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Tini a Tangaroa

Estimating the abundance of scampi in SCI 3 (Mernoo Bank) in 2016

New Zealand Fisheries Assessment Report 2018/24

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Photographic and trawl surveys of scampi in SCI 3 were conducted in September/October 2016 from the NIWA research vessel *Kaharoa*. This area was previously surveyed in 2001 (only the western area), 2009, 2010 and 2013. Photographic survey estimates of burrow abundance show a steady increase since 2009, while estimates of scampi abundance (visible animals, and animals out of burrows) show a smaller relative increase. Trawl survey catch rates also show an overall increase since 2009, with both the burrow abundance and trawl survey biomass increasing by a factor of 2.2 to 2.6 since 2009. However, both burrow abundance and trawl survey biomass estimates remain well below survey estimates from 2001 (when only part of the survey area was surveyed). Over 6300 scampi were tagged and released, as part of an investigation into growth, with releases distributed across the fishing ground. To date, recaptures have been relatively low (32 individuals).

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 2015/16 were 974 t (limit 1224 t). The landings for scampi in SCI 3 were 336 t (TACC 340 t) in 2015/16, decreasing from the 374 t landed in 2014/15, but maintaining the recent higher levels, compared to the 2007/08 to 2010/11 period. The other major fisheries are SCI 1 (TACC 120 t), SCI 2 (TACC 133 t), SCI 4A (TACC 120 t), and SCI 6A (TACC 306 t). Scampi are taken by light trawl gear, which catches the 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 emerged 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). 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 (Cryer et al. 2003a, Froglia et al. 1997, Smith et al. 2003, Tuck et al. 1997), 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 the European scampi, and has been carried out in New Zealand since 1998. Surveys in SCI 3 started in 2001, and this report documents the sixth survey of this area. Similar survey time series are available for SCI 1 (1998 – 2015, eight surveys), SCI 2 (2003 – 2015, six surveys), and SCI 6A (2007 – 2016, five 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 2014, Tuck 2016a, Tuck 2016b, Tuck & Dunn 2012), although the relationship between scampi and burrows may be different in SCI 6A (Tuck & Dunn 2009, Tuck et al. 2017, Tuck et al. 2007), and the index of visible scampi is used as the abundance index for this area (Tuck 2017).

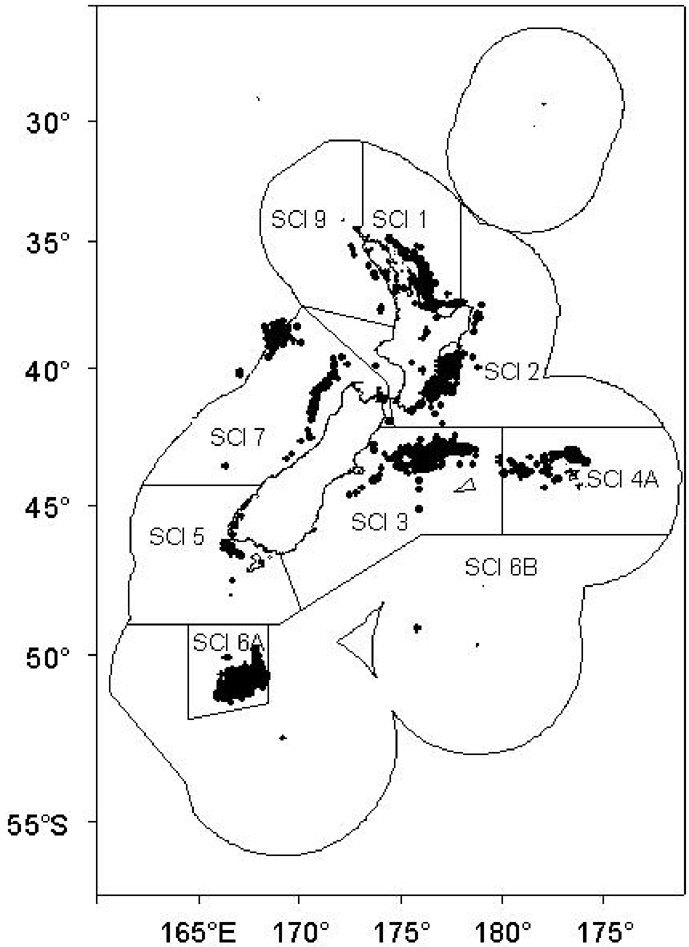

Figure 1: Spatial distribution of the scampi fishery since 1988–89 (ungroomed data). Each dot shows the mid-point of one or more tows recorded on TCEPR with scampi as the target species.

OVERALL OBJECTIVE: To estimate the abundance of scampi (*Metanephrops challengeri*) in SCI 3.

OBJECTIVES:

1. To estimate the relative abundance of scampi using photographic techniques and trawl survey information.
2. To estimate growth of scampi from tagging.

2. METHODS

The survey design was presented to the MPI Shellfish Working Group in August 2016. Previous surveys in SCI 3 have been conducted in 2001 (two surveys, before and after the short fishing season in that year; covering only strata 902 and 903 in SCI 3; (Cryer et al. 2003b)), and more recently in 2009, 2010 and 2013 (covering the full survey area shown in Figure 2) (Tuck et al. 2011, Tuck et al. 2015a). The original survey strata (902 and 903) were based on depth contours within the region, although some parts of stratum 902 (to the north-west and south of the main area of 902) have received very little scampi fishing (Figure 3).

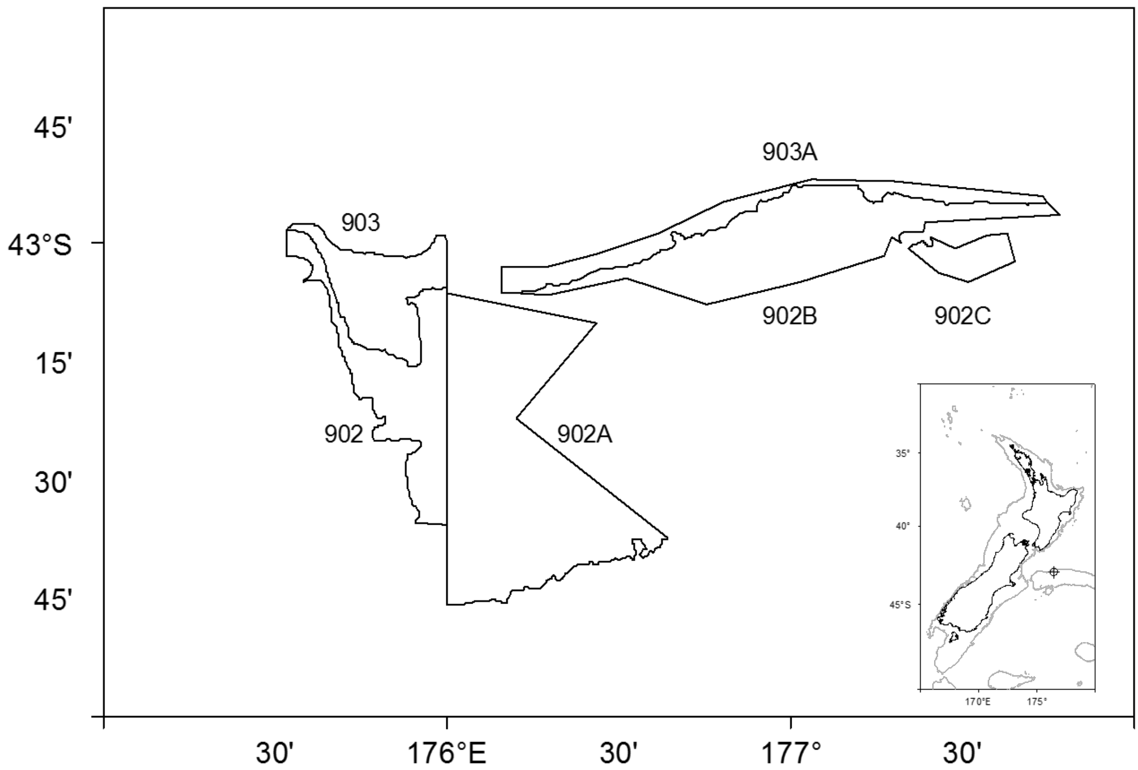

Figure 2: Survey strata for the 2009-2010 photographic surveys of SCI 3. Inset shows general vicinity of survey, and 500 m depth contour. Strata 902 and 903 were also surveyed in the two surveys conducted in 2001. See Figure 4 for area surveyed in 2016.

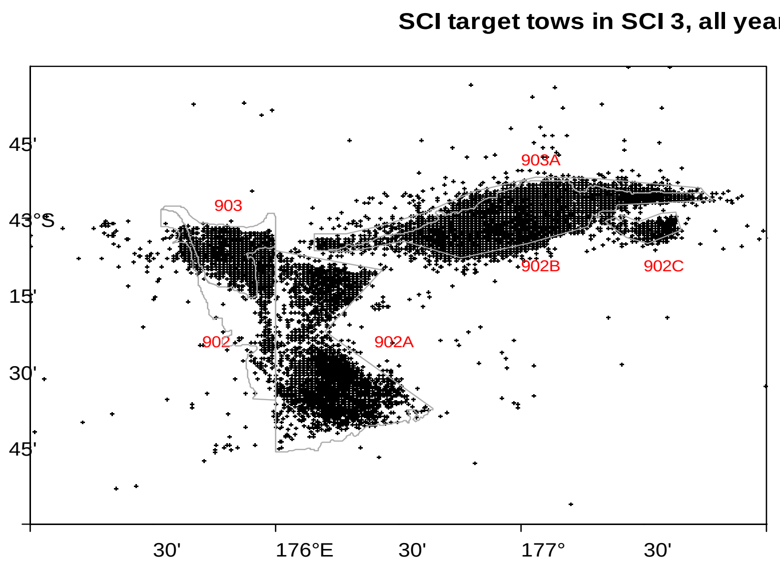

Figure 3: Survey strata for SCI 3 surveys shown in relation to the distribution of SCI targeted effort recorded on TCEPRs.

Parts of stratum 902 appear to be unsuitable for scampi (no commercial fishing recorded, survey stations there have not recorded burrows), and prior to the 2013 survey this stratum was therefore revised accordingly to exclude this unsuitable area. In addition, it was recommended by the Working Group in August 2013 that the larger strata (902A and 902B) were split (roughly in half), to account for any potential spatial patterns in density, and provide better coverage of random station locations across the grounds. Previous surveys have achieved low CVs for the photographic component of the survey (about 8% CV on burrows, 10–20% CV on animals, with 64 stations), while CVs for the trawl component have been more variable (5–25% CV on biomass with 18 stations). Dividing strata 902A and 902B leads to eight strata in total, and with a target of three stations per stratum, this requires an additional 6 trawl stations (about two days of work). Therefore, along with a revision of the strata, a slightly greater emphasis was put on trawl sampling (increasing trawl stations to 24, reducing photographic stations to 50), while not increasing the length of the survey. For the 2013 survey this resulted in CVs of 6% for the photo component and 12% for the trawl component.

For the 2016 survey, stations were allocated to strata on the basis of burrow abundance data from the 2013 survey using the *allocate* package (R.I.C.C Francis, unpublished), to minimise the CV obtained given a fixed number of stations. Random locations for photographic stations were generated within each strata using the Random Stations package (Doonan & Rasmussen 2012), constrained to keep all stations at least 2 nautical miles apart. The first three photographic stations from each strata were also assigned as trawl stations, with minimum distance between each trawl station checked, and a station dropped and the next on the list selected if the distance was less than 4 nautical miles. Numbers of stations allocated to the revised spatial strata (as used in 2013 and 2016) are provided in Table 1 and Figure 4.

Table 1: Details of strata and number of stations planned for SCI 3 survey in 2016. Mean burrow density from 2013 survey and the percentage of recent SCI 3 SCI landings by strata are also provided.

