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Estimating the abundance of scampi in SCI 6A (Auckland Islands) in 2013

New Zealand Fisheries Assessment Report 2015/10

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Photographic and trawl surveys of scampi in SCI 6A were conducted in March 2013 from the commercial scampi trawler *San Tongariro*. This area was last surveyed in 2009. New bathymetric data has been used to revise the stratification of the survey region. Photographic survey estimates of burrow abundance were slightly lower than those in 2009, but estimates of scampi abundance (visible animals, and animals out of burrows) were comparable with the previous survey. Trawl survey catch rates were slightly higher than in 2009, but comparable with estimates in 2007 and 2008. A tag mortality study was undertaken, and found that once injury to the hind gut by the T-bar tag was avoided, survival of tagged animals was high, and not significantly different from control animals. Mortality of tagged and released scampi was estimated to be 12%. Over 6600 scampi were tagged and released, as part of an investigation into growth, with releases distributed across the fishing ground. To date, over 100 tagged scampi have been recaptured. Sixty scampi were released with acoustic tags, divided between three moorings, to investigate emergence patterns. The moorings were successfully recovered at the end of the voyage with a deployment duration of 21 days, and data downloaded. While some animals showed a distinct periodicity in their detectability coincident with a 12.6 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). The total scampi landings in 2011/12 were 634 t (limit 1191 t). The landings for scampi in SCI 6A were 158 t (TACC 306 t) in 2011/12. The other major fisheries are SCI 1 (TACC 120 t), SCI 2 (TACC 100 t), SCI 3 (TACC 340 t), and SCI 4A (TACC 120 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. Available information is that scampi are quite long lived.

Scampi occupy burrows in muddy substrate, 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. 2003, Smith et al. 2003), although these approaches still face uncertainties over burrow occupancy and population size composition (ICES 2007, Sardà & Aguzzi 2012). Photographic surveying has been used extensively to estimate the abundance of the European scampi, and has been carried out in New Zealand since 1998. Surveys in SCI 6A started in 2007, and this report documents the fourth survey of this area. Longer series are available in SCI 1 (1998 – 2013, seven surveys), SCI 2 (2003 – 2013, five surveys) and SCI 3 (2001 – 2010, four surveys).

The survey estimates 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).

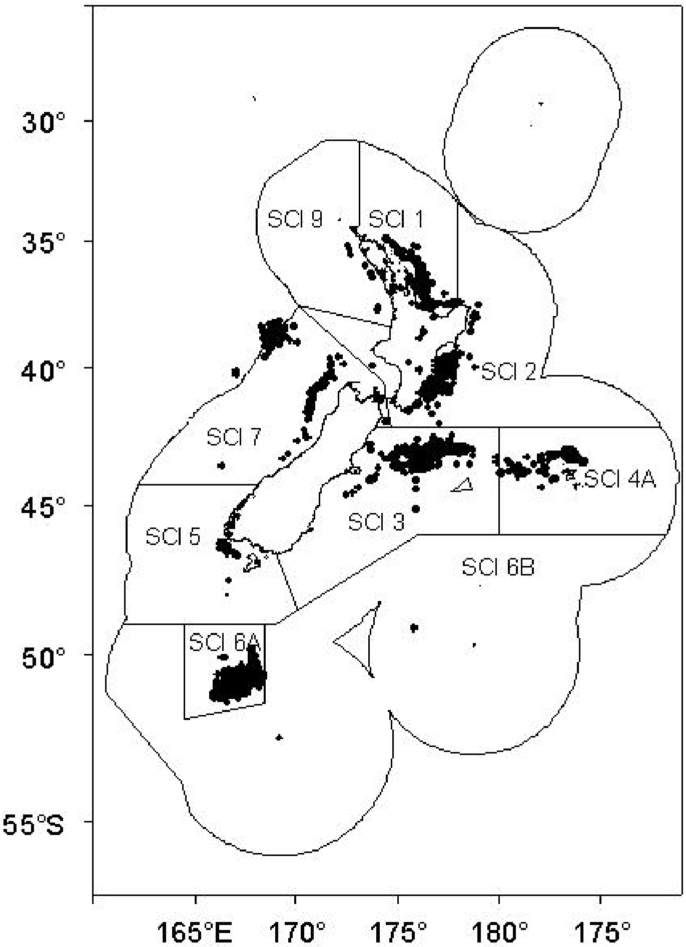

Figure 1: Spatial distribution of the scampi fishery since 1988–89. Each dot shows the mid-point of one or more tows recorded on TCEPR with scampi as the target species.

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

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

In February/March 2013 we undertook stratified random photographic surveys of scampi burrows within SCI 6A (Auckland Islands, 350–550 m depth), from the Sanford Ltd scampi trawler *San Tongariro*. This was the fourth photographic survey of the SCI 6A area (the previous surveys conducted in 2007 – 2009 (Tuck et al. 2007, Tuck et al. 2009a, Tuck et al. 2009b)). The survey was stratified on the basis of depth (50 m bands), using the overall extent of previously defined strata (Figure 2). Previous surveys in SCI 6A have used the same strata, accounting for about 90% of landings from the fishery over its history (Tuck & Dunn 2012), and a greater proportion in recent years.

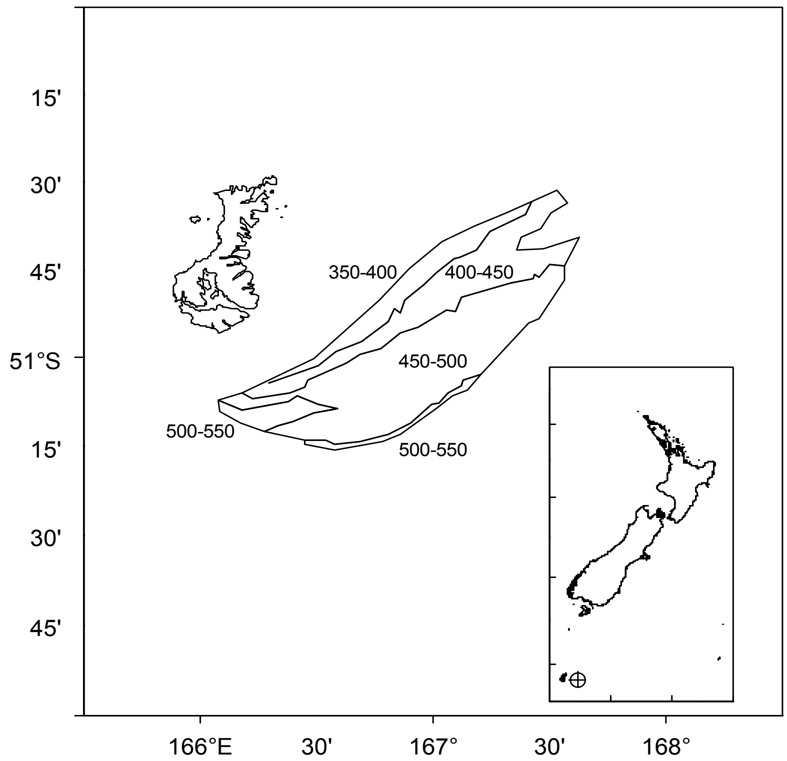

Figure 2: Survey strata for the 2007–2009 photographic surveys of SCI 6A.

A survey plan for the SCI 6A survey was presented to the MPI Shellfish Working Group in February 2013. This plan included proposed dates of the voyage, spatial extent of the survey and stratification, and a proposed allocation of stations to strata (based on previous survey density estimates). Methods were also presented for the analysis of the survey data, and also the estimation of growth from tagging and examination of emergence patterns and rates. The Working Group approved the approaches proposed (suggesting a slight modification to the survey stratification), but suggested investigating the possibility of changes in the spatial distribution of the scampi targeted fishery in recent years, and spatial patterns of scampi abundance within the larger strata (400–450 m and 450–500 m), and splitting the larger strata to improve the broader coverage of survey stations.

Photographic survey

A target of 40 photographic stations was set, on the basis of survey duration, and these were allocated to strata using the *allocate* package in R (aiming to minimise the overall survey CV), on the basis of burrow densities observed in the 2009 survey. A minimum of three stations was specified for each stratum. Positions of stations were randomised using the Random Stations package (Doonan & Rasmussen 2012) constrained to keep the midpoints of all stations at least 1 km apart. 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 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 that includes Nikon Coolpix 5000 cameras (5.0 million pixels, 2560 × 1920 resolution), 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 (typically 7 MB each). 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 to two DVDs.

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 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. This was done in a single transect as previous studies concluded that this was the most efficient approach, given the distribution pattern of scampi burrows and the various time constraints (steaming, deployment, hauling, downloading data, etc) (Watson & Cryer 2003).

The locations of planned photographic and trawl stations are shown in Figure 3. The number of planned and completed stations by strata are provided in Table 1.

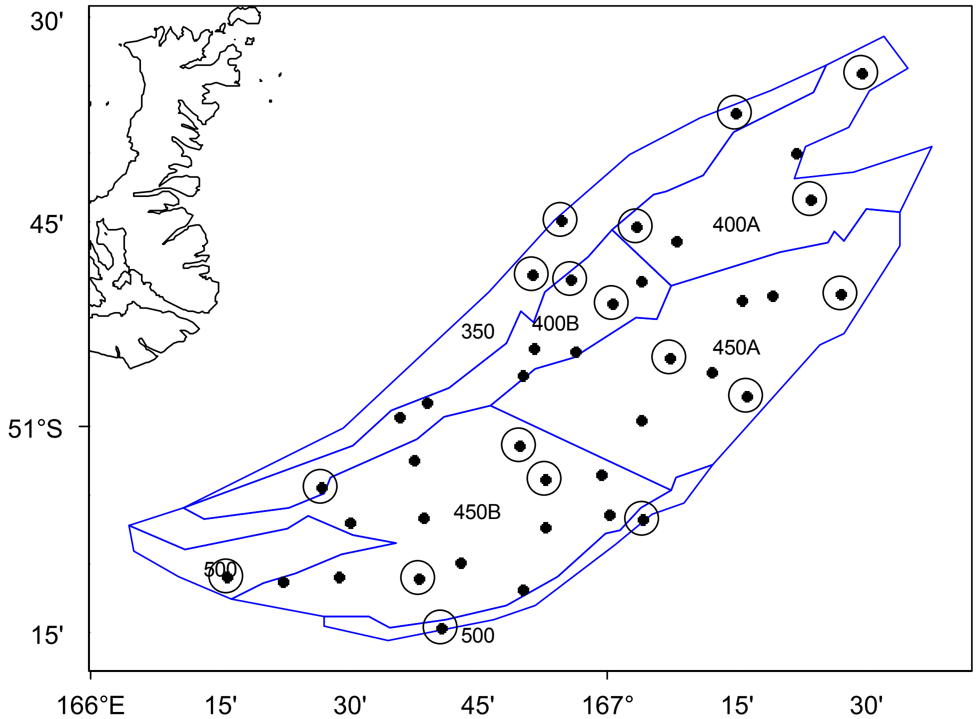

Figure 3: Planned station locations for the 2013 photographic survey of SCI 6A (black dots indicating the station midpoints). Stations with outer circle represent those selected as trawl stations.

Image selection and scoring

Images were examined and scored using a standardised protocol (Cryer et al. 2002) applied by a team of six trained readers. For each image, the main criteria 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 the "Didger" image analysis 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 4). 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 any 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" of scampi 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 burrow systems because burrow systems are relatively large compared with the quadrat (photograph) size and accepting all systems 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 recorded in spreadsheets for later compilation into a database containing all scampi image data, and annotated low resolution copies (one for each reader) of the image files are saved (to establish 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 6A (generated in 2009, and including images from 2007 and 2008)(Tuck et al. 2009a) was augmented with images from 2009, and reread in 2013 (at the same time as the SCI 6A 2013 survey images), with each image in each reference set being read by all 6 readers, using the standard image scoring and re-reading procedure.

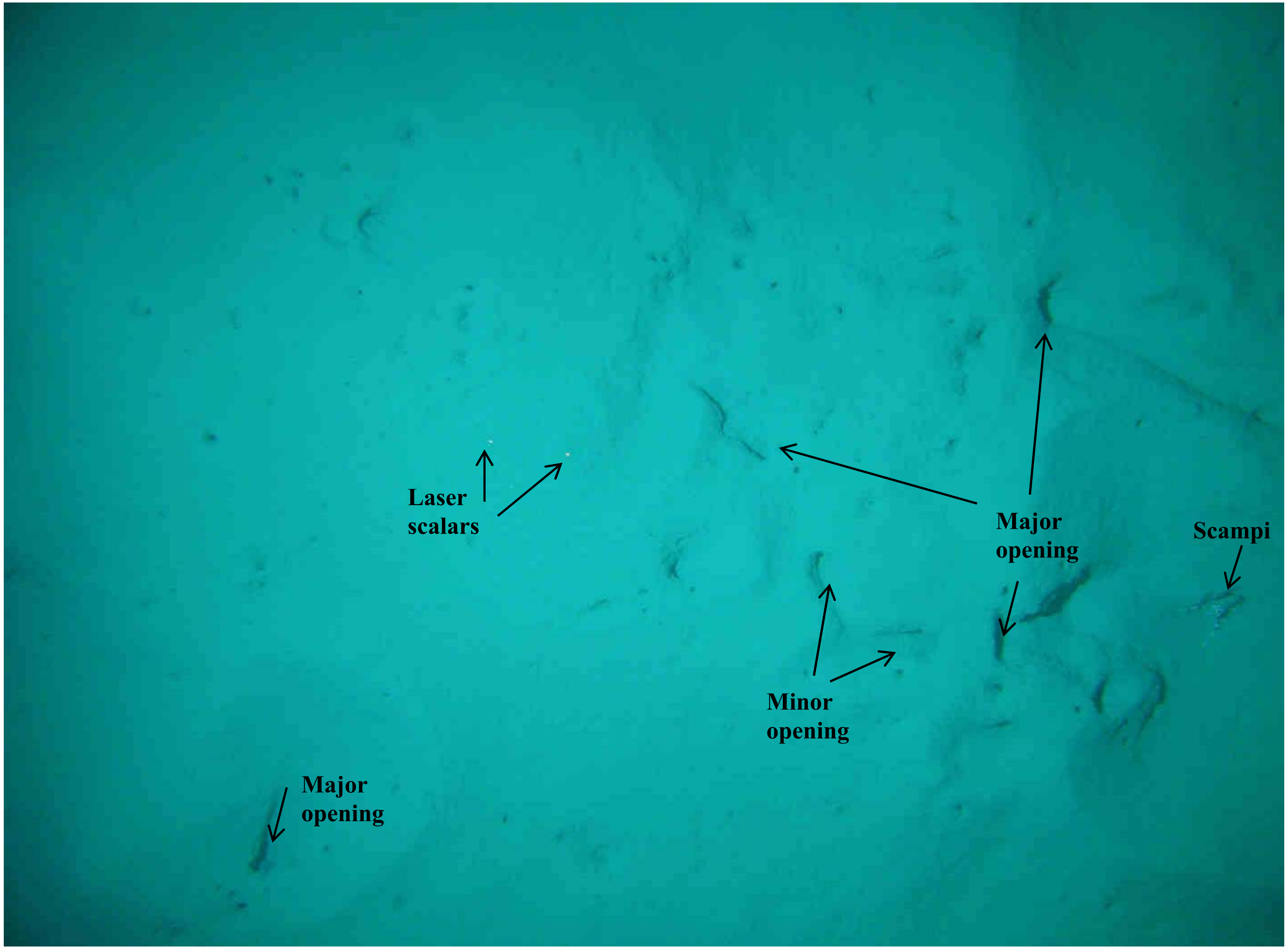

Figure 4: Example image from March 2006 survey in SCI 2 showing laser scaling dots, several characteristic scampi burrows and one large visible scampi.

Data analysis

Burrow and scampi counts from photographs were analysed using methods analogous to those in the *Trawlsurvey* Analysis Program (Vignaux 1994) 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 (under 2 m^2) or very large (over 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 for both surveys, with "correction factors" calculated for each reader, inter survey correction factors were calculated, 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.

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 (Figure 12). Trawl sampling was conducted with the *San Tongariro* scampi trawl, as with previous scampi surveys from this vessel (Tuck et al. 2007, Tuck et al. 2009a, Tuck et al. 2009b). As with previous surveys, although the vessel used a twin rig trawl, only the catch from the trawl with a small mesh codend (45 mm) was used as the research survey sample.

Scampi tagging

The second objective of the voyage 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. Given the cold surface water temperatures of the Auckland Islands region, it was not considered necessary to chill the water further with seawater ice. 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 5) 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 6A will be in 2016, so it is anticipated that recoveries will be from commercial fishing activity.

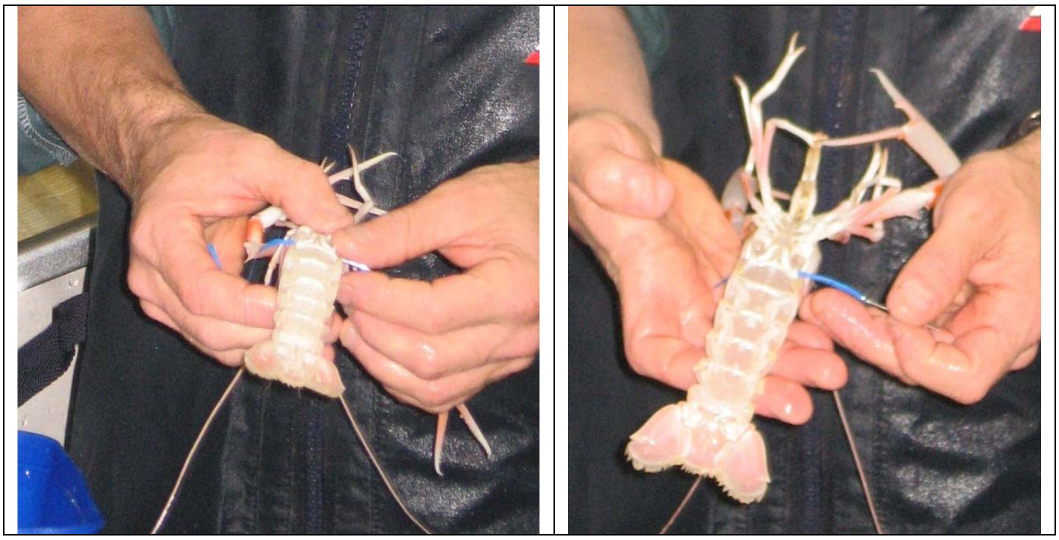

Figure 5: Photographs showing location of streamer tag in scampi.

