Ministry for Primary Industries
Manatū Ahu Matua

Estimating the abundance of scampi in SCI 3 (Mernoo Bank) in 2013

New Zealand Fisheries Assessment Report 2015/23

I.D. Tuck,
D. Parkinson,
H. Armiger,
M. Smith
A. Miller
N. Rush,
K. Spong

ISSN 1179-5352 (online)
ISBN 978-0-477-10592-7 (online)

April 2015

New Zealand Government

Growing and Protecting New Zealand

Requests for further copies should be directed to:

Publications Logistics Officer
Ministry for Primary Industries
PO Box 2526
WELLINGTON 6140

Email: brand@mpi.govt.nz
Telephone: 0800 00 83 33
Facsimile: 04-894 0300

This publication is also available on the Ministry for Primary Industries websites at:
http://www.mpi.govt.nz/news-resources/publications.aspx
http://fs.fish.govt.nz go to Document library/Research reports

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Tuck, I.D.; Parkinson, D.; Armiger, H.; Smith, M.; Miller, A.; Rush, N.; Spong, K. (2015). Estimating the abundance of scampi in SCI 3 (Mernoo Bank) in 2013.

***New Zealand Fisheries Assessment Report 2015/23.* 45 p.**

Photographic and trawl surveys of scampi in SCI 3 were conducted in September/October 2013 from the NIWA research vessel *Kaharoa*. This area was previously surveyed in 2001 (only the western area), 2009 and 2010. 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 were comparable to those of 2010, and higher than those in 2009. Almost 3400 scampi were tagged and released, as part of an investigation into growth, with releases distributed across the fishing ground, to date, recaptures have been low. Forty scampi were released with acoustic tags, divided between three moorings, to investigate emergence patterns. The moorings were successfully recovered in January, providing a deployment duration of over 100 days, and data downloaded. While some animals showed a distinct periodicity in their detectability coincident with a 12.42 hour (tidal) cycle, other animals showed no clear pattern.

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 2012/13 were 730 t (limit 1224 t). The landings for scampi in SCI 3 were 300 t (TACC 340 t) in 2012/13, increasing slightly from 256 t in 2010/11 and 278 t in 2011/12. The other major fisheries are SCI 1 (TACC 120 t), SCI 2 (TACC 100 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 (Froglia et al. 1997, Tuck et al. 1997, Cryer et al. 2003a, 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 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 fifth survey of this area. Longer survey time series are available in SCI 1 (1998 – 2013, seven surveys) and SCI 2 (2003 – 2013, five surveys), while the series for SCI 6A is slightly shorter (2007 – 2013, four 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 and SCI 2 (Tuck & Dunn 2012, Tuck 2014), although the relationship between scampi and burrows may be different in SCI 6A (Tuck et al. 2007, Tuck & Dunn 2009).

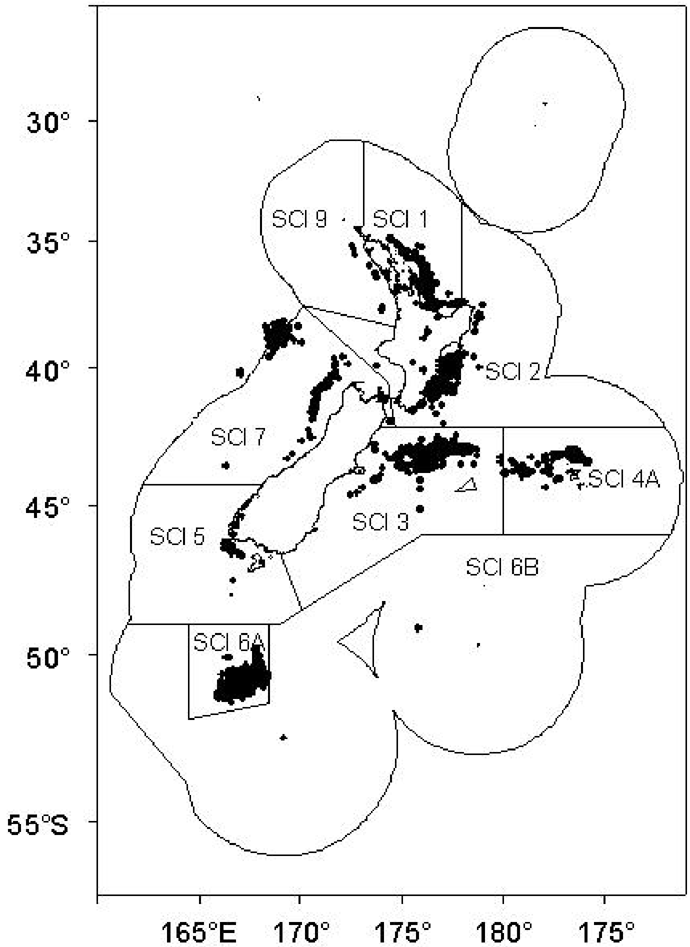


Figure 1: Spatial distribution of the scampi fishery since 1988–89 (ungroomed data). Each dot shows the mid-point of one or more tows recorded on TCEPR with scampi as the target species.

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.
3. To investigate scampi emergence rates through acoustic tagging.

2. METHODS

The survey design was presented to the MPI Shellfish Working Group in August 2013. Previous surveys in SCI 3 have been conducted in 2001 (two surveys, pre and post a short fishery in October, with the survey only covering the QMA 3 area; strata 902 and 903), and more recently in 2009 and 2010 (covering the full survey area shown in Figure 2). The original survey strata (902 and 903) were based on depth contours within the region, and 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).

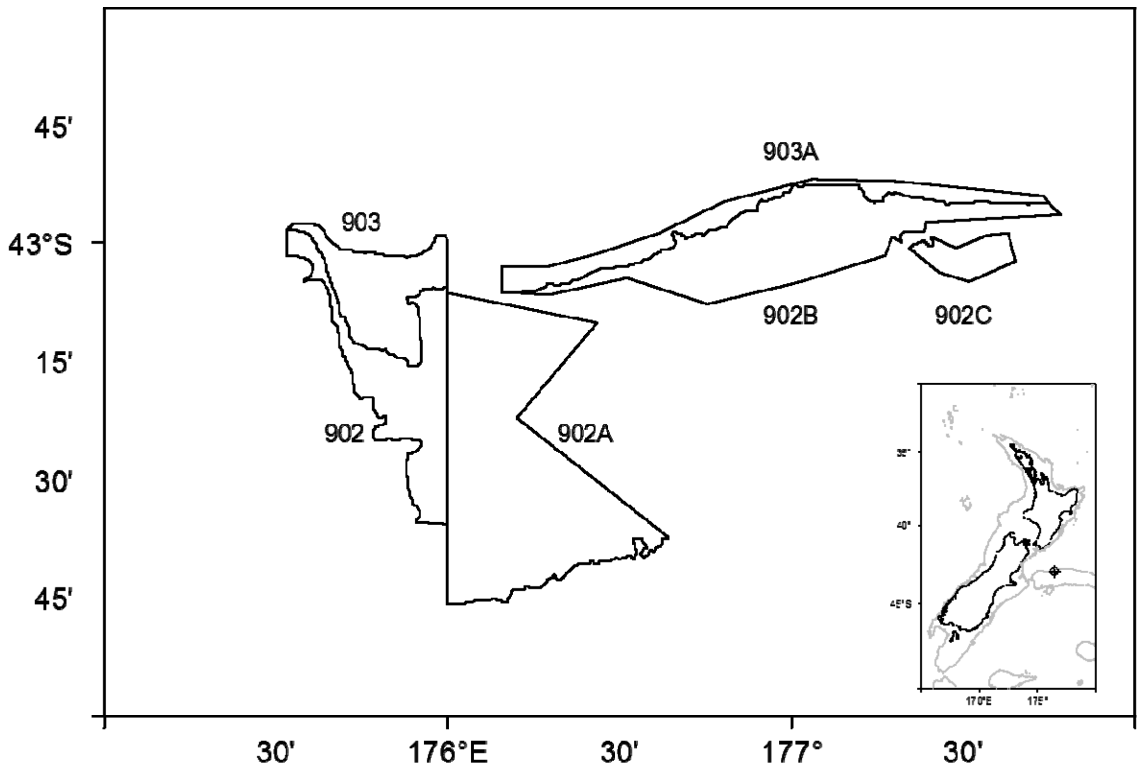


Figure 2: Survey strata for the 2009–2010 photographic surveys of SCI 3. Inset shows general vicinity of survey, and the 500 m depth contour.

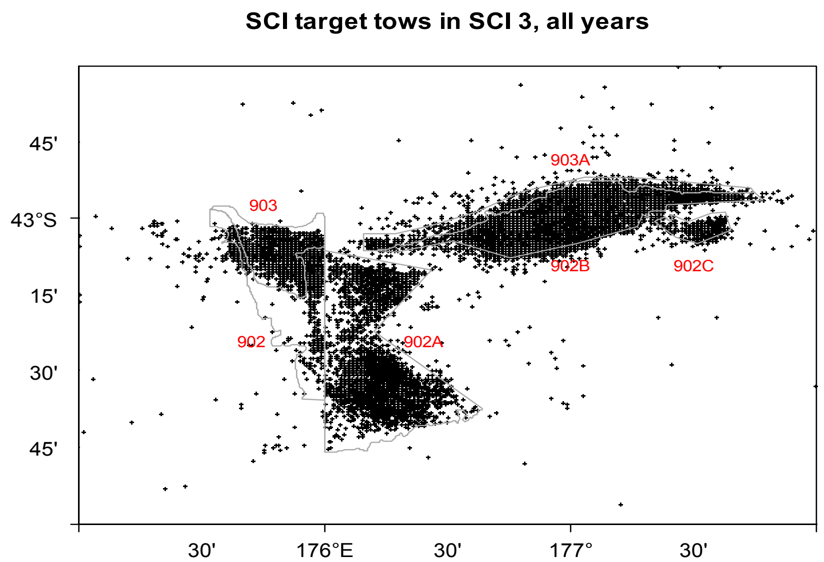


Figure 3: Survey strata for SCI 3 surveys shown in relation to the distribution of SCI targeted effort recorded on TCEPR.

Parts of stratum 902 appear to be unsuitable for scampi (no commercial fishing recorded, survey stations there have not recorded burrows), and this stratum was therefore revised accordingly to exclude this 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 would lead to eight strata in total, and with a target of three stations per stratum, this would require an additional 6 trawl stations (about two days of work). It was therefore proposed that along with a revision of the strata, a slightly greater emphasis be put onto the trawl component (increasing trawl stations to 24, reducing photographic stations to 50), while not increasing the length of the survey. Stations were allocated to strata on the basis of burrow abundance data from the 2009 and 2010 surveys using the *allocate* package (R.I.C.C Francis, unpublished), minimising the CV for a fixed number of stations. 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 photographic stations from each stratum were taken 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 each stratum and revised stratification are provided in Table 1 and Figure 4.

Table 1: Details of strata and number of stations planned for SCI 3 survey in 2013.

Stratum	Area (km^2)	Depth (m)	Photo stations	Trawl stations
902	439.84	300–400	6	3
903	552.08	400–500	5	3
902A1	700.41	300–400	4	3
902A2	1432.38	300–400	16	3
902B1	605.42	300–400	7	3
902B2	660.97	300–400	6	3
902C	172.45	300–400	3	3
903A	459.18	400–500	3	3

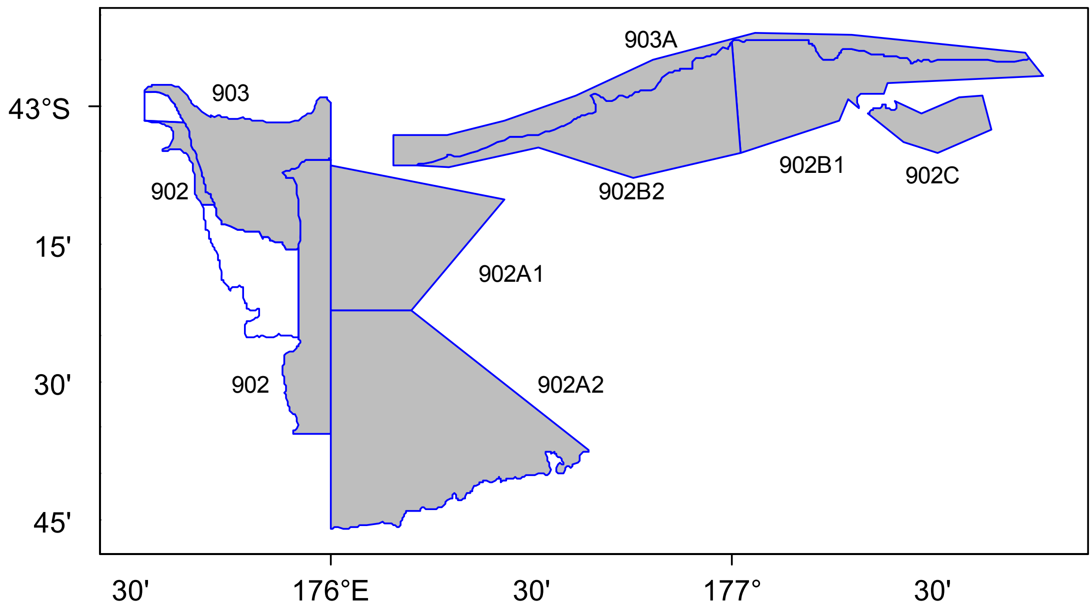


Figure 4: Revised strata for the 2013 survey of SCI 3.

In September/October 2013 we undertook stratified random photographic surveys of scampi burrows within SCI 3 (Mernoo Bank, 300–500 m depth), from the NIWA research vessel *Kaharoa*, using the revised design as discussed with and approved by the MPI Shellfish Working Group. This was the fifth photographic survey of the SCI 3 area (the previous surveys conducted in 2001 (two surveys), and 2009 – 2010 (Cryer et al. 2003b, Tuck et al. 2011)). 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 recent modifications to survey strata in SCI 3 (described above) have excluded areas with minimal scampi fishing, and the survey coverage accounts for about 99% of landings from the fishery over its history (Tuck 2013).

Photographic survey

As discussed above, a target of 50 photographic stations was set, on the basis of survey duration, and these were allocated to strata using the *allocate* package in R (to minimise the overall survey CV), on the basis of burrow densities observed in the 2009 and 2010 surveys. Photographic sampling was undertaken between about 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 counting 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, and much reduced (almost instantaneous) lag between triggering and 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 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 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 in the critical area 2–4 m off 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 the 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.