Stratum	Area (km^2)	Depth (m)	Photo stations	Trawl stations	Burrow density (m^{-2})	% of SCI catches
902	439.84	300–400	3	3	0.112	0.08
903	552.08	400–500	6	3	0.207	0.03
902A1	700.41	300–400	3	3	0.064	7.72
902A2	1432.38	300–400	11	3	0.084	33.56
902B1	605.42	300–400	11	3	0.205	19.52
902B2	660.97	300–400	6	3	0.192	33.32
902C	172.45	300–400	3	3	0.166	5.32
903A	459.18	400–500	7	3	0.165	0.46

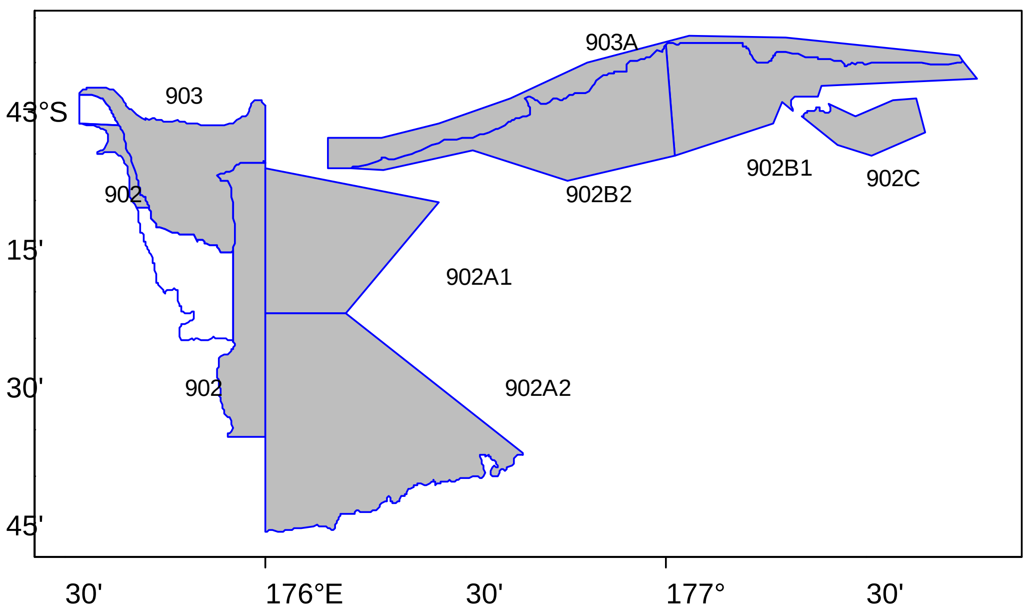

Figure 4: Revised strata for the 2013 survey of SCI 3, also used in the 2016 survey.

The survey, undertaken in September/October 2016, was the sixth photographic survey of the SCI 3 area. The previous surveys were conducted in 2001 (two surveys), and 2009, 2010 and 2013 (Cryer et al. 2003b, Tuck et al. 2011, Tuck et al. 2015a). The survey was stratified on the basis of depth (100 m bands) and region, using the overall extent of the 2009 and 2010 surveys (Figure 4). The 2013 modifications to survey strata in SCI 3 (described above) have excluded minimal scampi fishing, and the survey coverage accounts for about 99% of landings from the fishery over its history (Tuck 2013, Tuck 2016b).

Photographic survey

Photographic sampling was undertaken between about 0600 and 1800 NZST to coincide with the period of maximum trawl catchability of scampi (Tuck 2009). Although the time of day should have no direct effect on the visibility 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 has two main 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.

We used NIWA's deepwater digital camera system, with automatic flash exposure. Images were stored on 1 GB "flash" cards in the camera, allowing us to save images in raw format. After the completion of each station, the images were downloaded from the camera via a USB cable (avoiding the need to open the camera housing after each station), and the images were saved to the hard drives of a dedicated PC, and backed up on portable hard drives.

The camera was triggered using a combination of a time-delay switch and a micro ranger, as its cage was held in the critical area 2–4 m off the bottom 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, while the timer triggered the camera to also take a picture, once the time limit was reached. Our target was to expose roughly 40 frames as the ship drifted, using a time delay sufficient to ensure that adjacent photographs did not overlap. Visibility was good at most sites, but at some stations a substantial swell meant that maintenance of the critical altitude off the bottom was difficult, and run 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 exposed in the critical area were of good or excellent quality.

The locations of planned photographic stations are shown in Figure 5.

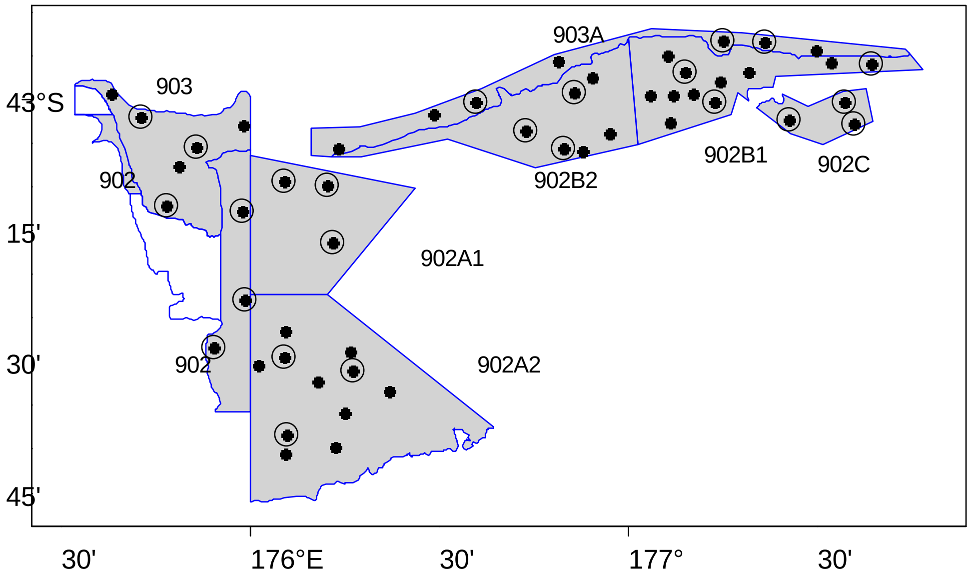

Figure 5: Station locations within each strata for 2016 survey for SCI 3. Camera stations are represented by closed symbols and trawl stations are represented by open symbols.

Image selection and scoring

Images were examined and scored using a standardised protocol (developed under MPI project SCI2000/02) (Cryer et al. 2002) that was followed a team of six trained readers. For each image, the main criteria of 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 was clearly and sharply visible was estimated and marked using polygons created using NICAMS (NIWA Image Capture and Manipulation System, developed using the ImageJ software). Each reader then assessed the number of burrow openings using the standardized protocol (Cryer et al. 2002). We have defined "major" and "minor" burrow openings which are, respectively, the type of opening at which scampi are usually observed, and the "rear" openings associated with most burrows. Based on our 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 6). We classified each opening (whether major or minor) as "highly characteristic" or "probable", based on the extent to which each is characteristic of burrows observed to be used by New Zealand scampi. A recent investigation into mud burrowing megafauna in scampi grounds concluded that it is unlikely the 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 considered to be "characteristic", were not counted. Our counts of burrow openings may, therefore, be conservative. Many ICES stock assessments of the related *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. 1997). We counted burrow openings rather than assumed burrows because burrows were 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. 1998, Marrs et al. 1996).

The criteria used by readers to judge whether or not a burrow should be scored are, of necessity, partially subjective; because we cannot be certain that any particular burrow belongs to a *M. challengeri* and if it is currently inhabited unless the individual is photographed in the burrow. However, after viewing large numbers of scampi associated with burrows, we have developed a set of descriptors that guide our decisions (Cryer et al. 2002). Using these descriptors as a guideline, each reader assesses each potential burrow opening (paying more attention to attributes with a high ranking such as surface tracks, sediment fans, a shallow descent angle) and scored it only if it is "probably" a scampi burrow. Scores were saved within 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.

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") was more than 1 were 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 was 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 re-examined by all readers. During the second read 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 provided 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 2016 survey data with previous surveys, the reference set for SCI 3 (initially generated in 2010, and including images from 2001 and 2009)(Tuck et al. 2011) was augmented with images from 2013, and reread in 2016 (at the same time as the SCI 3 2016 survey images), with each image in each reference set being read by all 6 readers, using 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 2016b). 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 strata and the 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 framework, with stratum_year, reader_year and readable area (offset) as explanatory variables, and station_year as random effects, with an assumed Poisson error distribution. The significance of terms was tested by sequentially dropping terms from a full model.

Data analysis

Burrow and scampi counts from photographs were analysed using methods analogous to those in the *SurvCalc* Analysis Program (Francis & Fu 2012) for trawl surveys, as previously described to the Shellfish Fishery Assessment Working Group (SFAWG). 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. The mean density of burrow openings at a given station was estimated as the sum of all counts (major or minor openings) divided by the sum of all readable areas. 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). Only indices for major burrow openings and for visible scampi are presented here because the SFAWG has agreed that these are likely to be the most reliable indices. The minor sensitivity of the indices to the reader “bias” identified for SCI 1 (Cryer et al. 2002) was investigated with reader_year “correction factors” calculated for each reader in each survey, and a “corrected” density index for major burrow openings is also provided. Confidence in the estimates was examined through a bootstrapping procedure, resampling stations (with replacement) within strata, selecting one reader (from three) within station.

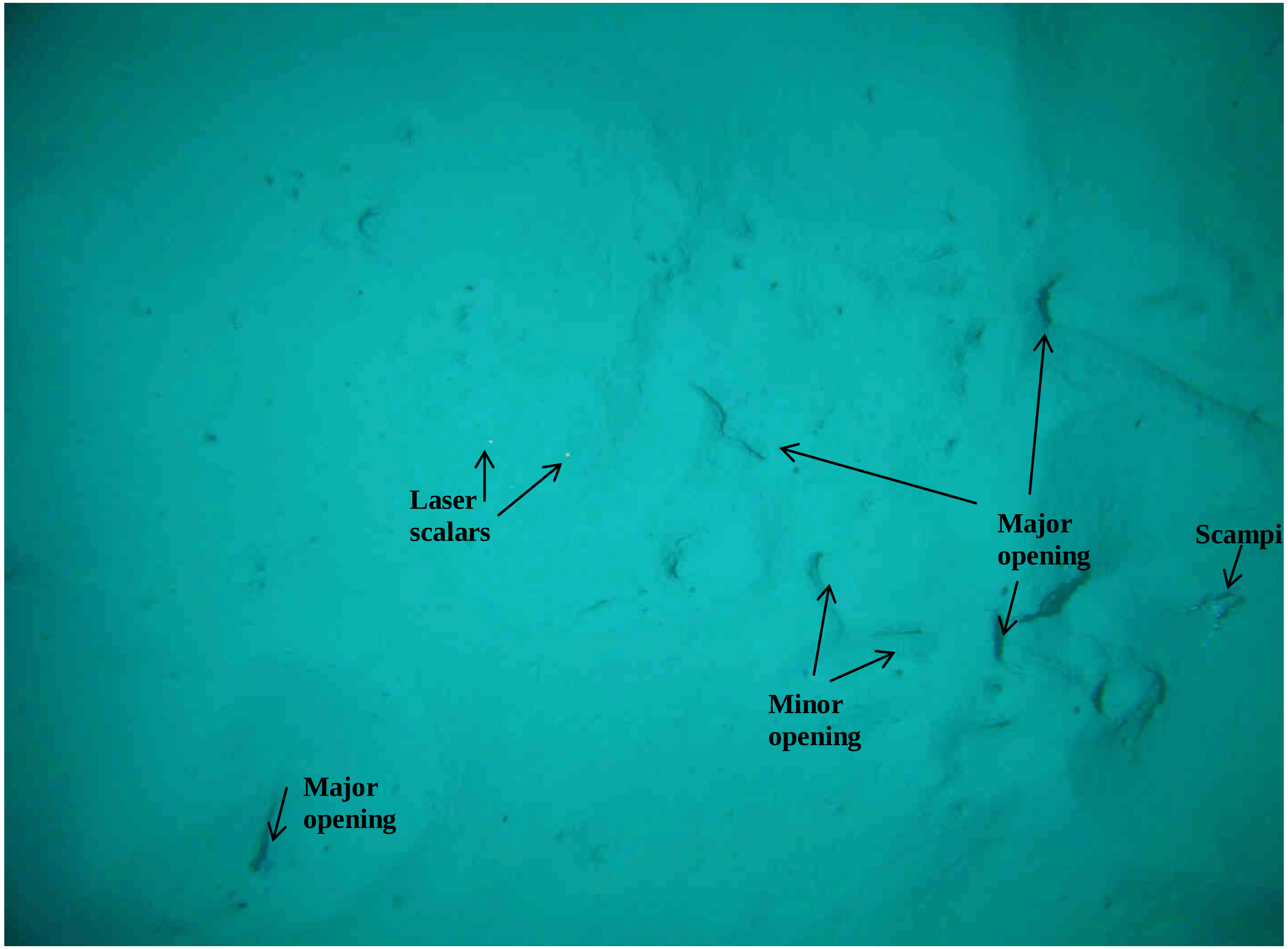

Figure 6: Example image from March 2006 survey in SCI 2 showing laser scaling dots, several characteristic scampi burrows and one large visible scampi.