The tagging study has a primary aim of providing data to estimate growth rates, but mark recapture data also offers the potential to investigate stock size, although use of the data in this way needs to make assumptions on tag mortality, animal mixing and detectability. In order to investigate tag mortality, tagged and control scampi were placed in individual plastic pipes within plastic fishbins, held within an aluminium frame, which was deployed on the seabed on an acoustic release mooring for 7 days. The mooring frame (with one fish bin in place) is shown in Figure 6. Scampi were placed in tubes of 52mm, 66 mm or 81 mm internal diameter, depending on animal size. Procedures used were approved by the NIWA Animal Ethics Committee prior to the survey.

The tag mortality study within the mooring frame was only conducted once, but following this study, a second study was conducted holding scampi in the same plastic fishbins on board the vessel, while at anchorage.

Acoustic tagging

The third objective of the study was to investigate burrow emergence patterns through acoustic tagging of scampi. Sixty scampi were released with acoustic tags, as part of acoustic mooring deployments, to investigate scampi emergence patterns, split between 3 separate moorings (20 at each). Forty tags were funded within the project, with the additional twenty purchased by NIWA. A small Vemco (V7-1L) acoustic tag (18 mm×7 mm diameter, 0.7 g in water) was attached to each animal, positioned between the walking legs (Figure 7). The moorings were deployed on 25th February 2013, and recovered on 18th March 2013, with a deployment duration of 21 days. Tags with a 130 second nominal delay were used, rather than the 90 second delay used in previous deployments on scampi (Tuck et al. 2013). This change was on the basis of advice from Vemco, based on the number of tags at each mooring, and the optimal delay for minimum interference between tags. The deployment duration was constrained by an appropriate weather window for mooring recovery towards the end of the voyage. Mooring design is shown in Figure 8.

Figure 6: Scampi tag mortality mooring frame.

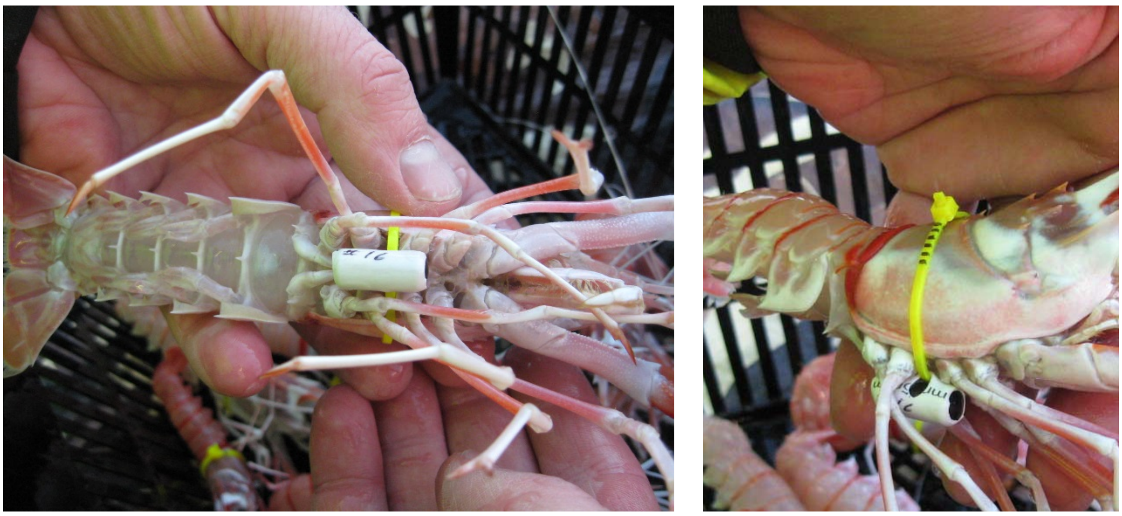

Figure 7: Scampi with acoustic tag attached.

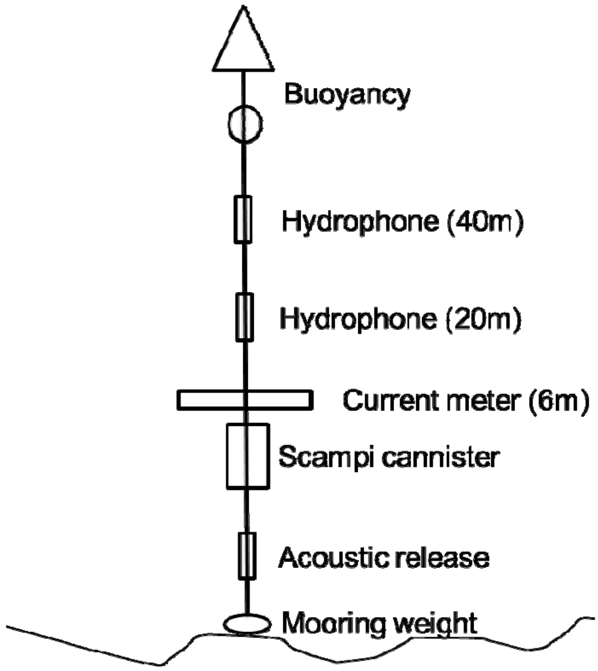

Figure 8: Diagram of acoustic mooring for deployment of scampi and hydrophones.

3. RESULTS

The voyage was completed successfully between 22nd February and 28th March 2013. Some ship time was lost due to poor weather, but survey objectives were met. Additional video work was also conducted on the vessel's triple rig trawl gear, examining the effects of a restrictor to reduce the gaping of the middle net in a triple rig set. Full details are reported separately (Pierre et al. 2013), but the video footage confirmed that the height of the opening during hauling was reduced by the restrictors by 75%.

In previous voyages it has become apparent that the bathymetric data the strata were defined from were not particularly accurate in some areas, requiring some stations to be moved to position them in the correct depth range. During the 2013 survey additional depth records were provided by the vessel, and the strata have been revised on the basis of this (Figure 9). All previous surveys have been analysed on the basis of these new strata definitions.

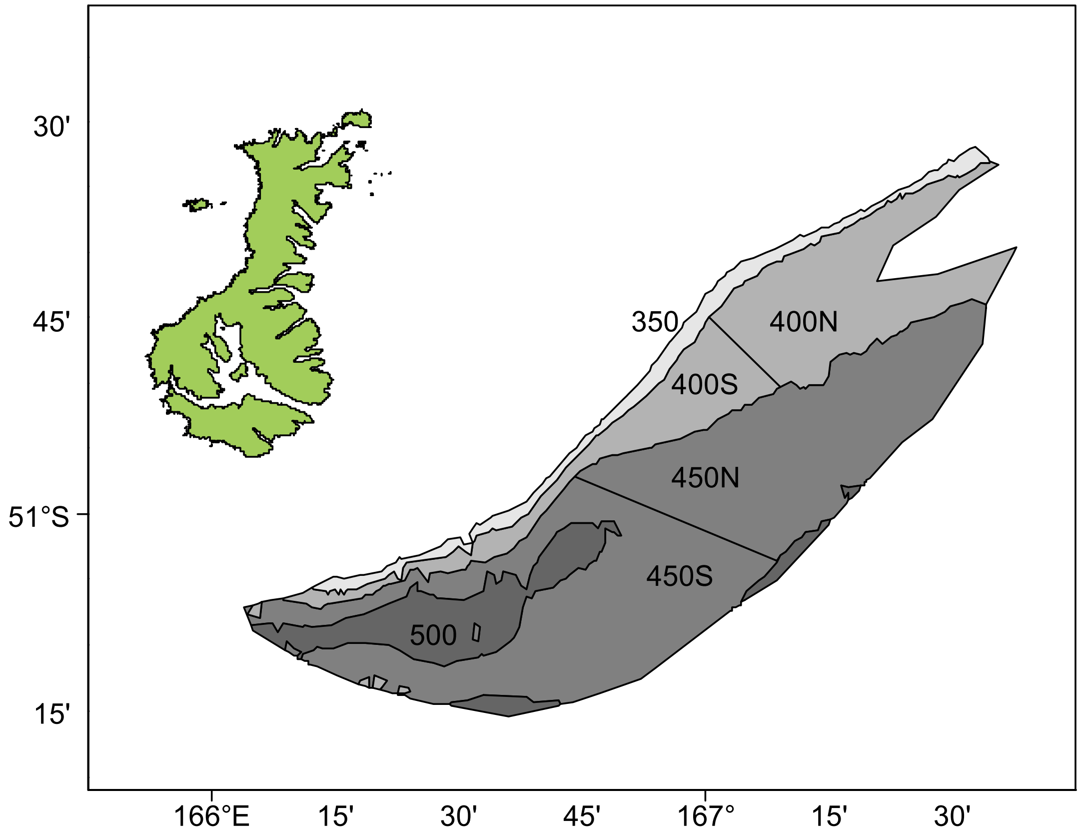

Figure 9: Revised strata defined on the basis of depth data provided by the San Tongariro.

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 8311 m^2 of seabed was viewed (acceptable quality images), with an average of 36 images at each station, an average seabed area viewed by each image of 5.77 m^2, and an average area viewed of 207.77 m^2 at each station.

The slight revision of the strata boundaries meant that the numbers of stations planned for each stratum were not quite achieved, but all strata had at least four photographic stations, and two trawl stations (Table 1).

As with the analysis of previous surveys (Tuck et al. 2009a) the calibration across years and between readers was conducted as a two stage process. To calibrate counts between years, the reference set count data were examined within a generalised linear modelling framework on burrow count data from individual images, with a poisson error distribution. A model testing the null hypotheses that there were no spatial trends in the count data and no differences between reader counts over time (2007, 2008, 2009 and 2013), detected highly significant station and reader effects (both considered as factors) (Table 2).

Table 1: Details of strata and number of stations for SCI 6A survey in 2013.

Stratum	Depth	Area (km^2)	Completed stations	
			Photo	Trawl
350	350–400	278	5	3
400N	400–450	789	4	3
400S	400–450	452	6	2
450N	450–500	1216	8	3
450S	450–500	1348	13	4
500	500–550	514	4	2

Table 2: Analysis of deviance for a generalised linear model relating the count of major burrow openings from second reads of the reference set to reader_year and station_year for SCI 6A.

	Df	Deviance	Resid. Df	Resid. Dev
NULL			3539	3359.3
readeryr	23	62.77	3516	3296.5
stnyr	16	420.01	3500	2876.5

Canonical indices or the reader_year terms are presented in Table 3 and plotted in Figure 10. These were calculated from the GLM indices and covariance matrix (Francis 1999). Not all readers were involved in the image reading process for both time steps, but for those that were, a correction factor was calculated to standardise the survey counts relative to 2013 as

$$Correction = \frac{1}{\left(I_{survey} / I_{2013} \right)}$$

where I_{survey} represents the canonical index for the survey, and I_{2013} represents the canonical index for 2013. Correction factors are also provided in Table 3. Counts were standardised to 2013, as that is the survey for which we also have data to estimate emergence from the acoustic tagging study. These correction factors were applied to the survey count data to estimate a "year effect corrected" data set comparable with 2013 counts. Where a current reader was not involved in scampi image reading in 2013, a correction factor of 1 was applied.

Having corrected for any drift in counting over time, reader bias in the "year effect corrected" count data was examined within a generalised linear modelling framework on burrow count data from individual images, with a poisson error distribution. A model testing the null hypotheses that there were no spatial trends in the count data and that all readers behaved similarly detected highly significant image area, station and reader effects (all except area considered as factors) (Table 4).

Canonical indices for the "year effect corrected" reads for reader effects are presented in Table 5, and plotted in Figure 11. These were calculated from the GLM indices and covariance matrix (Francis 1999).

The "bias correction" factor for each reader (C_i) is defined as follows

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

where c_i is the index of the ith reader, and $\bar{c}$ is the average of the reader indices. These correction factors were applied to the individual reader "year effect corrected" reads for the analysis of the count data.

Table 3: Canonical indices (and variance, CV and upper and lower 95% CI) for reader_year terms from a generalised linear model relating the count of major burrow openings from second reads of the reference set to reader_year, station and image area for SCI 6A.

Year	Indices	Variance	CVs	up95	low95	Correction factor
AM2013	1.8019	0.0335	0.1016	2.1681	1.4356	1.0000
BH2007	0.9060	0.1313	0.3999	1.6306	0.1814	1.0677
BH2008	0.8889	0.0252	0.1786	1.2065	0.5713	1.0883
BH2009	0.9674	0.0190	0.1426	1.2433	0.6914	1.0000
DP2007	0.2693	0.0135	0.4320	0.5019	0.0366	4.6146
DP2008	1.2309	0.0366	0.1555	1.6136	0.8481	1.0096
DP2009	1.0301	0.0196	0.1360	1.3103	0.7500	1.2063
DP2013	1.2427	0.0214	0.1178	1.5355	0.9498	1.0000
HA2007	0.6242	0.0617	0.3978	1.1208	0.1276	1.9410
HA2008	1.3739	0.0438	0.1524	1.7926	0.9552	0.8819
HA2009	1.3149	0.0255	0.1215	1.6346	0.9953	0.9214
HA2013	1.2116	0.0208	0.1191	1.5001	0.9231	1.0000
IT2007	1.1833	0.1516	0.3290	1.9620	0.4046	1.0633
IT2008	1.1163	0.0366	0.1714	1.4989	0.7337	1.1271
IT2009	0.9024	0.0189	0.1524	1.1774	0.6275	1.3942
IT2013	1.2582	0.0218	0.1172	1.5532	0.9632	1.0000
JD2007	0.6256	0.0339	0.2945	0.9941	0.2571	1.0804
JD2008	1.2151	0.0392	0.1628	1.6108	0.8193	0.5562
JD2009	0.6758	0.0134	0.1712	0.9072	0.4444	1.0000
MS2007	0.7703	0.0475	0.2828	1.2061	0.3346	1.7543
MS2008	1.1768	0.0335	0.1554	1.5426	0.8110	1.1484
MS2009	1.1403	0.0230	0.1329	1.4435	0.8371	1.1851
MS2013	1.3514	0.0237	0.1139	1.6591	1.0437	1.0000
NR2013	1.1417	0.0215	0.1284	1.4349	0.8485	1.0000

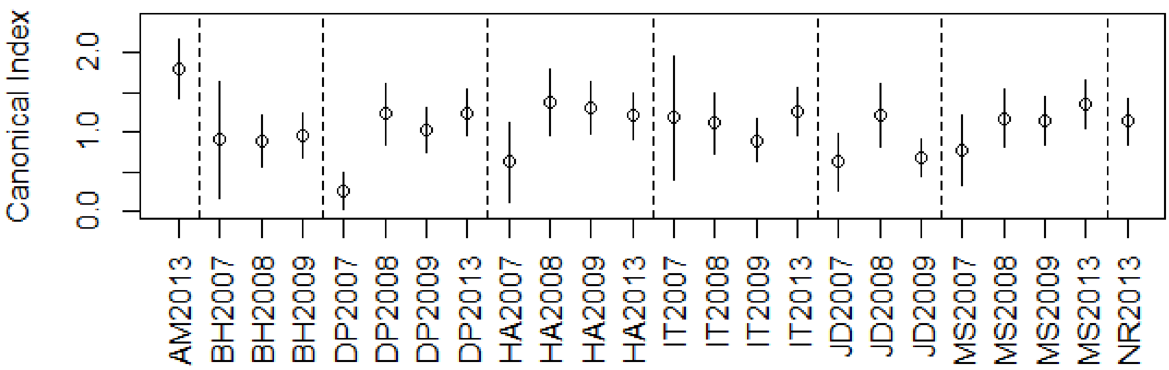

Figure 10: Canonical indices (and 95% CIs) for reader_year terms from a generalised linear model relating the estimated count of major burrow openings to reader, image area, and station for the SCI 6A reference set.

Table 4: Analysis of deviance for a generalised linear model relating the count of major burrow openings from second reads of the 2013 survey to reader, station and image area for SCI 6A.

	Df	Deviance	Resid. Df	Resid. Dev
NULL			4337	3159.9
reader	5	85.08	4332	3074.9
Image area	1	113.73	4331	2961.1
Station	44	294.45	4287	2666.7

Table 5: Canonical indices (and variance, CV and upper and lower 95% CI) for reader terms from a generalised linear model relating the count of major burrow openings from the "year effect corrected" data set to reader, station and image area for SCI 6A.

Reader	Indices	Variance	CVs	up95	low95	Bias correction
AM	1.5285	0.0152	0.0806	1.7748	1.2821	0.6827
DP	1.1901	0.0082	0.0763	1.3717	1.0086	0.8768
HA	0.8819	0.0057	0.0856	1.0328	0.7310	1.1832
IT	0.9695	0.0076	0.0901	1.1442	0.7947	1.0763
MS	1.1135	0.0093	0.0865	1.3062	0.9208	0.9371
NR	0.5774	0.0034	0.1015	0.6946	0.4603	1.8071

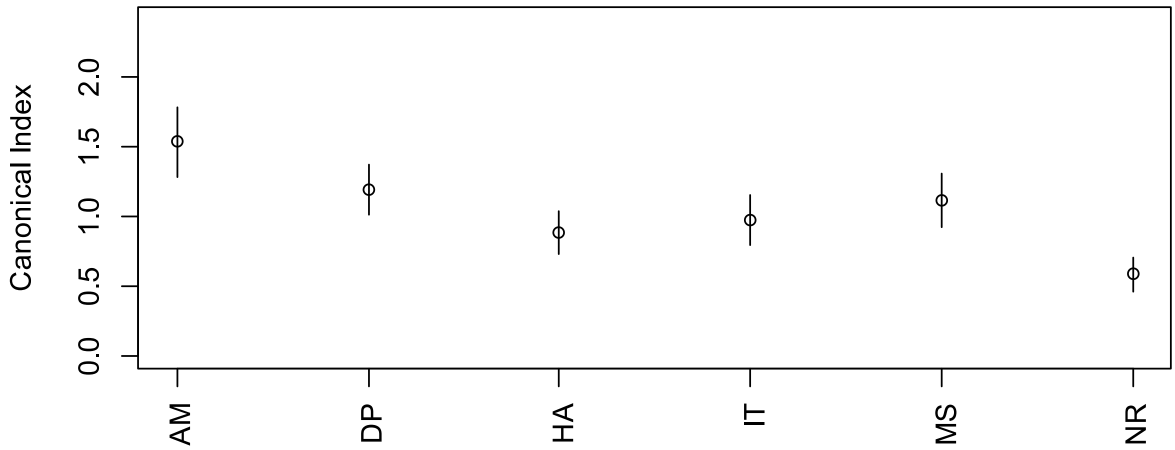

Figure 11: Canonical indices (and 95% CIs) for reader terms from a generalised linear model relating the estimated count of major burrow openings to reader, image area, and station for the SCI 1 "year effect corrected" counts.