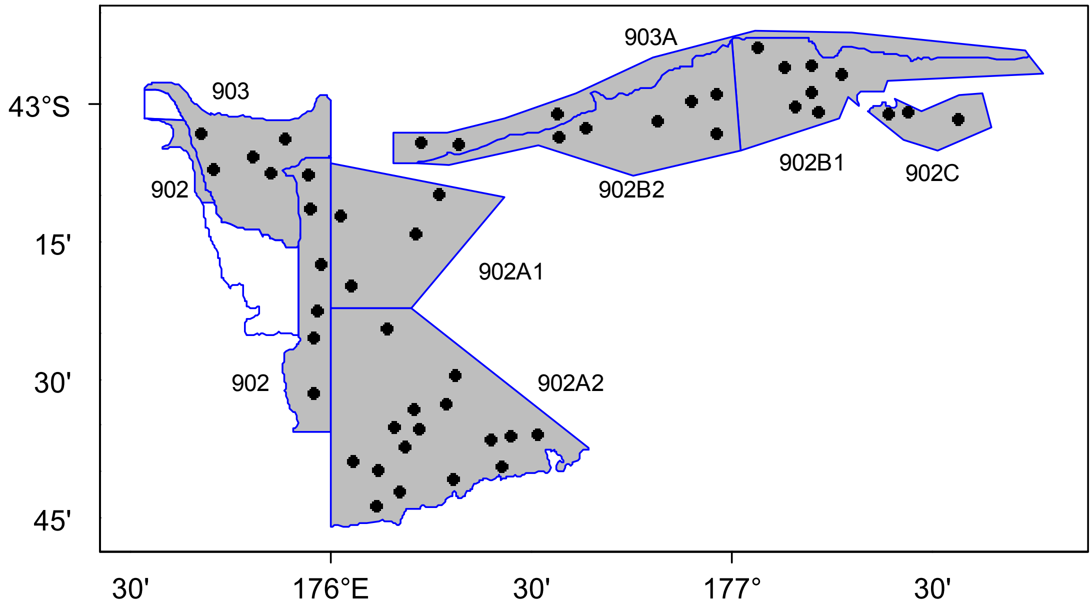


Figure 5: Planned station locations for the 2013 photographic survey of SCI 3 (black dots indicating the station midpoints).

Image selection and scoring

Images were examined and scored using a standardised protocol (developed under MPI project SCI2000/02) (Cryer et al. 2002) applied by 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 is clearly and sharply visible was estimated and marked using polygons in 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 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 are not "characteristic" are 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 count burrow openings rather than assumed burrows 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).

The criteria used by readers to judge whether or not a burrow should be scored are, of necessity, partially subjective; we cannot be certain that any particular burrow belongs to a *M. challengeri* and 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 scores it only if it is “probably” a scampi burrow. Scores are 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”) 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) are re-examined by all readers. During the second read process, each reader has access to the score and annotated files of all other readers and, after re-assessing their own interpretation against the original image, are 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.

To enable comparison of the 2013 survey data with previous surveys, the reference set for SCI 3 (generated in 2010, and including images from 2001 and 2009)(Tuck et al. 2011) was augmented with images from 2010, and reread in 2013 (at the same time as the SCI 3 2013 survey images), with each image in each reference set being read by all six readers, using the standard image scoring and re-reading procedure.

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.

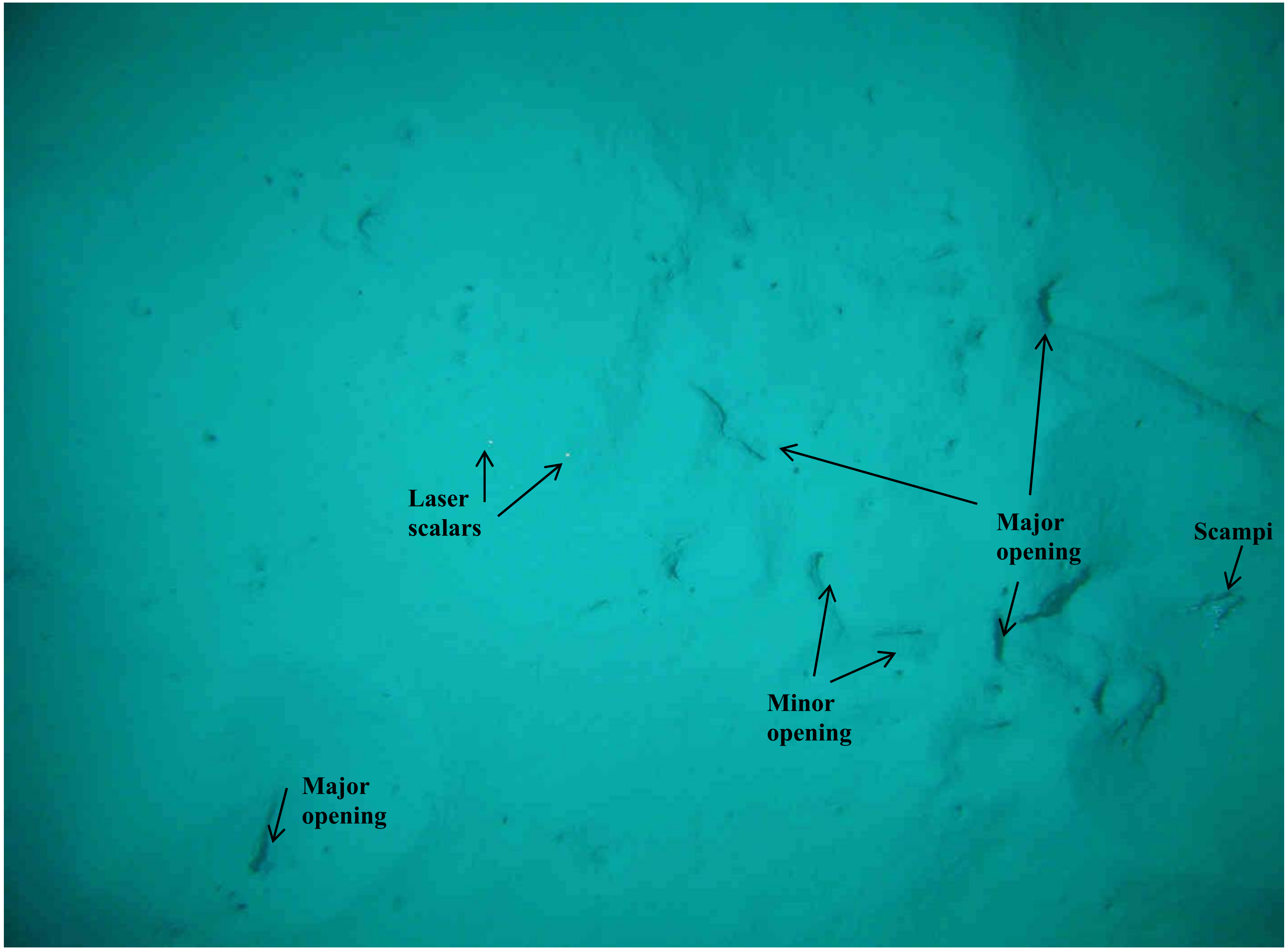


Figure 6: Example image from March 2006 survey in SCI 2 showing laser scaling dots, several characteristic scampi burrows and one large visible scampi.

Trawl survey

Trawl survey sampling was undertaken between roughly 0600 and 1800 NZST, during the second half of the voyage, after the photographic survey had been completed. The first three 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 (Cryer et al. 2003b, Tuck et al. 2011).

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 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 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, 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 2016, and so it is anticipated that recoveries will be from commercial fishing activity. At the request of MPI and the Shellfish Working Group, no tag mortality component was included in the survey, as it was considered very unlikely that tag recapture data would be used to estimate stock size for this fishery.

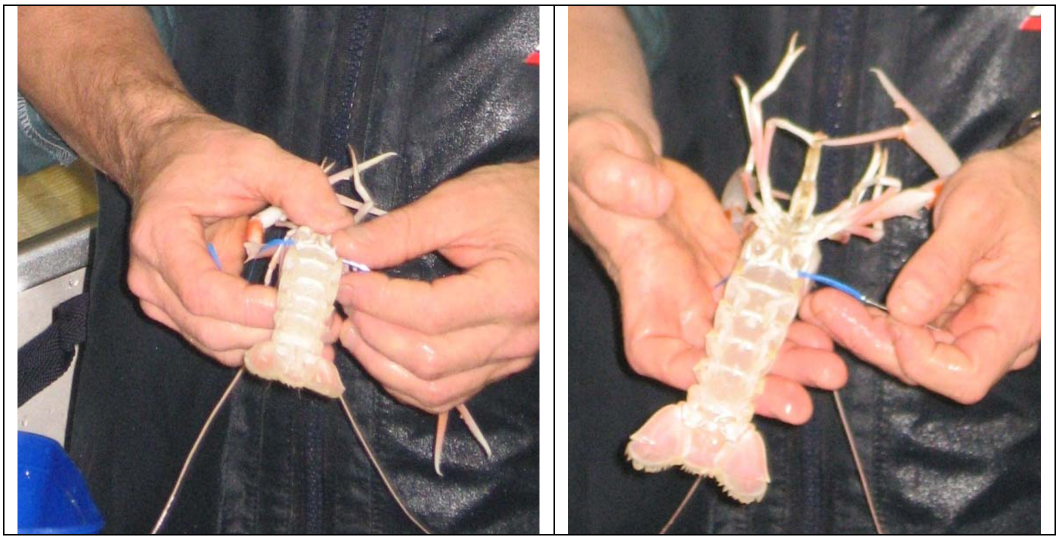


Figure 7: Photographs showing location of streamer tag in scampi.

Acoustic tagging

The third objective of the study was to investigate burrow emergence patterns through acoustic tagging of scampi. Forty scampi were released with acoustic tags, as part of acoustic mooring deployments, to investigate scampi emergence patterns, split between three separate moorings (13 or 14 at each). A small Vemco (V7-2L) acoustic tag (20 mm*7 mm dia, 0.75 g in water) was attached to each animal, positioned between the walking legs (Figure 8). The moorings were deployed on 11th October 2013, and recovered by RV *Tangaroa* on 25th January 2014, with a deployment duration of just over 100 days. These slightly larger tags were used, rather than the V7-1L used in previous deployments on scampi (Tuck et al. 2013, Tuck et al. in press). This change was on the basis of advice from Vemco, based on the battery life required for a long deployment, the number of tags at each mooring, and the optimal delay for minimum interference between tags. Mooring design is shown in Figure 9.

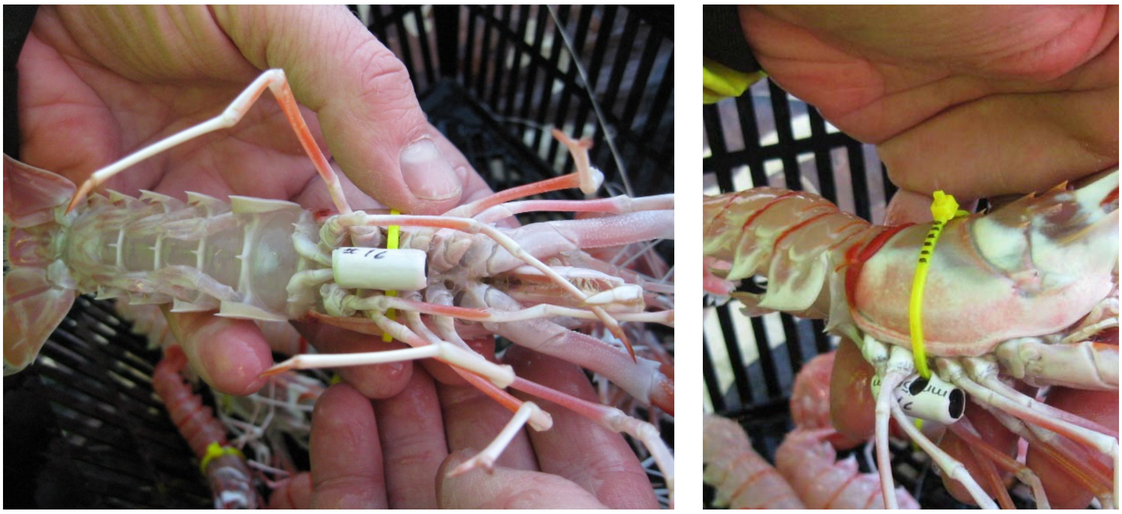


Figure 8: Scampi with acoustic tag attached.

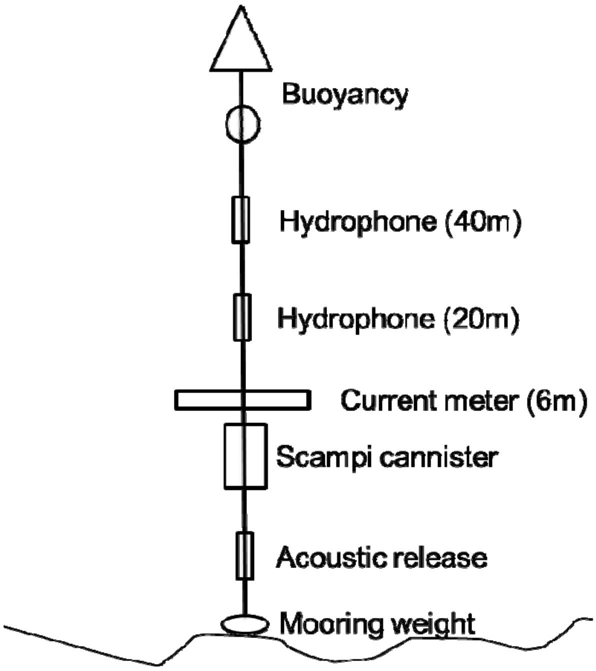


Figure 9: Diagram of acoustic mooring for deployment of scampi and hydrophones.

3. RESULTS

The voyage was completed successfully between 16th September and 14th October 2013. All photographic stations were completed, but very poor weather during the voyage meant that some time was lost, and three trawl stations could not be completed.

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 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. Over the whole survey, a total area of 11 340 m^2 of seabed was viewed (acceptable quality images), with an average of 39.5 images at each station, an average seabed area viewed by each image of 5.74 m^2, providing an average area viewed of 226.80 m^2 at each station.

Problems with underwater visibility and weather conditions meant that some stations had to be abandoned, and repeated later if possible. This meant that the numbers of stations planned for some strata were not quite achieved, while others were exceeded, but all strata had at least three photographic stations (Table 2).

Following suggestions from the Shellfish Working Group, calibration across years and between readers was conducted in a single analysis, rather than the two stage process implemented previously (Tuck et al. 2009). All the image count data (including reference set counts) were combined into a single dataset. Terms were created for reader_year (combination of reader and the year in which the image was read), strata_year (combination of survey strata and year the image was recorded in) and station_year (combination of station number and survey year). Burrow count data from individual images were examined within a generalised linear mixed modelling framework, with strata_year, reader_year and readable area as explanatory variables, and image and station_year as random effects, and a poisson error distribution. The significance of effects was tested by sequentially adding terms, and a model testing the null hypotheses that there were no strata_year or reader_year no differences between burrow counts over time, detected highly significant effects (both considered as factors) (Table 3).

Table 2: Details of strata and number of photo stations completed for SCI 3 survey in 2013.

			Photo stations	
Stratum	Area (km^2)	Depth (m)	Planned	Completed
902	439.84	300–400	6	6
903	552.08	400–500	5	5
902A1	700.41	300–400	4	3
902A2	1432.38	300–400	16	18
902B1	605.42	300–400	7	6
902B2	660.97	300–400	6	6
902C	172.45	300–400	3	3
903A	459.18	400–500	3	3

Table 3: Analysis of deviance for a generalised linear mixed model relating the count of major burrow openings to reader_year, strata_year, and readable area for SCI 3.