Trawl survey

Trawl survey sampling was undertaken between roughly 0600 and 1800 NZST, during the second half of the voyage, after the photographic stations had been completed. The first three photographic stations allocated to each strata were reselected as trawl stations. Trawl sampling was conducted with the *RV Kaharoa* scampi trawl, as with previous scampi surveys from this vessel (Cryer et al. 2003b, Tuck et al. 2011). Trawl survey analysis was undertaken using the SurvCalc package (Francis & Fu 2012).

Scampi tagging

The second objective of the voyages was to tag and release scampi to investigate growth. Where time allowed, all scampi caught on each tow that were considered in good health (lively with no visible injuries) 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 a punctured carapace were excluded, and 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 (Figure 7) with sequentially numbered streamer tags (Hallprint type 4S), 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 at the moult, and therefore the T-bar tag approach has also been examined. The next scheduled research sampling in SCI 3 will be in 2019, and so it is anticipated that recoveries will be from commercial fishing activity. Tag mortality studies have not been included in previous SCI 3 surveys, and were not conducted during this survey, as it is considered very unlikely tag recapture data would be used to estimate stock size for this fishery.

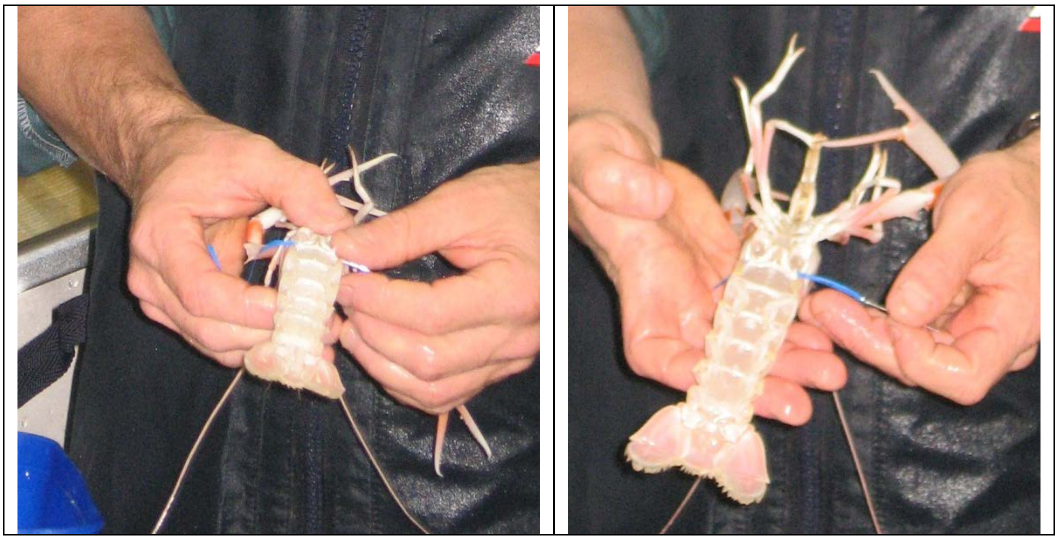

Figure 7: Photographs showing location of streamer tag in scampi.

3. RESULTS

The voyage was completed successfully between 7th September and 4th October 2016. All photographic and trawl stations were completed, but some trawl stations were moved from their planned locations, owing to skipper concerns over the suitability of the seabed for trawling over the whole station.

3.1 Photographic survey

Visibility was good at most sites, but at some stations the substantial swell meant that maintenance of the critical altitude off the bottom was difficult, and run duration was extended when this occurred to allow for images lost to over and under exposure. Almost all the photographs exposed in the critical area were of good or excellent quality. Over the whole survey, a total area of 10 249 m^2 of seabed was viewed (acceptable quality images), with an average of 37.5 images at each station, an average seabed area viewed by each image of 5.36 m^2, providing an average area viewed of 201 m^2 at each station (Table 2).

Calibration of across years and between readers was conducted in a single analysis (as described above), rather than the two stage reader calibration process implemented previously (Tuck et al. 2009). The significance of effects was tested by sequentially adding terms, and a model testing the null hypotheses that there were no stratum_year or reader_year no 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 2: Details of strata and number of photo stations completed for SCI 3 survey in 2016. Mean viewed images and area viewed per station also provided.

			Photo stations		Viewed	
Stratum	Area (km^2)	Depth (m)	Planned	Completed	images	Area viewed (m^2)
902	439.84	300–400	3	3	37.3	5.71
903	552.08	400–500	6	7	39.7	5.58
902A1	700.41	300–400	3	3	36.7	5.11
902A2	1432.38	300–400	11	11	35.8	4.68
902B1	605.42	300–400	11	11	37.8	5.18
902B2	660.97	300–400	6	6	39.0	6.29
902C	172.45	300–400	3	3	41.0	5.82
903A	459.18	400–500	7	7	36.6	5.21

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 for SCI 3.

	Df	Sum sq	Mean Sq	F value	P
Reader_year	28	786.81	28.100	28.100	<0.0001
Stratum_year	27	286.14	10.598	10.598	<0.0001

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 ith reader_year, and $\bar{c}$ is the average of the reader_year indices. These correction factors were applied to the individual reader reads for the analysis of the image data, estimating overall abundance.

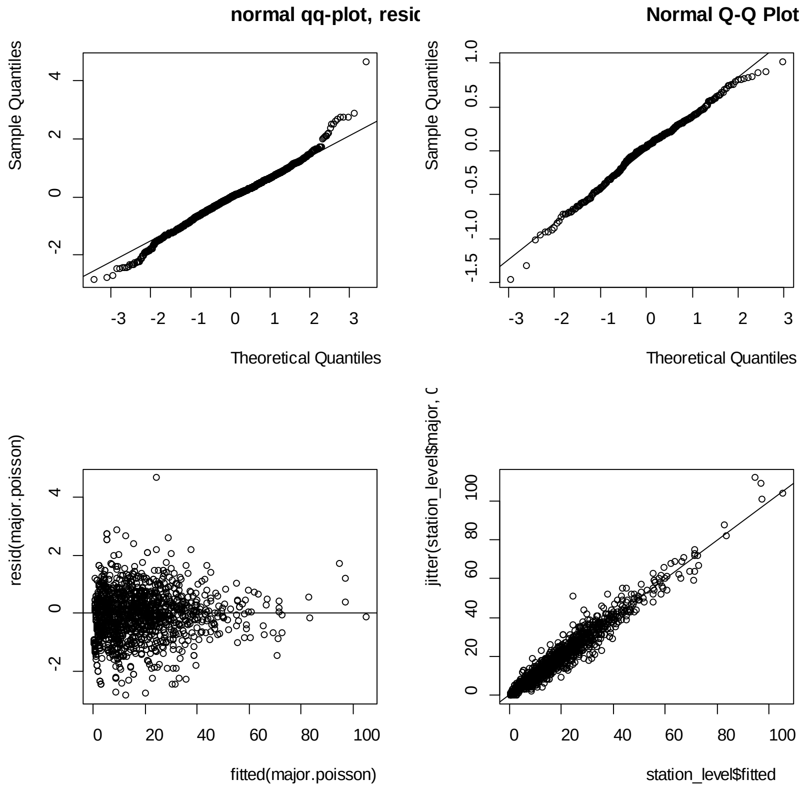

Figure 8: Diagnostic plots for generalised linear mixed effects model examining reader_year effects on counts of major burrow openings.

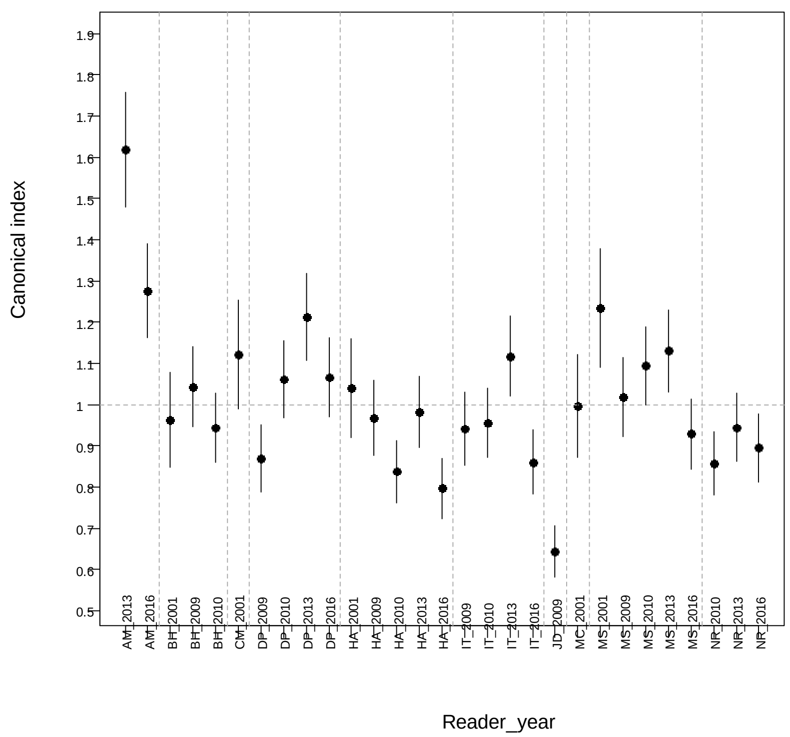

Figure 9: Canonical indices (and CV) for reader_year terms from a generalised linear mixed model relating the count of major burrow openings to reader_year, stratum_year, and readable area for SCI 3.

Table 4: Canonical indices (and variance, CV and upper and lower 95% CI) 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 for SCI 3.

Reader_Year	Indices	Variance	cvs	Upper 95	Lower 95	Correction factor
AM_2013	1.6187	0.0194	0.0860	1.8969	1.3404	0.6266
AM_2016	1.2760	0.0131	0.0895	1.5045	1.0476	0.7949
BH_2001	0.9630	0.0132	0.1192	1.1926	0.7333	1.0533
BH_2009	1.0431	0.0096	0.0938	1.2388	0.8475	0.9723
BH_2010	0.9442	0.0071	0.0889	1.1122	0.7763	1.0742
CM_2001	1.1206	0.0175	0.1180	1.3850	0.8561	0.9052
DP_2009	0.8687	0.0067	0.0945	1.0329	0.7045	1.1676
DP_2010	1.0609	0.0088	0.0884	1.2485	0.8733	0.9561
DP_2013	1.2119	0.0112	0.0874	1.4237	1.0001	0.8369
DP_2016	1.0667	0.0093	0.0905	1.2599	0.8736	0.9508
HA_2001	1.0400	0.0145	0.1160	1.2813	0.7988	0.9752
HA_2009	0.9685	0.0083	0.0942	1.1511	0.7860	1.0472
HA_2010	0.8373	0.0056	0.0892	0.9867	0.6878	1.2114
HA_2013	0.9815	0.0075	0.0884	1.1552	0.8079	1.0333
HA_2016	0.7965	0.0054	0.0924	0.9437	0.6493	1.2734
IT_2009	0.9417	0.0079	0.0943	1.1194	0.7641	1.0770
IT_2010	0.9553	0.0072	0.0886	1.1246	0.7860	1.0618
IT_2013	1.1175	0.0095	0.0874	1.3129	0.9220	0.9076
IT_2016	0.8607	0.0061	0.0909	1.0171	0.7043	1.1784
JD_2009	0.6442	0.0039	0.0974	0.7697	0.5187	1.5746
MC_2001	0.9960	0.0155	0.1248	1.2446	0.7473	1.0184
MS_2001	1.2340	0.0209	0.1171	1.5229	0.9450	0.8220
MS_2009	1.0176	0.0091	0.0938	1.2084	0.8268	0.9968
MS_2010	1.0938	0.0092	0.0876	1.2854	0.9023	0.9273
MS_2013	1.1307	0.0100	0.0882	1.3302	0.9311	0.8970
MS_2016	0.9291	0.0072	0.0916	1.0993	0.7589	1.0917
NR_2010	0.8564	0.0059	0.0894	1.0096	0.7033	1.1843
NR_2013	0.9446	0.0070	0.0884	1.1117	0.7775	1.0738
NR_2016	0.8948	0.0068	0.0920	1.0595	0.7302	1.1335

Reader_year effects were also tested for scampi counts in the same way, but were not found to be significant, supporting our previous observations that identification and counting of scampi is far less subjective than burrow openings (Tuck et al. 2016, Tuck et al. 2017).