The numbers of completed stations by stratum are provided in Table 1. The locations of photographic stations, and relative burrow densities, are shown in Figure 12. The burrow density estimates varied from 0.003 – 0.084 m^{-2}. Densities of all scampi, and scampi out of their burrows ranged from 0 to 0.023 and 0.017 m^{-2}, respectively. Scaling the densities to the combined area of the strata (4597 km^2) leads to abundance estimates from 179 million burrows or, assuming 100% occupancy, the same number of animals (Table 6).

Overall, the density of scampi major burrow openings was estimated to be 0.039 m^{-2}. The density was highest in the deeper strata (450N, 450S and 500). The CVs from the bootstrapped estimates were very similar to those of the original estimates (bootstrapping of the corrected estimates, resampling stations with replacement within strata, and selecting one of the three readers for each station) (Table 6).

The estimated mean density of all visible scampi was 0.007 m^{-2}, with the highest density observed in the 450N and 450S strata. Scaling the observed densities of visible scampi to strata area leads to an abundance estimate of 31.5 million animals for the surveyed area (Table 7). Counting animals out of burrows and walking free on the surface reduced this estimate to 17.5 million animals (Table 8). The CVs for visible scampi and scampi out of burrows from the bootstrapped estimates were comparable with those of the original estimates.

The trend in overall abundance in major burrow openings is shown in Figure 13. Estimated abundance was particularly low for the 2008 survey, but excluding that value, the year effect corrected estimates show a steady decline in abundance over the series of surveys. There were some initial problems identified with the estimation of image area for the 2008 survey, but these have been corrected (Tuck et al. 2009b). Very low numbers of burrows were counted in the 2008 survey, and reanalysis of these survey images may be appropriate. The survey estimates uncorrected for any year effect suggest that the abundance in 2007 and 2009 was similar (the 2008 estimate remaining low), and abundance declined between 2009 and 2013. The indices of scampi abundance (visible scampi, and scampi out of burrows) are presented in Figure 14. These show a similar declining trend between 2007 and 2009, with the 2013 estimate similar to that in 2009.

Overall survey mean densities for the current and previous surveys in SCI 6A are provided in Table 9. The count of visible scampi as a percentage of burrows (which could be considered a minimum estimate of occupancy) was 17%, and has generally ranged between 10% and 20% over the series of surveys (Table 9), except in 2008, when very low numbers of burrows were counted. This range of 10–20% is comparable with other scampi 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 55% in 2013, and has consistently been higher in this region than other areas.

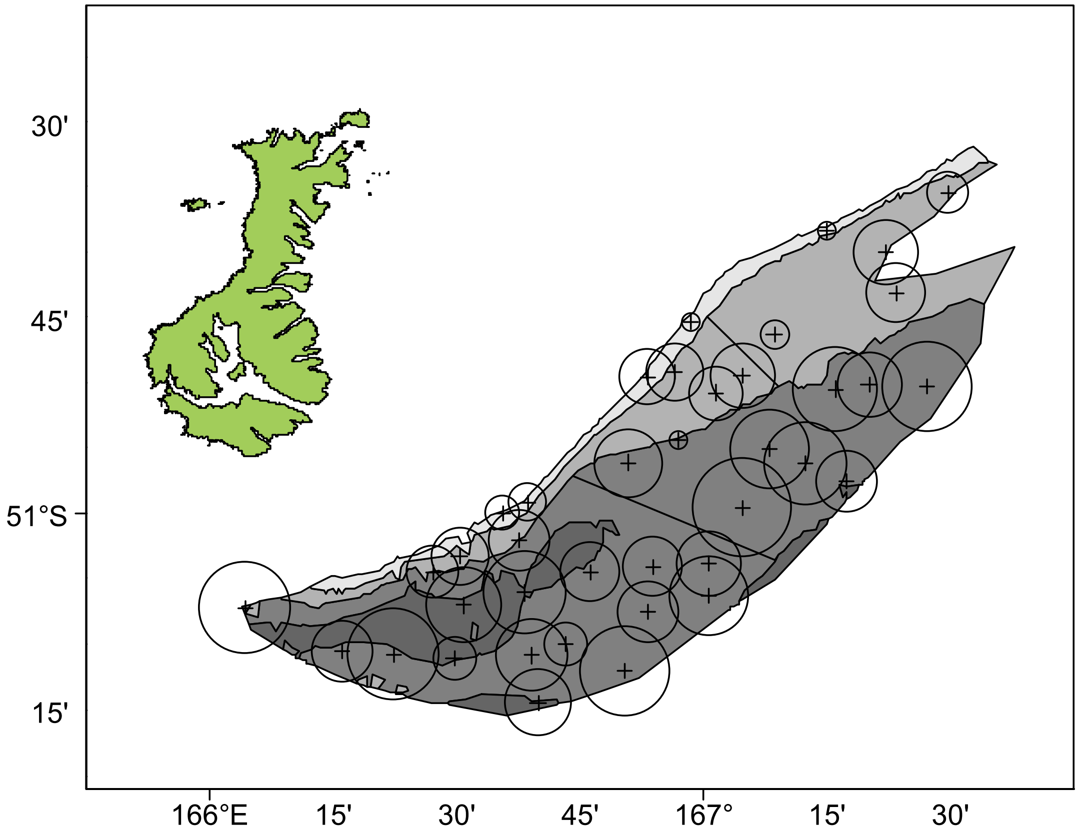

Figure 12: Station locations for the 2013 photographic survey of SCI 6A (size of symbol represents relative burrow density). Largest circle represents 0.084 burrows .m^{-2}.

Table 6: Estimates of the density and abundance of major burrow openings from the SCI 6A survey for 2013. Counts by each reader have been scaled by correction factors for reader effect. Bootstrap estimates of density and abundance (for the whole survey) based on median of 4000 sets of resampling stations within strata and reader within station.

Major burrows						Stratum	Total	Bootstrap
	350	400N	400S	450N	450S	500		Estimate
Area (km^2)	278	789	452	1216	1348	514	4597	
Stations	5	4	6	8	13	4	40	
Mean density (.m^{-2})	0.0130	0.0225	0.0273	0.0562	0.0404	0.0463	0.0392	0.0389
CV	0.55	0.27	0.25	0.14	0.16	0.23	0.09	0.08
Abundance (Millions)	3.61	17.72	12.35	68.31	54.51	23.78	180.29	179.02

Table 7: Estimates of the density and abundance of visible scampi from the SCI 6A survey for 2013. Bootstrap estimates of density and abundance (for the whole survey) based on median of 4000 sets of resampling stations within strata and reader within station.

Scampi (visible)						Stratum	Total	Bootstrap
	350	400N	400S	450N	450S	500		Estimate
Area (km^2)	278	789	452	1216	1348	514	4597	
Stations	5	4	6	8	13	4	40	
Mean density (.m^{-2})	0.0000	0.0052	0.0042	0.0117	0.0078	0.0013	0.0069	0.0069
CV		0.50	0.63	0.25	0.23		0.15	0.15
Abundance (Millions)	0.00	4.14	1.91	14.28	10.54	0.69	31.56	31.54

Table 8: Estimates of the density and abundance of scampi out of burrows from the SCI 6A 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 4000 sets of resampling stations within strata and reader within station.

Scampi (out of burrow)						Stratum	Total	Bootstrap
	350	400N	400S	450N	450S	500		Estimate
Area (km^2)	278	789	452	1216	1348	514	4597	
Stations	5	4	6	8	13	4	40	
Mean density (.m^{-2})	0.0000	0.0036	0.0031	0.0065	0.0038	0.0004	0.0038	0.0038
CV		0.75	0.65	0.30	0.32		0.21	0.20
Abundance (Millions)	0.00	2.84	1.41	7.93	5.11	0.22	17.51	17.50

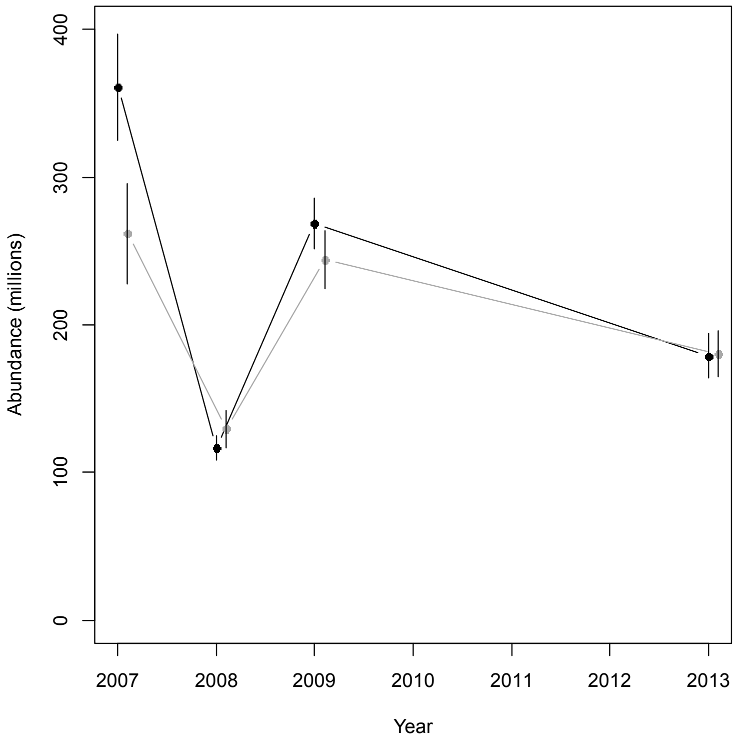

Figure 13: Estimated abundance of scampi major burrow openings (± CV) for SCI 6A. Black lines represent estimates with year effects applied, while grey lines represent estimates with no year effect applied.

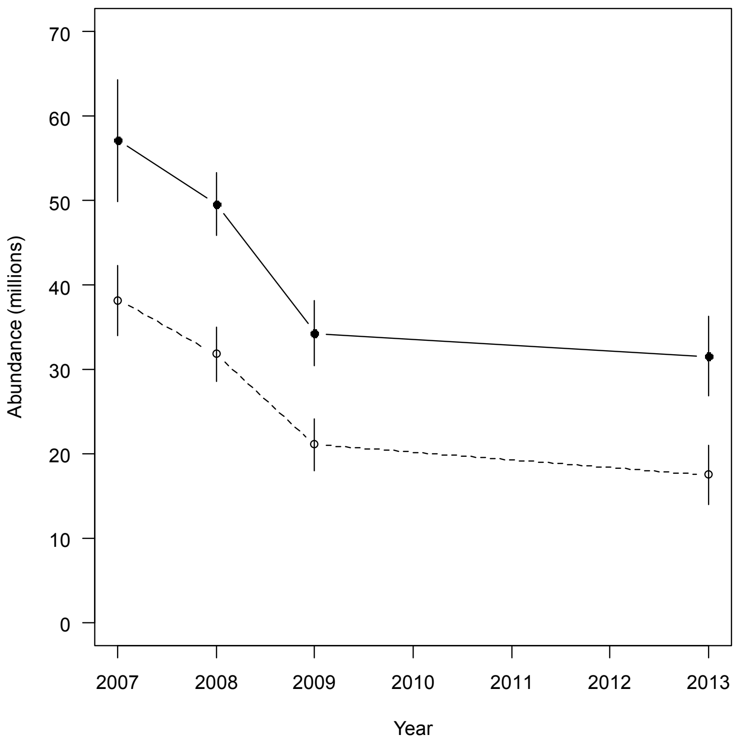

Figure 14: Estimated abundance of scampi (all visible – solid line; out – dashed line) (± CV) for SCI 6A.

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

	Major opening	Visible scampi	Scampi "out"	Scampi as % of openings	% of visible scampi "out"
2007	0.0785	0.0124	0.0083	15.83%	66.79%
2008	0.0254	0.0108	0.0069	42.37%	64.16%
2009	0.0584	0.0075	0.0046	12.77%	61.62%
2013	0.0389	0.0069	0.0038	17.62%	55.49%

3.2 Trawl survey

The locations of trawl survey stations, and relative scampi catch rates, are shown in Figure 15. Some stations had to be moved from their proposed locations to ensure they were in the correct depth range. As discussed above, new bathymetric data for the region has been obtained, and used to revise the survey strata. Biomass estimates are provided by revised strata for the 2013 survey in Table 10, and are compared with previous surveys estimated over the same strata in Table 11. Details of each survey analysis is provided in Appendix 2.

Table 10: Trawl survey estimates by revised stratum for SCI 6A. Mean values expressed as kg.mile^{-1} with the San Tongariro scampi trawl gear.

	Stratum						
	350	400N	400S	450N	450S	500	Total
Area (km^2)	278	789	752	1216	1348	514	4897
N. stations	3	3	2	3	4	2	17
Mean (kg.mile^{-1})	5.44	10.63	16.54	9.95	7.14	9.46	10.64
CV	0.21	0.07	0.18	0.06	0.09	0.33	0.06
Biomass (tonnes)	38.87	215.64	319.81	311.20	247.41	125.02	1257.95

Table 11: Trawl survey estimates by revised strata and year for SCI 6A.

Stratum		2007			2008			2009			2013		
	Area	N	Biomass (tonnes)	CV	N	Biomass (tonnes)	CV	N	Biomass (tonnes)	CV	N	Biomass (tonnes)	CV
350	278	1	52.42	0.44	3	100.71	0.21	3	34.04	0.50	3	38.87	0.21
400 all	1241	3	263.71	0.51	2	277.32	0.28						
400N	789							3	137.10	0.08	3	215.64	0.07
400S	452							2	154.29	0.33	2	319.81	0.18
450N	1216	3	435.41	0.28	3	236.23	0.06	2	60.01	0.47	3	311.20	0.06
450S	1348	5	248.53	0.22	2	493.02	0.40	4	317.15	0.09	4	247.41	0.09
500	514	1	73.42*	0.58	2	121.88	0.34	6	119.03	0.14	2	125.02	0.33
Total	4597	13	1073.48	0.18	12	1229.17	0.18	20	821.63	0.09	17	1257.95	0.06

*- based on catch rate in same depth in area outside main fishery

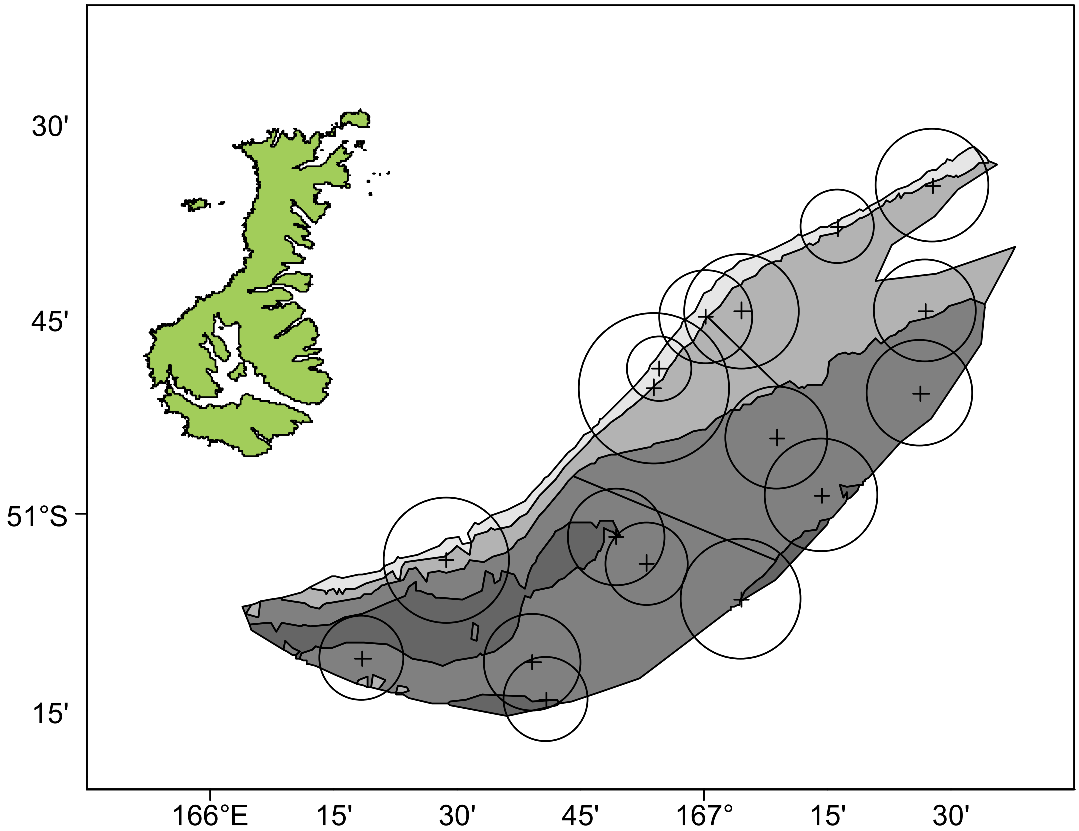

Figure 15: Trawl station locations for the 2013 photographic survey of SCI 6A (size of symbol represents relative scampi catch rate). Largest circle represents 19.5 kg.mile^{-1}.

The overall raised trawl survey estimate was 1258 tonnes (6% CV) (Table 10). Given that scampi live in burrows and are only available to trawl gear when emerged on the seabed, this is likely to be an underestimate of the stock biomass. This is an increase on the 2009 estimate (821 t, 9% CV), but comparable to estimates in 2007 (1073 t, 18% CV) and 2008 (1229 t, 18% CV) (Figure 16).

Over the whole SCI 6A trawl survey (from the small mesh codend), 430 kg of scampi was caught, accounting for 8.6% of the total catch (4993 kg), with scampi being the third most abundant species. By weight, the most, dominant species caught in research trawls were javelin fish (32.4%), ling (9.8%), scampi (8.6%), and oblique banded rattail (6.3%). Within commercial fishing activities, scampi forms a greater proportion of the total catch, as bycatch mitigation in the roof of the net allow some fish to escape. Although a commercial net was used for the survey (as in previous years), this bycatch mitigation gap was closed. A reduction in fish bycatch in the commercial fishery has been noted in recent years with the introduction of this mitigation (Anderson 2012).