	Df	Sum sq	Mean Sq	F value	P
Strata_year	19	427.82	22.517	22.517	<0.0001
Reader_year	22	280.42	12.746	12.746	<0.0001

Canonical indices of the reader_year terms are presented in Table 4 and plotted in Figure 10. 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.

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, strata_year, and readable area for SCI 3.

Reader_Year	Indices	Variance	CVs	Upper 95%	Lower 95%	Correction factor
AM_2013	1.5011	0.0048	0.0462	1.6398	1.3624	0.6744
BH_2001	0.8817	0.0051	0.0813	1.0251	0.7384	1.1481
BH_2009	1.0642	0.0035	0.0558	1.1829	0.9455	0.9513
BH_2010	0.9132	0.0023	0.0523	1.0087	0.8177	1.1085
CM_2001	1.2016	0.0065	0.0671	1.3628	1.0405	0.8424
DP_2009	0.8372	0.0024	0.0590	0.9361	0.7383	1.2092
DP_2010	1.0685	0.0029	0.0507	1.1768	0.9601	0.9474
DP_2013	1.1040	0.0030	0.0499	1.2142	0.9938	0.9169
HA_2001	0.9540	0.0040	0.0662	1.0804	0.8276	1.0612
HA_2009	1.0273	0.0034	0.0570	1.1444	0.9102	0.9854
HA_2010	0.8482	0.0020	0.0527	0.9376	0.7587	1.1935
HA_2013	0.9496	0.0024	0.0515	1.0474	0.8519	1.0660
IT_2009	0.9394	0.0030	0.0581	1.0486	0.8303	1.0776
IT_2010	1.0338	0.0027	0.0503	1.1378	0.9299	0.9792
IT_2013	1.0314	0.0026	0.0497	1.1339	0.9289	0.9815
JD_2009	0.6807	0.0020	0.0655	0.7699	0.5914	1.4872
MC_2001	0.9985	0.0061	0.0781	1.1545	0.8425	1.0138
MS_2001	1.2380	0.0085	0.0747	1.4229	1.0531	0.8177
MS_2009	1.0236	0.0034	0.0566	1.1396	0.9076	0.9890
MS_2010	1.1430	0.0030	0.0480	1.2527	1.0332	0.8857
MS_2013	1.0648	0.0030	0.0512	1.1738	0.9559	0.9507
NR_2010	0.9219	0.0023	0.0523	1.0183	0.8254	1.0981
NR_2013	0.8574	0.0020	0.0525	0.9474	0.7674	1.1806

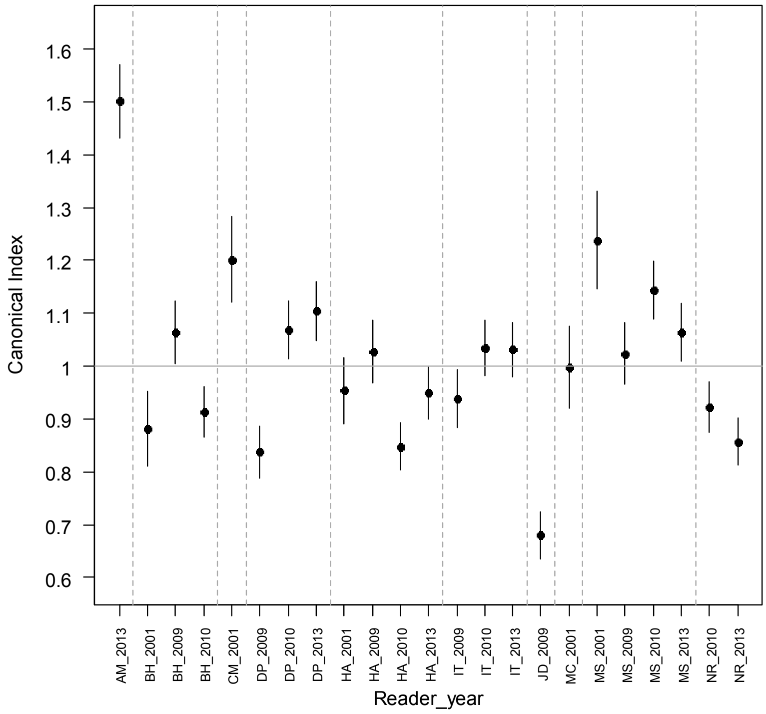


Figure 10: Canonical indices (and CV) for reader_year terms from a generalised linear mixed model relating the count of major burrow openings to reader_year, strata_year, and readable area for SCI 3.

Reader_year effects were also tested for scampi counts in the same way, but were not found to be significant, supporting our previously assumed (but untested) view that identification and counting of scampi is far less subjective than burrow openings.

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 11. The uncorrected burrow density estimates varied from 0.02 – 0.38 m^{-2}, and correction factors had only minimal effects on overall density estimates. Densities of all scampi, and scampi out of their burrows ranged from 0 to 0.08 (Figure 12) and 0.02 m^{-2}, respectively. Scaling the densities to the combined area of the strata (5022 km^2) leads to abundance estimates from 683 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 scampi major burrow openings was estimated to be 0.13 m^{-2}. The density was highest in the stratum 903 and both parts of 902B. 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 0.02 m^{-2}, with the highest density observed in the 902B stratum. Scaling the observed densities of visible scampi to strata area leads to a minimum abundance estimate of 130 million animals for the surveyed area (Table 6). Counting animals out of burrows and walking free on the surface reduced this estimate to 29 million animals (Table 7). The CVs for visible scampi and scampi out of burrows from the bootstrapped estimates were comparable with those of the original estimates.

The trend in abundance in major burrow openings is shown in Figure 13 (for individual strata) and Figure 14 (for larger areas). For the combined 902 and 903 strata (surveyed since 2001), the abundance shows a considerable decline between 2001 and 2009, but a steady increase since that survey. 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. The survey estimates uncorrected for reader_year effect (Appendix 1) are very 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 15. These show a similar decline between 2001 and 2009 (for the 902 and 903 strata). Since 2009, the abundance estimates of scampi have increased slightly, although the whole survey estimate of visible scampi declines 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 20%. 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 22% in 2013, which is comparable with other surveys in SCI 1, SCI 2 and SCI 3 (Tuck et al. 2013), but lower than observed in SCI 6A (Tuck et al. in press).

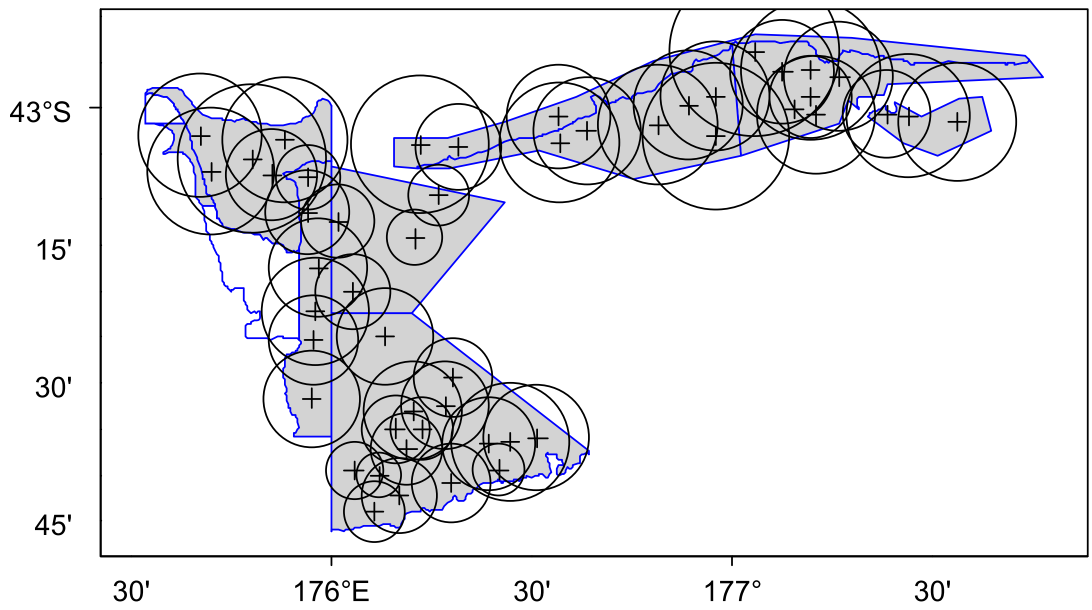


Figure 11: Station locations for the 2013 photographic survey of SCI 3 (area of symbol represents relative burrow density). Largest circle represents 0.38 burrows .m^{-2} (uncorrected for reader_year).

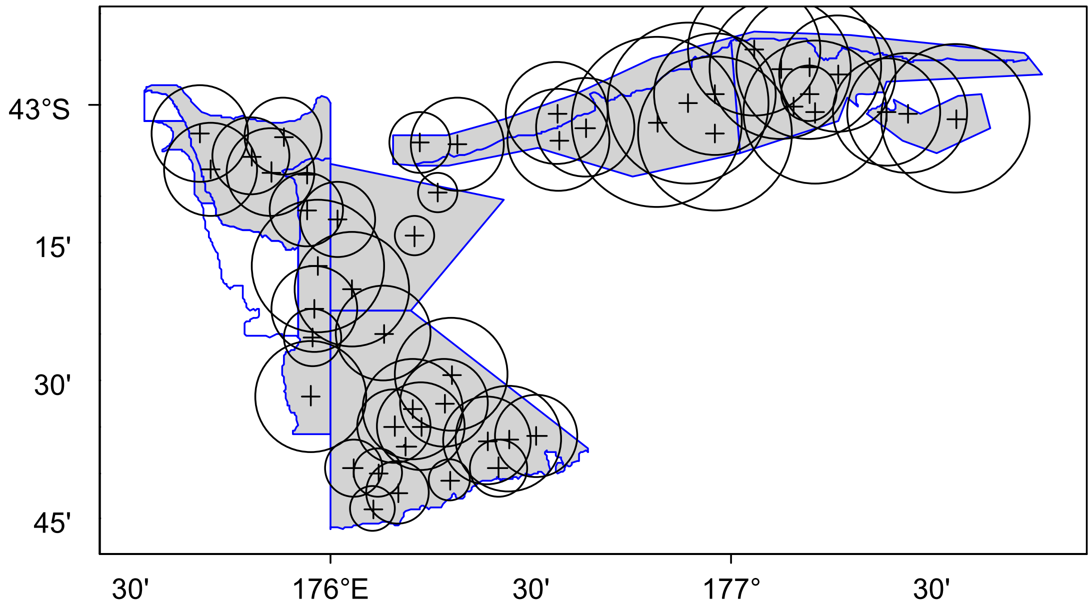


Figure 12: Station locations for the 2013 photographic survey of SCI 3 (area of symbol represents relative visible scampi density). Largest circle represents 0.08 visible scampi .m^{-2}.

Table 5: Estimates of the density and abundance of major burrow openings from the SCI 3 survey for 2013. 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	6	5	3	18	6	6	3	3	50	
Mean density (.m^{-2})	0.1094	0.1914	0.0614	0.0754	0.1871	0.1853	0.1453	0.1541	0.1267	0.1361
CV	0.17	0.14	0.17	0.12	0.18	0.08	0.16	0.21	0.06	0.06
Abundance (Millions)	48.14	105.85	42.95	108.02	113.20	122.45	24.99	70.71	636.32	683.47

Table 6: Estimates of the density and abundance of visible scampi from the SCI 3 survey for 2013. 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	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	0.0260
CV	0.34	0.11	0.49	0.19	0.18	0.19	0.20	0.26	0.09	0.08
Abundance (Millions)	9.17	11.36	12.88	21.01	25.85	33.64	7.43	9.51	130.85	130.69

Table 7: Estimates of the density and abundance of scampi out of burrows from the SCI 3 survey for 2013. 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	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	0.0057
CV	0.56	0.63	1.00	0.32	0.28	0.27	0.42	0.31	0.21	0.19
Abundance (Millions)	1.55	0.87	5.09	4.99	6.95	5.55	1.19	3.03	29.22	28.65

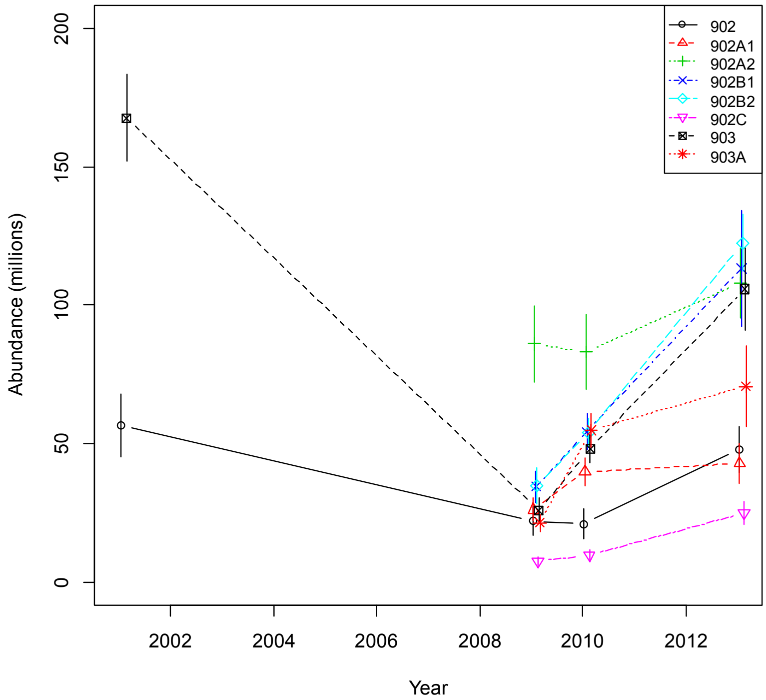


Figure 13: Estimated abundance of scampi major burrow openings (± CV) for SCI 3 by strata. The 2001 estimates are based on the October/November survey.

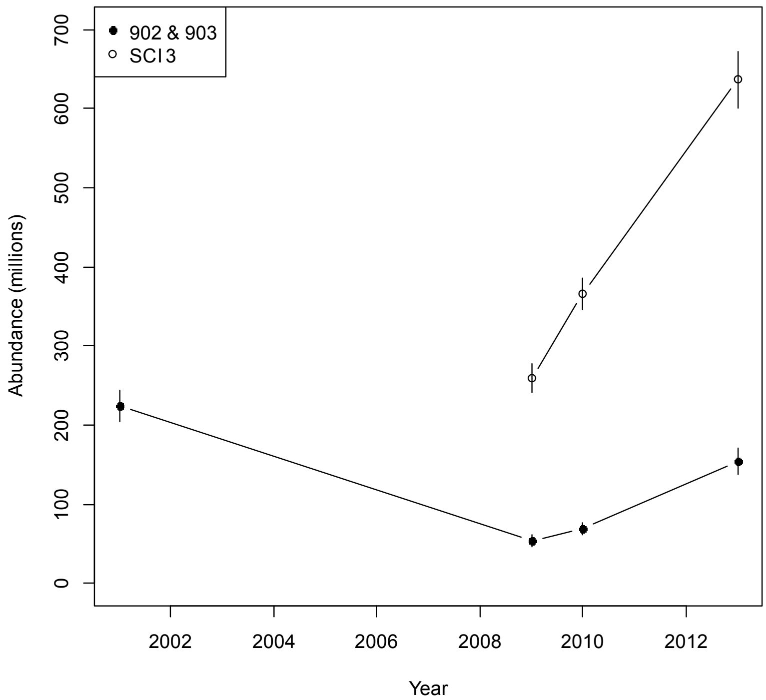


Figure 14: Estimated abundance of scampi major burrow openings (± CV) for SCI 3 for combined 902 and 903 strata, and whole SCI 3 survey area. The 2001 estimate is based on the October/November survey.

