	3	9	3	11	8	6	40
Mean (/sq m)	0.0000	0.0056	0.0109	0.0064	0.0110	0.0055	0.0077
CV		0.33	0.32	0.31	0.29	0.57	0.16
Millions	0.00	4.41	8.19	7.76	14.78	2.81	37.94

Reader_year corrected analysis (Method 1)

2007							
Major	350	4001	4002	4502	4501	500	Fishery
Area (sq km)	278	789	752	1 216	1 348	514	4 897
Count (stations)	3	10	3	6	5	5	32
Mean (/sq m)	0.0124	0.0506	0.0573	0.1008	0.0817	0.0924	0.0749
CV	0.52	0.22	0.29	0.18	0.24	0.21	0.11
Millions	3.45	39.93	43.09	122.58	110.17	47.48	366.71

Reader_year corrected analysis (Method 1)

2008							
Major	350	4001	4002	4502	4501	500	Fishery
Area (sq km)	278	789	752	1 216	1 348	514	4 897
Count (stations)	4	6	3	9	9	10	41
Mean (/sq m)	0.0031	0.0168	0.0180	0.0362	0.0321	0.0229	0.0259
CV	0.62	0.22	0.42	0.11	0.13	0.16	0.08
Millions	0.86	13.23	13.57	44.00	43.33	11.77	126.76

Reader_year corrected analysis (Method 1)

2009							
Major	350	4001	4002	4502	4501	500	Fishery
Area (sq km)	278	789	752	1 216	1 348	514	4 897
Count (stations)	6	6	2	10	14	5	43
Mean (/sq m)	0.0050	0.0320	0.0611	0.0621	0.0751	0.0746	0.0587
CV	0.51	0.17	0.57	0.08	0.09	0.15	0.10
Millions	1.39	25.27	45.94	75.48	101.20	38.34	287.61

Reader_year corrected analysis (Method 1)

2013							
Major	350	4001	4002	4502	4501	500	Fishery
Area (sq km)	278	789	752	1 216	1 348	514	4 897
Count (stations)	5	4	6	8	13	4	40
Mean (/sq m)	0.0080	0.0153	0.0182	0.0367	0.0271	0.0290	0.0253
CV	0.55	0.28	0.26	0.14	0.16	0.24	0.09
Millions	2.23	12.03	13.72	44.59	36.54	14.88	124.00

Reader_year corrected analysis (Method 1)

2016							
Major	350	400A	400B	450A	450B	500	Fishery
Area (sq km)	278	789	752	1 216	1 348	514	4 897
Count (stations)	3	5	4	12	13	3	40
Mean (/sq m)	0.0035	0.0456	0.0161	0.0384	0.0335	0.0512	0.0341
CV	0.76	0.40	0.34	0.16	0.14	0.35	0.12
Millions	0.98	35.96	12.08	46.67	45.18	26.34	167.20

Reader_year corrected analysis (Method 1)

2019							
Major	350	400N	400S	450N	450S	500	Fishery
Area (sq km)	278	789	752	1 216	1 348	514	4 897
Count (stations)	3	9	3	11	8	6	40
Mean (/sq m)	0.0097	0.0222	0.0405	0.0804	0.0526	0.0583	0.0509
CV	0.88	0.46	0.30	0.13	0.21	0.16	0.10
Millions	2.70	17.51	30.44	97.81	70.97	29.96	249.39