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Tini a Tangaroa

Estimating the abundance of scampi in SCI 3 (Mernoo Bank) in 2019

New Zealand Fisheries Assessment Report 2021/17

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Photographic and trawl surveys of scampi (*Metanephrops challengeri*) in SCI 3 were conducted in September 2019 from the RV *Kaharoa*. This area was last surveyed in 2016. Although the survey stratification remained consistent for surveys since 2013, greater emphasis (more stations) was placed on the trawl component of the survey in 2019, and less on the photographic component than in previous years. The photographic survey estimated a scampi burrow abundance of 871 million (coefficient of variation, CV 6%) over the whole area, continuing the increase observed since the 2009 survey. The photographic estimates of visible scampi and scampi out of burrows also increased from those in 2016. The trawl survey estimate of 1220 t (CV 6%) (or 16.4 million individuals, CV 6%) represents a significant increase from the previous estimate from 2016 (913 t, CV 12%), which in turn was a significant increase from the 2013 estimate (551 t, CV 12%). Given that scampi live in burrows and are only available to trawl gear when they emerge on the seabed, trawl survey estimates are likely to be considerable underestimates of the stock biomass or abundance.

Almost 2750 scampi were tagged and released to investigate growth rates, with releases distributed across the fishing grounds. A range of additional data were collected during the survey, including visually detected *Microsporidian* infection rates in scampi, CTD profiles, sediment samples, and acoustic seabed measurements, and stomach contents of potential scampi predators.

1. INTRODUCTION

The scampi fishery is based on the species *Metanephrops challengeri,* which is widely distributed around New Zealand (Figure 1). National scampi landings in 2018–19 were 1069 t (limit 1312 t). The landings for scampi in SCI 3 were 413 t in 2018–19 (TACC was increased from 340 t to 408 t at the start of the 2018–19 fishing year). Landings have been maintained at around 300 t through much of the history of the fishery, but did drop to around 200 t in 2007–08 and 2008–09, and were around 340 t (the TACC prior to 2018–19) between 2014–15 and 2017–18. The other major fisheries are SCI 1 (TACC 120 t), SCI 2 (TACC 153 t), SCI 4A (TACC 120 t), and SCI 6A (TACC 306 t). Scampi are taken by light trawl gear, which catches scampi that have emerged from burrows in the bottom sediment. The main fisheries are in waters 300–500 m deep, although the range is slightly deeper in the SCI 6A region (350–550 m). Little is known about the growth rate and maximum age of scampi.

Scampi occupy burrows in muddy substrates and are only available to trawl fisheries when they emerge on the seabed (Bell et al. 2006). Scampi emergence patterns have been inferred from changes in catch rates (for both European and New Zealand species) and have been shown to vary seasonally in relation to moult and reproductive cycles, and over shorter time scales in relation to diel and tidal cycles (Aguzzi et al. 2003; Bell et al. 2006; Tuck et al. 2015). Uncertainty over trawl catchability associated with these emergence patterns has led to the development of survey approaches based on counts of scampi burrows rather than visible animals (Cryer et al. 2003; Froglia et al. 1997; Smith et al. 2003; Tuck et al. 1997), although these approaches still face uncertainties over burrow occupancy and population size composition (ICES 2007; Sardà & Aguzzi 2012). Photographic surveying has been used extensively to estimate the abundance of European scampi and has been carried out in New Zealand since 1998. Surveys in SCI 3 started in 2001, and this report documents the seventh survey of this area. Similar survey time series are available for SCI 1 (1998–2018, nine surveys), SCI 2 (2003–2018, seven surveys), and SCI 6A (2007–2019, six surveys).

Photographic surveys provide three scampi abundance indices: the density of visible scampi observed either within a burrow entrance (doorkeepers) or walking free on the seabed; the density of emerged scampi (animals fully emerged from a burrow); and the density of major burrow openings (counts of which are now standardised among readers and between surveys, following development of a between-reader calibration process). The index of major burrow openings has been used as an abundance index in recent stock assessments for SCI 1, SCI 2, and SCI 3 (Tuck, 2019, 2020). The relationship between scampi and burrows may be different in SCI 6A (Tuck & Dunn 2009; Tuck et al. 2007), and the index of visible scampi was used in the initial assessments for SCI 6A (Tuck 2017), although the DWWG agreed that the index of emerged scampi was more appropriate for the most recent SCI 6A assessment (Tuck 2021), and this may well be explored in future assessments of other stocks.