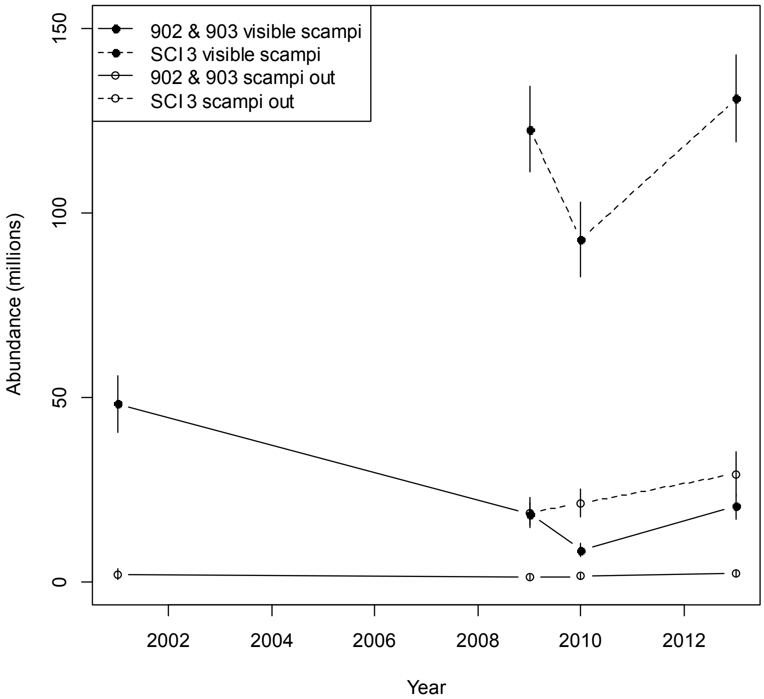


Figure 15: Estimated abundance of scampi (± CV) for SCI 3 for combined 902 and 903 strata, and whole SCI 3 survey area. The 2001 estimates are based on the October/November survey.

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	0.2258	0.0486	0.0022	21.51%	4.44%
2009	0.0537	0.0185	0.0013	34.42%	7.11%
2010	0.0700	0.0087	0.0016	12.46%	18.15%
2013	0.1551	0.0207	0.0024	13.34%	11.75%
SCI 3					
2009	0.0516	0.0244	0.0037	47.27%	15.35%
2010	0.0729	0.0185	0.0043	25.37%	23.04%
2013	0.1267	0.0261	0.0058	20.56%	22.33%

3.2 Trawl survey

The locations of trawl survey stations, and relative scampi catch rates, are shown in Figure 16. The time lost to poor weather mean that only two of the planned stations in stratum 902A2 were completed, and only one in stratum 902B1. To enable estimation of a CV, stations in 902B1 and 902B2 were therefore analysed together for the combined stratum 902B. Biomass estimates are provided by strata for the 2013 survey in Table 9, and are compared with previous surveys estimated over the same strata in Table 10.

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

Strata	902	903	902A1	902A2	902B	902C	903A	Total
Area (km^2)	440	552	700	1432	1269	172	460	5025
N. stations	3	3	3	2	4	3	3	21
Mean (kg.mile^{-1})	7.59	4.56	5.95	2.84	5.98	10.33	4.50	5.08
CV	0.36	0.40	0.15	0.58	0.08	0.05	0.17	0.12
Biomass (tonnes)	72.1	54.4	90.1	87.9	163.8	38.4	44.7	551.3

The overall raised trawl survey estimate was 551 tonnes (12% CV) (Table 9), or 8.17 million animals (11% 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 is comparable with the 2010 estimate (596 t, 4% CV), and an increase from the estimates in 2009 (412 t, 26% CV) (Table 10 and Figure 17). In the early part of the series (2001), only the western strata were surveyed. Biomass in stratum 902 in 2013 appears comparable with 2001, while the biomass in stratum 903 appears to have declined. However, all the estimates at the stratum level have high CVs. The trends in scampi abundance (in numbers) estimated from the trawl surveys follow very similar patterns to those shown by biomass (Figure 18).

Over the whole SCI 3 trawl survey, 364 kg of scampi were caught, accounting for 3.6% of the total catch (10 214 kg), with scampi being the seventh most abundant species. By weight, the most, dominant species in the catches were javelin fish (18.2%), sea perch (15.9%), hoki (14.1%), Bollon's rattail (10.1%), Dark ghost shark (8.1%), ling (5.4%), and scampi (3.6%). Within commercial fishing activities, scampi forms a greater proportion of the total catch, as bycatch mitigation approaches reduce fish 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 of revised stratum area for 902.

Biomass	2001 pre fishery				2001 post fishery				2009				2010				2013			
	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
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
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
902A2																	2	2.84	0.58	87.90
902B									4	1.81	0.41	49.66	3	4.50	0.09	123.35	4	5.98	0.08	163.80
902C									3	6.51	0.10	24.18	2	10.13	0.06	37.65	3	10.33	0.05	38.38
903A									3	0.85	0.09	8.49	3	3.86	0.19	38.36	3	4.50	0.17	44.69
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

Numbers	2001 pre fishery				2001 post fishery				2009				2010				2013			
	N	Mean	CV	millions	N	Mean	CV	millions	N	Mean	CV	millions	N	Mean	CV	millions	N	Mean	CV	tonnes
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
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
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
902A2																	2	59.32	0.22	1.84
902B									4	27.25	0.48	0.75	3	75.73	0.14	2.08	4	108.79	0.18	2.98
902C									3	74.01	0.03	0.27	2	143.41	0.05	0.53	3	146.86	0.11	0.55
903A									3	11.98	0.16	0.12	3	62.79	0.12	0.62	3	58.71	0.20	0.58
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

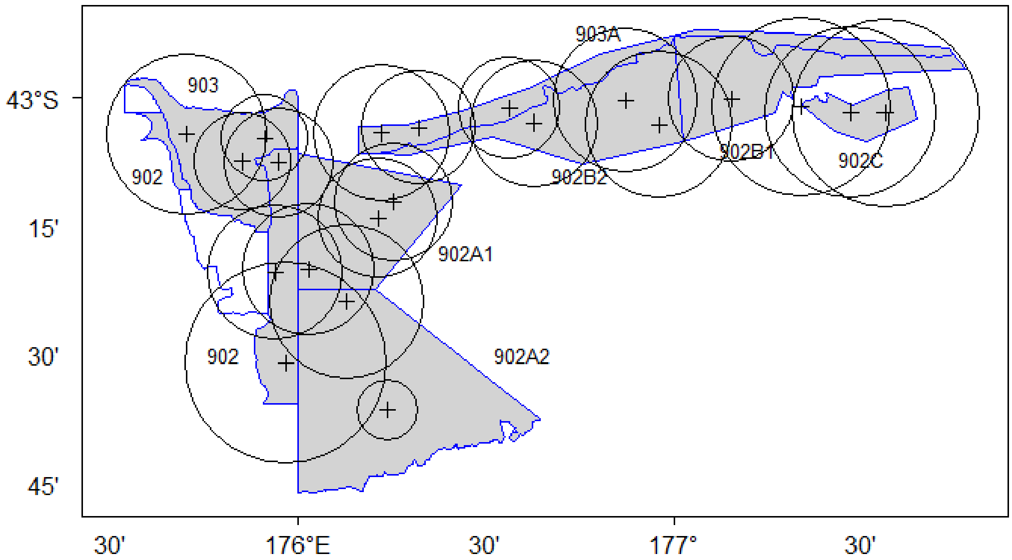


Figure 16: Trawl station locations for the 2013 photographic survey of SCI 3 (area of symbol represents relative scampi catch rate). Largest circle represents 13 kg.mile^{-1}.

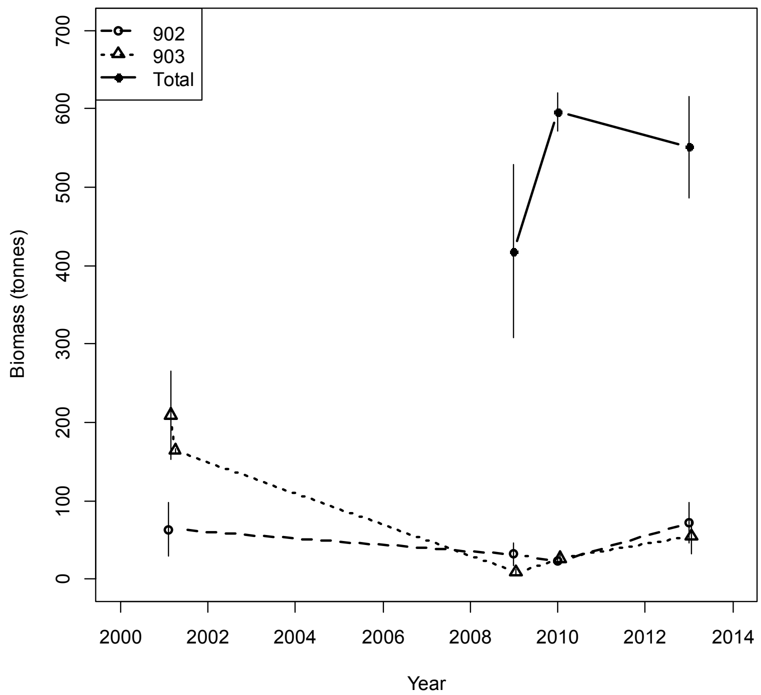


Figure 17: Plot of time series of trawl survey biomass estimates (± CV) for SCI 3. Total estimate includes biomass estimates for strata not surveyed in 2001.

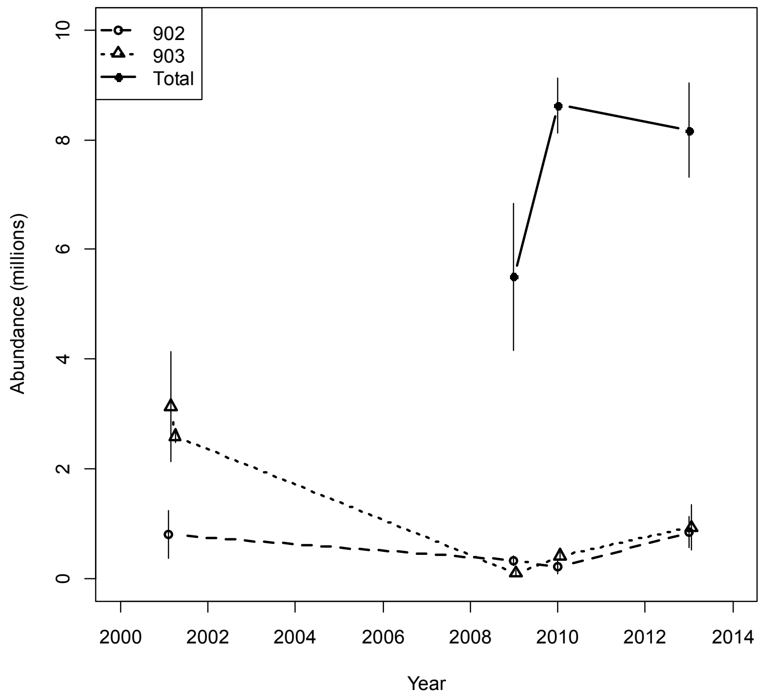


Figure 18: Plot of time series of trawl survey abundance (millions) estimates (± CV) for SCI 3. Total estimate includes abundance estimates for strata not surveyed in 2001.

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=0.60 and 0.75, for burrows and visible scampi, respectively) (Figure 19 and Figure 20).

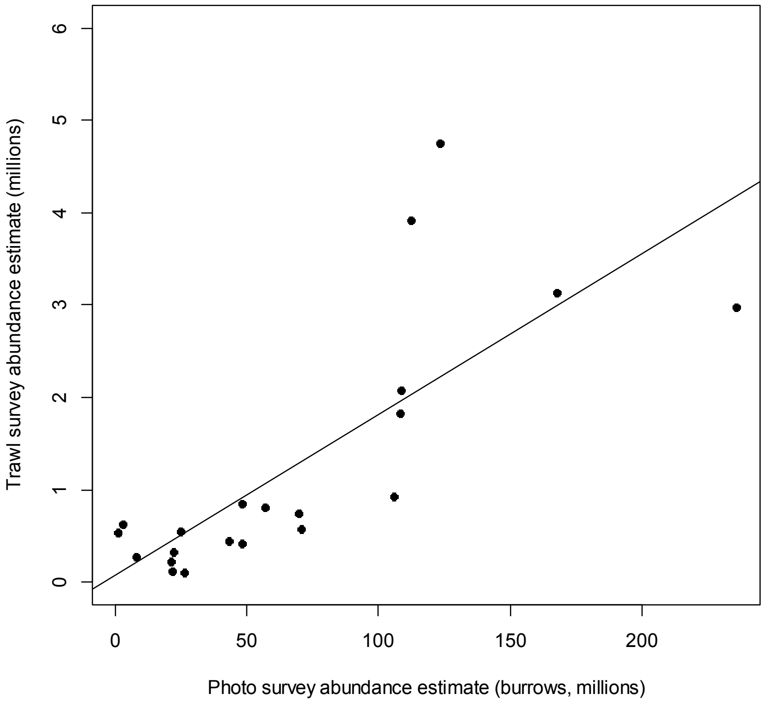


Figure 19: Relationship between strata level photographic survey estimates of burrow abundance and trawl survey estimates of scampi abundance. Line represents least squares linear regression (r^2 = 0.6).