The number of completed stations by strata are provided in Table 2. The locations of photographic stations, and relative burrow densities, are shown in Figure 10. The uncorrected burrow density estimates ranged from 0.01 – 0.29 m^{-2}, and correction factors had relatively little effect on overall density estimates. Densities of all scampi, and scampi out of their burrows ranged from 0 to 0.10 (Figure 11) and 0.02 m^{-2}, respectively. Scaling the densities to the combined area of the strata (5022 km^2) leads to abundance estimates of 747 million burrows or, assuming 100% occupancy, a maximum abundance estimate of the same number of animals (Table 5). Analysis of all SCI 3 surveys (with and without reader_year corrections) are presented in Appendix 1.

Overall, the density of major burrow openings was estimated to be 0.148 m^{-2}. The density was highest in both parts of 902B, 903A and in 903. 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 original corrected estimates (Table 5).

The estimated mean density of all visible scampi was 0.04 m^{-2}, with the highest density observed in the 902B1, 902B2 and 902C strata. Scaling the observed densities of visible scampi in each stratum produces a minimum abundance estimate of 206 million animals for the surveyed area (Table 6). Counting animals out of burrows and walking free on the surface reduced this estimate to 21 million animals (Table 7). The CVs for visible scampi and scampi out of burrows from the bootstrapped estimates were higher than those for burrows, but comparable with those of the original estimates.

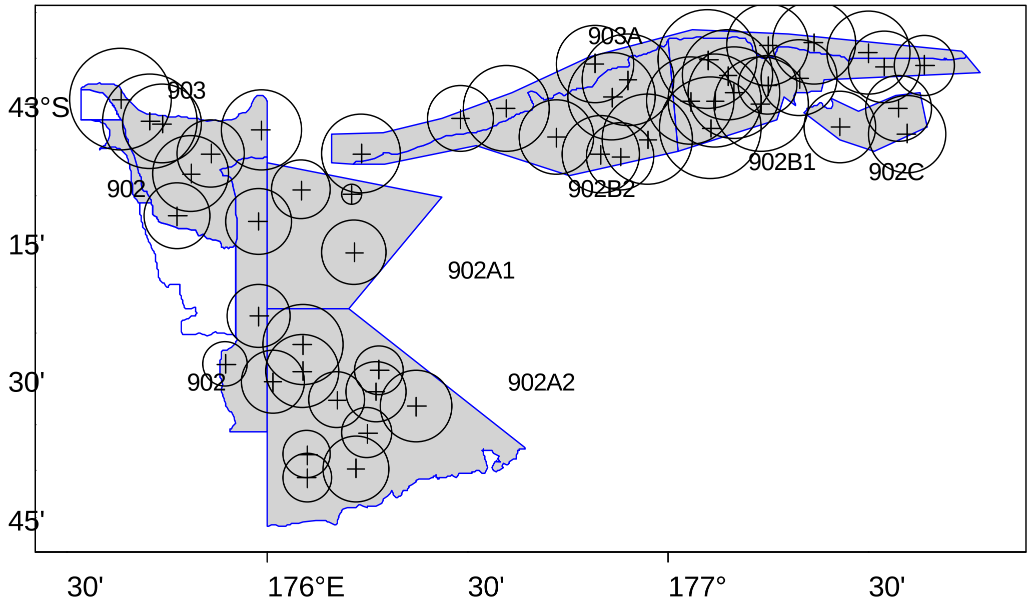

Figure 10: Station locations for the 2016 photographic survey of SCI 3 (the area of each circle represents relative burrow density). Largest circle represents 0.29 burrows .m^{-2} (uncorrected for reader_year).

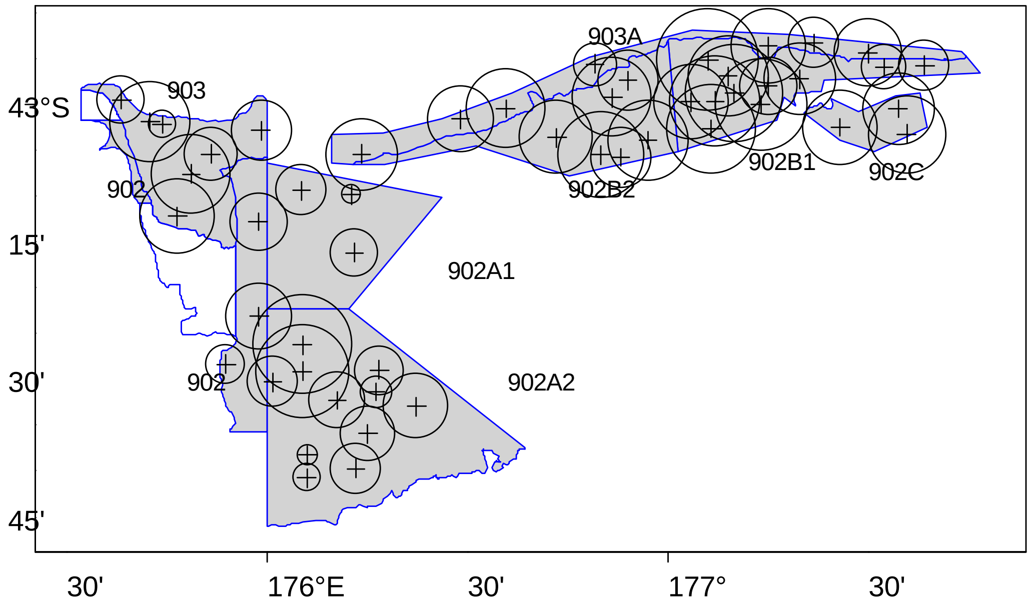

Figure 11: Station locations for the 2016 photographic survey of SCI 3 (the area of symbol represents relative visible scampi density). Largest circle represents 0.10 visible scampi .m^{-2}.

Table 5: Estimates of the density and abundance of major burrow openings from the SCI 3 survey for 2016. Counts by each reader have been scaled by correction factors for reader_year. 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.

Major burrows	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	Bootstrap
Area (km^2)	440	553	700	1432	605	661	172	459	5022	
Stations	3	7	3	11	11	6	3	7	51	
Mean density ($.m^{-2}$)	0.0992	0.1962	0.0801	0.1156	0.2110	0.1980	0.1556	0.1927	0.1489	0.1483
CV	0.18	0.13	0.44	0.11	0.10	0.10	0.06	0.08	0.05	0.05
Abundance (Millions)	43.63	108.47	56.06	165.57	127.66	130.90	26.77	88.46	747.53	746.38

Table 6: Estimates of the density and abundance of visible scampi from the SCI 3 survey for 2016. 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.

Visible scampi	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	Bootstrap
Area (km^2)	440	553	700	1432	605	661	172	459	5022	
Stations	3	7	3	11	11	6	3	7	51	
Mean density ($.m^{-2}$)	0.0318	0.0409	0.0179	0.0360	0.0646	0.0558	0.0570	0.0445	0.0412	0.0411
CV	0.26	0.21	0.43	0.26	0.14	0.12	0.05	0.15	0.08	0.08
Abundance (Millions)	14.01	22.63	12.50	51.52	39.07	36.90	9.81	20.42	206.86	206.76

Table 7: Estimates of the density and abundance of scampi out of burrows from the SCI 3 survey for 2016. Scampi "out" were defined as those for which the telson was not obscured by the burrow. 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.

Scampi out	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	Bootstrap
Area (km^2)	440	553	700	1432	605	661	172	459	5022	
Stations	3	7	3	11	11	6	3	7	51	
Mean density ($.m^{-2}$)	0.0038	0.0074	0.0009	0.0021	0.0089	0.0047	0.0075	0.0044	0.0042	0.0041
CV	1.00	0.42	0.49	0.43	0.26	0.30	0.24	0.49	0.16	0.15
Abundance (Millions)	1.66	4.07	0.64	2.97	5.38	3.11	1.29	2.00	21.13	21.13

The trend in abundance in major burrow openings is shown in Figure 12 (for individual strata) and Figure 13 (for larger areas). For the combined 902 and 903 strata (surveyed since 2001), the abundance shows a considerable decline between 2001 and 2009 (to about 25% of the 2001 estimated abundance), but an increase between 2009 and 2013, and the 2016 estimate being comparable with that of 2013 (at almost 70% of the 2001 estimated abundance). Estimated abundance for the current survey extent (encompassing over 98% of scampi targeted fishing in the SCI 3 area (Tuck 2013), but only surveyed since 2009) shows a steady increase (Figure 13). The survey estimates which were not corrected for reader_year effect (Appendix 1) are generally similar to the corrected estimates, and show the same pattern. The indices of scampi abundance (visible scampi, and scampi out of burrows) are presented in Figure 14. These show a similar decline between 2001 and 2009 (for the 902 and 903 strata). Since 2009, the abundance estimates of scampi have increased, although the overall SCI 3 survey area estimate of visible scampi declined between 2009 and 2010.

Overall survey mean densities for the current and previous surveys in SCI 3 are provided in Table 8. The count of visible scampi as a percentage of burrows (which could be considered a minimum estimate of occupancy) was 27% in 2016. The range observed is comparable with other SCI survey data (Tuck et al. 2013). The proportion of scampi seen out of their burrows (scampi out as a proportion of all visible scampi) was 10% in 2016, which is towards the lower end of the range observed in other surveys in SCI 1, SCI 2 and SCI 3 (Tuck et al. 2013), but lower than observed in SCI 6A (Tuck et al. 2015b).

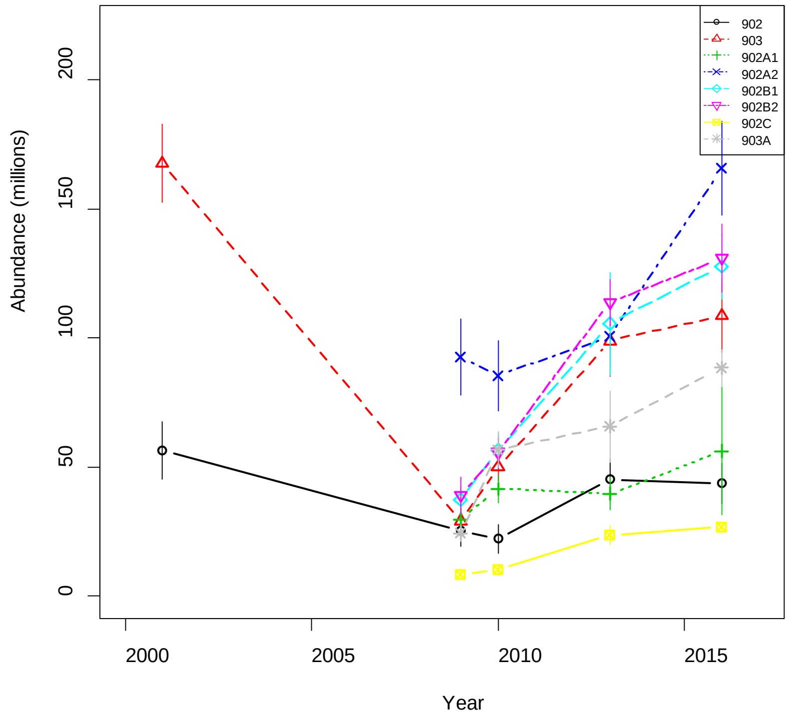

Figure 12: Estimated abundance of scampi major burrow openings (± CV) for SCI 3 by strata. The 2001 estimates are based on the October/November survey.