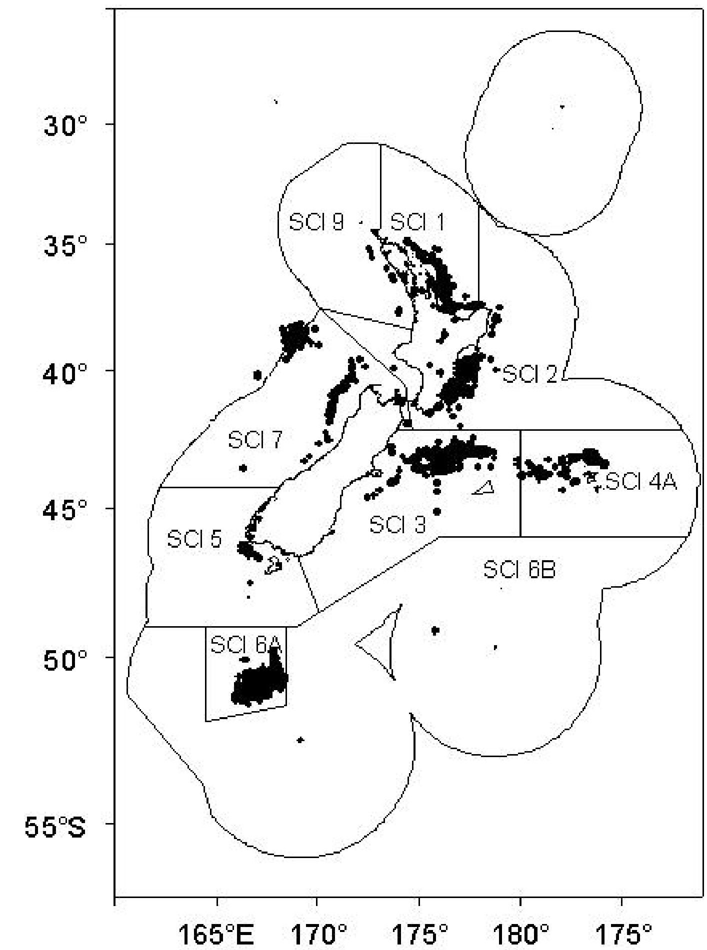

Figure 1: Spatial distribution of the scampi fishery from 1988–89 to 2018–19 (ungroomed data). Each dot shows the mid-point of one or more tows recorded on Trawl Catch Effort Processing Return forms or the Electronic Reporting System with scampi as the target species.

This report fulfils the final reporting requirement for Fisheries New Zealand research project SCI2019-01.

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

Objective:

1. To estimate the relative abundance of scampi in SCI 3 using photographic techniques and trawl survey information.
2. To estimate growth of scampi from tagging in SCI 3.

2. METHODS

A survey design, based on the design of the 2016 survey (50 photographic stations, 24 trawl stations), was presented to the Fisheries New Zealand Shellfish (Science) Working Group (SFWG) and submitted to Fisheries New Zealand in July 2019. Photo stations were allocated to strata on the basis of burrow abundance data from the 2016 surveys using the *allocate* package (Francis, 2006), which minimises the estimated coefficient of variation (CV) achieved 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 random photographic stations generated from each stratum were taken as trawl stations, with the minimum distance between each trawl station checked, and a station dropped as a trawl station and the next on the list selected if the distance was less than 4 nautical miles.

Feedback from the SFWG led to a slight shift in priority for the survey, with more emphasis being placed on the trawl component of the work. Following discussions, it was agreed to reduce the photographic component of the survey to 40 stations (with stations allocated to strata as above), with the aim of completing trawl sampling at as many of the photographic stations as time allowed (with at least 3 in each stratum), with trawl sampling allocated to strata on the same basis as the photographic stations. Thirty-four trawl stations were identified in the revised design, but it was acknowledged that it would be very unlikely these would all be completed if much survey time was lost to poor weather.

The survey, undertaken in September 2019, was the seventh photographic survey of the SCI 3 area. The previous surveys were conducted in 2001 (two surveys), and 2009, 2010, 2013, and 2016 (Cryer et al. 2003; Tuck et al. 2011; Tuck et al. 2015a; Tuck et al. 2018). Following previous survey designs, a random stratified survey was conducted, with stratification on the basis of depth (100 m bands) and general region. Strata boundaries were revised in 2013 to exclude some areas where little commercial scampi fishing occurs. The revised survey coverage accounts for about 99% of landings from the fishery over its history (Tuck 2019). Survey coverage and stratum boundaries are shown in Figure 2.