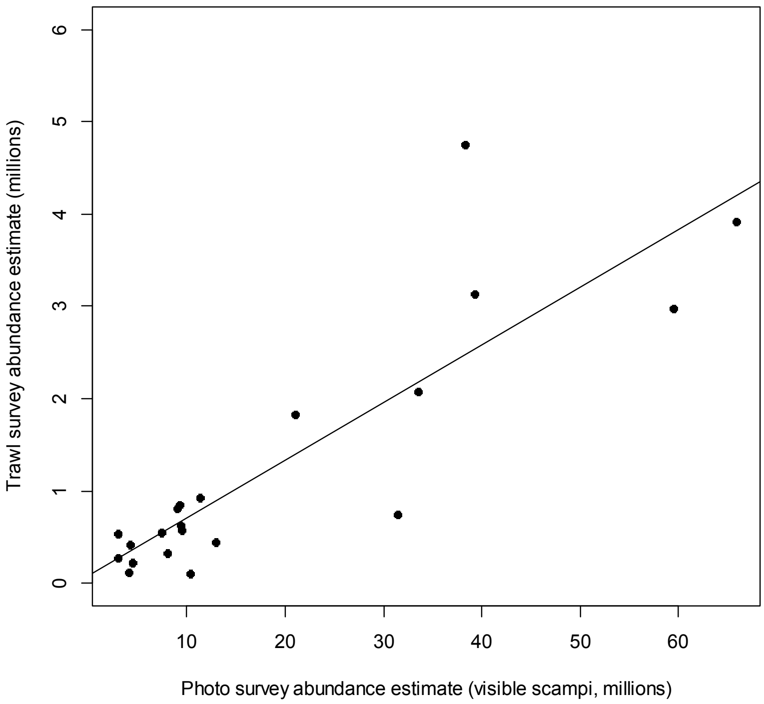


Figure 20: Relationship between strata level photographic survey estimates of visible scampi abundance and trawl survey estimates of scampi abundance. Line represents least squares linear regression (r^2 = 0.75).

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 2016, and so it is anticipated that recoveries will be from commercial fishing activity. Over the whole survey, almost 3400 scampi were tagged with either streamer (2119) or T-bar (1277) tags, which were then released. Catches were predominantly male, and this is reflected in the tagged animals (2085 males, 1311 females). The length distributions of the tagged scampi are presented in Figure 21. 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). The tagged scampi were released at 28 separate locations (Figure 22). 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 seven days) survival has been estimated at 76% in SCI 2 (Tuck et al. 2013) and 88% in SCI 6A (Tuck et al. in press), the difference assumed to be related to warmer surface water temperatures in SCI 2.

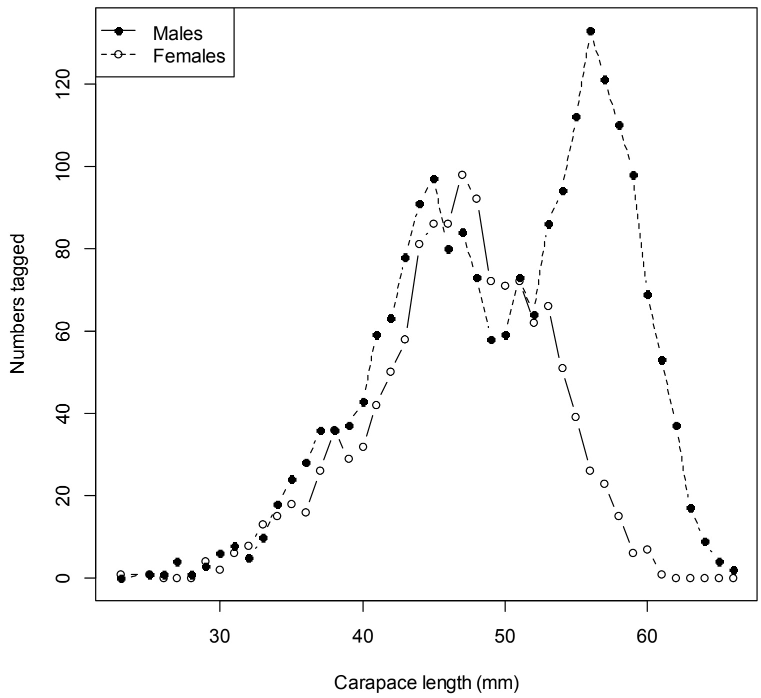


Figure 21: Length distribution of scampi tagged and released during the KAH1308 voyage.

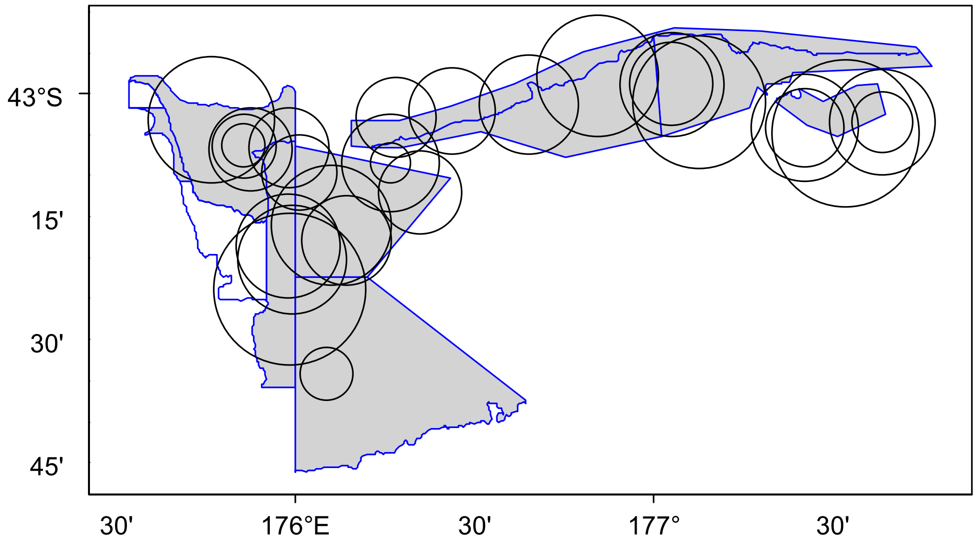


Figure 22: Map showing distribution of 2013 scampi release locations, and relative numbers released at each location. Largest circles represent 302 animals. The smallest release batch was 23 animals, and the average release batch was 125 animals

To date (August 2014) five recoveries have been reported to NIWA. Over the same period (since October 2013) we have had 29 recoveries from the scampi tagged in SCI 6A (tagged in March 2013). Recoveries have been consistently low from SCI 3 (0 from 1944 in 2009, 3 from 3577 in 2010, and now 5 so far from 3396 in 2013). Tag recoveries have also been very 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.

3.4 Emergence patterns from acoustic tagging

The acoustic tagging moorings were recovered successfully after a deployment duration of 106 days. Locations of mooring deployments are shown in Figure 23. All three moorings were deployed in the 902 stratum. Distances between moorings were 1.4 to 1.5 km. Maximum tag detection range is estimated to be up to 400 m when scampi are out of their burrows. Summary plots of the current meter data are provided in Appendix 2. All three current meters provided data for the full duration of the deployment.

Summary details of detections by hydrophone for each tagged scampi are provided in Appendix 3. Of the 40 tags deployed, 5 were not detected after the day of deployment, and a further 11 only provided data for a very short period (not detected beyond five days after deployment; Figure 24). Eleven of the tags were detected for over thirty days, although these were not always detected continually throughout the study.

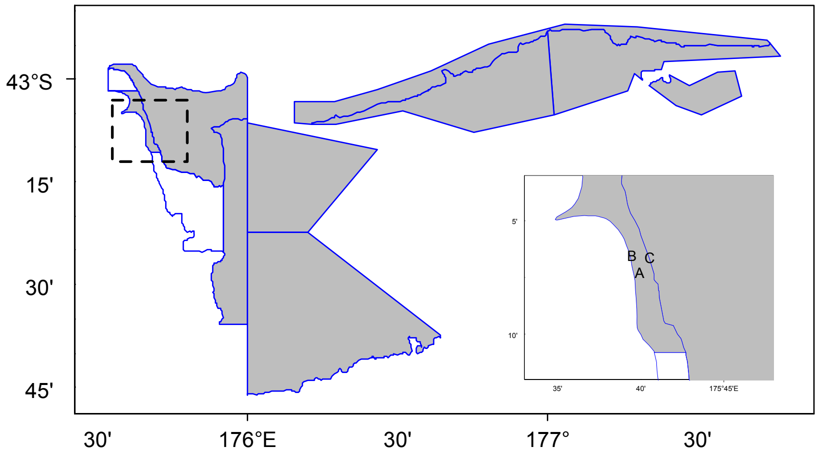


Figure 23: Locations of three acoustic moorings (moorings A, B and C) deployed to investigate scampi emergence patterns. Dashed box shows location in inset.

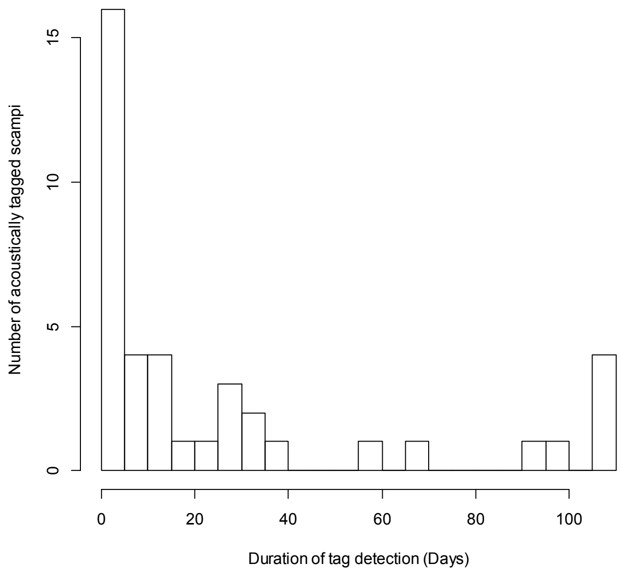


Figure 24: Histogram of tag detectability duration (time of last detection from deployment).

Detection plots (actograms) are provided for each of the scampi tags detected over 500 times or last detected over 30 days from release, in Figure 25 (Mooring 1), Figure 26 (Mooring 2) and Figure 27 (Mooring 3). Although 11 tags were detected over 30 days after release, detections were often very sporadic, and only 5 animals (scampi 1, 15, 19, 29 and 34) had long periods of detections (Figure 28). Of these 5 scampi, only 2 show strong periodicity in detections (Figure 29).

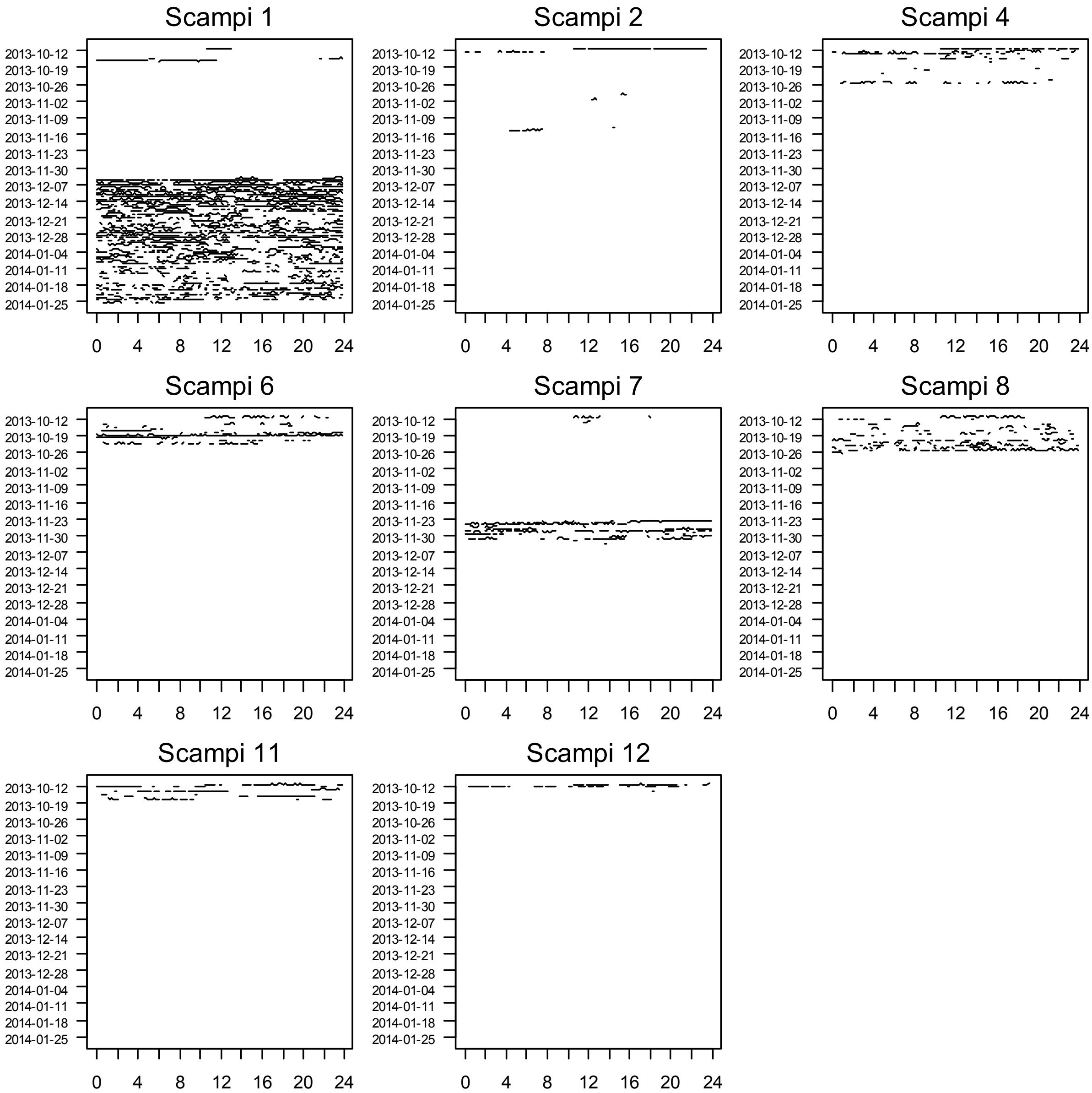


Figure 25: Detection plots (actograms) for scampi detected over 500 times, or last detected over 30 days from release, from mooring 1. Lines represent relative number of detections per 10 minute interval by date (y axis) and time of day (x axis). Maximum detections was 13 per 10 minute interval for all scampi