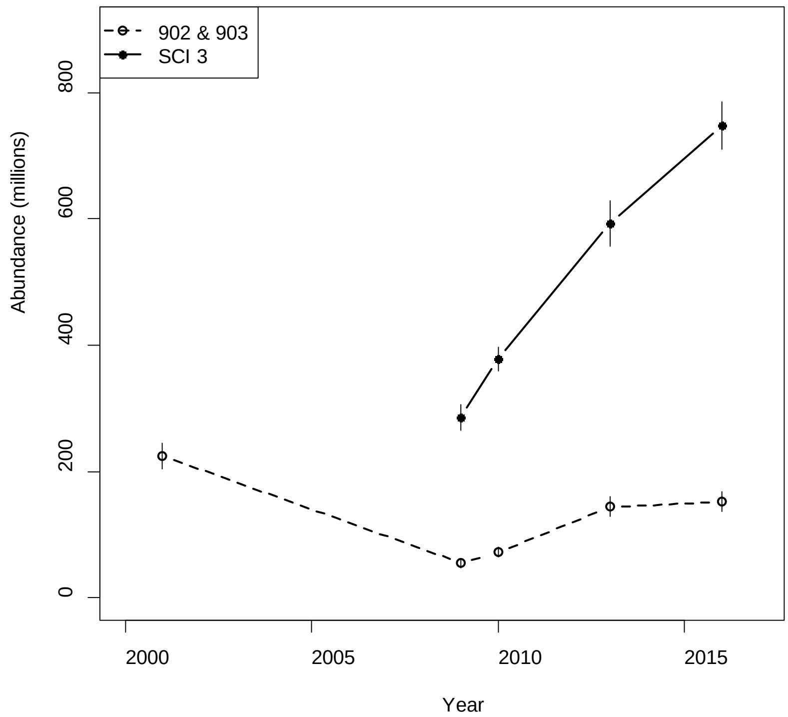

Figure 13: Estimated abundance of scampi major burrow openings (± CV) for SCI 3 for combined 902 and 903 strata, and whole SCI 3 survey area. The 2001 estimate is based on the October/November survey.

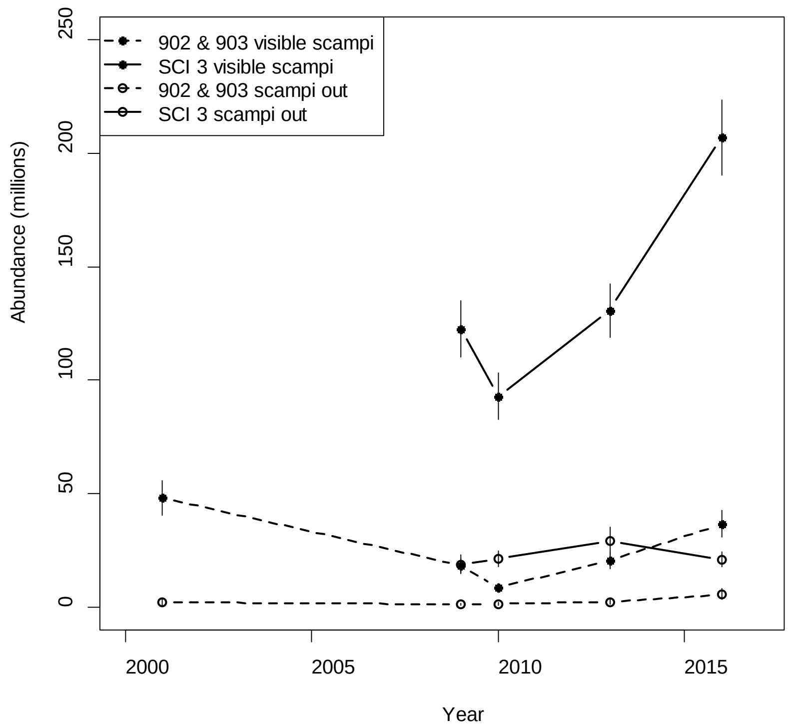

Figure 14: Estimated abundance of scampi (± CV) for SCI 3 for combined 902 and 903 strata, and whole SCI 3 survey area. The 2001 estimates are based on the October/November survey.

Table 8. Overall survey mean densities (m^{-2}) of major burrow openings, visible scampi and scampi out of burrows, for the series of SCI 3 surveys (data for the combined 902 & 903 strata and the current survey coverage presented in separate blocks).

	Major opening	Visible scampi	Scampi "out"	Scampi as % of openings	% of visible scampi "out"
902&903					
2001	0.2256	0.0486	0.0022	21.54%	4.44%
2009	0.0547	0.0185	0.0013	33.78%	7.11%
2010	0.0725	0.0087	0.0016	12.02%	18.35%
2013	0.1451	0.0207	0.0024	14.25%	11.60%
2016	0.1532	0.0369	0.0058	24.09%	15.65%
SCI 3					
2009	0.0569	0.0244	0.0037	42.88%	15.16%
2010	0.0753	0.0185	0.0043	24.58%	23.24%
2013	0.1180	0.0261	0.0058	22.12%	22.22%
2016	0.1489	0.0412	0.0042	27.67%	10.21%

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 strata for the 2016 survey in Table 9, and are compared with previous survey estimates in Table 10.

Table 9: Trawl survey estimates by strata for SCI 3. Mean values expressed as kg.nautical $mile^{-1}$ with the *Kaharoa* scampi trawl gear.

	Stratum								
Strata	902	903	902A1	902A2	902B1	902B2	902C	903A	Total
Area (km^2)	440	552	700	1432	605	661	172	459	5023
N. stations	3	3	3	3	3	3	3	3	24
Mean ($kg.mile^{-1}$)	5.42	7.39	5.49	7.62	14.07	9.69	8.67	10.10	8.42
CV	0.23	0.17	0.21	0.25	0.45	0.24	0.29	0.21	0.12
Biomass (tonnes)	51.48	88.10	83.03	235.81	183.94	138.32	32.28	100.17	913.12

The overall raised trawl survey estimate was 913 tonnes (12% CV) (Table 9), or 14.23 million animals (14% CV) (Table 10). Given that scampi live in burrows and are only available to trawl gear when they emerge on the seabed, this is likely to be a considerable underestimate of the stock biomass. This represents a considerable increase on the 2013 survey estimate (551 t, 12% CV), which was comparable with the 2010 estimate (596 t, 4% CV), and an increase from 2009 (418 t, 26% CV) (Table 10 and Figure 16). In the early part of the series (2001), only the western strata were surveyed. Biomass in stratum 902 in 2016 appears comparable with 2001, while the biomass in stratum 903 appears to have declined, and for the combined 902 and 903 strata, the 2016 biomass is just over half that estimated in 2001. However, all the estimates at the stratum level have high CVs. The trends in scampi abundance estimated from the trawl surveys follow very similar patterns to those shown by biomass (Figure 17).

Over the whole SCI 3 trawl survey, 621 kg of scampi were caught, accounting for 5.7% of the total catch (10 978 kg), with scampi being the fifth most abundant species. By weight, the most, dominant species in the catches were javelinfish (20.5%), sea perch (17.4%), hoki (12.7%), Bollon's rattail (9.5%), scampi (5.7%), silver warehou (5.4%), and dark ghost shark (5.2%). Within commercial fishing activities, scampi forms a greater proportion of the total catch, as bycatch mitigation approaches are now used to reduce the finfish catch. A reduction in fish bycatch in the commercial fishery has been noted in recent years with the introduction of this mitigation (Anderson 2012).

Table 10: Trawl survey estimates of scampi biomass by stratum and year for SCI 3, calculated on basis or revised stratum area for 902.

Biomass	2001 pre fishery				2001 post fishery				2009				2010				2013				2016			
	N	Mean	CV	tonnes	N	Mean	CV	tonnes	N	Mean	CV	tonnes	N	Mean	CV	tonnes	N	Mean	CV	tonnes	N	Mean	CV	tonnes
902	2	6.68	0.55	63.43					3	3.35	0.45	31.80	2	2.38	0.19	22.58	3	7.59	0.36	72.10	3	5.42	0.23	51.48
903	3	17.53	0.27	209.04	2	13.73	0.01	163.73	3	0.71	0.49	8.44	2	2.22	0.14	26.42	3	4.56	0.40	54.37	3	7.39	0.17	88.1
904	1	5.25		50.23	1	10.80		103.33																
902A									4	6.40	0.36	295.54	3	7.53	0.06	347.73								
902A1																	3	5.95	0.15	90.07	3	5.49	0.21	83.03
902A2																	2	2.84	0.58	87.90	3	7.62	0.25	235.81
902B									4	1.81	0.41	49.66	3	4.50	0.09	123.35	4	5.98	0.08	163.80				
902B1																					3	14.07	0.45	183.94
902B2																					3	9.69	0.24	138.32
902C									3	6.51	0.10	24.18	2	10.13	0.06	37.65	3	10.33	0.05	38.38	3	8.67	0.29	32.28
903A									3	0.85	0.09	8.49	3	3.86	0.19	38.36	3	4.50	0.17	44.69	3	10.10	0.21	100.17
Total	6	10.41		322.70	3	8.62		267.07	20	3.85	0.26	418.12	15	5.49	0.04	596.08	21	5.08	0.12	551.31	24	8.42	0.12	913.12

Numbers	2001 pre fishery				2001 post fishery				2009				2010				2013				2016			
	N	Mean	CV	millions	N	Mean	CV	millions	N	Mean	CV	millions	N	Mean	CV	millions	N	Mean	CV	millions	N	Mean	CV	millions
902	2	85.40	0.54	0.81					3	34.55	0.27	0.33	2	23.27	0.56	0.22	3	89.46	0.33	0.85	3	69.92	0.22	0.66
903	3	263.44	0.32	3.14	2	218.00	0.05	2.60	3	9.29	0.43	0.11	2	34.86	0.16	0.42	3	78.00	0.44	0.93	3	133.33	0.29	1.59
904	1	98.00		0.94	1	190.00		1.82																
902A									4	84.98	0.33	3.92	3	103.14	0.08	4.76								
902A1																	3	29.58	0.32	0.45	3	73.78	0.35	1.12
902A2																	2	59.32	0.22	1.84	3	119.67	0.29	3.70
902B									4	27.25	0.48	0.75	3	75.73	0.14	2.08	4	108.79	0.18	2.98				
902B1																					3	232.56	0.51	3.04
902B2																					3	159.00	0.21	2.27
902C									3	74.01	0.03	0.27	2	143.41	0.05	0.53	3	146.86	0.11	0.55	3	116.67	0.29	0.43
903A									3	11.98	0.16	0.12	3	62.79	0.12	0.62	3	58.71	0.20	0.58	3	142.67	0.20	1.41
Total	6	157.78		4.89	3	142.51		4.42	20	50.64	0.24	5.50	15	79.43	0.06	8.63	21	75.30	0.11	8.17	24	131.20	0.14	14.23

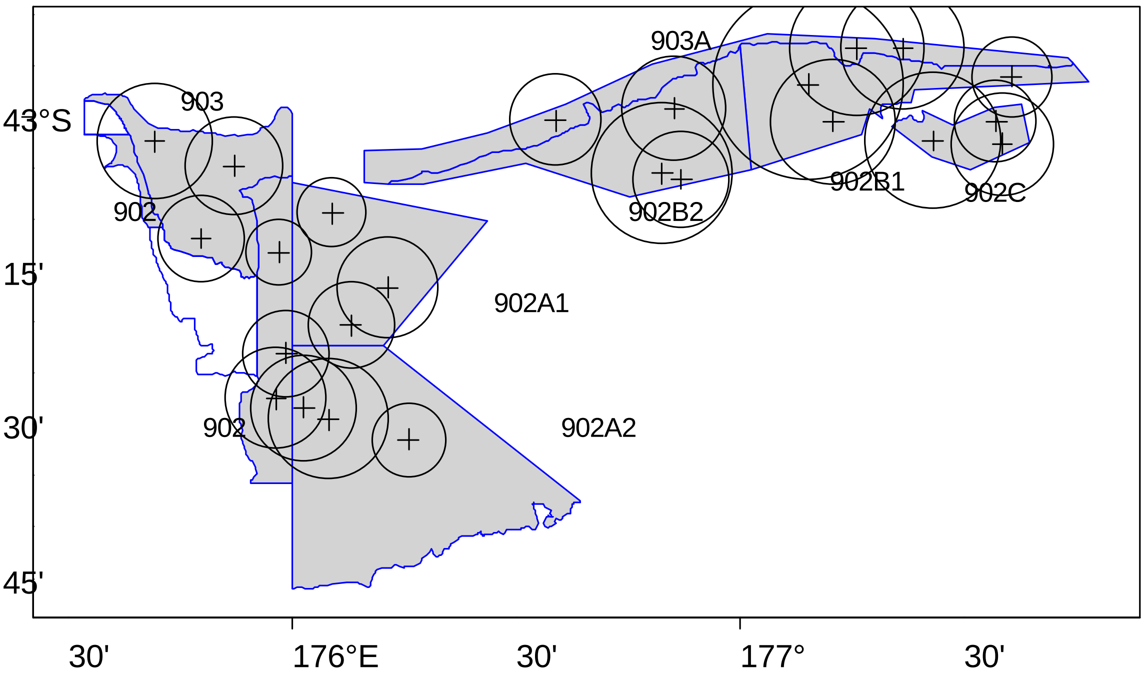

Figure 15: Trawl station locations for the 2016 photographic survey of SCI 3 (the area of each circle represents the relative scampi catch rate). Largest circle represents 26 kg.mile^{-1}.