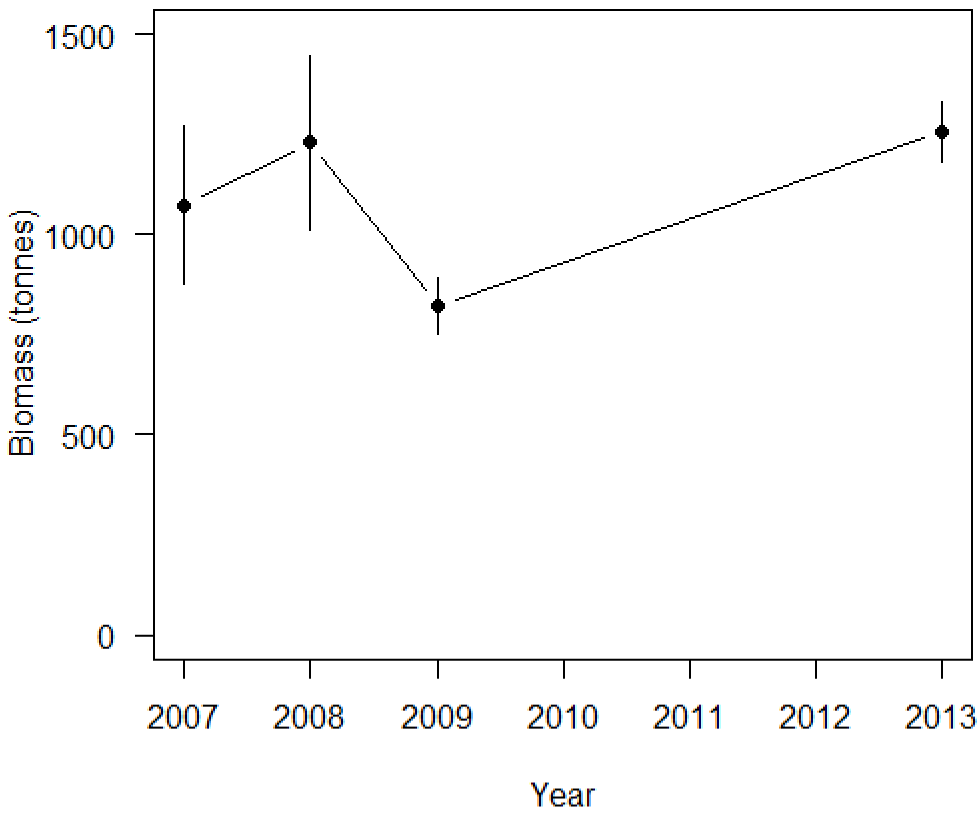

Figure 16: Plot of time series of trawl survey biomass estimates (± CV) for SCI 6A.

Estimates of scampi abundance (numbers) from the trawl survey for all years are also provided in Appendix 2. Across the survey series, strata level estimates of abundance from trawl and photographic survey methods (visible animals) are positively correlated (r^2=0.46), and the ratios of trawl:visible scampi and trawl:scampi out were 0.36 and 0.52 (median of strata values). The trawl:scampi out ratio for the 2012 SCI 1 and SCI 2 surveys was similar (0.47), but the trawl:visible scampi ratio was far lower (0.07), reflecting the greater proportion of scampi seen out of burrows in SCI 6A.

3.3 Tagging and tag mortality

Undamaged active scampi were tagged from each trawl catch, and released for the growth investigation. The next scheduled research sampling in SCI 6A will be in 2016, so it is anticipated that recoveries will be from commercial fishing activity. Over the whole survey, 6618 scampi were tagged with either streamer (4069) or T-bar (2549) tags, and were then released. Catches were predominantly female, and this is reflected in the tagged animals (2469 males, 4149 females). The length distributions of the tagged scampi are presented in Figure 17. The tagged scampi were released at 46 separate locations (Figure 18). No scampi were released while the vessel was fishing, and no recaptures were made by the *San Tongariro* during the survey, although a small number of recaptures were made by other vessels fishing in the region at the time of the survey.

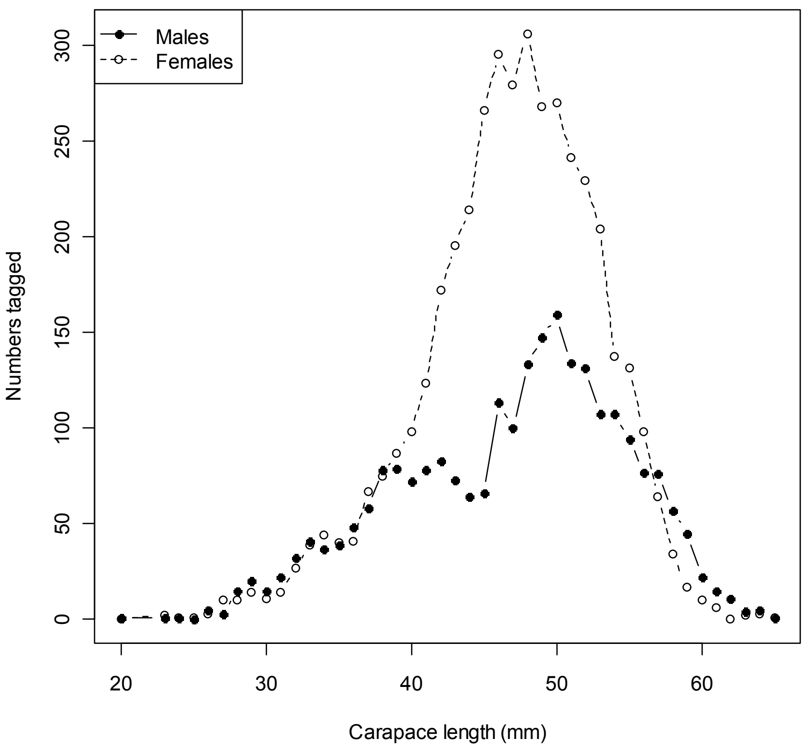

Figure 17: Length distribution of scampi tagged and released during the TON1301 voyage.

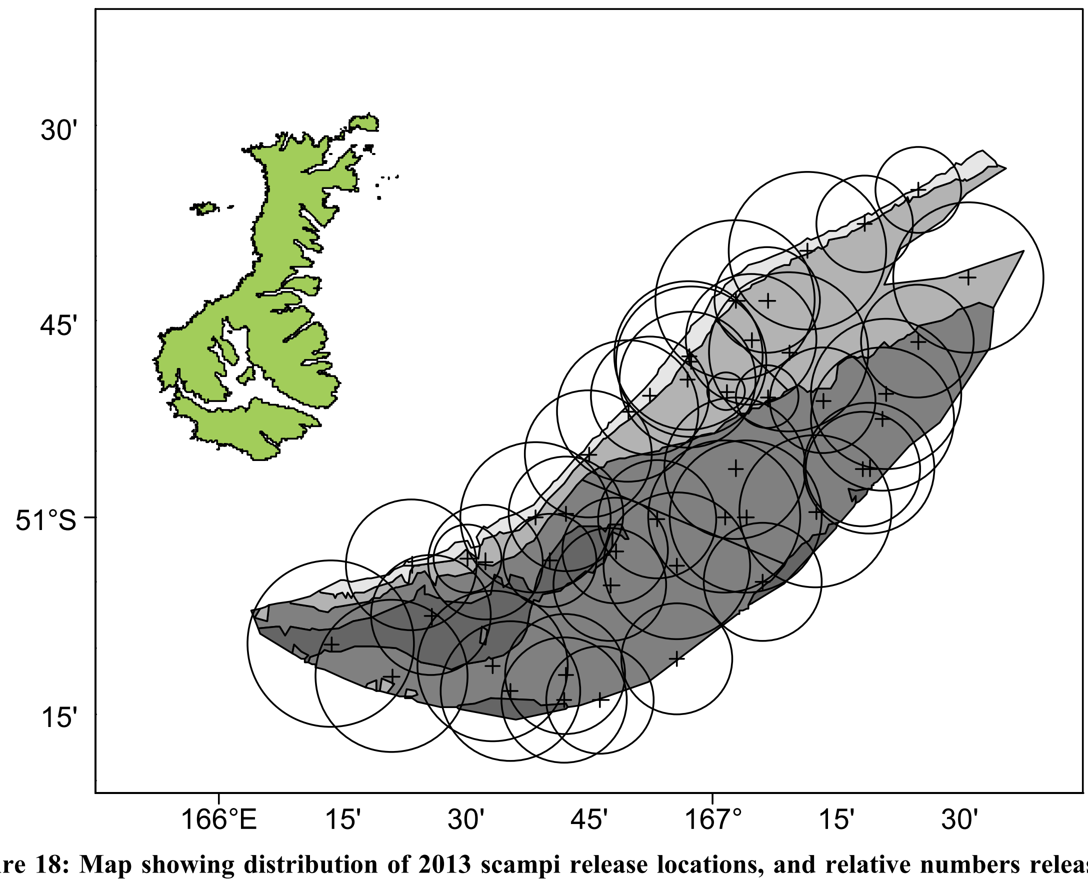

Figure 18: Map showing distribution of 2013 scampi release locations, and relative numbers released at each location. Largest circles represent 238 animals. The smallest release batch was 13 animals, and the average release batch was 144 animals.

Over 100 recaptures have been reported to date (December 2013). Data from these animals will be used with recaptures from previous tagging exercises in this fishery to estimate growth within the stock assessment to be undertaken following the completion of the 2012/13 fishing year.

One scampi tag was recovered from a ling stomach from a fish caught by an angler off the west coast of North Island (Figure 19). There was no other evidence of the scampi in the stomach.

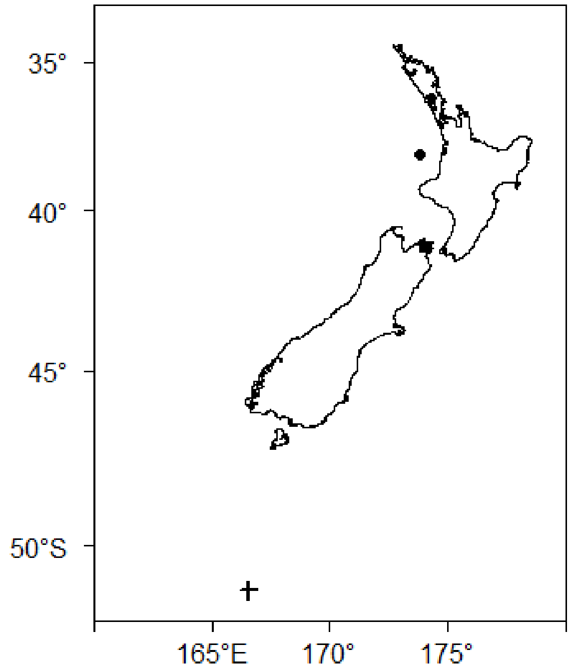

Figure 19: Location of release of scampi (50 mm female) with T-bar tag 4084 on 16th March 2013 (+), and location of tag recovery (•) from ling (60 cm) stomach on 10th October 2013.

In order to investigate tag mortality, tagged and control scampi were placed in individual plastic pipes within plastic fish bins, which were held within an aluminium frame that was deployed on the seabed on an acoustic release mooring for seven days. Of the 117 scampi held within the cage, 81 survived the duration of the experiment (Table 12). Survival in the three treatments was 92.1% (control), 21.2% (T-bar tags), and 81.8% (streamer tags). A chi-squared test indicated that there was a significant difference between the survival of control and tagged scampi (χ^2 = 22.3078, d.f.=1, p≥0.001), which was attributable to tag type. There was a significant difference between the survival of T-bar and streamer tags (χ^2 = 24.2647, d.f.=1, p≥0.001), but no significant difference between the survival of control and streamer tagged scampi (χ^2 = 2.042, d.f.=1, p=0.153).

Table 12: Details of scampi survival from SCI 6A cage manipulation.

Tag type	Alive		Dead		Total	
	Male	Female	Male	Female	Male	Female
Streamer	3	24	2	4	5	28
T-Bar	2	5	9	17	11	22
Control	10	37	1	3	11	40

Examination of the dead T-bar tagged scampi showed that most of the animals had been tagged in the centre of the abdomen, and tags in this location may have damaged the hind gut. Poor weather during the trip, and time pressures for the other work objectives prevented a second deployment of the tag mortality mooring frame to investigate survival with other abdominal tag locations, but time spent at anchorage did allow animals to be tagged and held for up to three days in cages placed within seawater tanks on the vessel. This did not fully replicate the seven day seabed manipulation study, although observation of other scampi held at the same time suggested that mortality associated with trawl capture (and presumably other damage) usually occurred within the first day of holding. After those animals that died within the first day had been removed, survival was usually high.

A second manipulation was conducted examining survival of T-bar tagged scampi when the tag was placed in the side of the abdomen (animals being held in the cages within seawater tanks on board the vessel). Of the 62 scampi held within the cage, 59 survived the manipulation (Table 13). Survival in the two treatments was 97.6% (control), 95.0% (T-bar tags). A chi-squared test indicated that there was no significant difference between the survival of control or tagged scampi ($\chi^2 = 0.4255$, d.f.=1, p=0.5142). The overall survival rates observed within this manipulation are not comparable with those of the first study, as these animals were not tagged immediately after capture. The first study will have included some scampi that were damaged by the trawl capture (but not visibly so), that subsequently died from their injuries. The second study will have not included these animals, as they would have died before the tagging took place. The study does however suggest that the high mortality associated with the T-bar tagging was related to tag location, and that scampi tagged on the side of the abdomen would not suffer mortality any higher than control animals.

Table 13: Details of scampi survival from SCI 6A on board vessel manipulation.

Tag type	Alive		Dead		Total	
	Male	Female	Male	Female	Male	Female
T-Bar	8	30	0	2	8	32
Control	12	30	1	0	13	30

All the tagging conducted during the voyage took place after the second manipulation, and all T-bar tagged animals were tagged in the side of the abdomen. Therefore, we assume no tag associated mortality (no significant difference between survival of control or streamer animals in manipulation 1, no significant difference between survival of control or T-bar animals in manipulation 2), and a capture and release associated mortality equivalent to that observed for the control and streamer animals in manipulation 1 (12%).

3.4 Emergence patterns from acoustic tagging

The acoustic tagging moorings were recovered successfully after a deployment duration of 21 days. Locations of mooring deployments are shown in Figure 20. All three moorings were deployed in the 400S stratum. Distances between moorings were 2.3 km (moorings 1 and 2), 2.5 km (moorings 2 and 3), and 4.5 km (moorings 1 and 3). Maximum tag detection range is estimated to be about 400 m. Summary plots of the current meter data are provided in Appendix 3. The current meter at mooring 1 stopped recording after 9 days, while the other two recorded data for the full duration of the deployment.

Summary details of detections by hydrophone for each tagged scampi are provided in Appendix 4. Of the 60 tags deployed, over half were either not detected at all, or had a short detectability duration (not detected two days after deployment; Figure 21). Nineteen of the tags were detected within the last few days of the deployment, although these were not always detected continually throughout the study.

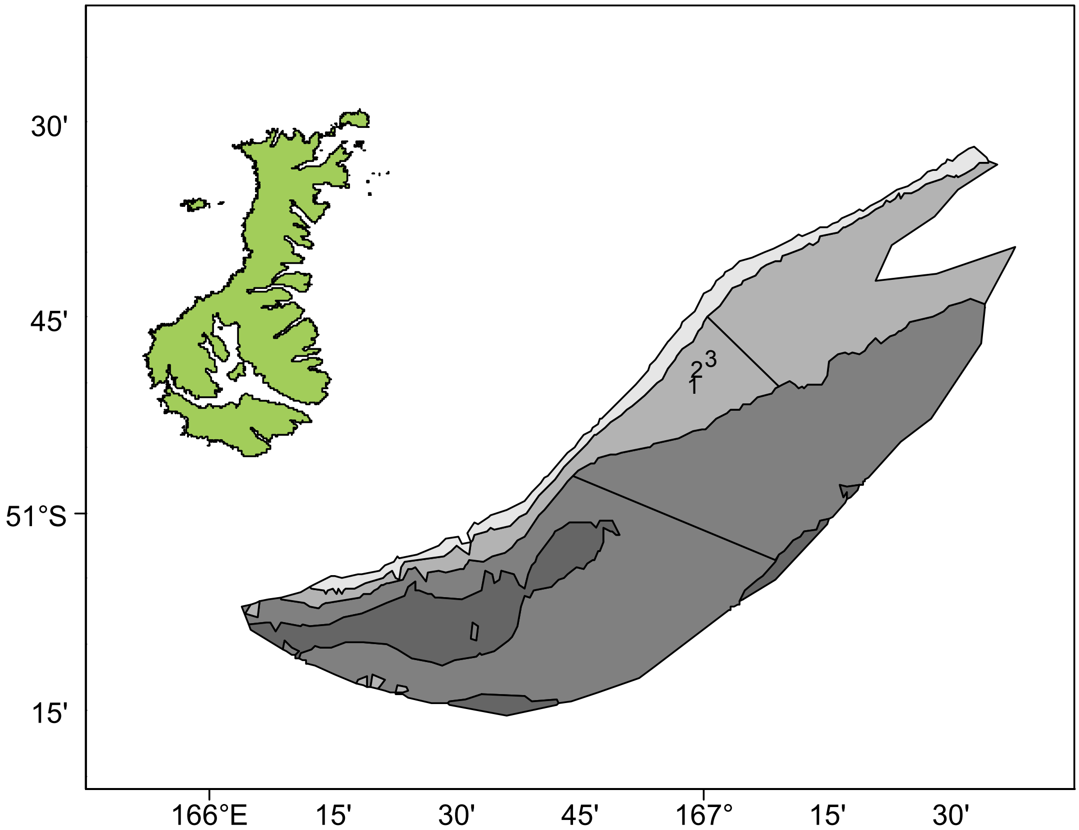

Figure 20: Locations of three acoustic moorings (moorings 1, 2 and 3) deployed to investigate scampi emergence patterns.

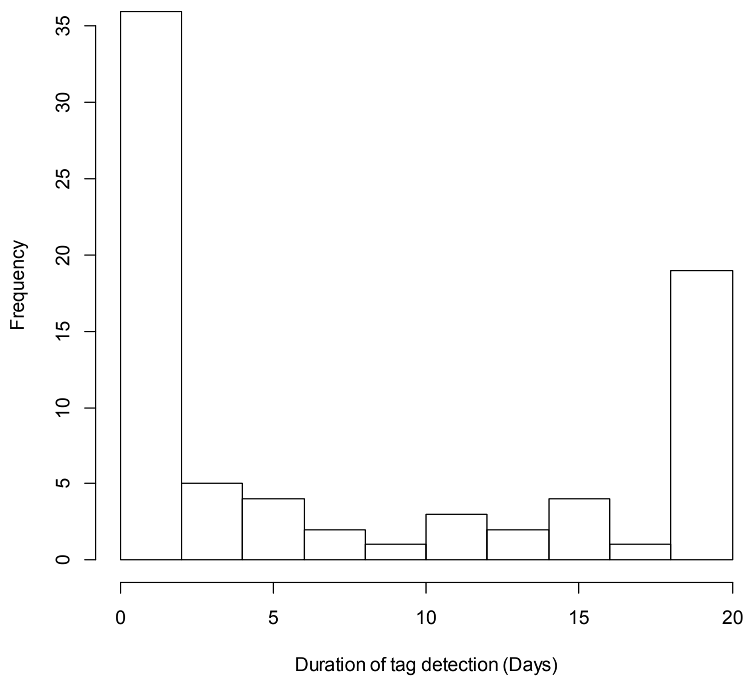

Figure 21: Histogram of tag detectability duration (time of last detection from deployment).