Numbers of stations allocated to each stratum and planned station locations are provided in Table 1 and Figure 3. The predicted CV for the photographic survey was 5.4%. The distribution of all photographic stations sampled within SCI 3 since 2009 (when surveys of the complete area were started) is shown in Appendix 1. A subset (generally the first few randomly allocated within each strata) of these stations has also been sampled by trawling.

Table 1: Details of strata and number of stations planned for SCI 3 in 2019.

Stratum	Depth (m)	Area (km^2)	Photo stations	Trawl stations
902	300–400	439.84	3	3
903	400–500	552.08	5	4
902A1	300–400	700.41	6	5
902A2	300–400	1 432.38	9	7
902B1	300–400	605.42	6	5
902B2	300–400	660.97	5	4
902C	300–400	172.45	3	3
903A	400–500	459.18	3	3
Total		5 022.73	40	34

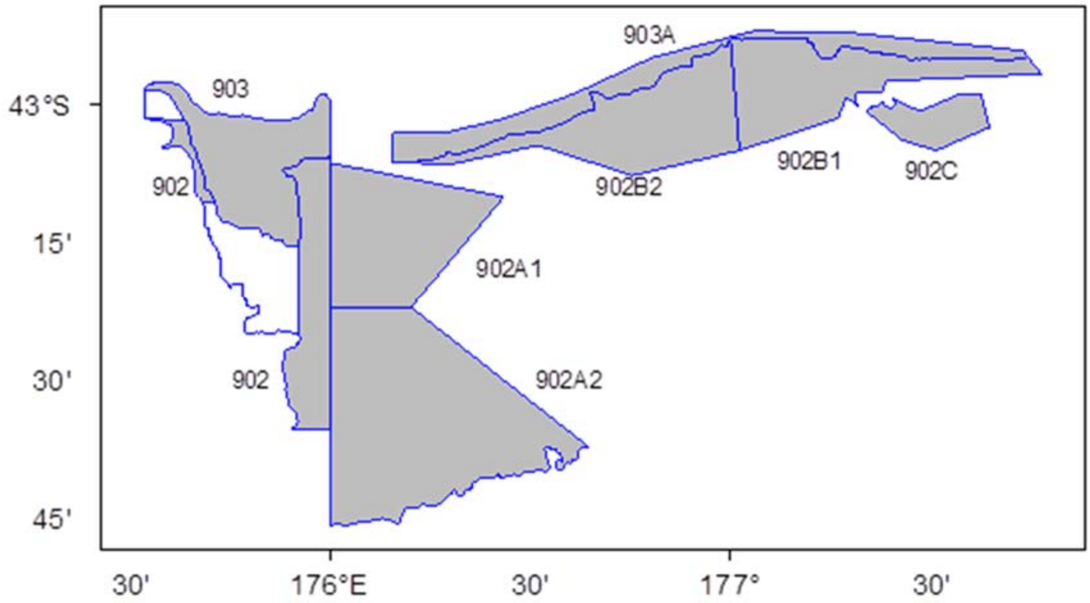

Figure 2: **Survey strata for the 2019 photographic survey of SCI 3.**

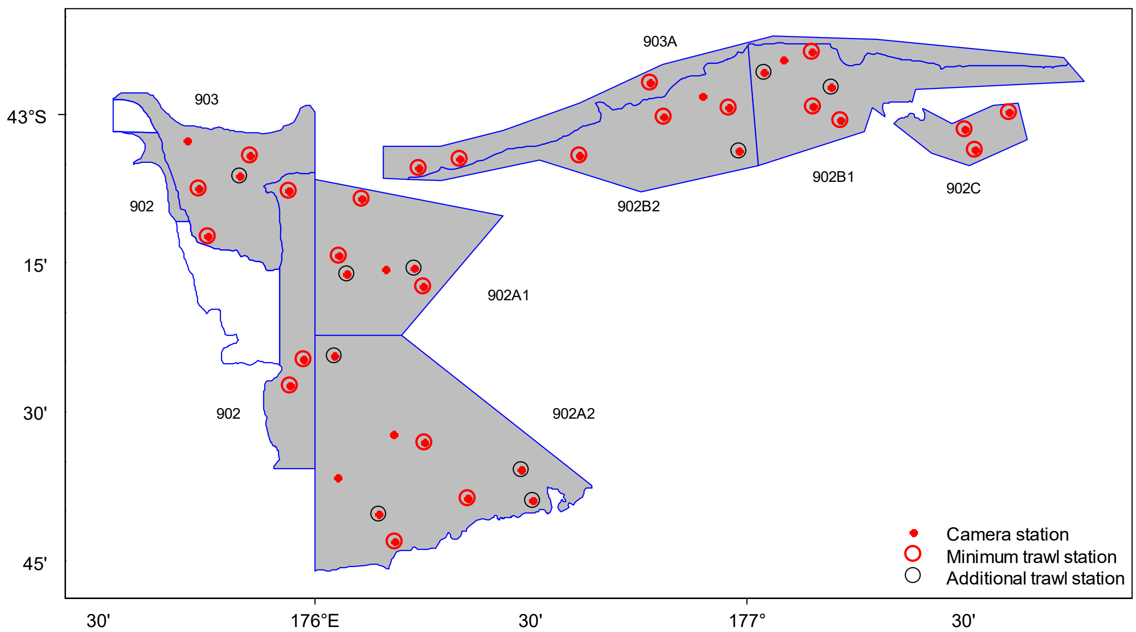

Figure 3: **Proposed station locations within each stratum for the 2019 survey in SCI 3. Camera stations are represented by filled symbols. Trawl stations are represented by larger open symbols.**

2.1 Photographic survey

Photographic sampling was undertaken between 0600 and 1800 NZST to coincide with the period of maximum trawl catchability of scampi. Although the time of day has no direct effect on the visibility of burrow openings, sampling at a time when the greatest numbers of scampi are likely to be out of their burrows also provides a useful scampi abundance index, which has two further advantages. First, a larger number of individuals can be measured for a photographic length frequency distribution, and second, the presence of scampi at or near burrow openings is an excellent aid to the identification of burrow types that are likely to be built by scampi. Additionally, with the potential use of a scampi index in assessments, it is important to sample the population when they are consistently available.

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

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

Image selection and scoring

Images were examined and scored using a standardised protocol (Cryer et al. 2002) applied by a team of six trained readers. For each image, the main criteria for usability were the ability to discern fine seabed detail and the visibility of more than 50% of the frame (free from disturbed sediment, poor flash coverage, or other features). If these criteria were met, the image was "adopted" and "initiated" (Cryer et al. 2002). The percentage of the frame within which the seabed is clearly and sharply visible was estimated and marked using polygons in NICAMS (NIWA Image Capture and Manipulation System, developed using the ImageJ software). The criteria used by readers to judge whether or not a burrow should be scored were, of necessity, partially subjective, because readers could not be certain that any particular burrow belonged to a scampi and was currently inhabited unless the individual was photographed in the burrow. However, after viewing large numbers of scampi associated with burrows, NIWA has developed a set of descriptors that guide our decisions (Cryer et al. 2002). NIWA defined "major" and "minor" burrow openings, respectively, as the type of opening at which scampi are usually observed and the "rear" openings associated with most burrows. Based on examination of a large number of images of scampi associated with burrows, "major" and "minor" openings each have their own characteristics and should be scored separately (Figure 4).

Each opening (whether major or minor) was classed as "highly characteristic" or "probable", based on the extent to which each is characteristic of burrows observed to be used by New Zealand scampi. Scores are saved in a database within the NICAMS system. All survey images (and associated annotations) from surveys (and reference sets) since 2012 are maintained on NIWA's *prod_nicams* database on the Biscay database server, which is backed up daily. Annotated images from previous surveys, and associated datasets are saved in the Fisheries New Zealand project archive. Within NICAMS, features counted by each reader are individually identifiable within each image, providing an audit trail. An investigation into mud burrowing megafauna in scampi grounds concluded that it is unlikely that other species present would generate burrows that would be confused with those generated by scampi (Tuck & Spong 2013). Burrows and holes which could conceivably be used by scampi, but which were not thought to be "characteristic" were not counted. The counts of burrow openings may, therefore, be conservative. Many ICES stock assessments of European scampi (*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). Burrow openings, rather than assumed burrow systems, were counted 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. 1998; Marrs et al. 1996).

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

Reader and year calibration

To enable comparison of the 2019 survey data with previous surveys, a reference set of SCI 3 images collected in 2001, 2009, 2010, 2013, and 2016 was re-read in 2019 (at the same time as the 2019 survey images), with each image in each reference set being read by all six readers, following the standard image scoring and re-reading procedure.