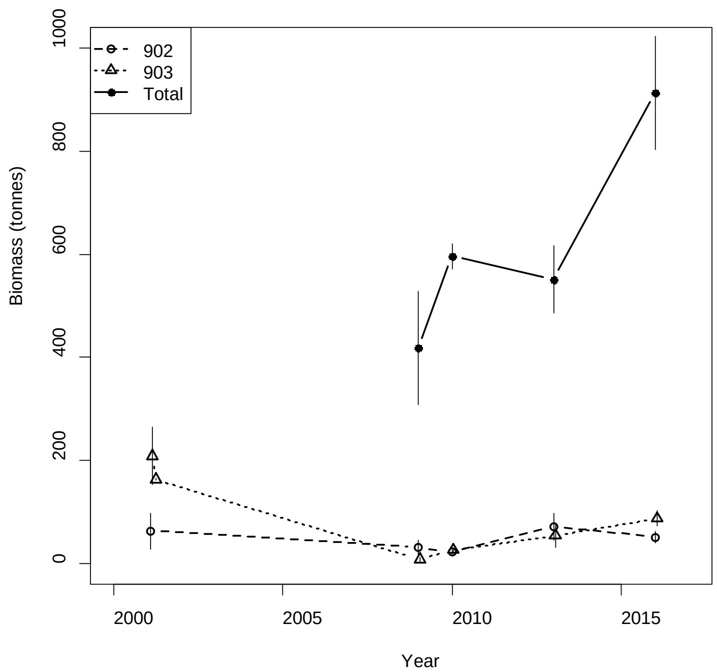

Figure 16: Plot of time series of trawl survey biomass estimates (± CV) for SCI 3. Total estimate includes biomass estimates for strata not surveyed in 2001.

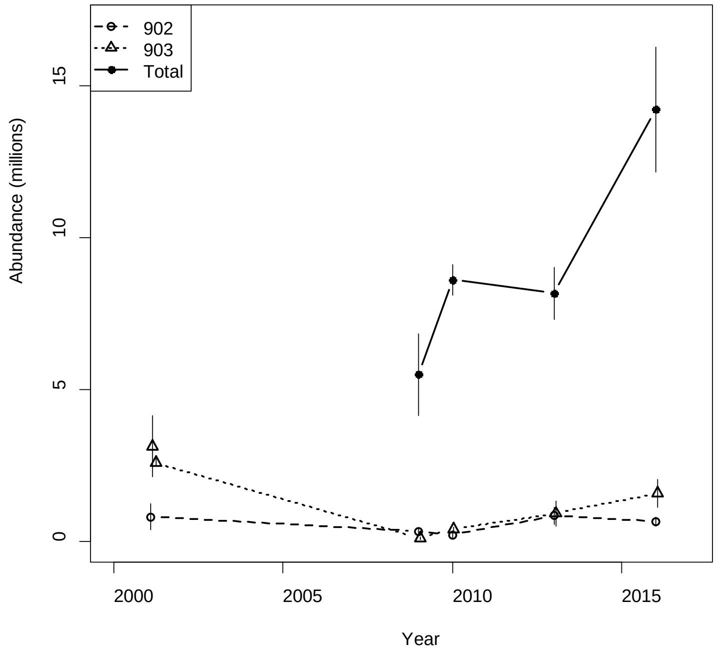

Figure 17: Plot of time series of trawl survey abundance estimates (± CV) for SCI 3. Total estimate includes abundance estimates for strata not surveyed in 2001.

Estimates of scampi abundance (numbers) from the trawl survey for all years are also provided in Table 10. Across the survey series, strata level estimates of abundance from trawl and photographic survey methods (burrows and visible animals) are positively correlated (r^2=0.69 and 0.79, for burrows and visible scampi, respectively) (Figures 18 and 19).

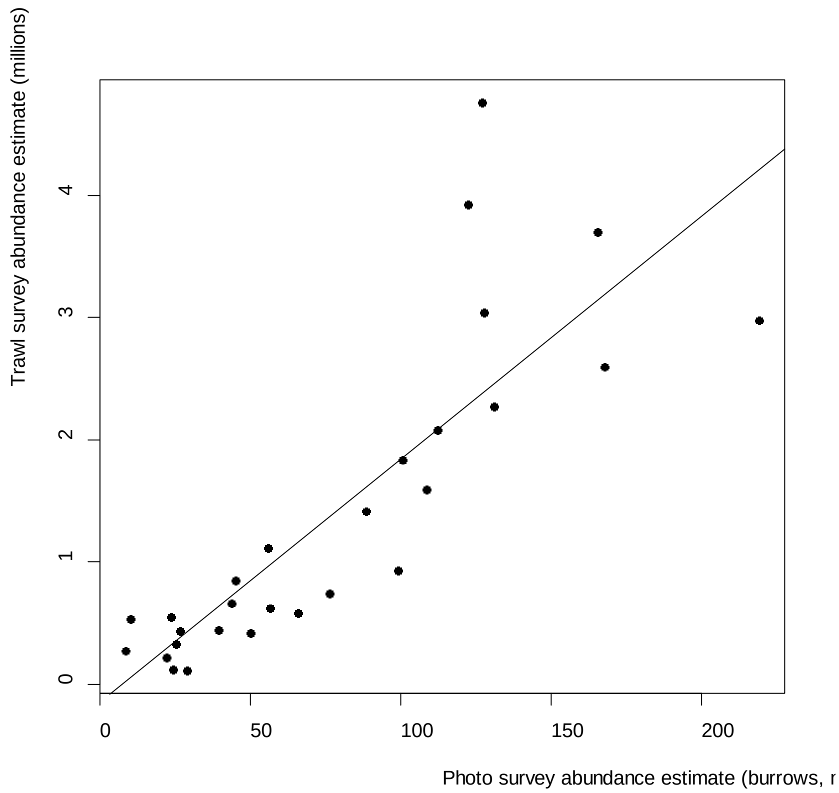

Figure 18: Relationship between strata level photographic survey estimates of burrow abundance and trawl survey estimates of scampi abundance. Line represents least squares linear regression (r^2 = 0.69).

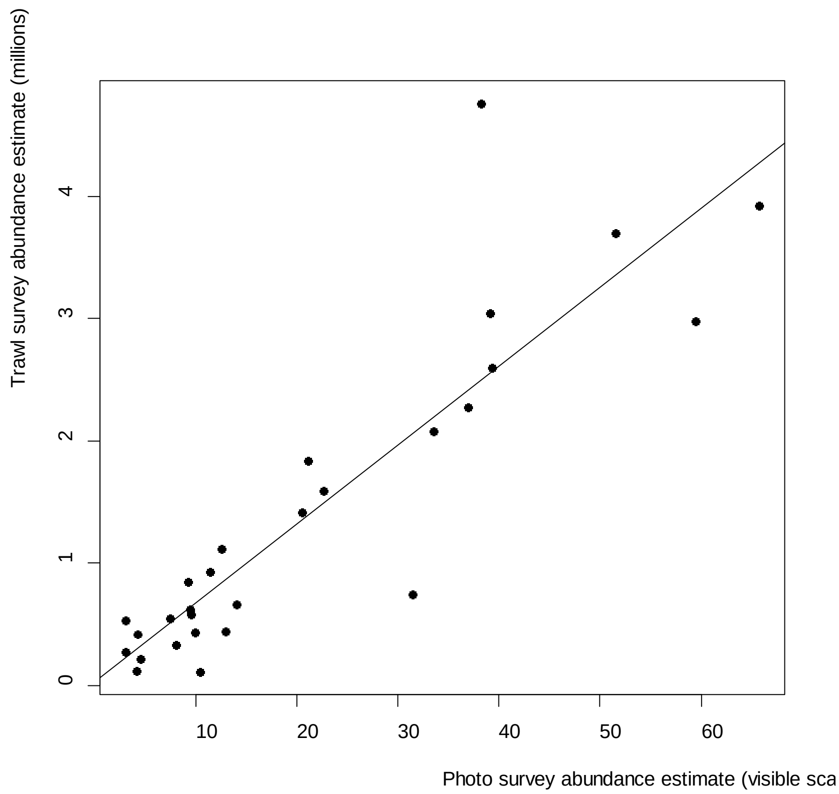

Figure 19: Relationship between strata level photographic survey estimates of visible scampi abundance and trawl survey estimates of scampi abundance. Line represents least squares linear regression (r^2 = 0.79).

3.3 Tagging

Undamaged active scampi were tagged from each trawl catch, and released for the growth investigation. The next scheduled research sampling in SCI 3 will be in 2019, and so it is anticipated that recoveries will be from commercial fishing activity. Over the whole survey, over 6300 scampi were tagged with either streamer (6152) or T-bar (193) tags, which were then released. Catches were predominantly male, and this is reflected in the tagged animals (4336 males, 2009 females). The length distributions of the tagged scampi are presented in Figure 20. The predominance of males in catches and tag releases is consistent with previous surveys in SCI 3 at this time of year (Tuck et al. 2011, Tuck et al. 2015a). The tagged scampi were released at 62 separate locations (Figure 21). No scampi were released while the vessel was fishing, and no recaptures were made by the *Kaharoa* during the survey. Tagging mortality was not investigated during this voyage (following recommendations of the Shellfish Assessment Working Group), but when examined elsewhere, short term (up to 7 days) survival has been estimated at 76% in SCI 2 (Tuck et al. 2013) and 88% in SCI 6A (Tuck et al. 2015b), the difference assumed to be related to warmer surface water temperatures in SCI 2.

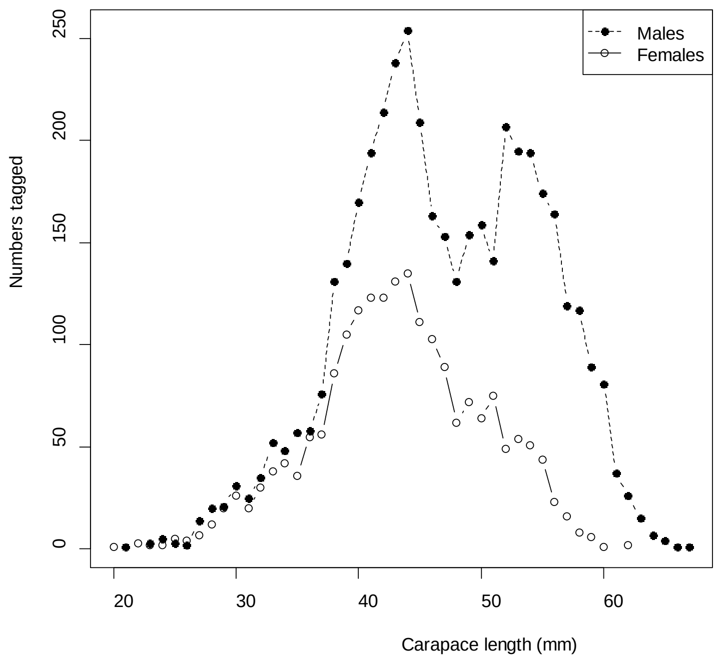

Figure 20: Length distribution of scampi tagged and released during the 2016 SCI 3 survey.