Detection plots are provided for each of the scampi tags detected over 500 times in Figure 22 (Mooring 1), Figure 24 (Mooring 2) and Figure 26 (Mooring 3), with periodograms for these plots provided in Figure 23, Figure 25 and Figure 27. While some animals appear to show clear periodicity in their detectability coincident with a 12.6 hour (tidal) cycle (e.g., scampi 23 and 47), these tend to be in the minority. No animals show any 24 hour periodicity in their detectability.

Four acoustically tagged scampi (tags 1, 8, 10 and 44) were recaptured by commercial trawlers after recovery of the moorings. All three scampi were alive at the time of capture, but only two of the tags (scampi 10 and 44) were detected throughout the deployment. The detection plots and periodograms are shown in Figure 22 and Figure 23 for scampi 10, and Figure 26 and Figure 27 for scampi 44.

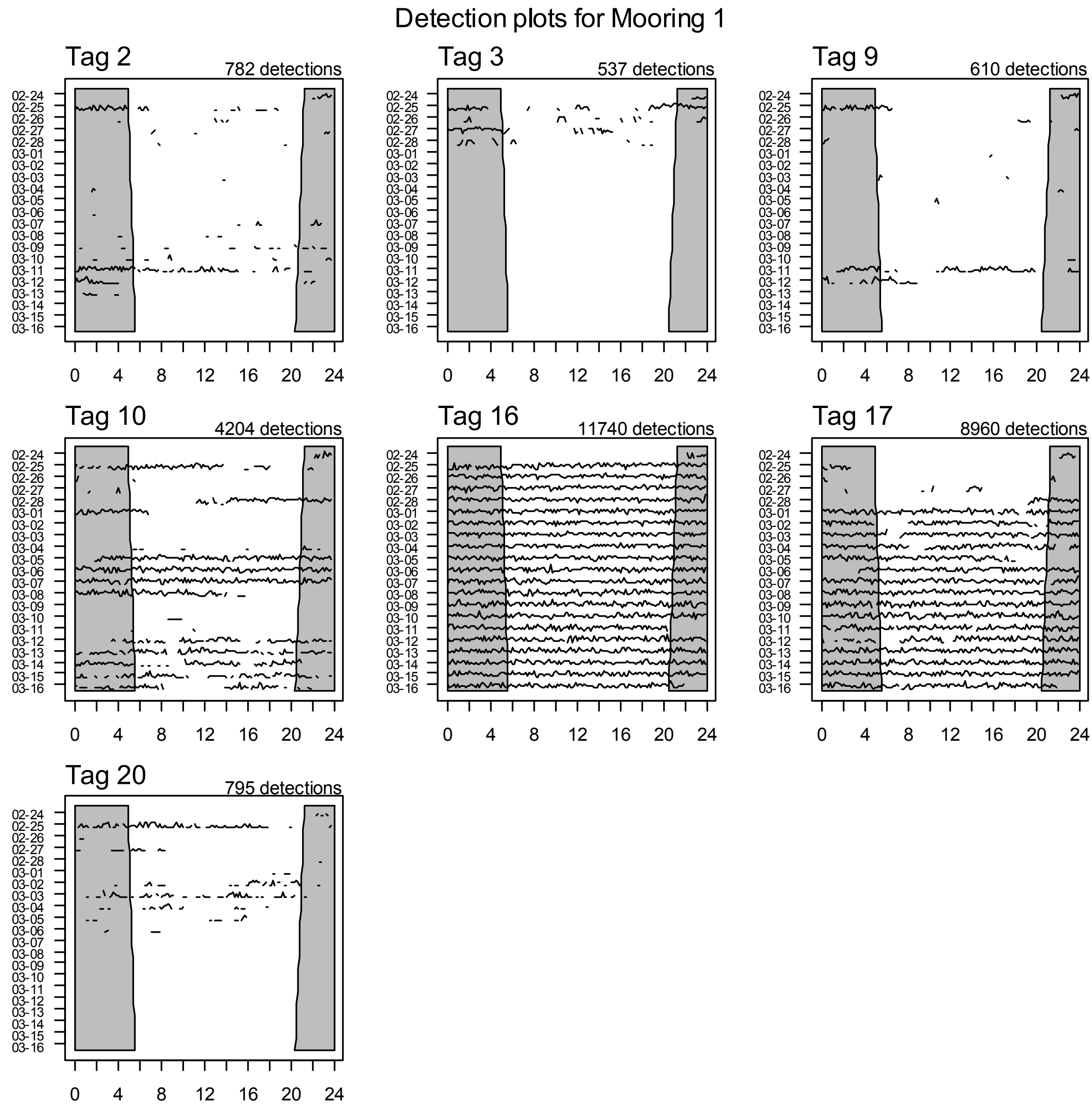

Figure 22: Detection plots for scampi detected over 500 times from mooring 1. Lines represent relative number of detections per 10 minute interval by date (y axis) and time of day (x axis). The maximum number of detections was 9 per 10 minute interval for all scampi. Grey shaded portion of plot represents night (prior to dawn and after dusk).

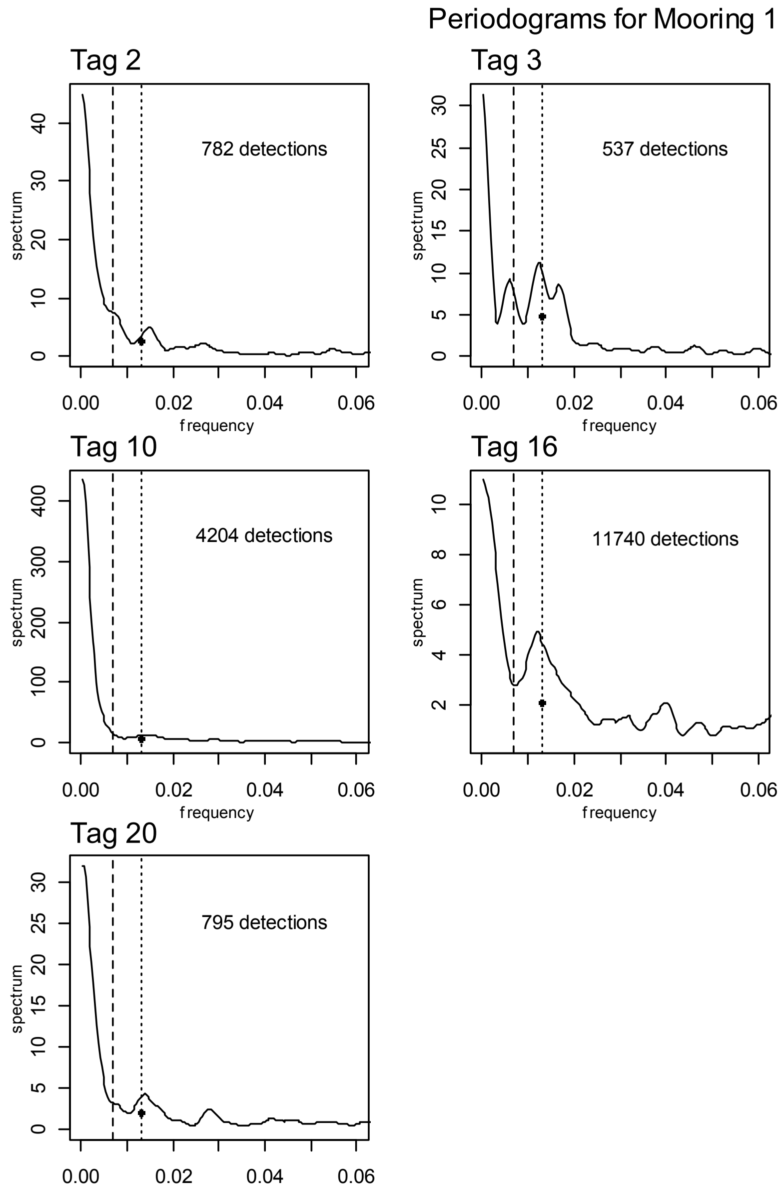

Figure 23: Smoothed periodogram for scampi detected over 500 times from mooring 1. Dashed line represents period of 24 hour cycle, dotted line represents period of 12.6 hour cycle. Closed symbols represent lower 95% confidence limits of the cycles at the 24 hour and 12.6 hour frequency.

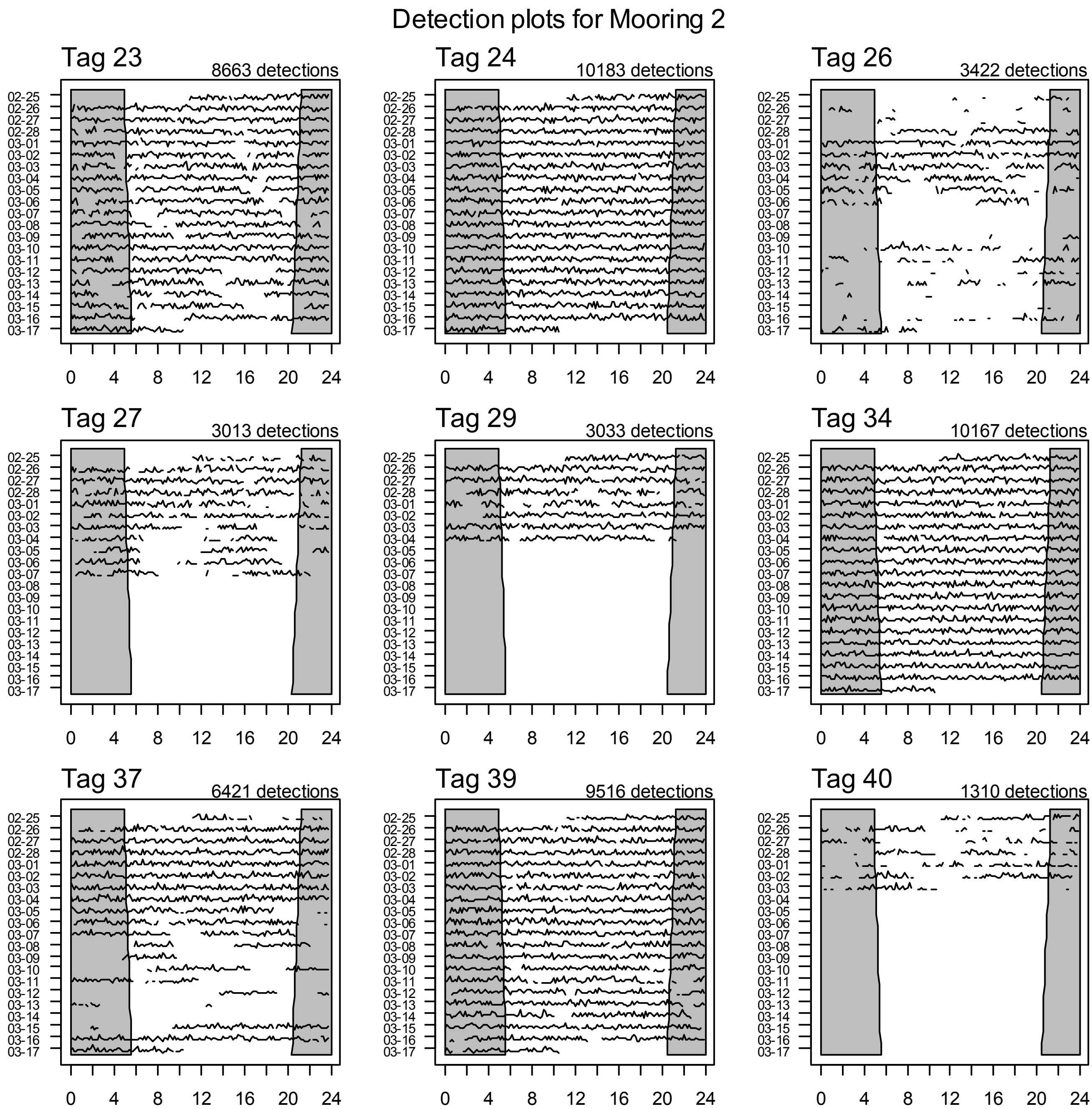

Figure 24: Detection plots for scampi detected over 500 times from mooring 2. Lines represent relative number of detections per 10 minute interval by date (y axis) and time of day (x axis). The maximum number of detections was 9 per 10 minute interval for all scampi. Grey shaded portion of plot represents night (prior to dawn and after dusk).

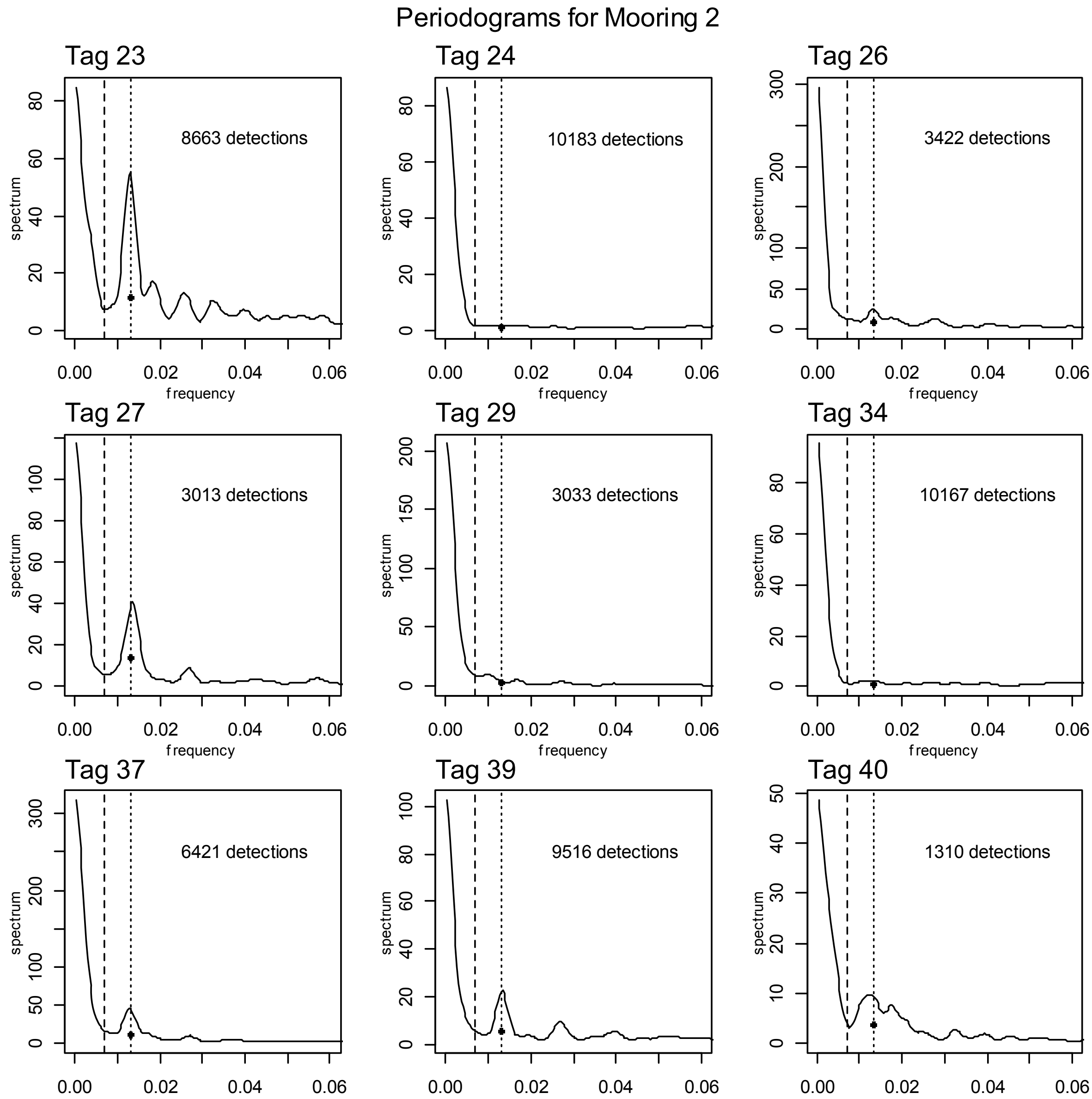

Figure 25: Smoothed periodogram for scampi detected over 500 times from mooring 2. Dashed line represents period of 24 hour cycle, dotted line represents period of 12.6 hour cycle. Closed symbols represent lower 95% confidence limits of the cycles at the 24 hour and 12.6 hour frequency.

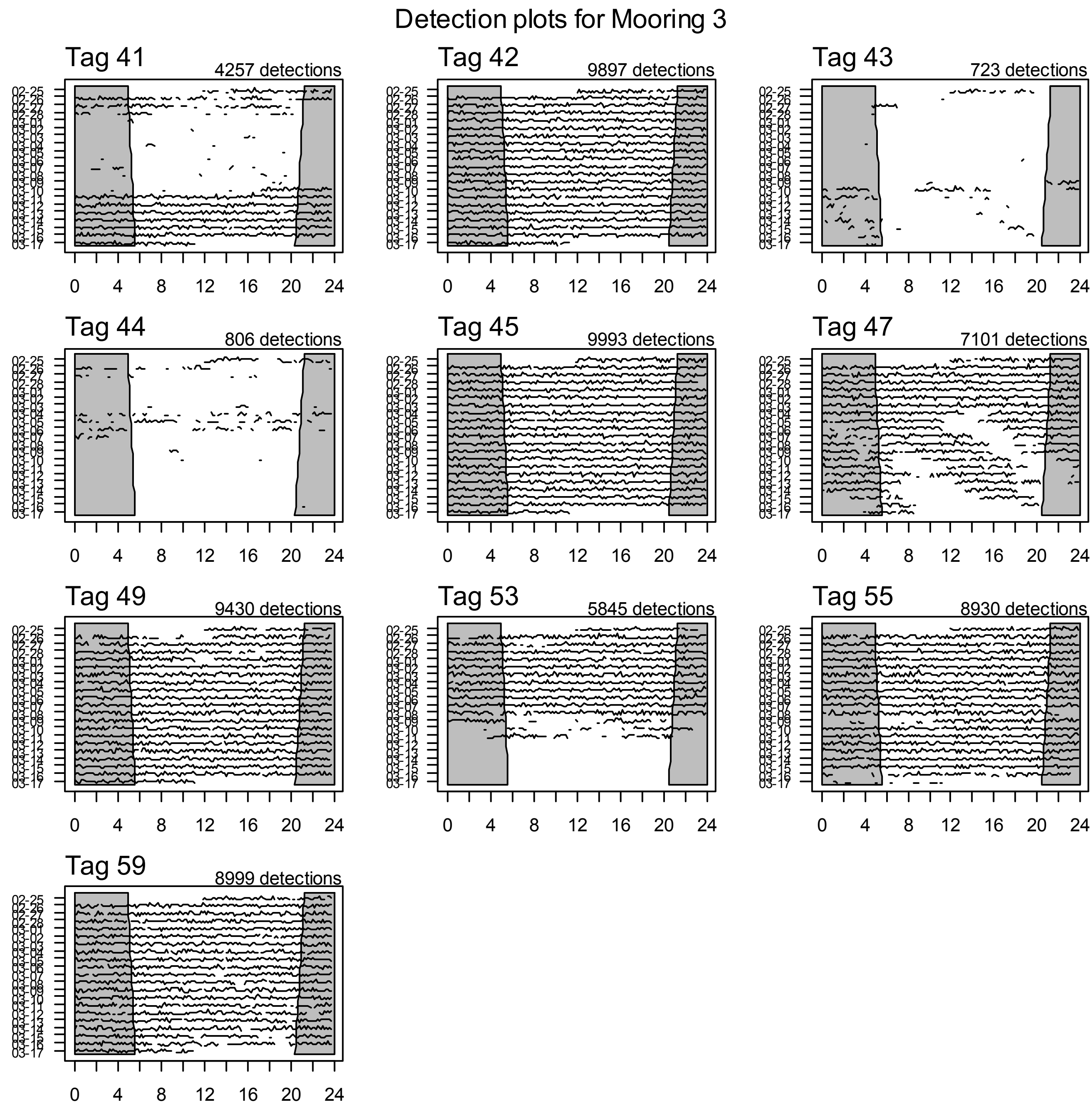

Figure 26: Detection plots for scampi detected over 500 times from mooring 3. Lines represent relative number of detections per 10 minute interval by date (y axis) and time of day (x axis). The maximum number of detections was 9 per 10 minute interval for all scampi. Grey shaded portion of plot represents night (prior to dawn and after dusk).