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

Following the recommendation of the Deepwater Working Group (January 29th 2020), the station level burrow (and scampi) count data were examined within a GLMM framework with *station_year,* and *readable_area* (offset) as explanatory variables, and *reader_year* as random effects, and a negative binomial or Poisson error distribution (determined by examination of diagnostics). Model selection was conducted in a backwards manner removing terms from the full model on the basis of AIC. This model was then used to predict burrow counts (given actual *readable_area*) for each station within each survey for a generic reader. Predicted burrow counts were used with readable area to estimate predicted burrow density.

Data analysis

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

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

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

where $s^2_{(y)}$ is the variance of the overall mean density, $\overline{x}_{(y)}$, 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 openings, all visible scampi, and scampi "out" of their burrows (i.e., walking free on the sediment surface). The sensitivity of the indices to the reader "bias" was investigated using the approach described above, and a "corrected" density index for major burrow openings is also provided.

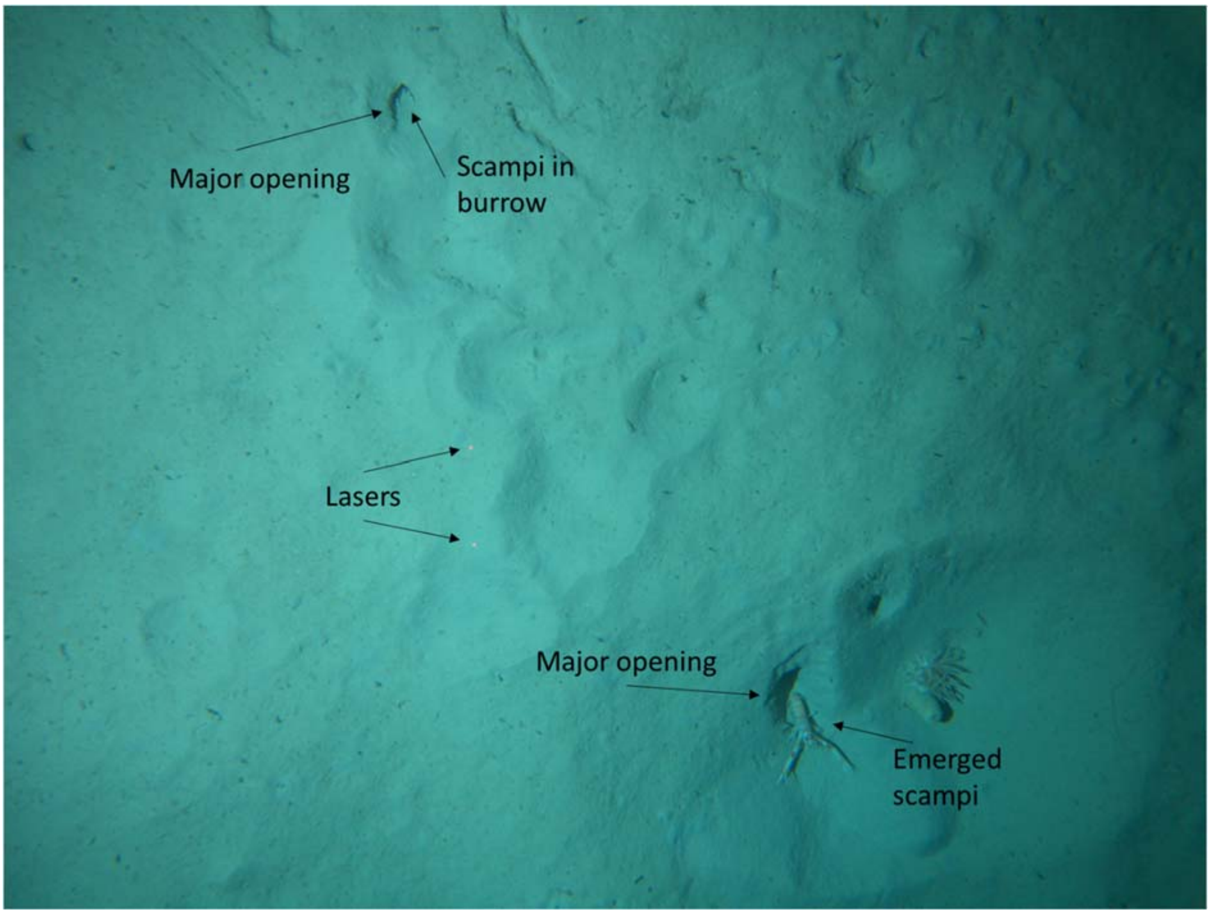

Figure 4: Example image from recent scampi survey showing laser scaling dots, characteristic scampi burrows, and scampi.