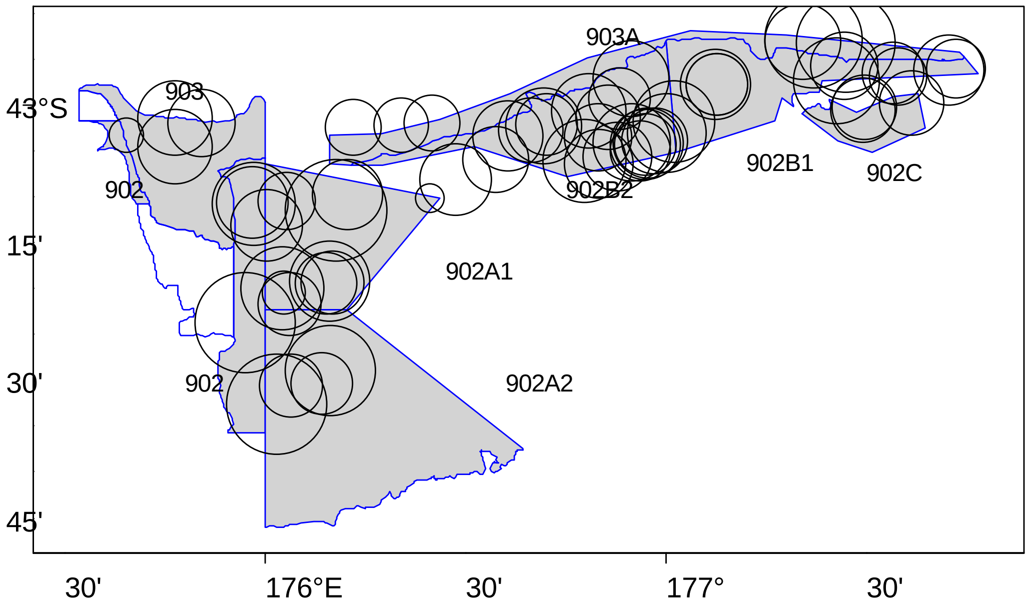

Figure 21: Map showing distribution of 2016 scampi release locations (the area of each circle represents the relative scampi numbers released at each location). Largest circles represent 205 animals. The smallest release batch was 18 animals, and the average release batch was 106 animals

To date (September 2017) 32 recoveries have been reported to NIWA. Over a slightly longer period we have had 287 recoveries from the scampi tagged in SCI 6A (tagged in March 2016). Recoveries have been consistently low from SCI 3, although recoveries from the 2016 tagging are an improvement on previous years. Tag recoveries have also been low from SCI 1 and SCI 2. 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, or higher recaptures may reflect greater exploitation rates in SCI 6A, where emergence from burrows may be greater.

4. CONCLUSIONS

A photographic and trawl surveys of scampi in SCI 3 was conducted in September and October 2016. The survey was conducted over the same strata as the 2013 survey, having been slightly modified from that in surveys in 2009 and 2010, to exclude some areas considered unsuitable for scampi. The photographic survey estimated a scampi burrow abundance of 746 million over the whole area, continuing the trend in increasing abundance observed since 2009. Trawl survey catch rates in SCI 3 also increased, continuing the overall trend since the 2009 survey. The trawl survey estimate of scampi biomass over the whole SCI 3 survey area was 913 tonnes. However, both burrow abundance and trawl survey biomass estimates for the area consistently surveyed remain well below survey estimates from 2001. Across the survey series, stratum level estimates of abundance from trawl and photographic survey methods (burrows and visible animals) are positively correlated, with visible animals showing a stronger correlation with trawl survey estimates than burrow counts.

Over 6300 scampi were tagged and released, as part of an investigation into growth, and to date, 32 scampi have been recaptured.

5. ACKNOWLEDGMENTS

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, while Dean Stotter, Steve George, Emma Jones, Caroline Roberts and Alaric McCarthy (University of Auckland) were the scientific staff for the voyage. We thank the EPA for their help in complying with the requirements of the Exclusive Economic Zone and Continental Shelf Regulations 2013, in relation to the release of tagged scampi. Scampi tag recoveries have been made and reported to NIWA by the fishing industry. The voyage was funded within project DEE201604. This report was reviewed by Bruce Hartill.

6. REFERENCES

Aguzzi, J.; Sarda, F.; Abello, P.; Company, J.B.; Rotllant, G. (2003). Diel and seasonal patterns of *Nephrops norvegicus* (Decapoda : Nephropidae) catchability in the western Mediterranean. *Marine Ecology Progress Series 258*: 201–211.

Anderson, O.F. (2012). Fish and invertebrate bycatch and discards in New Zealand scampi fisheries from 1990–91 until 2009–10. *New Zealand Aquatic Environment and Biodiversity Report 100*: 65 p.

Bell, M.C.; Redant, F.; Tuck, I.D. (2006). *Nephrops* species. *In*: Phillips, B. (ed.). Lobsters: biology, management, aquaculture and fisheries, pp. 412–461. Blackwell Publishing, Oxford.

Cryer, M.; Downing, K.; Hartill, B.; Drury, J.; Armiger, H.J.; Middleton, C.; Smith, M.D. (2003a). Digital photography as a stock assessment tool for *Metanephrops challengeri* on New Zealand's continental slope. *FAO fisheries proceedings ; 3/1 In:Deep Sea 2003 : Conference on the Governance and Management of Deep-sea Fisheries. Part 1. Conference reports. 1-5 December 2003, Queenstown, New Zealand / edited by Ross Shotton.*: 299-307.

Cryer, M.; Hartill, B.; Drury, J.; Tuck, I.D.; Armiger, H.; Smith, M.; Middleton, C. (2003b). Indices of relative abundance for scampi, *Metanephrops challengeri*, based on photographic surveys before and after fishing in QMA 3, 2001. Final Research Report for Ministry of Fisheries research project SCI2000-02. 33 p.

Cryer, M.; Hartill, B.; Drury, J.; Tuck, I.D.; Cadenhead, H.J.; Smith, M.D.; Middleton, C. (2002). Indices of relative abundance for scampi, *Metanephrops challengeri*, based on photographic surveys in QMA 1, 1998–2002. Final Research Report for Ministry of Fisheries Research Projects SCI2000-02 & SCI2001-01. 16 p.

Cryer, M.; Stotter, D.R. (1997). Trawling and tagging of scampi off the Alderman Islands, western Bay of Plenty, September 1995 (KAH9511). *New Zealand Fisheries Data Report 84*.

Cryer, M.; Stotter, D.R. (1999). Movement and growth rates of scampi inferred from tagging, Alderman Islands, western Bay of Plenty. *NIWA Technical Report No. 49*: 36 p.

Doonan, I.J.; Rasmussen, S. (2012). Random Station User Manual (RandonStation v1.00-2012-06-13). *NIWA unpublished report No.* 47 p.

Francis, R.I.C.C. (1999). The impact of correlations in standardised CPUE indices. *New Zealand Fisheries Assessment Research Document 1999/42*: 30.

Francis, R.I.C.C.; Fu, D. (2012). SurvCalc v1.2. *NIWA Technical Report 134*.

Froglia, C.; Atkinson, R.J.A.; Tuck, I.D.; Arneri, E. (1997). Underwater television survey, a tool to estimate *Nephrops* stock biomass in the Adriatic trawling grounds. *Proceedings of the Croatian Acadamy, Split 1995*: 657–666.

ICES (2007). Report of the workshop on the use of UWTV surveys for determining abundance in *Nephrops* stocks throughout European waters (WKNEPHTV). *ICES ACFM No.* 291 p.

Marrs, S.J.; Atkinson, R.J.A.; Smith, C.J. (1998). The towed underwater TV technique for use in stock assessment of *Nephrops norvegicus. ICES Report of the Study Group on life histories of Nephrops norvegicus La Coruna, Spain.*

Marrs, S.J.; Atkinson, R.J.A.; Smith, C.J.; Hills, J.M. (1996). Calibration of the towed underwater TV technique for the use in stock assessment of *Nephrops norvegicus*. *Study project in support of the Common Fisheries Policy No. XIV/1810/C1/94.* 155 p.

Sardà, F.; Aguzzi, J. (2012). A review of burrow counting as an alternative to other typical methods of assessment of Norway lobster populations. *Reviews in Fish Biology and Fisheries 22(2)*: 409-422.

Smith, C.J.; Marrs, S.J.; Atkinson, R.J.A.; Papadopoulou, K.N.; Hills, J.M. (2003). Underwater television for fisheries-independent stock assessment of *Nephrops norvegicus* from the Aegean (eastern Mediterranean) Sea. *Marine Ecology Progress Series 256*: 161–170.

Snedecor, G.W.; Cochran, W.C. (1989). Statistical Methods. Iowa State University Press, Iowa. 503 p.

Tuck, I.D. (2009). Characterisation of scampi fisheries and the examination of catch at length and spatial distribution of scampi in SCI 1, 2, 3, 4A and 6A. *New Zealand Fisheries Assessment Report 2009/27*: 102 p.

Tuck, I.D. (2013). Characterisation and length-based population model for scampi (*Metanephrops challengeri*) on the Mernoo Bank (SCI 3). *New Zealand Fisheries Assessment Report 2013/24*: 165 p.

Tuck, I.D. (2014). Characterisation and length-based population model for scampi (*Metanephrops challengeri*) in the Bay of Plenty (SCI 1) and Hawke Bay/Wairarapa (SCI 2). *New Zealand Fisheries Assessment Report 2014/33*: 172 p.

Tuck, I.D. (2016a). Characterisation and length-based assessment model for scampi (*Metanephrops challengeri*) in the Bay of Plenty (SCI 1) and Hawke Bay– Wairarapa (SCI 2). *New Zealand Fisheries Assessment Report 2016/51*: 194 p.

Tuck, I.D. (2016b). Characterisation and length-based population model for scampi (*Metanephrops challengeri*) on the Mernoo Bank (SCI 3). *New Zealand Fisheries Assessment Report 2016/55*: 221 p.

Tuck, I.D. (2017). Characterisation and length-based population model for scampi (*Metanephrops challengeri*) at the Auckland Islands (SCI 6A). *New Zealand Fisheries Assessment Report 2017/56*: 180 p.

Tuck, I.D.; Atkinson, R.J.A.; Chapman, C.J. (1994). The structure and seasonal variability in the spatial distribution of *Nephrops norvegicus* burrows. *Ophelia 40*: 13–25.

Tuck, I.D.; Chapman, C.J.; Atkinson, R.J.A.; Bailey, N.; Smith, R.S.M. (1997). A comparison of methods for the stock assessment of the Norway lobster, *Nephrops norvegicus* in the Firth of Clyde. *Fisheries Research 32*: 89–100.

Tuck, I.D.; Dunn, A. (2009). Length-based population model for scampi (*Metanephrops challengeri*) in the Bay of Plenty (SCI 1) and Wairarapa / Hawke Bay (SCI 2). Final Research Report for Ministry of Fisheries research project SCI2008-03. 30 p.

Tuck, I.D.; Dunn, A. (2012). Length-based population model for scampi (*Metanephrops challengeri*) in the Bay of Plenty (SCI 1), Wairarapa / Hawke Bay (SCI 2) and Auckland Islands (SCI 6A). *New Zealand Fisheries Assessment Report 2012/1*: 125 p.

Tuck, I.D.; Hartill, B.; Parkinson, D.; Drury, J.; Smith, M.; Armiger, H. (2009). Estimating the abundance of scampi - Relative abundance of scampi, *Metanephrops challengeri*, from a photographic survey in SCI 6A (2009). Final Research Report for Ministry of Fisheries research project SCI2008-01. 26 p.

Tuck, I.D.; Hartill, B.; Parkinson, D.; Smith, M.; Armiger, H.; Rush, N.; Drury, J. (2011). Estimating the abundance of scampi – Relative abundance of scampi, *Metanephrops challengeri*, from photographic surveys in SCI 3 (2009 & 2010). *Final Research Report for Ministry of Fisheries research projects SCI2009-01 & SCI2010-01*: 29 p.

Tuck, I.D.; Parkinson, D.; Armiger, H.; Smith, M.; Miller, A.; Rush, N.; Spong, K. (2015a). Estimating the abundance of scampi in SCI 3 (Mernoo Bank) in 2013. *New Zealand Fisheries Assessment Report 2015/23*: 49 p.

Tuck, I.D.; Parkinson, D.; Armiger, H.; Smith, M.; Miller, A.; Rush, N.; Spong, K. (2015b). Estimating the abundance of scampi in SCI 6A (Auckland Islands) in 2013. *New Zealand Fisheries Assessment Report 2015/10*: 52 p.

Tuck, I.D.; Parkinson, D.; Armiger, H.; Smith, M.; Miller, A.; Rush, N.; Spong, K. (2016). Estimating the abundance of scampi in SCI 1 (Bay of Plenty) and SCI 2 (Wairarapa / Hawke Bay) in 2015. *New Zealand Fisheries Assessment Report 2016/17*: 60 p.