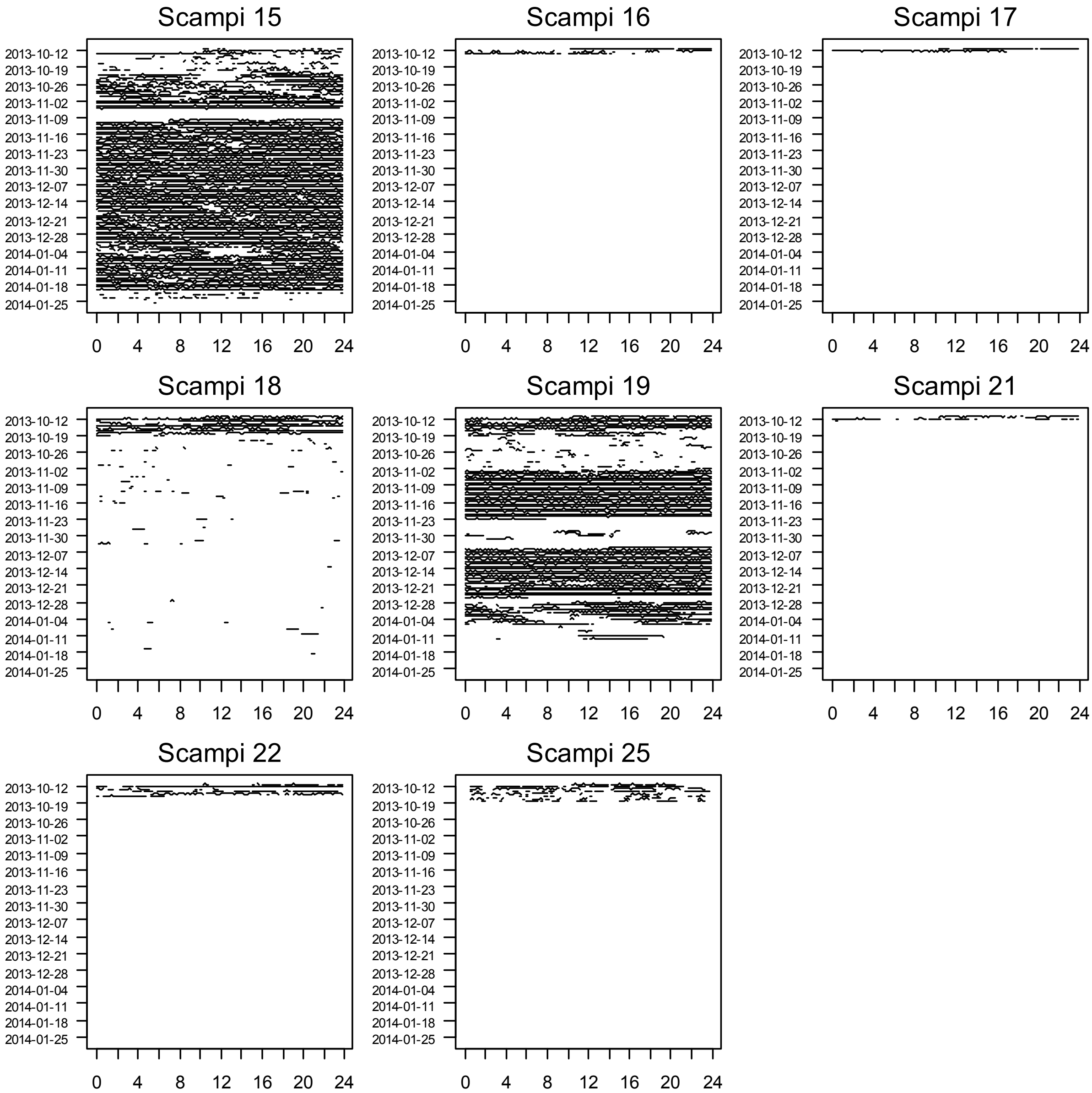


Figure 26: Detection plots (actograms) for scampi detected over 500 times, or last detected over 30 days from release, from mooring 2. Lines represent relative number of detections per 10 minute interval by date (y axis) and time of day (x axis). Maximum detections was 13 per 10 minute interval for all scampi.

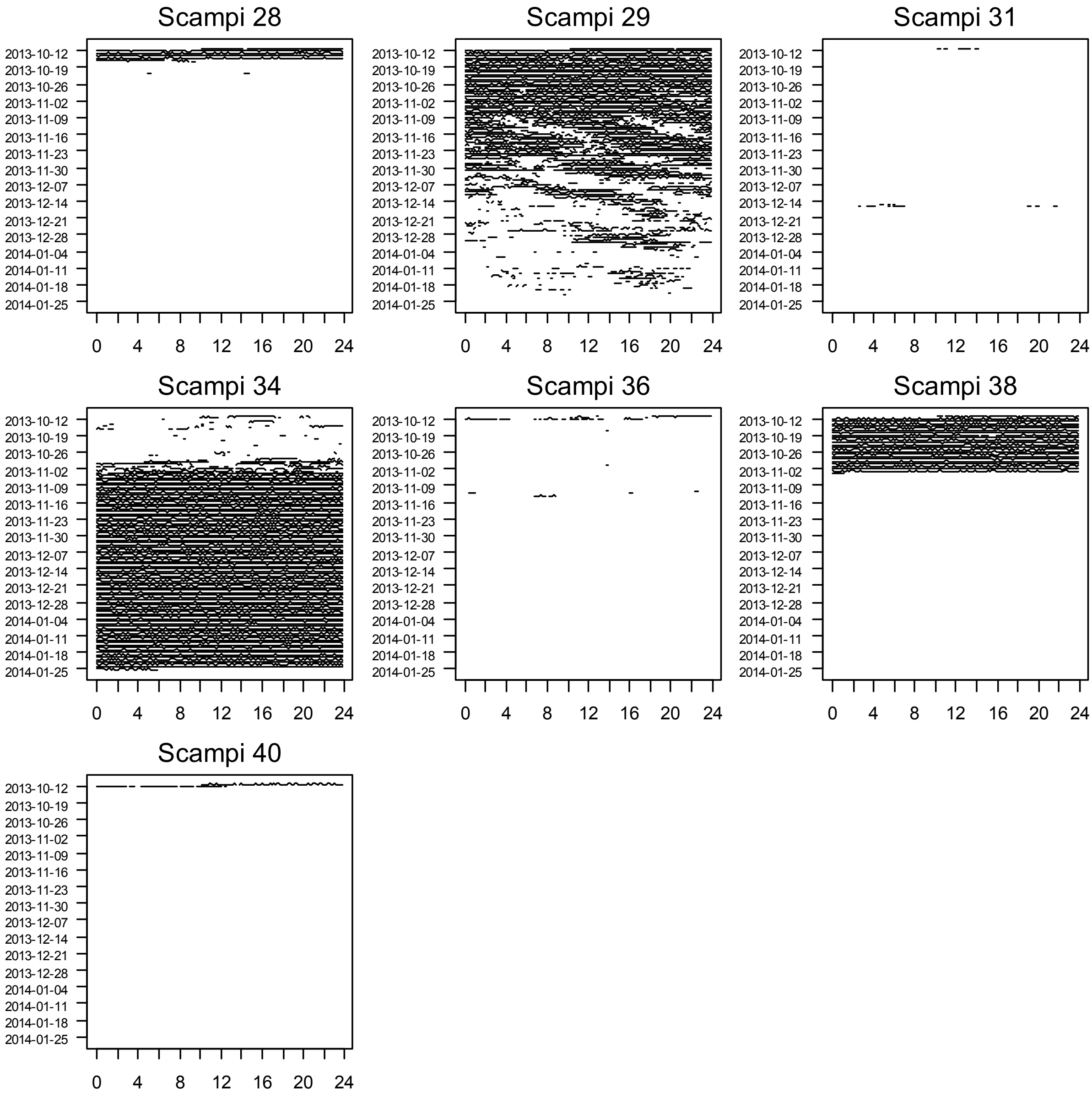


Figure 27: Detection plots (actograms) for scampi detected over 500 times, or last detected over 30 days from release, from mooring 3. Lines represent relative number of detections per 10 minute interval by date (y axis) and time of day (x axis). Maximum detections was 13 per 10 minute interval for all scampi.

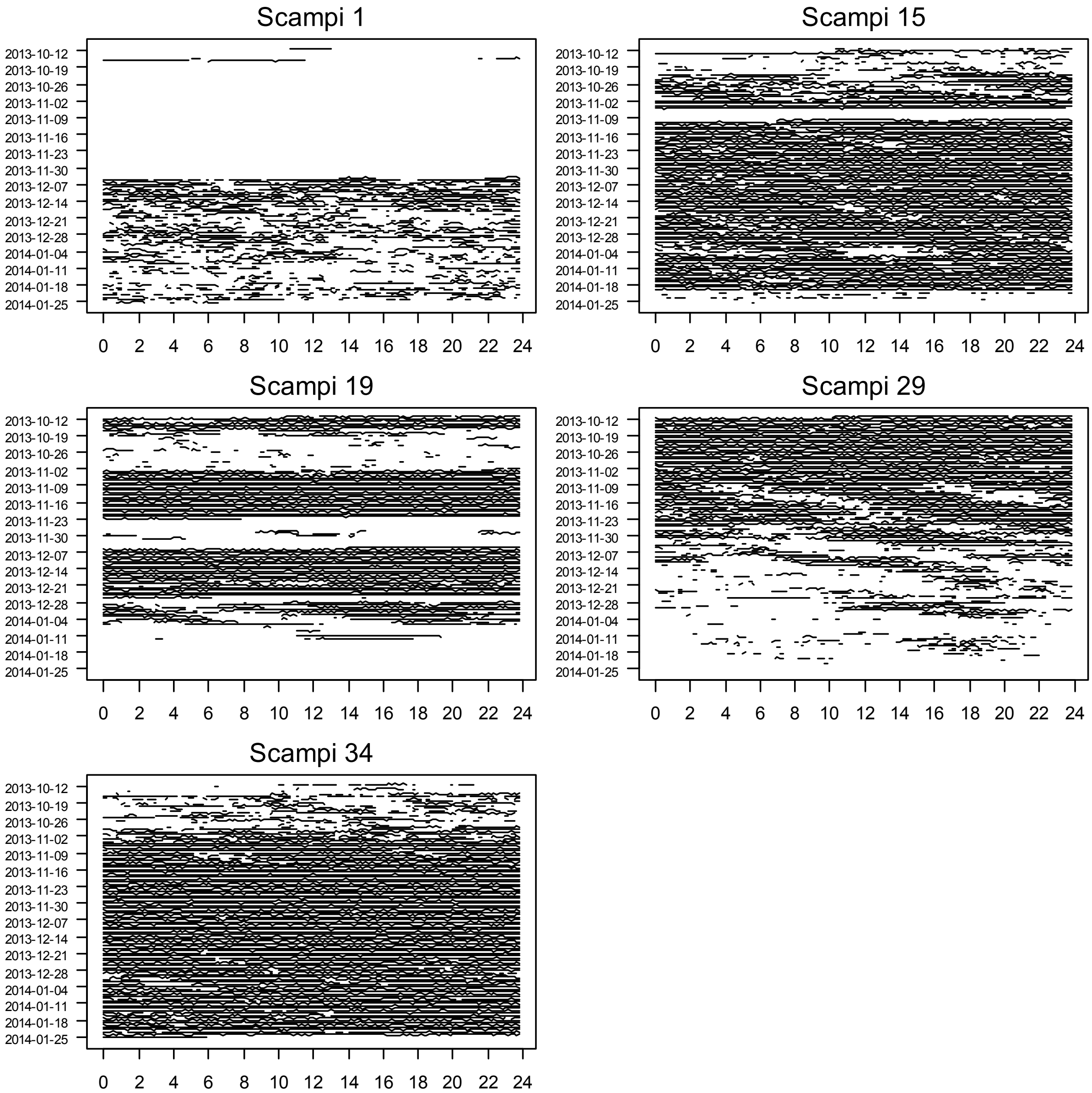


Figure 28: Detection plots (actograms) for scampi with long periods of detections. Lines represent relative number of detections per 10 minute interval by date (y axis) and time of day (x axis). Maximum detections was 13 per 10 minute interval for all scampi.

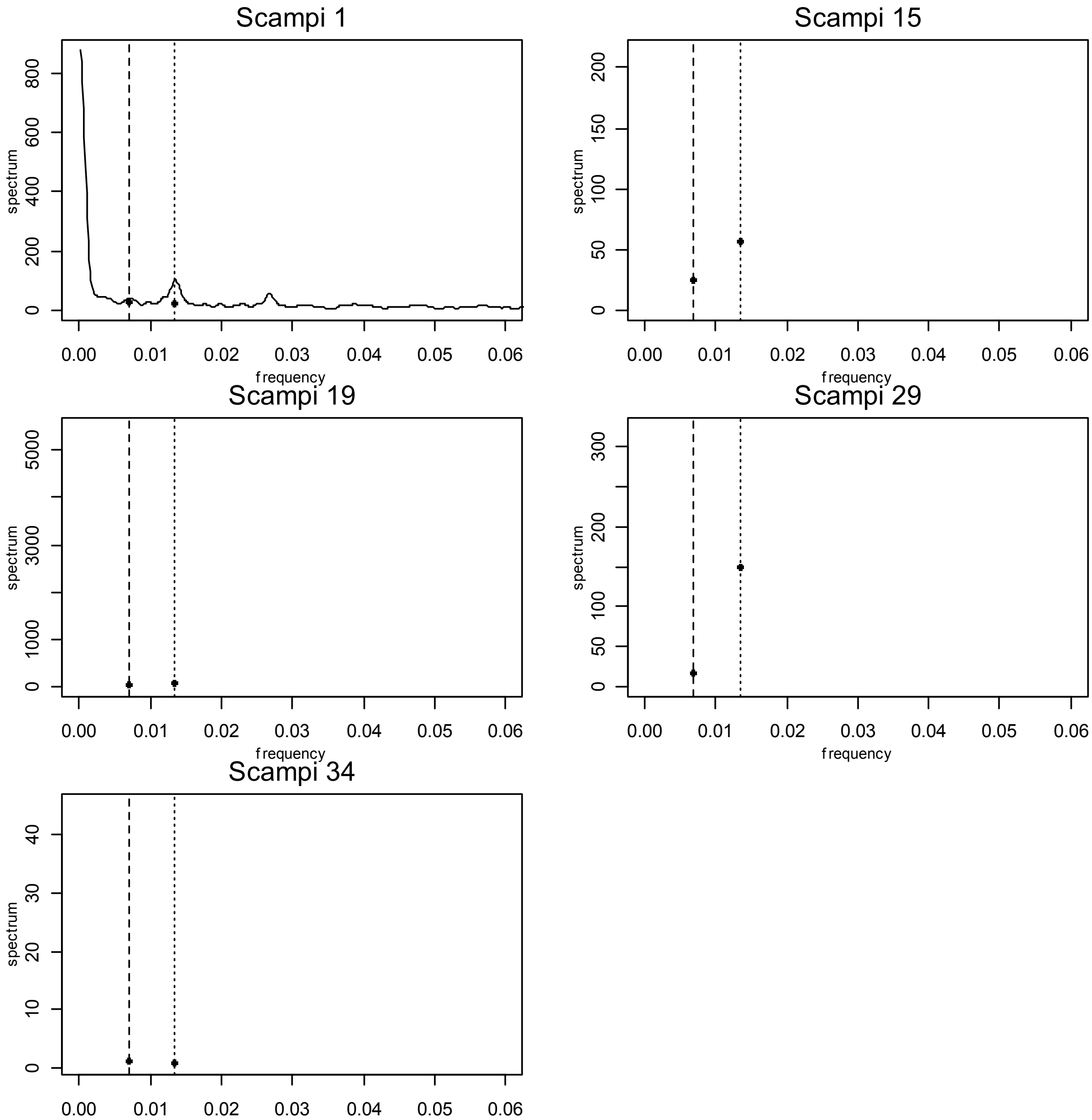


Figure 29: Smoothed periodogram for scampi with long periods of detections. Dashed line represents period of 24 hour cycle, dotted line represents period of 12.42 hour cycle. Closed symbols represent lower 95% confidence limits of the cycles at the 24 hour and 12.42 hour frequency.