2.2 Trawl survey

Trawl survey sampling was undertaken between 0600 and 1800 NZST, during the second half of the voyage, after the photographic survey had been completed. Between three and seven of the random photographic stations allocated to each stratum were reselected as trawl stations (Table 1). Trawl sampling was conducted with standardised RV *Kaharoa* scampi gear trawl, as used for previous scampi surveys from this vessel.

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

Scampi tagging

The second objective of the voyage was to tag and release scampi to investigate growth. When time allowed, all scampi caught during each tow that were considered to be in good health were tagged and released. All scampi were rapidly sorted from the catch and stored in darkened non-draining bins of refrigerated, well aerated seawater. Any animals with carapace punctures were excluded, and, for tagged animals, any damaged or missing limbs were recorded. Animals were tagged between the carapace and cuticle of the first abdominal segment through the musculature of the abdomen with sequentially numbered streamer tags (Hallprint type 4S, Figure 5), Hallprint T-bar tags, or both. The streamer tags have been used successfully in previous scampi studies (Cryer & Stotter 1997, 1999; Tuck & Dunn 2012), although tag return data suggest that some tag loss may be occurring following moulting, and T-bar tags were therefore also used for this survey. The next scheduled research survey in SCI 3 is planned for 2022, and so it is anticipated that recoveries will be from commercial fishing activity. Tag mortality has been examined previously (Tuck et al. 2015b), but, at the request of Fisheries New Zealand, no tag mortality component was included in this survey because it was considered very unlikely that tag recapture data would be used to estimate stock size for this fishery.

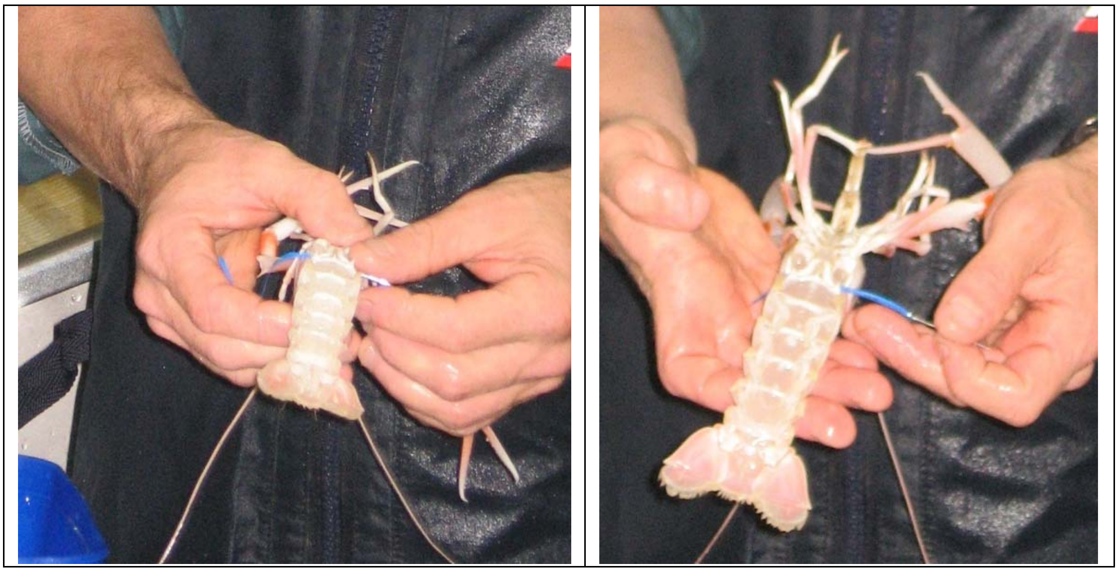

Figure 5: Photographs showing location of streamer tags in scampi.

2.3 Other data

In addition to the main survey objectives, a range of other tasks were undertaken during the voyage as the opportunity arose.

Microsporidian infection of scampi

From samples of scampi collected from SCI 6A during the 2007 and 2008 surveys, a new *microsporidian* parasite was identified and described (Stentiford et al. 2010). Infected scampi displayed an unusual external appearance (Figure 6) and appeared to be lethargic. Histology was used to demonstrate replacement of skeletal and other muscles by the parasite, and infection at visually detectable levels is considered fatal. Low levels of infection were reported during these first observations (Tuck et al. 2009), but routine recording of infection rates was only started in 2019 (Tuck et al. 2020).