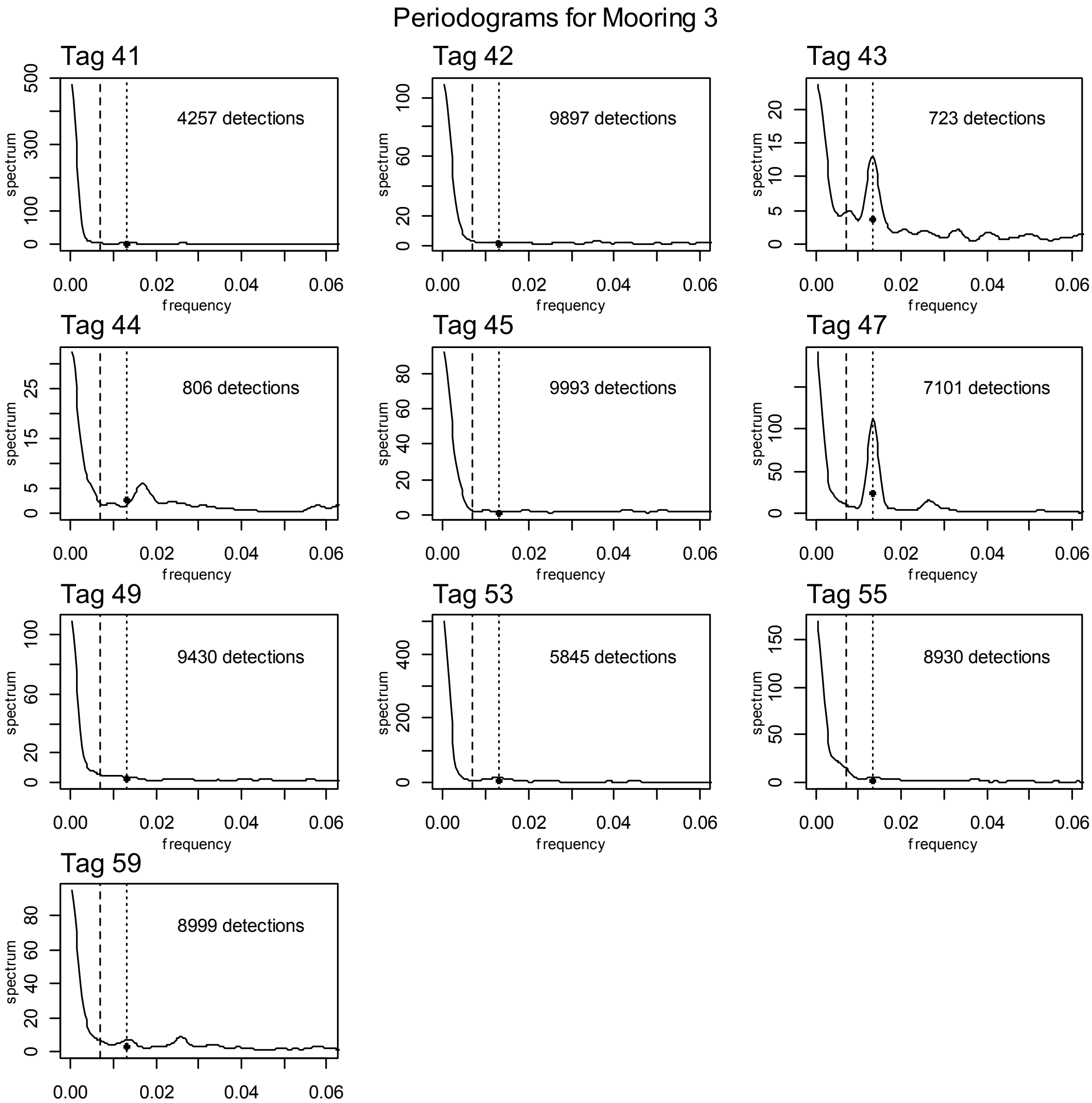

Figure 27: Smoothed periodogram for scampi detected over 500 times from mooring 3. Dashed line represents period of 24 hour cycle, dotted line represents period of 12.6 hour cycle. Closed symbols represent lower 95% confidence limits of the cycles at the 24 hour and 12.6 hour frequency.

In order to estimate a population level detection pattern, the data for the 15 scampi that were detectable for the full duration deployment were examined (the detection plots and periodograms for these individuals are presented in Figure 28 and Figure 29). The tags have a nominal delay of 130 seconds, and so on average would be detected 4.6 times per 10 minute interval if they were continually available. Assuming that an animal would be seen if it is detectable more than 2 times per 10 minute interval, then the number of detectable animals (of the 15) can be estimated for each time interval. The combined detection plot for these 15 scampi is presented in Figure 30, which (for clarity in observing any pattern) only shows periods when at least 8 of the 15 scampi were detectable. The periodogram for these combined data (Figure 31) shows no clear 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 pattern in detectability may suggest that scampi behave differently within this region. It has already been noted that scampi appear more available (a greater proportion of animals observed outside burrows) than in other stocks.

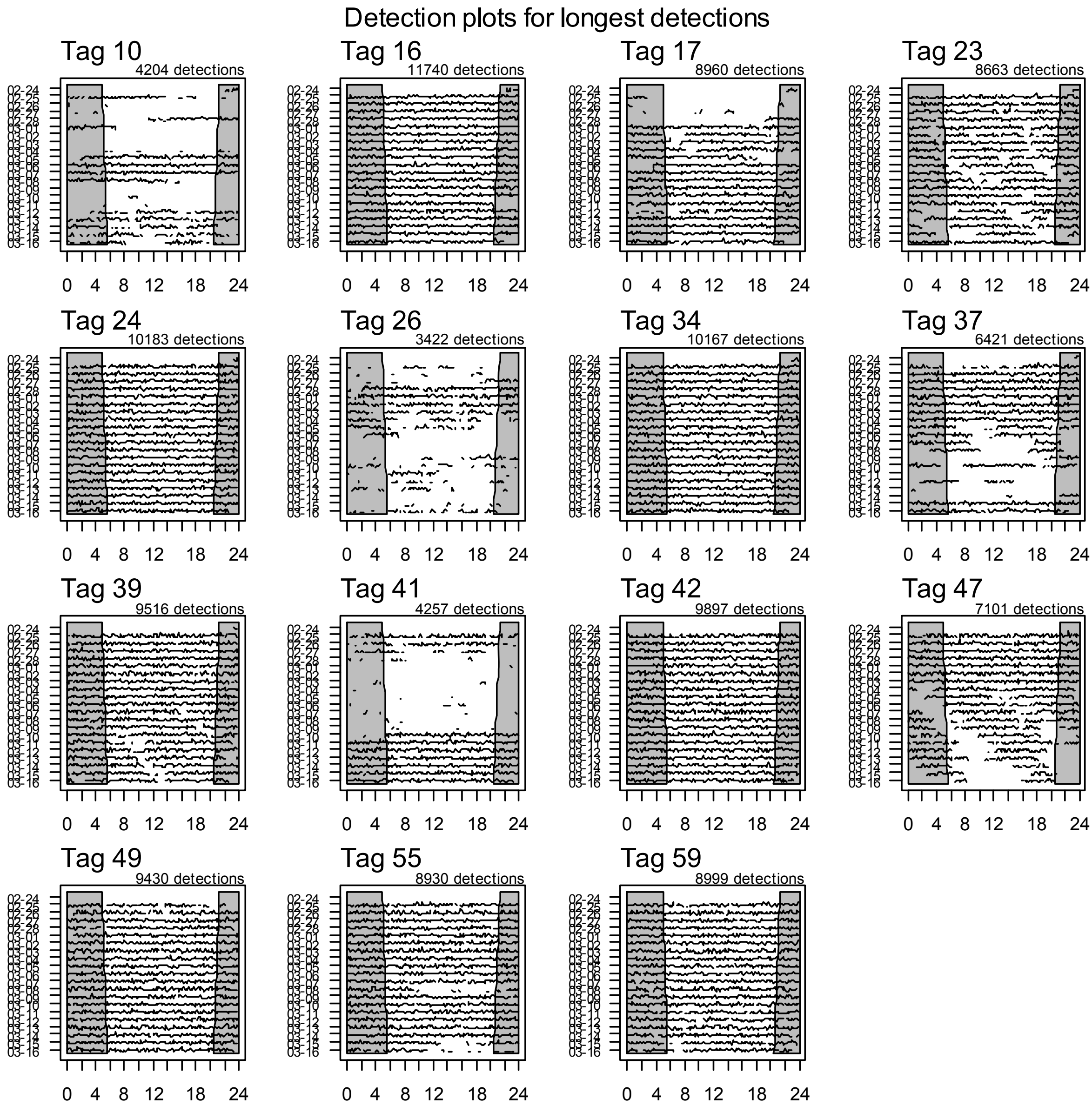

Figure 28: Detection plots for scampi detected for the full duration of the deployment. Lines represent relative number of detections per 10 minute interval by date (y axis) and time of day (x axis). The maximum number of detections was 9 per 10 minute interval for all scampi. Grey shaded portion of plot represents night (prior to dawn and after dusk).

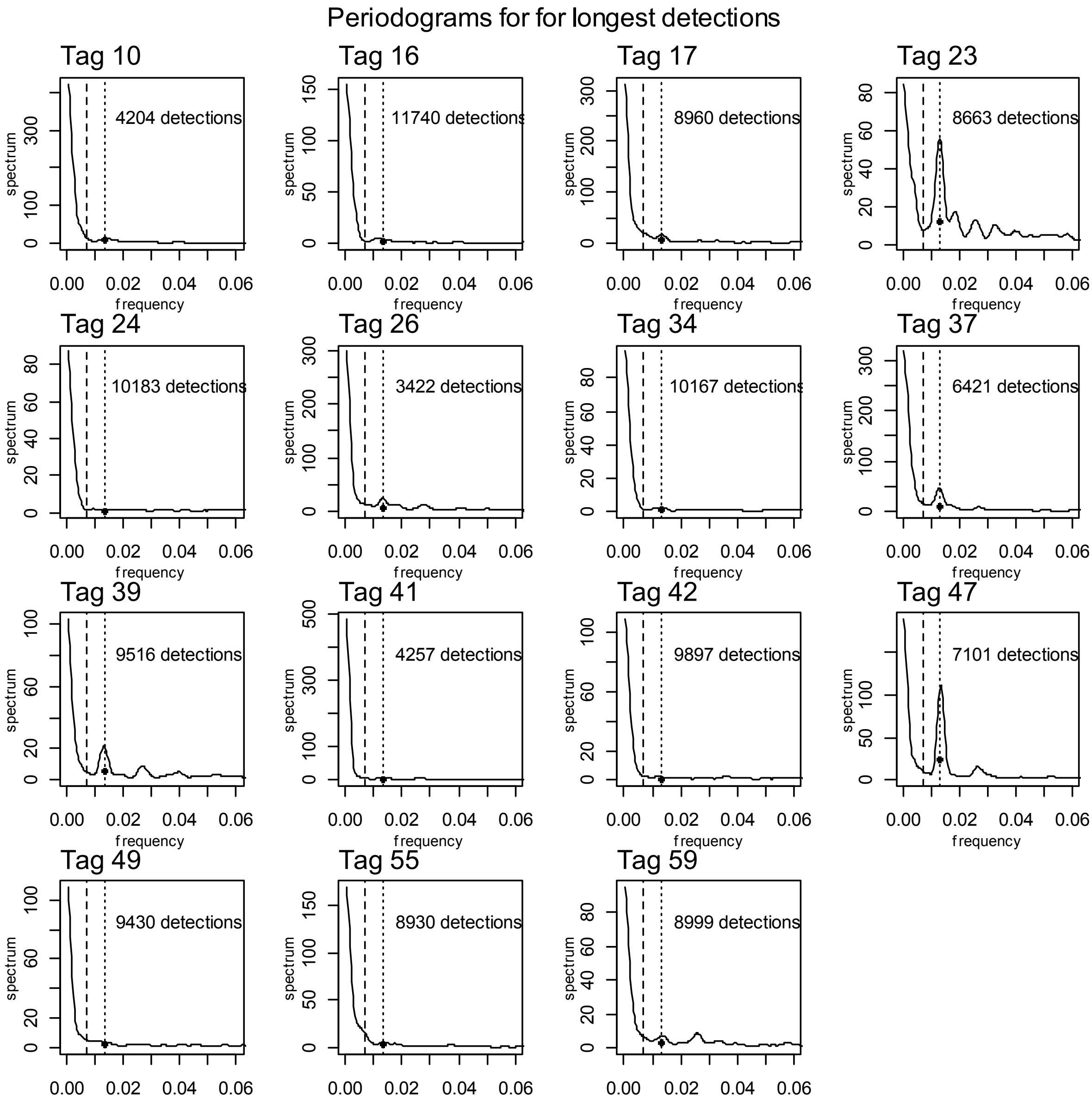

Figure 29: Smoothed periodogram for scampi detected for the full duration of the deployment. Dashed line represents period of 24 hour cycle, dotted line represents period of 12.6 hour cycle. Closed symbols represent lower 95% confidence limits of the cycles at the 24 hour and 12.6 hour frequency.

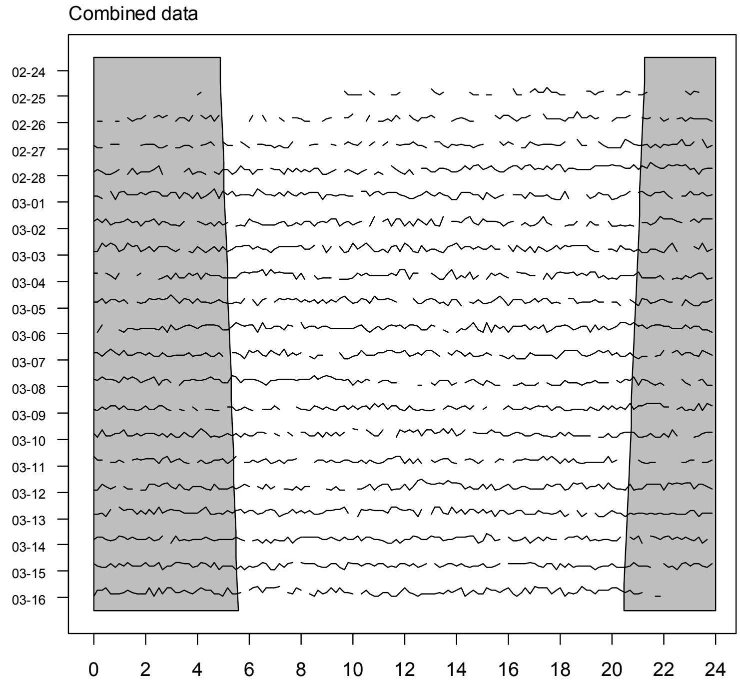

Figure 30: Detection plot of combined data for 15 scampi from SCI 6A. Line shown where at least 8 of the 15 scampi were detectable.

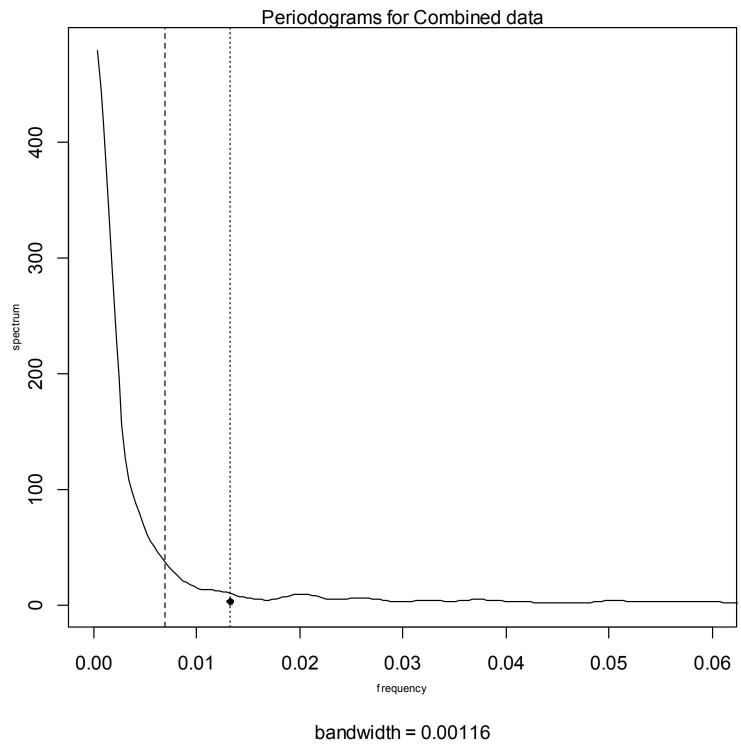

Figure 31: Smoothed periodogram of combined data for 15 scampi from SCI 6A.