Previous analyses of this type of scampi emergence data have combined data from a number of animals to estimate a population level detection pattern (Tuck et al. 2013, Tuck et al. in press). The tags have a nominal delay of 80 seconds, and so on average would be detected 7.5 times per 10 minute interval if they were continually available. Assuming that an animal would be seen if it is detectable more than 4 times per 10 minute interval, then the number of detectable animals (of the five) can be estimated for each time interval. The periodogram for these combined data (Figure 30) shows weak evidence of 12.42 hourly (tidal) periodicity in the numbers of scampi detectable. The previous application of this approach in SCI 1 and SCI 2 (Tuck et al. 2013) identified a clear daily and tidal periodicity in scampi detectability. The lack of any strong pattern in detectability in these data may relate to the low numbers of individuals included in the analysis, and their availability within the long duration of the deployment.

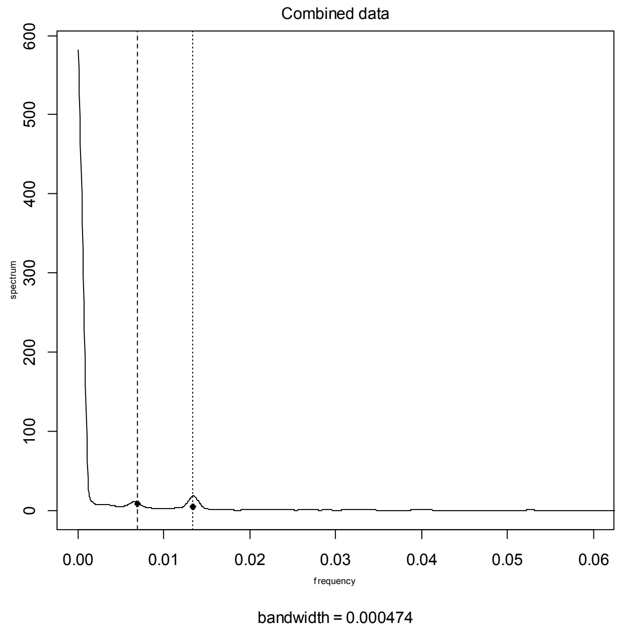


Figure 30: Smoothed periodogram of combined data for five scampi from SCI 3.

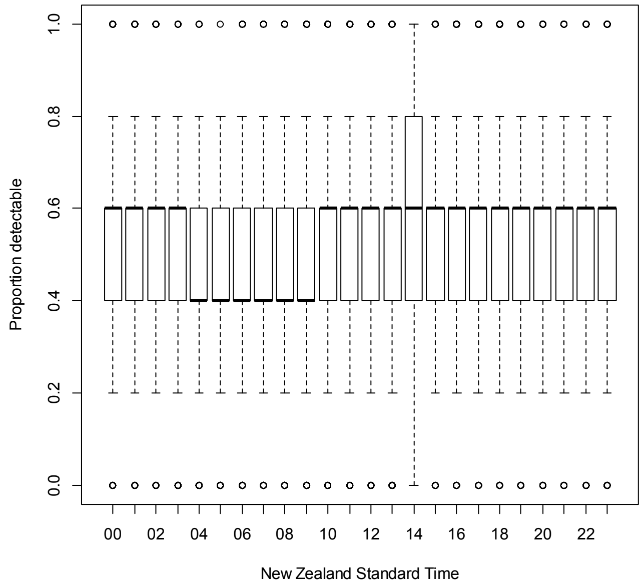


Figure 31: Boxplot of proportion detectable (individuals with at least 4 detections per 10 minute interval) in relation to time of day, averaged over full duration of SCI 3 study.

Over the whole deployment, the five scampi were detectable (at least 4 detections per 10 minute interval) 51.7% of the time (mean value), with the 5% and 95% quantiles being 20.0% and 80.0%, respectively. There was no evidence of any pattern in relation to time of day (Figure 31).

Using the proportion detectable as an estimate of the proportion of scampi that would either be out of burrows or in their burrow entrance (as opposed to hidden within a burrow), the density of visible scampi in each survey can be scaled to a population density estimate, to in turn estimate burrow occupancy and various catchability terms (Table 11) required as priors in the assessment model (Tuck

& Dunn 2012). Estimates from the SCI 3 survey are very similar to those previously estimated from SCI 1.

Table 11: Best estimates of catchability terms for trawl caught scampi, visible scampi and scampi burrows, estimated from 2013 SCI 3 photo survey observations and scampi emergence study. Estimated values for SCI 1 (Tuck et al. 2013) also provided for comparison.

	SCI 1	SCI 3	Source
Major opening	0.0794 m^{-2}	0.1267 m^{-2}	survey
Visible scampi	0.0175 m^{-2}	0.0261 m^{-2}	survey
Scampi "out"	0.0036 m^{-2}	0.0058 m^{-2}	survey
Scampi as % of openings	22%	21%	Visible/openings
% of scampi “out”	21%	22%	Out/visible
Median emergence	52%	52%	Acoustic tags
Estimated scampi density	0.0337 m^{-2}	0.0505 m^{-2}	Visible/emergence
Estimated occupancy	42%	40%	Est den/major
q trawl	0.107	0.115	Out/Est den
q scampi	0.52	0.517	Vis/Est den
q photo	2.36	2.51	Major/Est den

4. CONCLUSIONS

A photographic and trawl surveys of scampi in SCI 3 was conducted in September and October 2013. The survey was conducted over slightly revised strata from that in previous surveys in 2009 and 2010, to exclude some areas considered unsuitable for scampi. Two existing strata were also split in half, and the emphasis of the survey was changed slightly to enable more trawl stations (and fewer photographic stations) within the same overall duration. The photographic survey estimated a scampi burrow abundance of 683 million over the whole area, continuing the trend in increasing abundance observed since 2009. Trawl survey catch rates in SCI 3 were comparable with 2010, but higher than the 2009 survey. The trawl survey estimate of scampi biomass over the whole SCI 3 survey area was 551 tonnes. 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.

Almost 3400 scampi were tagged and released, as part of an investigation into growth, but to date, only 5 scampi have been recaptured. Forty scampi were released with acoustic tags, divided between three hydrophone moorings, to investigate emergence patterns. The moorings were recovered after a 106 day deployment. Most tags were not detected after a few days, and of those that were detected through most of the deployment, only 2 showed strong periodicity in detection. Of those tags considered to have continued operating throughout the deployment, scampi were estimated to have been detectable 52% of the time, with no evidence any pattern in relation to time of day.

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 Neil Bagley, Jim Drury, Ben Lennard, Dan MacGibbon, Nicola Rush and Caroline Williams were the scientific staff for the voyage. Mooring positions were selected on the basis of advice from the fishing industry, and we are grateful for their cooperation in avoiding those locations during the duration of the mooring study. 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 deployment of the moorings. The acoustic moorings were provided by Mike Brewer and Fiona Elliot of the NIWA Marine Physics team. The moorings were recovered at the end of the Chatham Rise trawl survey from *RV Tangaroa*, and we are very grateful the scientists and crew involved were able to find the time within this demanding survey. Scampi tag recoveries have been made and reported to NIWA by the fishing industry. The voyage was funded within project SCI201002C. 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.

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. (Unpublished report held by MFish, Wellington.)

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. (Unpublished report held by Ministry of Primary Industries, Wellington)

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 (49)*.

Doonan, I.J.; Rasmussen, S. (2012). Random Station User Manual (RandonStation v1.00-2012-06-13). NIWA unpublished report. 47 p.

Francis, R.I.C.C. (1999). The impact of correlations in standardised CPUE indices. New Zealand Fisheries Assessment Research Document 99/42. 30 p. (Unpublished report held by NIWA library, Wellington.)

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. 291 p. (Unpublished report held by ICES, Copenhagen.)

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 XIV/1810/C1/94. 155 p. (Unpublished report held by DGXIV, EU, Brussels.)

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.

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

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

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

Tuck, I.; 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 SCI201002A. 54 p. (Unpublished report held by MFish, Wellington.)

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

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 Wiararapa / Hawke Bay (SCI 2). Final Research Report for Ministry of Fisheries research projects SCI2006-01 & SCI2008-03W. 30 p. (Unpublished report held by MFish, Wellington.)

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

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. (Unpublished report held by MPI, Wellington.)

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 project SCI2009-01 & SCI2010-01. 29 p. (Unpublished report held by MPI, Wellington.)

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. (Unpublished report held by MFish, Wellington.)

APPENDIX 1: Summary of photo survey workup

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

Reader_year corrected analysis

2001

Major burrows	902	903	902&903
Area (km^2)	440	553	993
Stations	7	9	16
Mean density (.m^{-2})	0.1289	0.3029	0.2258
CV	0.20	0.09	0.09
Abundance (Millions)	56.72	167.53	224.25

Visible scampi	902	903	Fishery
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	Fishery
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

Reader_year corrected 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})	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0537
CV	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.14
Abundance (Millions)	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31	53.35
	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	
Visible scampi	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	902&903
Area (km^2)	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31	
Stations	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	
Mean density (.m^{-2})	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.0185
CV	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31	0.17
Abundance (Millions)	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	18.37
	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	
Scampi out	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31	902&903
Area (km^2)	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	
Stations	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	
Mean density (.m^{-2})	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31	0.0013
CV	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.43
Abundance (Millions)	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	1.31

Reader_year corrected 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})	0.0481	0.0874	0.0570	0.0581	0.0899	0.0818	0.0574	0.1197	0.0729	0.0700
CV	0.26	0.10	0.13	0.16	0.12	0.10	0.19	0.11	0.05	0.11
Abundance (Millions)	21.16	48.31	39.91	83.20	54.42	54.08	9.87	54.93	365.87	69.47

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

Reader_year corrected analysis
2013

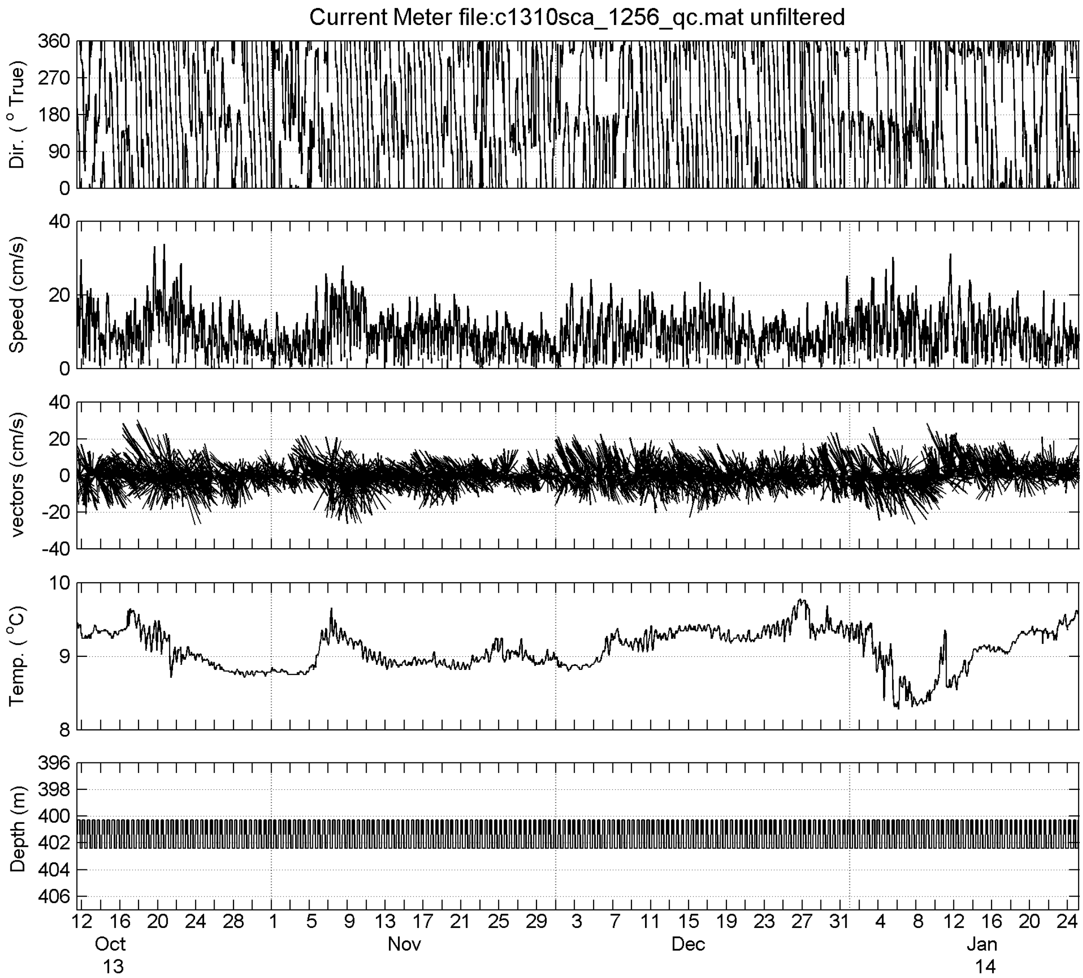
Major burrows	902	903	90211	90212	90221	90222	9023	9031	Fishery	902&903
Area (km^2)	440	553	700	1432	605	661	172	459	5022	
Stations	6	5	3	18	6	6	3	3	50	
Mean density (.m^{-2})	0.1094	0.1914	0.0614	0.0754	0.1871	0.1853	0.1453	0.1541	0.1267	0.1551
CV	0.17	0.14	0.17	0.12	0.18	0.08	0.16	0.21	0.06	0.11
Abundance (Millions)	48.14	105.85	42.95	108.02	113.20	122.45	24.99	70.71	636.32	153.99

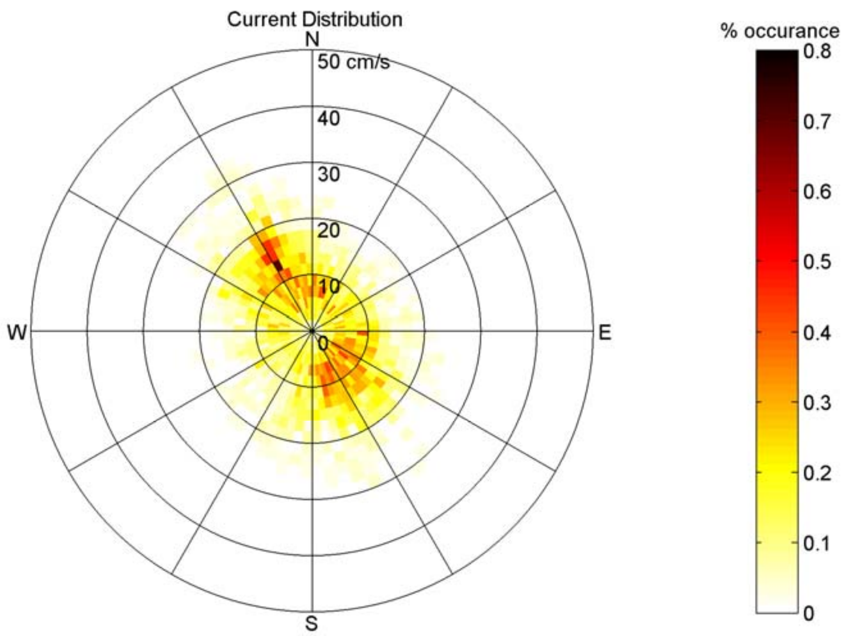
Visible scampi	902	903	90211	90212	90221	90222	9023	9031	Fishery	902&903
Area (km^2)	440	553	700	1432	605	661	172	459	5022	
Stations	6	5	3	18	6	6	3	3	50	
Mean density (.m^{-2})	0.0208	0.0205	0.0184	0.0147	0.0427	0.0509	0.0432	0.0207	0.0261	0.0207
CV	0.34	0.11	0.49	0.19	0.18	0.19	0.20	0.26	0.09	0.17
Abundance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