All scampi measured during the survey were examined and categorised as infected or non-infected on the basis shown in Figure 6. Carapace colouration can vary with moult stage and the colour and texture of the major flexor muscles and telson muscles was considered the main diagnostic.

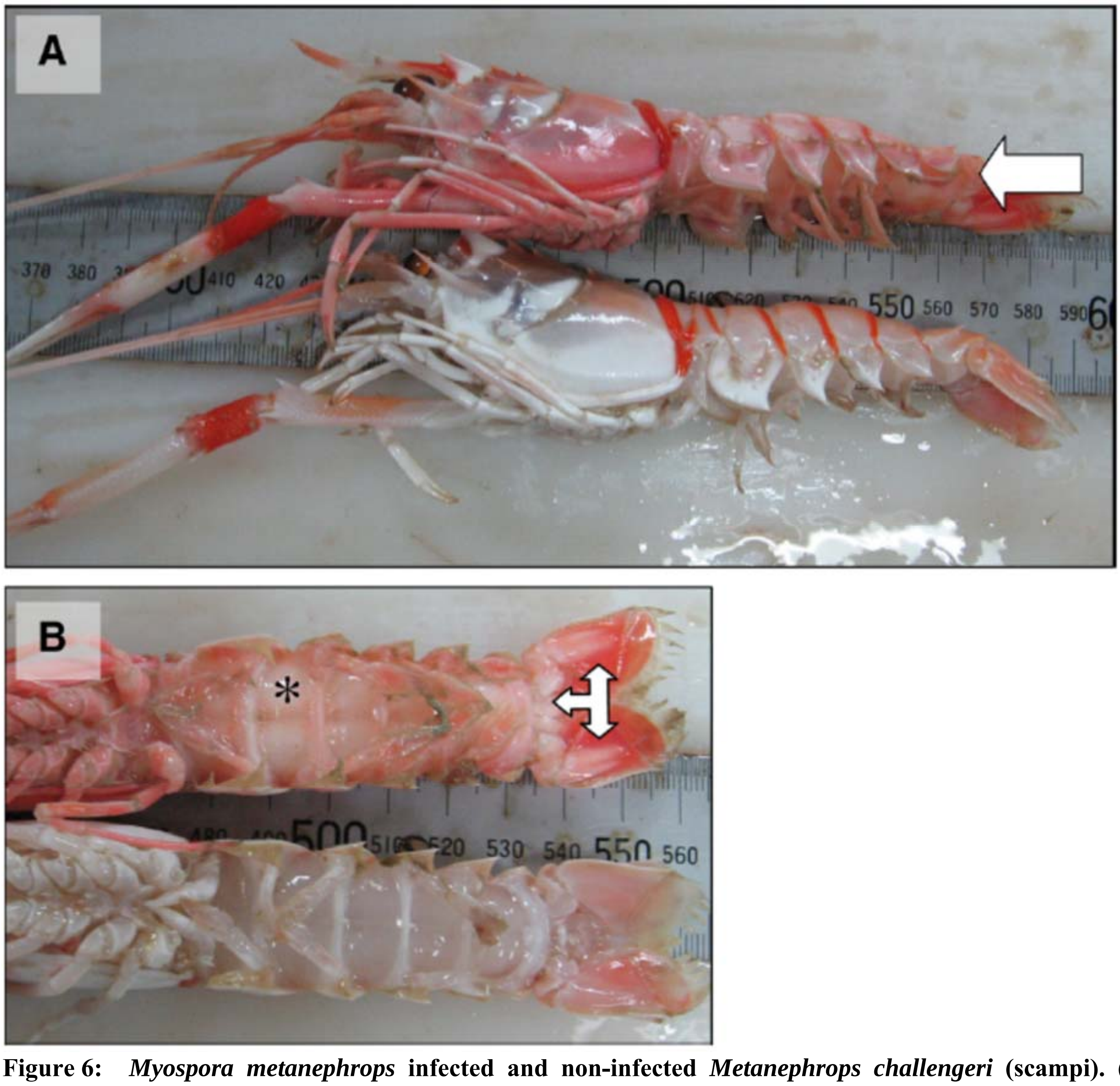

Figure 6: *Myospora metanephrops* infected and non-infected *Metanephrops challengeri* (scampi). (A) Infected scampi (arrow) appears differentially pigmented with increased opacity in all body sections relative to non-infected scampi. (B) Infection is most apparent in major flexor muscles (asterisk)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