Over the whole deployment, scampi were detectable (more than 2 detections per 10 minute interval) 66% 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 32).

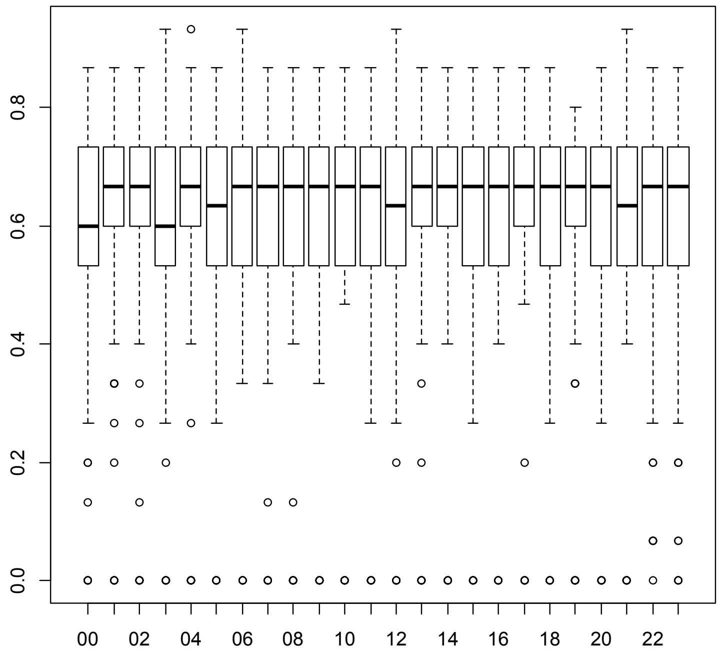

Figure 32: Boxplot of proportion detectable (individuals with more than 2 detections per 10 minute interval)(± CV) in relation to time of day, averaged over the full duration of the SCI 6A study.

Using the proportion detectable as an estimate of the proportion of scampi that would be out of their burrows or in their burrow entrance, 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 14) required as priors in the assessment model (Tuck & Dunn 2012).

Table 14: Best estimates of catchability terms for trawl caught scampi, visible scampi and scampi burrows, estimated from 2013 photo survey observations and scampi emergence study. Estimated values for SCI 1 (Tuck et al. 2013) also provided for comparison.

	SCI 1	SCI 6A	Source
Major opening	0.0794 m^{-2}	0.0389 m^{-2}	survey
Visible scampi	0.0175 m^{-2}	0.0069 m^{-2}	survey
Scampi "out"	0.0036 m^{-2}	0.0038 m^{-2}	survey
Scampi as % of openings	22%	18%	Visible/openings
% of scampi “out”	21%	55%	Out/visible
Median emergence	52%	66%	Acoustic tags
Estimated scampi density	0.0337 m^{-2}	0.0105 m^{-2}	Visible/emergence
Estimated occupancy	42%	27%	Est den/major
q trawl	0.107	0.36	Out/Est den
q scampi	0.52	0.66	Vis/Est den
q photo	2.36	3.72	Major/Est den

Five scampi were detected at more than one mooring (Appendix 4 and Figure 33). There were consistent blocks of detections on both hydrophones, rather than random events, suggesting that the detections were genuine. All detections at multiple moorings progressed in a northerly direction, with one scampi released at mooring 1 later detected at mooring 2, and four scampi released at mooring 2 later detected at mooring 3. Given the distances between moorings (2.3 – 2.5 km), this is considered to represent movement of the tag. Movement intervals (time between last detection at original mooring and first detection at second mooring) ranged from 0.9 – 10.1 days, with inferred movement speeds from 0.25 – 2.8 $km.day^{-1}$. Scampi are not thought to undertake migrations (although there are very few data available to investigate this). These movements are assumed to be as a result of predation by fish, which are likely to be far more mobile than scampi. The fact that tags 28, 30 and 36 all show very similar patterns (released at mooring 2, detected there until the early morning of 25 Feb, detected at mooring 3 (2.5 km away) late that evening (21 hours later) and again at about 6 am the following morning), may suggest they were all eaten by the same fish.

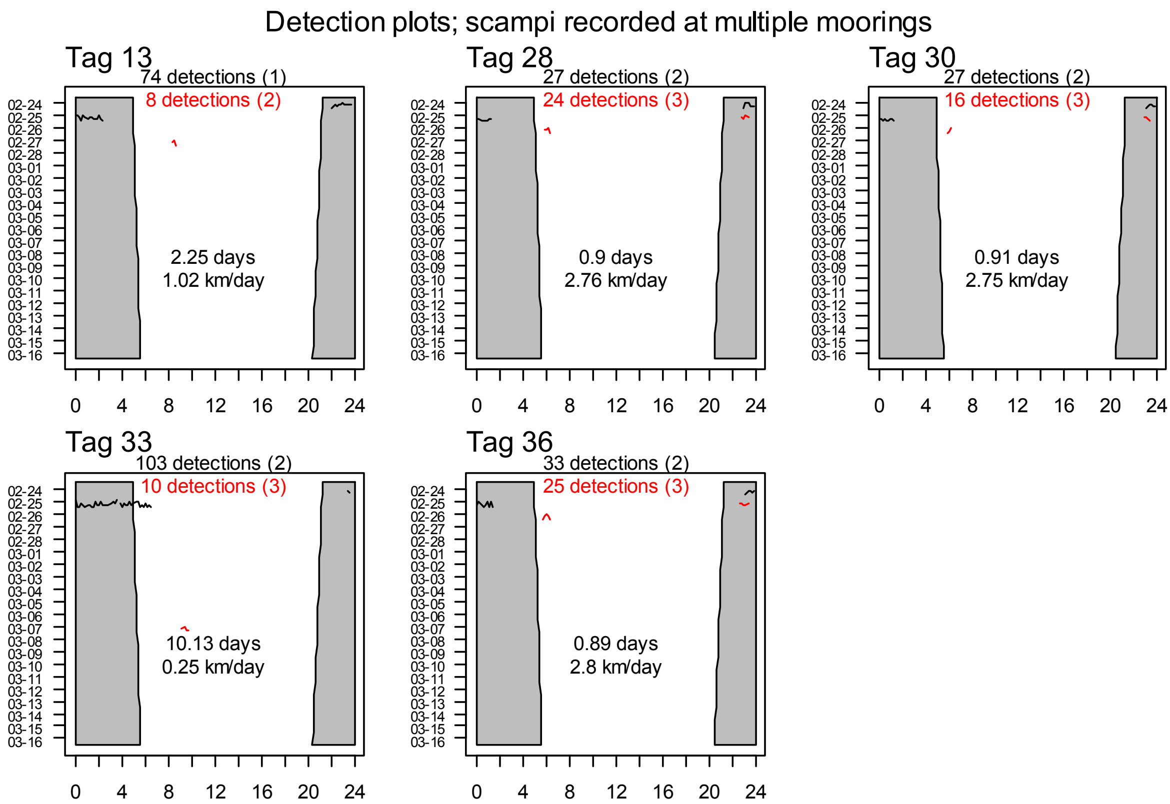

Figure 33: Detection plot for scampi detected at more than one mooring. Lines represent relative number of detections per 10 minute interval by date (y axis) and time of day (x axis). The maximum number of detections was 9 per 10 minute interval for all scampi. Grey shaded portion of plot represents night (prior to dawn and after dusk). Number of detections indicated on figure, with number in parenthesis representing mooring number. Mooring locations shown in Figure 20. Interval between last detection at original mooring and first detection at second mooring also provided on figure, with inferred movement speed.

4. CONCLUSIONS

A photographic and trawl survey of scampi in SCI 6A was conducted in February and March 2013. The survey covered the same area as previous surveys, but was analysed over revised strata, on the basis of new bathymetric data made available by the survey vessel. The photographic survey estimated a scampi burrow abundance of 179 million over the whole area. The photographic estimate in 2013 was lower than the previous survey in 2009. Trawl survey catch rates in SCI 6A were higher than in 2009, but similar to the 2007 survey. The raised trawl survey estimate of scampi biomass over the whole SCI 6A survey area was 1258 tonnes. Over 6000 scampi were tagged and released, as part of an investigation into growth, and to date, over 100 scampi have been recaptured.

Tag mortality investigations were undertaken, and having corrected the T-bar tagging technique to avoid animal damage, no tagging effect was detected, and mortality associated with the capture, tagging and release process was estimated to be 12%.

Sixty scampi were released with acoustic tags, divided between three hydrophone moorings, to investigate emergence patterns. The moorings were recovered after a 21 day deployment. Most tags showed no evidence of periodicity in detection. Of those tags considered to have continued operating throughout the deployment, scampi were estimated to have been detectable 66% of the time, with no evidence of any pattern in relation to time of day.

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APPENDIX 1: Photo survey analysis with revised strata boundaries

Analysis for burrows excluding year corrections (as plotted in Figure 13).

2007

Major burrows	350	4001	4002	4501	4502	500	Total
Area (km^2)	278	789	452	1348	1216	514	4597
Stations	3	10	3	5	6	5	32
Mean density ($.m^{-2}$)	0.0083	0.0368	0.0519	0.0570	0.0788	0.0669	0.0570
CV	0.54	0.28	0.32	0.25	0.25	0.24	0.13
Abundance (Millions)	2.31	29.00	23.44	76.90	95.80	34.39	261.83

2008

Major burrows	350	4001	4002	4501	4502	500	Total
Area (km^2)	278	789	452	1348	1216	514	4597
Stations	4	6	3	9	9	10	41
Mean density ($.m^{-2}$)	0.0034	0.0181	0.0179	0.0368	0.0366	0.0235	0.0281
CV	0.62	0.27	0.46	0.20	0.10	0.19	0.10
Abundance (Millions)	0.95	14.26	8.10	49.56	44.45	12.07	129.39

2009

Major burrows	350	4001	4002	4501	4502	500	Total
Area (km^2)	278	789	452	1348	1216	514	4597
Stations	6	6	2	14	10	5	43
Mean density ($.m^{-2}$)	0.0047	0.0276	0.0589	0.0682	0.0558	0.0672	0.0531
CV	0.52	0.16	0.56	0.10	0.09	0.13	0.08
Abundance (Millions)	1.30	21.75	26.63	91.87	67.89	34.55	243.99

2013

Major burrows	350	4001	4002	4501	4502	500	Total
Area (km^2)	278	789	452	1348	1216	514	4597
Stations	5	4	6	13	8	4	40
Mean density ($.m^{-2}$)	0.0130	0.0225	0.0273	0.0404	0.0562	0.0463	0.0392
CV	0.55	0.27	0.25	0.16	0.14	0.23	0.09
Abundance (Millions)	3.61	17.72	12.35	54.51	68.31	23.78	180.29

Final data with year and reader corrections

2007 survey

Major burrows	350	400N	400S	450N	450S	500	Total	Bootstrap
Area (km^2)	278	789	452	1216	1348	514	4597	Estimate
Stations	3	10	3	6	5	5	32	
Mean density ($.m^{-2}$)	0.0127	0.0523	0.0597	0.1043	0.0840	0.0950	0.0785	
CV	0.53	0.22	0.30	0.18	0.24	0.22	0.11	0.10
Abundance (Millions)	3.54	41.24	26.97	126.85	113.26	48.85	360.70	360.91

Scampi (visible)	350	400N	400S	450N	450S	500	Total	Bootstrap
Area (km^2)	278	789	452	1216	1348	514	4597	Estimate
Stations	3	10	3	6	5	5	32	
Mean density ($.m^{-2}$)	0.0061	0.0123	0.0086	0.0145	0.0113	0.0189	0.0126	
CV	0.52	0.21	0.35	0.14	0.41	0.33	0.14	0.13
Abundance (Millions)	1.69	9.67	3.89	17.65	15.25	9.72	57.87	57.13

Scampi (out of burrow)	350	400N	400S	450N	450S	500	Total	Bootstrap
Area (km^2)	278	789	452	1216	1348	514	4597	Estimate
Stations	3	10	3	6	5	5	32	
Mean density ($.m^{-2}$)	0.0061	0.0075	0.0072	0.0105	0.0066	0.0109	0.0083	
CV	0.52	0.21	0.46	0.18	0.34	0.29	0.12	0.11
Abundance (Millions)	1.69	5.94	3.25	12.79	8.91	5.61	38.19	38.16

2008 survey

Major burrows	350	400N	400S	450N	450S	500	Total	Bootstrap
Area (km^2)	278	789	452	1216	1348	514	4597	Estimate
Stations	4	6	3	9	9	10	41	
Mean density ($.m^{-2}$)	0.0029	0.0166	0.0168	0.0355	0.0300	0.0224	0.0254	
CV	0.59	0.22	0.40	0.12	0.11	0.15	0.07	0.07
Abundance (Millions)	0.82	13.07	7.59	43.19	40.47	11.53	116.67	116.97

Scampi (visible)	350	400N	400S	450N	450S	500	Total	Bootstrap
Area (km^2)	278	789	452	1216	1348	514	4597	Estimate
Stations	4	6	3	9	9	10	41	
Mean density ($.m^{-2}$)	0.0047	0.0094	0.0136	0.0131	0.0103	0.0091	0.0107	
CV	0.17	0.19	0.10	0.14	0.21	0.21	0.08	0.08
Abundance (Millions)	1.32	7.42	6.13	15.94	13.85	4.70	49.35	49.56

Scampi (out of burrow)	350	400N	400S	450N	450S	500	Total	Bootstrap
Area (km^2)	278	789	452	1216	1348	514	4597	Estimate
Stations	4	6	3	9	9	10	41	
Mean density ($.m^{-2}$)	0.0047	0.0068	0.0105	0.0062	0.0065	0.0074	0.0069	
CV	0.17	0.26	0.24	0.18	0.30	0.23	0.11	0.10
Abundance (Millions)	1.32	5.36	4.76	7.60	8.73	3.80	31.57	31.79

2009 survey

Major burrows	350	400N	400S	450N	450S	500	Total	Bootstrap
Area (km^2)	278	789	452	1216	1348	514	4597	Estimate
Stations	6	6	2	10	14	5	43	
Mean density (.m^{-2})	0.0050	0.0309	0.0630	0.0621	0.0738	0.0752	0.0583	
CV	0.50	0.16	0.58	0.09	0.09	0.15	0.08	0.06
Abundance (Millions)	1.38	24.35	28.49	75.53	99.53	38.65	267.93	268.28

Scampi (visible)	350	400N	400S	450N	450S	500	Total	Bootstrap
Area (km^2)	278	789	452	1216	1348	514	4597	Estimate
Stations	6	6	2	10	14	5	43	
Mean density (.m^{-2})	0.0024	0.0058	0.0073	0.0083	0.0087	0.0077	0.0075	
CV	1.00	0.37	0.53	0.23	0.20	0.28	0.13	0.11
Abundance (Millions)	0.68	4.59	3.32	10.11	11.75	3.93	34.39	34.27

Scampi (out of burrow)	350	400N	400S	450N	450S	500	Total	Bootstrap
Area (km^2)	278	789	452	1216	1348	514	4597	Estimate
Stations	6	6	2	10	14	5	43	
Mean density (.m^{-2})	0.0024	0.0034	0.0073	0.0026	0.0062	0.0057	0.0046	
CV	1.00	0.53	0.53	0.34	0.26	0.32	0.17	0.15
Abundance (Millions)	0.68	2.67	3.32	3.17	8.36	2.95	21.15	21.11

2013 survey

Major burrows	350	400N	400S	450N	450S	500	Total	Bootstrap
Area (km^2)	278	789	452	1216	1348	514	4597	Estimate
Stations	5	4	6	8	13	4	40	
Mean density (.m^{-2})	0.0130	0.0225	0.0273	0.0562	0.0404	0.0463	0.0392	0.0389
CV	0.55	0.27	0.25	0.14	0.16	0.23	0.09	0.08
Abundance (Millions)	3.61	17.72	12.35	68.31	54.51	23.78	180.29	179.02

Scampi (visible)	350	400N	400S	450N	450S	500	Total	Bootstrap
Area (km^2)	278	789	452	1216	1348	514	4597	Estimate
Stations	5	4	6	8	13	4	40	
Mean density (.m^{-2})	0.0000	0.0052	0.0042	0.0117	0.0078	0.0013	0.0069	0.0069
CV		0.50	0.63	0.25	0.23		0.15	0.15
Abundance (Millions)	0.00	4.14	1.91	14.28	10.54	0.69	31.56	31.54

Scampi (out of burrow)	350	400N	400S	450N	450S	500	Total	Bootstrap
Area (km^2)	278	789	452	1216	1348	514	4597	Estimate
Stations	5	4	6	8	13	4	40	
Mean density (.m^{-2})	0.0000	0.0036	0.0031	0.0065	0.0038	0.0004	0.0038	0.0038
CV		0.75	0.65	0.30	0.32		0.21	0.20
Abundance (Millions)	0.00	2.84	1.41	7.93	5.11	0.22	17.51	17.50

APPENDIX 2: Trawl survey analysis with revised strata boundaries

Analysis for biomass

2007	350	400 all+	450N	450S	500#	Total
Area (km^2)	278	1241	1216	1348	514	4597
Stations	1	3	3	5	1	13
Mean (kg.mile^{-1})	7.33	8.26	13.93	7.17	5.56	9.08
CV	0.44*	0.51	0.28	0.22	0.58*	0.18
Biomass(tonnes)	52.4	263.7	435.4	248.5	73.4	1073.5

2008	350	400 all+	450N	450S	500	Total
Area (km^2)	278	1541	1216	1348	514	4897
Stations	3	2	3	2	2	12
Mean (kg.mile^{-1})	14.09	7.00	7.56	14.22	9.22	10.40
CV	0.21	0.28	0.06	0.40	0.34	0.18
Biomass(tonnes)	100.7	277.3	236.2	493.0	121.9	1229.2

2009	350	400N	400S	450N	450S	500	Total
Area (km^2)	278	789	752	1216	1348	514	4897
Stations	3	3	2	2	4	6	20
Mean (kg.mile^{-1})	4.19	5.95	7.02	1.69	8.05	7.93	6.12
CV	0.50	0.08	0.33	0.47	0.09	0.14	0.09
Biomass(tonnes)	34.0	137.1	154.3	60.0	317.2	119.0	821.6

2013	350	400N	400S	450N	450S	500	Total
Area (km^2)	278	789	752	1216	1348	514	4897
Stations	3	3	2	3	4	2	17
Mean (kg.mile^{-1})	5.44	10.63	16.54	9.95	7.14	9.46	10.64
CV	0.21	0.07	0.18	0.06	0.09	0.33	0.06
Biomass(tonnes)	38.9	215.6	319.8	311.2	247.4	125.0	1257.9

*- in 2007, only one trawl station was completed in each of the 350–400 and 500–550 m strata. For overall estimation of survey CV strata with only one station were assumed to have average standard error of the mean of the other strata.