Tuck, I.D.; Parkinson, D.; Armiger, H.; Smith, M.; Miller, A.; Rush, N.; Spong, K. (2017). Estimating the abundance of scampi in SCI 6A (Auckland Islands) in 2016. *New Zealand Fisheries Assessment Report 2017/06*: 40 p.

Tuck, I.D.; Parkinson, D.; Drury, J.; Armiger, H.; Miller, A.; Rush, N.; Smith, M.; Hartill, B. (2013). Estimating the abundance of scampi - Relative abundance of scampi, *Metanephrops challengeri*, from a photographic survey in SCI 1 and SCI 2 (2012). *Final Research Report for Ministry of Fisheries research project SCI2010-02A*: 54 p.

Tuck, I.D.; Parkinson, D.; Hartill, B.; Drury, J.; Smith, M.; Armiger, H. (2007). Estimating the abundance of scampi - relative abundance of scampi, *Metanephrops challengeri*, from a photographic survey in SCI 6A (2007). *Final Research Report for Ministry of Fisheries research project SCI2006-02*: 29 p.

Tuck, I.D.; Spong, K. (2013). Burrowing megafauna in SCI 3. *New Zealand Fisheries Assessment Report 2013/20*: 50 p.

APPENDIX 1:

Summary of photo survey analyses where reader counts are not adjusted for interannual variability, and where GLM coefficients are used to correct for interannual variability.

Uncorrected analysis

2001

Major burrows	902	903	902&903
Area (km^2)	440	553	993
Stations	7	9	16
Mean density ($.m^{-2}$)	0.1328	0.3309	0.2431
CV	0.20	0.09	0.09
Abundance (Millions)	58.42	182.98	241.40

Visible scampi	902	903	902&903
Area (km^2)	440	553	993
Stations	7	9	16
Mean density ($.m^{-2}$)	0.0203	0.0711	0.0486
CV	0.41	0.17	0.16
Abundance (Millions)	8.95	39.30	48.24

Scampi out	902	903	902&903
Area (km^2)	440	553	993
Stations	7	9	16
Mean density ($.m^{-2}$)	0.0000	0.0039	0.0022
CV		0.68	0.68
Abundance (Millions)	0.00	2.14	2.14

Uncorrected analysis

2009

Major burrows	902	903	90211	90212	90221	90222	9023	9031	Fishery	902&903
Area (km^2)	440	553	700	1432	605	661	172	459	5022	
Stations	9	8	8	12	11	8	3	5	64	
Mean density ($.m^{-2}$)	0.0504	0.0470	0.0376	0.0601	0.0572	0.0529	0.0453	0.0468	0.0516	0.0485
CV	0.23	0.18	0.16	0.16	0.16	0.19	0.20	0.14	0.07	0.14
Abundance (Millions)	22.18	25.98	26.29	86.05	34.62	34.95	7.79	21.47	259.33	48.16

Visible scampi	902	903	90211	90212	90221	90222	9023	9031	Fishery	902&903
Area (km^2)	440	553	700	1432	605	661	172	459	5022	
Stations	9	8	8	12	11	8	3	5	64	
Mean density ($.m^{-2}$)	0.0182	0.0187	0.0134	0.0394	0.0269	0.0229	0.0172	0.0089	0.0244	0.0185
CV	0.22	0.24	0.22	0.17	0.15	0.31	0.39	0.25	0.10	0.17
Abundance (Millions)	8.02	10.35	9.39	56.39	16.26	15.15	2.95	4.07	122.59	18.37

Scampi out	902	903	90211	90212	90221	90222	9023	9031	Fishery	902&903
Area (km^2)	440	553	700	1432	605	661	172	459	5022	
Stations	9	8	8	12	11	8	3	5	64	
Mean density ($.m^{-2}$)	0.0010	0.0015	0.0010	0.0048	0.0082	0.0060	0.0013	0.0019	0.0037	0.0013
CV	0.50	0.61	0.69	0.43	0.25	0.60	1.00	0.55	0.22	0.43
Abundance (Millions)	0.45	0.85	0.69	6.82	4.94	3.98	0.23	0.85	18.82	1.31

Uncorrected analysis
2010

Major burrows	902	903	90211	90212	90221	90222	9023	9031	Fishery	902&903
Area (km^2)	440	553	700	1432	605	661	172	459	5022	
Stations	6	9	10	9	11	10	3	4	62	
Mean density (.m^{-2})	0.0476	0.0852	0.0578	0.0550	0.0888	0.0786	0.0562	0.1185	0.0711	0.0686
CV	0.29	0.10	0.14	0.16	0.12	0.10	0.18	0.14	0.05	0.11
Abundance (Millions)	20.96	47.14	40.45	78.74	53.70	51.92	9.67	54.38	356.95	68.10

Visible scampi	902	903	90211	90212	90221	90222	9023	9031	Fishery	902&903
Area (km^2)	440	553	700	1432	605	661	172	459	5022	
Stations	6	9	10	9	11	10	3	4	62	
Mean density (.m^{-2})	0.0101	0.0076	0.0123	0.0207	0.0237	0.0290	0.0176	0.0205	0.0185	0.0087
CV	0.37	0.24	0.23	0.24	0.27	0.15	0.54	0.45	0.11	0.22
Abundance (Millions)	4.46	4.20	8.60	29.63	14.33	19.17	3.02	9.41	92.81	8.66

Scampi out	902	903	90211	90212	90221	90222	9023	9031	Fishery	902&903
Area (km^2)	440	553	700	1432	605	661	172	459	5022	
Stations	6	9	10	9	11	10	3	4	62	
Mean density (.m^{-2})	0.0030	0.0005	0.0044	0.0039	0.0052	0.0062	0.0051	0.0063	0.0043	0.0016
CV	0.60	1.00	0.42	0.40	0.44	0.30	0.63	0.50	0.17	0.53
Abundance (Millions)	1.32	0.25	3.09	5.64	3.17	4.12	0.88	2.91	21.38	1.57

Uncorrected analysis
2013

Major burrows	902	903	90211	90212	90221	90222	9023	9031	Fishery	902&903
Area (km^2)	440	553	700	1432	605	661	172	459	5022	
Stations	6	5	3	18	6	6	3	3	50	
Mean density (.m^{-2})	0.1121	0.2072	0.0640	0.0838	0.2050	0.1922	0.1655	0.1652	0.1362	0.1651
CV	0.16	0.15	0.17	0.13	0.20	0.11	0.18	0.27	0.07	0.11
Abundance (Millions)	49.31	114.61	44.81	120.00	124.05	127.05	28.47	75.82	684.11	163.92

Visible scampi	902	903	90211	90212	90221	90222	9023	9031	Fishery	902&903
Area (km^2)	440	553	700	1432	605	661	172	459	5022	
Stations	6	5	3	18	6	6	3	3	50	
Mean density (.m^{-2})	0.0208	0.0205	0.0184	0.0147	0.0427	0.0509	0.0432	0.0207	0.0261	0.0207
CV	0.34	0.11	0.49	0.19	0.18	0.19	0.20	0.26	0.09	0.17
Abundance (Millions)	9.17	11.36	12.88	21.01	25.85	33.64	7.43	9.51	130.85	20.54

Scampi out	902	903	90211	90212	90221	90222	9023	9031	Fishery	902&903
Area (km^2)	440	553	700	1432	605	661	172	459	5022	
Stations	6	5	3	18	6	6	3	3	50	
Mean density (.m^{-2})	0.0035	0.0016	0.0073	0.0035	0.0115	0.0084	0.0069	0.0066	0.0058	0.0024
CV	0.56	0.63	1.00	0.32	0.28	0.27	0.42	0.31	0.21	0.44
Abundance (Millions)	1.55	0.87	5.09	4.99	6.95	5.55	1.19	3.03	29.22	2.41

Uncorrected analysis
2016

Major burrows	902	903	90211	90212	90221	90222	9023	9031	Fishery	902&903
Area (km^2)	440	553	700	1432	605	661	172	459	5022	
Stations	3	7	3	11	11	6	3	7	51	
Mean density (.m^{-2})	0.0991	0.1886	0.0764	0.1097	0.2056	0.1909	0.1475	0.1805	0.1428	0.1489
CV	0.21	0.14	0.44	0.12	0.10	0.10	0.08	0.08	0.06	0.12
Abundance (Millions)	43.60	104.28	53.46	157.15	124.39	126.21	25.37	82.85	717.30	147.88

Visible scampi	902	903	90211	90212	90221	90222	9023	9031	Fishery	902&903
Area (km^2)	440	553	700	1432	605	661	172	459	5022	
Stations	3	7	3	11	11	6	3	7	51	
Mean density (.m^{-2})	0.0318	0.0409	0.0179	0.0360	0.0646	0.0558	0.0570	0.0445	0.0412	0.0369
CV	0.26	0.21	0.43	0.26	0.14	0.12	0.05	0.15	0.08	0.16
Abundance (Millions)	14.01	22.63	12.50	51.52	39.07	36.90	9.81	20.42	206.86	36.64

Scampi out	902	903	90211	90212	90221	90222	9023	9031	Fishery	902&903
Area (km^2)	440	553	700	1432	605	661	172	459	5022	
Stations	3	7	3	11	11	6	3	7	51	
Mean density (.m^{-2})	0.0038	0.0074	0.0009	0.0021	0.0089	0.0047	0.0075	0.0044	0.0042	0.0058
CV	1.00	0.42	-	0.43	0.26	0.30	0.24	0.49	0.16	0.42
Abundance (Millions)	1.66	4.07	0.64	2.97	5.38	3.11	1.29	2.00	21.13	5.73

Reader_year corrected analysis for burrow counts
2001

Major burrows	902	903	902&903
Area (km^2)	440	553	993
Stations	7	9	16
Mean density ($.m^{-2}$)	0.1281	0.3032	0.2256
CV	0.20	0.09	0.09
Abundance (Millions)	56.36	167.65	224.01

Reader_year corrected analysis for burrow counts
2009

Major burrows	902	903	90211	90212	90221	90222	9023	9031	Fishery	902&903
Area (km^2)	440	553	700	1432	605	661	172	459	5022	
Stations	9	8	8	12	11	8	3	5	64	
Mean density ($.m^{-2}$)	0.0575	0.0526	0.0423	0.0647	0.0617	0.0591	0.0489	0.0531	0.0569	0.0547
CV	0.24	0.17	0.16	0.16	0.15	0.18	0.19	0.13	0.07	0.14
Abundance (Millions)	25.30	29.06	29.62	92.59	37.35	39.06	8.41	24.37	285.77	54.37

Reader_year corrected analysis for burrow counts
2010

Major burrows	902	903	90211	90212	90221	90222	9023	9031	Fishery	902&903
Area (km^2)	440	553	700	1432	605	661	172	459	5022	
Stations	6	9	10	9	11	10	3	4	62	
Mean density ($.m^{-2}$)	0.0502	0.0903	0.0592	0.0596	0.0934	0.0842	0.0594	0.1236	0.0753	0.0725
CV	0.26	0.11	0.13	0.16	0.12	0.10	0.20	0.12	0.05	0.11
Abundance (Millions)	22.08	49.96	41.46	85.39	56.50	55.64	10.22	56.72	377.96	72.04

Reader_year corrected analysis for burrow counts
2013

Major burrows	902	903	90211	90212	90221	90222	9023	9031	Fishery	902&903
Area (km^2)	440	553	700	1432	605	661	172	459	5022	
Stations	6	5	3	18	6	6	3	3	50	
Mean density ($.m^{-2}$)	0.1027	0.1788	0.0565	0.0702	0.1743	0.1720	0.1374	0.1430	0.1180	0.1451
CV	0.18	0.14	0.16	0.12	0.19	0.08	0.16	0.21	0.06	0.11
Abundance (Millions)	45.21	98.88	39.57	100.51	105.46	113.70	23.64	65.62	592.58	144.09

Reader_year corrected analysis for burrow counts
2016

Major burrows	902	903	90211	90212	90221	90222	9023	9031	Fishery	902&903
Area (km^2)	440	553	700	1432	605	661	172	459	5022	
Stations	3	7	3	11	11	6	3	7	51	
Mean density ($.m^{-2}$)	0.0992	0.1962	0.0801	0.1156	0.2110	0.1980	0.1556	0.1927	0.1489	0.1532
CV	0.18	0.13	0.44	0.11	0.10	0.10	0.06	0.08	0.05	0.10
Abundance (Millions)	43.63	108.47	56.06	165.57	127.66	130.90	26.77	88.46	747.53	152.10