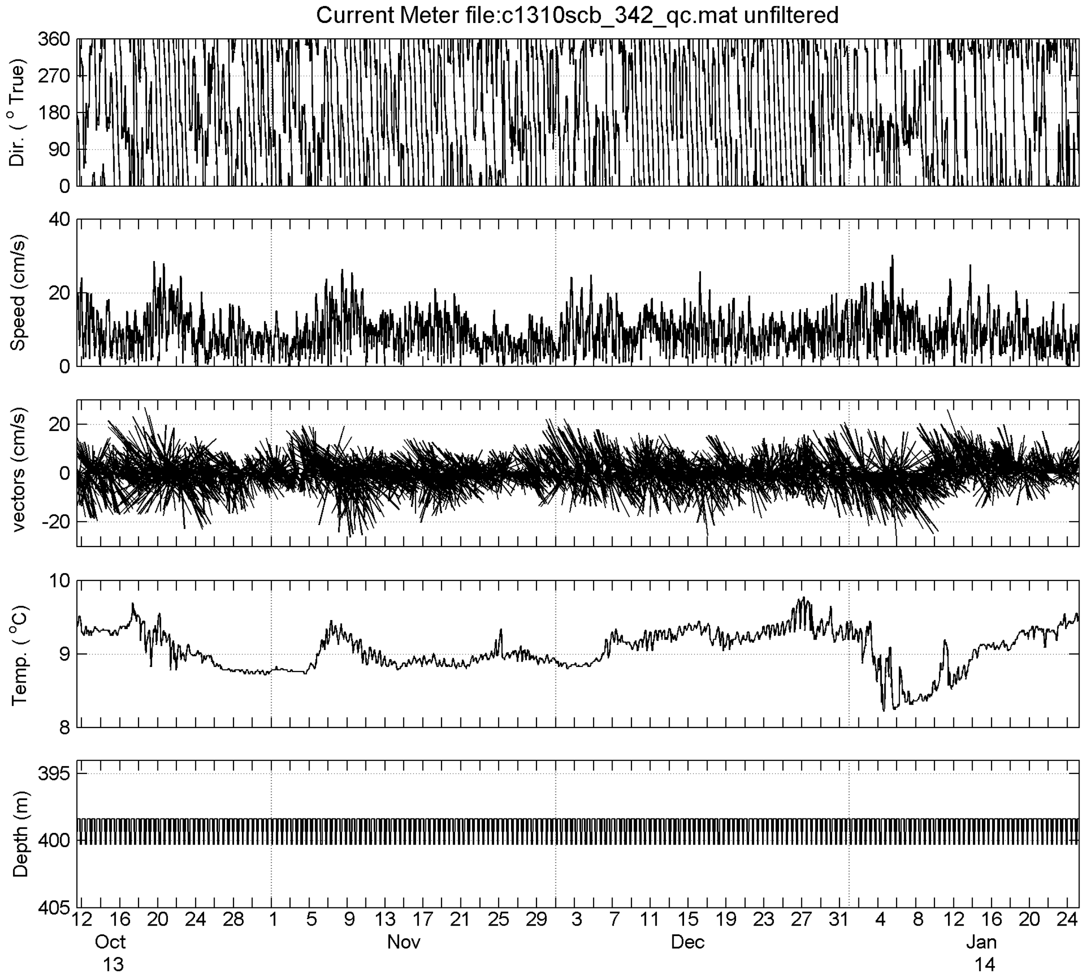
APPENDIX 2: Current meter summary data

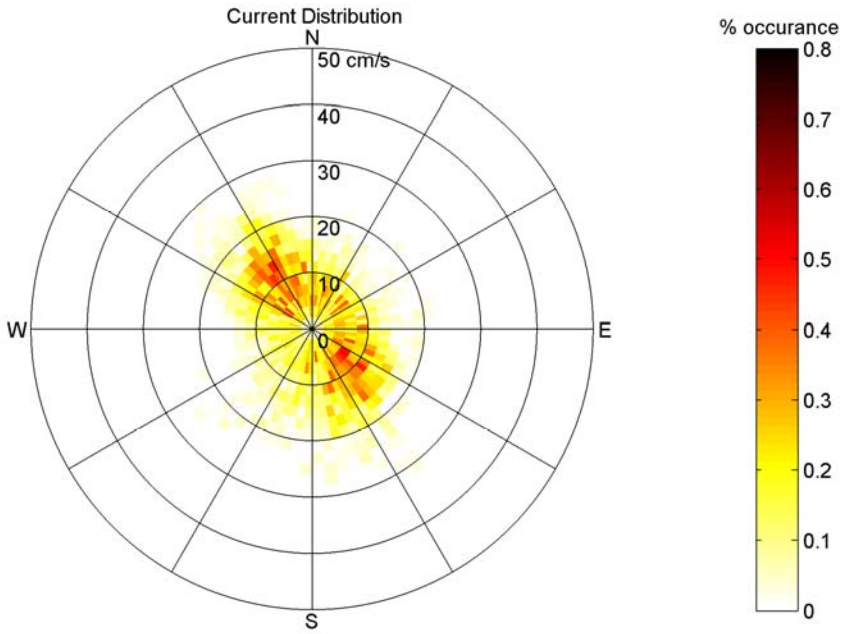
Summary of data downloaded from current meter at mooring A.



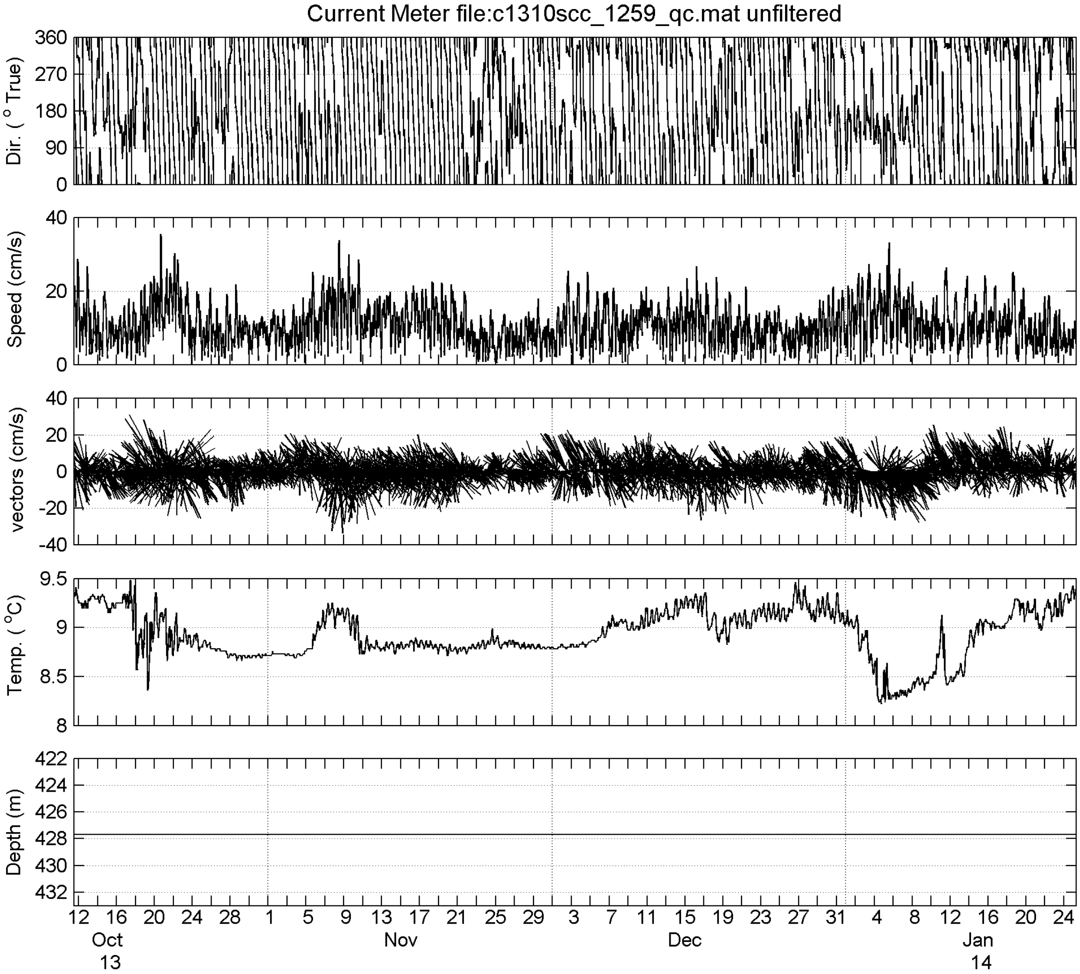


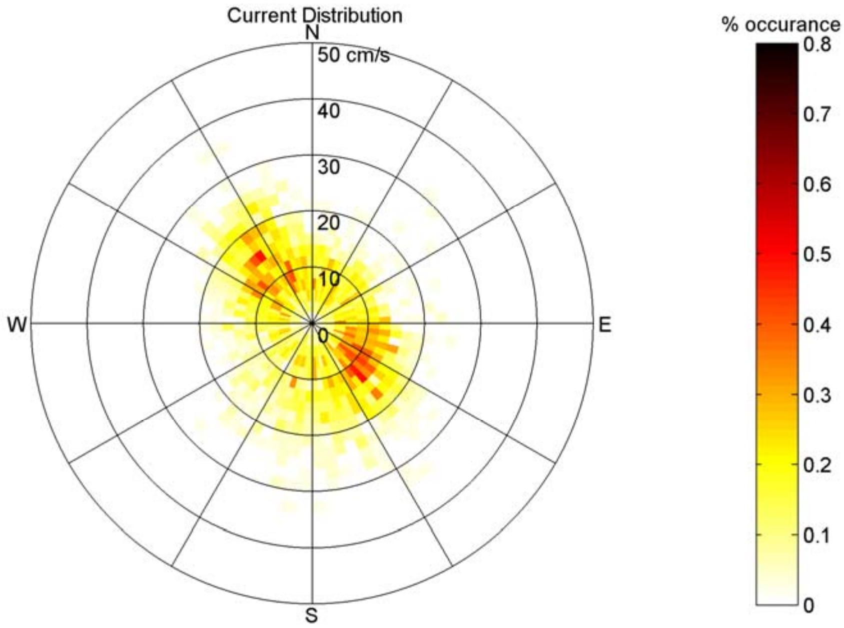
Summary of data downloaded from current meter at mooring B.





Summary of data downloaded from current meter at mooring C.





APPENDIX 3: Acoustic tagging data

Transmitter	Scampi No.	Carapace length (mm)	Sex (M/F)	Mooring A Bottom	Mooring A Top	Mooring B Bottom	Mooring B Top	Mooring C Bottom	Mooring C Top	last date	days at liberty
A69-1303-30628	1	51	F	0	0	0	0	103	16774	25/01/2014	106
A69-1303-30627	2	45	F	445	235	58	55	467	382	14/11/2013	34
A69-1303-30626	3	55	M	0	0	1	6	761	286	12/10/2013	1
A69-1303-30625	4	36	M	37	29	27	20	929	1195	10/11/2013	30
A69-1303-30624	5	56	M	0	0	0	0	50	86	11/10/2013	0
A69-1303-30623	6	55	M	0	0	0	0	1597	2168	22/10/2013	11
A69-1303-30622	7	51	M	24	14	100	50	1147	1983	7/12/2013	57
A69-1303-30621	8	38	F	0	0	0	0	2185	581	26/10/2013	15
A69-1303-30620	9	34	M	0	0	5	2	50	51	11/10/2013	0
A69-1303-30619	10	47	F	0	0	0	0	168	184	13/10/2013	2
A69-1303-30618	11	52	M	0	0	0	0	558	930	17/10/2013	6
A69-1303-30617	12	45	M	0	0	3	5	407	203	19/11/2013	39
A69-1303-30616	13	49	F	119	84	0	0	243	280	27/10/2013	16
A69-1303-30615	14	40	M	0	0	1	1	48	34	11/10/2013	0
A69-1303-30614	15	37	M	0	0	5171	74679	0	0	25/01/2014	106
A69-1303-30613	16	53	M	0	0	987	864	0	0	21/10/2013	10
A69-1303-30612	17	47	M	80	26	770	304	0	0	7/11/2013	27
A69-1303-30611	18	51	M	333	94	5411	1965	20	14	18/01/2014	99
A69-1303-30610	19	40	F	0	0	54676	27172	0	0	13/01/2014	94
A69-1303-30609	20	42	F	18	13	99	89	0	0	14/10/2013	3
A69-1303-30608	21	42	M	0	0	478	539	5	10	19/10/2013	8
A69-1303-30607	22	45	F	0	0	1453	2036	0	0	16/10/2013	5
A69-1303-30606	23	52	M	0	0	214	235	0	0	12/10/2013	1
A69-1303-30605	24	59	M	0	0	281	295	0	0	12/10/2013	1
A69-1303-30604	25	43	M	0	0	1029	2384	1	0	19/10/2013	8
A69-1303-30603	26	46	F	0	0	151	192	0	0	14/10/2013	3
A69-1303-30602	27	49	M	0	0	84	169	0	0	12/10/2013	1
A69-1303-30601	28	42	F	4106	2806	0	0	0	0	25/10/2013	14
A69-1303-30600	29	34	M	4985	47082	0	0	0	0	25/01/2014	106
A69-1303-30599	30	53	F	98	81	0	0	0	0	11/10/2013	0
A69-1303-30598	31	55	F	110	114	0	0	0	0	16/12/2013	66
A69-1303-30597	32	56	M	176	95	69	41	0	0	7/11/2013	27
A69-1303-30596	33	45	M	253	179	0	0	0	0	22/10/2013	11
A69-1303-30595	34	38	M	87711	84243	0	0	0	0	25/01/2014	106
A69-1303-30594	35	46	M	141	131	1	1	0	0	14/10/2013	3
A69-1303-30593	36	42	M	516	519	0	0	0	0	13/11/2013	33
A69-1303-30592	37	53	M	114	91	0	0	0	0	12/10/2013	1
A69-1303-30591	38	48	F	22335	21065	0	0	0	0	4/11/2013	24
A69-1303-30590	39	58	M	45	40	0	0	0	0	11/10/2013	0
A69-1303-30589	40	56	F	712	647	0	0	0	0	12/10/2013	1