#- in 2007 there were no trawl stations within the 500–550 m stratum within the main area of the fishery. One station was completed within the secondary area and the catch rate from this station has been assumed for the main area.

+- in 2007 and 2008, insufficient stations were completed in the separate 400–450 A and B strata to provide estimates for both, and so they have been pooled

Analysis for numbers

2007	350	400 all+	450N	450S	500#	Total
Area (km^2)	278	1241	1216	1348	514	4597
Stations	1	3	3	5	1	13
Mean ($numbers.mile^{-1}$)	46.67	97.23	97.19	179.51	94.07	115.57
CV	0.07*	0.53	0.22	0.25	0.03	0.18
Numbers (millions)	0.33	3.10	0.25	3.40	5.60	13.7

2008	350	400 all+	450N	450S	500	Total
Area (km^2)	278	1541	1216	1348	514	4897
Stations	3	2	3	2	2	12
Mean ($numbers.mile^{-1}$)	168.59	88.86	199.42	108.89	140.00	142.92
CV	0.16	0.23	0.42	0.15	0.29	0.19
Numbers (millions)	1.21	3.52	6.91	3.40	1.85	16.89

2009	350	400N	400S	450N	450S	500	Total
Area (km^2)	278	789	752	1216	1348	514	4897
Stations	3	3	2	2	4	6	20
Mean ($numbers.mile^{-1}$)	43.17	65.40	83.11	102.18	20.00	100.96	73.97
CV	0.53	0.10	0.32	0.08	0.60	0.13	0.09
Numbers (millions)	0.31	1.33	1.61	3.54	0.63	1.33	8.74

2013	350	400N	400S	450N	450S	500	Total
Area (km^2)	278	789	752	1216	1348	514	4897
Stations	3	3	2	3	4	2	17
Mean ($numbers.mile^{-1}$)	68.44	112.34	123.92	98.93	141.12	85.63	119.61
CV	0.24	0.11	0.10	0.06	0.07	0.05	0.04
Numbers (millions)	0.49	2.28	2.40	3.43	4.41	1.13	14.14

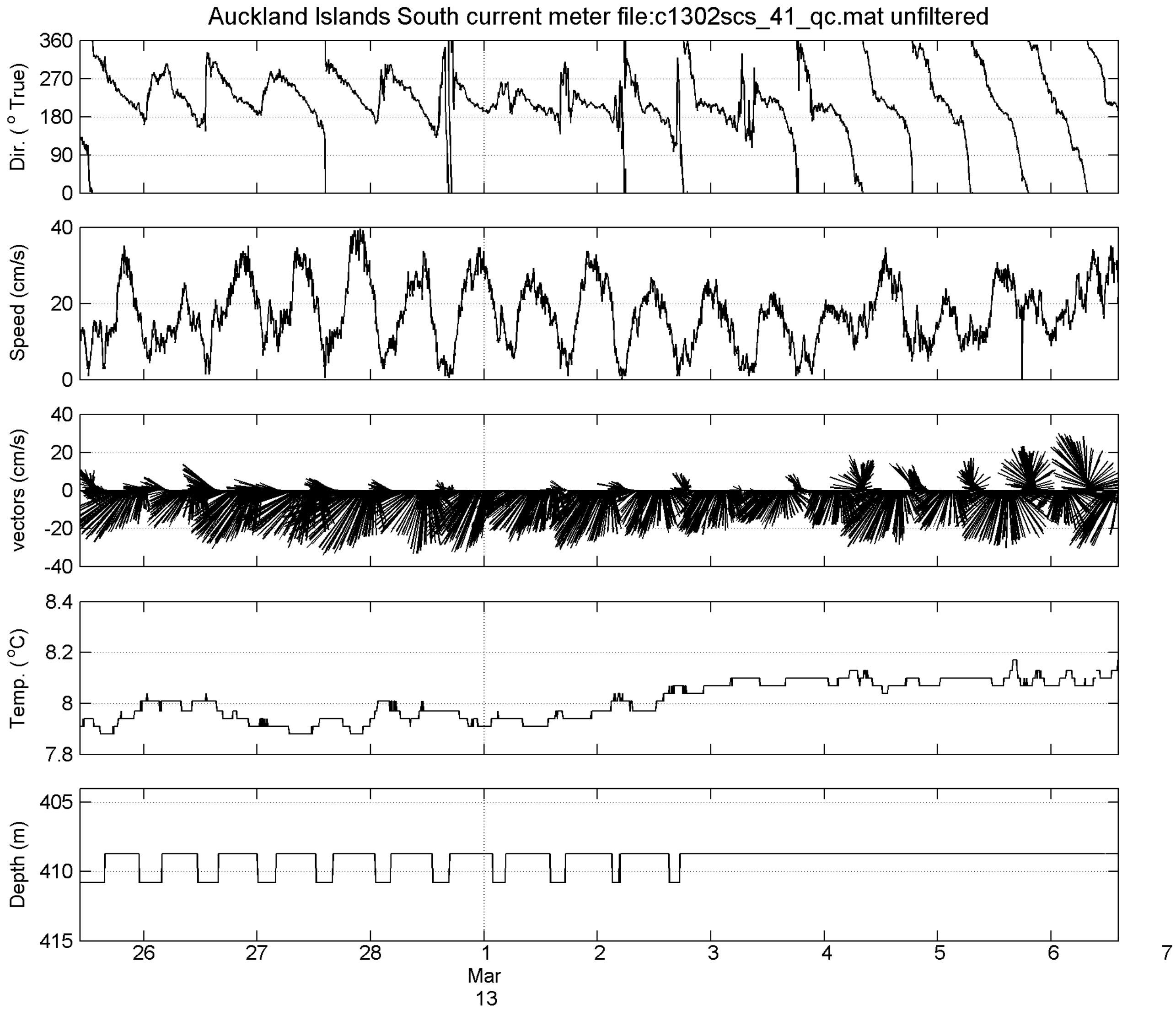
*- in 2007, only one trawl station was completed in each of the 350–400 and 500–550 m strata. For overall estimation of survey CV strata with only one station were assumed to have average standard error of the mean of the other strata.

#- in 2007 there were no trawl stations within the 500–550 m stratum within the main area of the fishery. One station was completed within the secondary area and the catch rate from this station has been assumed for the main area.

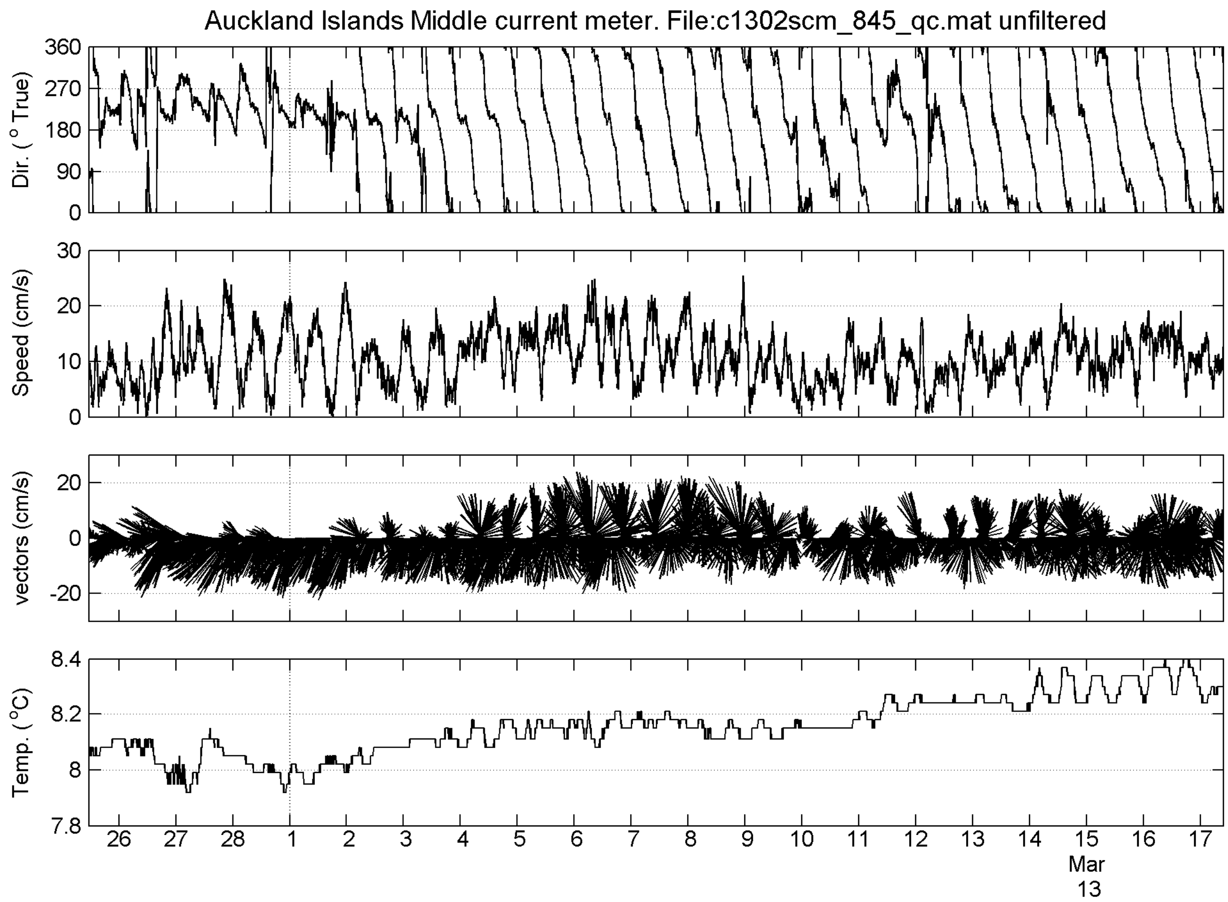
+- in 2007 and 2008, insufficient stations were completed in the separate 400–450 A and B strata to provide estimates for both, and so they have been pooled

APPENDIX 3: Current meter summary data

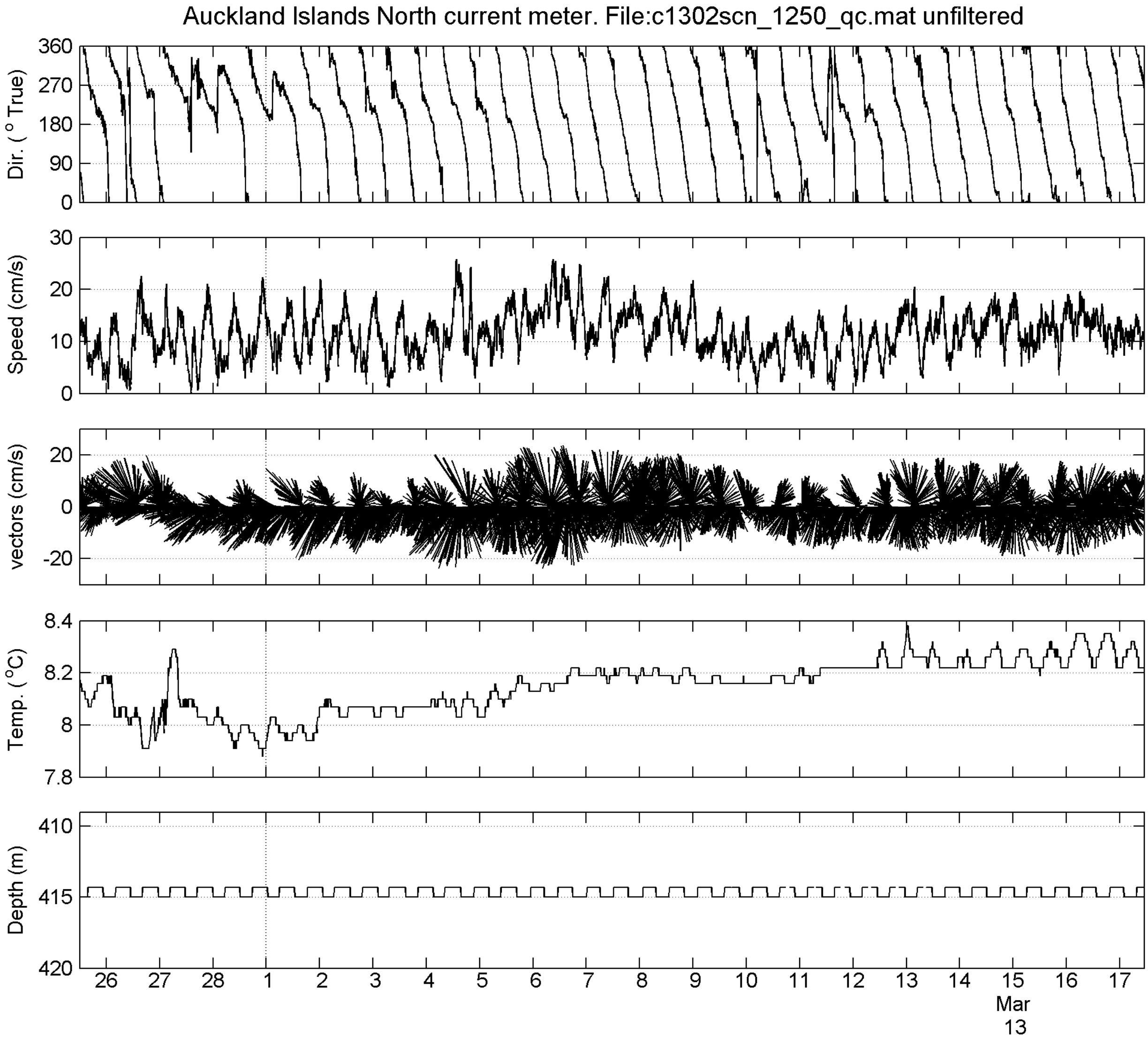
Summary of data downloaded from current meter at mooring 1.



Summary of data downloaded from current meter at mooring 2.



Summary of data downloaded from current meter at mooring 3.



APPENDIX 4: Acoustic tagging data

				Mooring 1		Mooring 2		Mooring 3		
Transmitter	Tag	CL	Sex	Bottom	Top	Bottom	Top	Bottom	Top	Duration
A69-1303-24847	1	52	F	449	312	0	0	0	0	1.3
A69-1303-24848	2	44	F	782	692	0	0	0	0	16.6
A69-1303-24849	3	50	M	537	219	0	0	0	0	4.1
A69-1303-24850	4	55	F	91	77	0	0	0	0	0.4
A69-1303-24851	5	53	M	124	55	0	0	0	0	0.9
A69-1303-24852	6	48	F	72	64	0	0	0	0	0.2
A69-1303-24853	7	46	M	86	62	0	0	0	0	0.3
A69-1303-24854	8	50	F	130	22	0	0	0	0	10.4
A69-1303-24855	9	42	F	396	610	0	0	0	0	15.5
A69-1303-24856	10	55	M	4204	2007	0	0	0	0	20
A69-1303-24857	11	50	M	109	73	0	0	0	0	0.7
A69-1303-24858	12	51	F	184	145	0	0	0	0	0.5
A69-1303-24859	13	59	M	66	74	7	8	0	0	2.4
A69-1303-24860	14	64	M	85	54	0	0	0	0	0.5
A69-1303-24861	15	57	M	356	420	0	0	0	0	4.4
A69-1303-24862	16	42	F	11740	10071	0	0	0	0	20
A69-1303-24863	17	54	F	8960	4171	0	0	0	0	20
A69-1303-24864	18	53	F	51	11	0	0	0	0	0.2
A69-1303-24865	19	53	M	59	34	0	0	0	0	0.5
A69-1303-24866	20	51	F	464	795	0	0	0	0	9.4
A69-1303-25177	21	51	M	0	0	124	35	0	0	0.4
A69-1303-25178	22	47	F	0	0	228	114	0	0	3.2
A69-1303-25179	23	45	M	0	0	8663	1134	0	0	20
A69-1303-25180	24	46	M	0	0	10183	5943	0	0	20
A69-1303-25181	25	55	F	0	0	217	148	0	0	19.9
A69-1303-25182	26	48	M	0	0	2722	3422	0	0	20
A69-1303-25183	27	45	F	0	0	3013	333	0	0	10.5
A69-1303-25184	28	47	F	0	0	27	20	24	7	1.3
A69-1303-25185	29	55	F	0	0	3033	1469	0	0	7.4
A69-1303-25186	30	49	M	0	0	27	25	16	12	1.3
A69-1303-25187	31	62	M	0	0	85	82	0	0	5.3
A69-1303-25188	32	54	M	0	0	275	186	0	0	13.6
A69-1303-25189	33	52	F	0	0	103	41	10	1	10.4
A69-1303-25190	34	48	F	0	0	10167	7178	0	0	20
A69-1303-25191	35	55	F	0	0	163	106	0	0	13.2
A69-1303-25192	36	42	F	0	0	33	27	25	22	1.3
A69-1303-25193	37	50	F	0	0	6421	1866	0	0	20
A69-1303-25194	38	44	F	0	0	117	129	0	0	14.9
A69-1303-25195	39	46	F	0	0	9516	6871	0	0	20
A69-1303-25196	40	47	M	0	0	1310	818	0	0	6.9
A69-1303-25197	41	44	F	0	0	0	0	4257	4021	20
A69-1303-25198	42	49	M	0	0	0	0	9897	6339	20
A69-1303-25199	43	50	F	0	0	0	0	324	723	19.8
A69-1303-25200	44	41	M	0	0	0	0	338	806	19.8
A69-1303-25201	45	52	M	0	0	0	0	9993	2680	20
A69-1303-25202	46	53	F	0	0	0	0	177	70	0.6
A69-1303-25203	47	34	M	0	0	0	0	7101	2531	19.9
A69-1303-25204	48	47	M	0	0	0	0	457	448	15.8
A69-1303-25205	49	41	M	0	0	0	0	9430	1137	20
A69-1303-25206	50	56	M	0	0	0	0	265	139	0.8
A69-1303-25207	51	39	F	0	0	0	0	28	17	0.1
A69-1303-25208	52	55	F	0	0	0	0	227	219	3.4
A69-1303-25209	53	51	F	0	0	0	0	5845	1819	14.4
A69-1303-25210	54	47	F	0	0	0	0	341	76	3.8
A69-1303-25211	55	33	M	0	0	0	0	8930	9083	20
A69-1303-25212	56	54	M	0	0	0	0	102	52	0.6
A69-1303-25213	57	52	M	0	0	0	0	57	64	4.1
A69-1303-25214	58	49	F	0	0	0	0	299	47	1
A69-1303-25215	59	52	M	0	0	0	0	8999	551	20
A69-1303-25216	60	46	F	0	0	0	0	23	15	0.1