CTD profiles

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

Acoustic seabed measurements and sediment sampling

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

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

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

Predation on scampi

Recent ecosystem modelling applications on the Chatham Rise (McGregor et al. 2019) suggest that predation pressure on scampi may have varied considerably over time, and understanding this may help understand observed population fluctuations. There are limited data on scampi predators, and so where possible the stomach contents of a variety of fish species caught during research trawling were examined, to quantify the incidence of scampi (scampi presence and size in relation to fish species and size), and the proportion of the stomach contents containing scampi. Specific sampling protocols followed those developed for stomach content sampling on the Chatham Rise and Sub-Antarctic surveys (Darren Stevens, NIWA, pers. comm.), and data were recorded within the *biological_table* of the *trawl* database.

3. RESULTS

The voyage was completed successfully between 2 and 30 September 2019. All photographic stations were completed, and 30 of the potential 34 trawl stations were completed. Weather was very poor during some parts of the voyage, with no survey work being possible on eight days.

3.1 Photographic survey

Visibility was very good, but large swells during some parts of the survey meant that it was difficult to maintain the camera at a consistent altitude above the seabed. Over the whole survey, a total area of 8978 m^2 of seabed was viewed (acceptable quality images), with an average of 38.5 images per station, an average seabed area viewed by each image of 6.33 m^2, providing an average area viewed of 243.86 m^2 at each station. Previous surveys in SCI 3 have had an average viewable area per station of 195–285 m^2.

For the GLMM of major burrow openings a Poisson error distribution provided the best fit to the data (Table 2), with the final model retaining the fixed effect *station_year* and the random effect *reader_year* (both considered as factors) (Table 3). Diagnostic plots for the model are shown in Figure 8.

Table 2: AIC values for models considered examining major burrow openings.

Fixed effects	Random effect	Offset	distribution	AIC
station_year	*reader_year*	Log(*readable area*)	Negative binomial	12 152.89
-	*reader_year*	Log(*readable area*)	Negative binomial	16 634.46
station_year	-	Log(*readable area*)	Negative binomial	12 946.78
station_year	*reader_year*	Log(*readable area*)	Poisson	12 150.85
-	*reader_year*	Log(*readable area*)	Poisson	24 125.99
station_year	-	Log(*readable area*)	Poisson	12 973.46

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

	Df	Sum sq	Mean Sq	F value
station_year	387	11 335	29.29	29.29

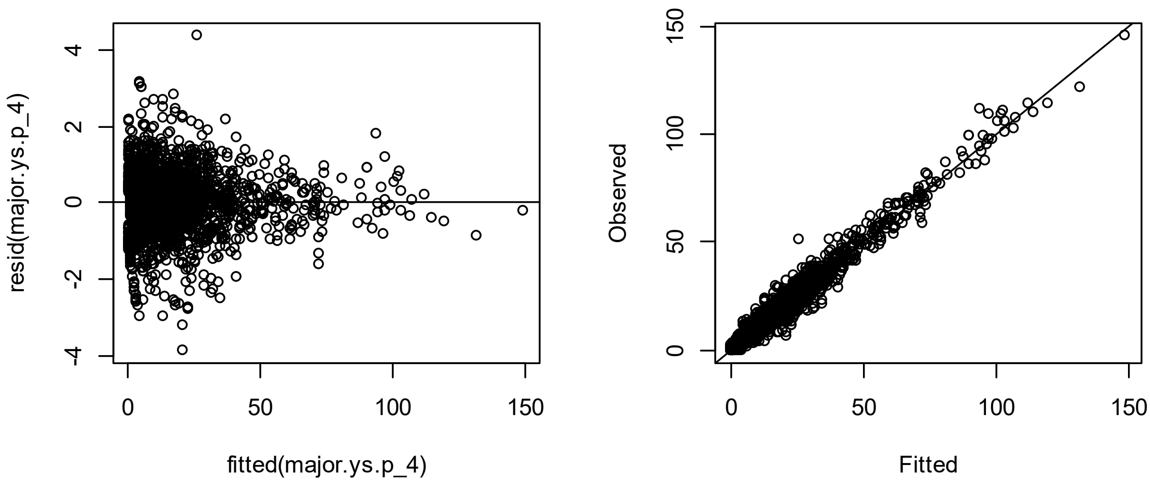

Figure 8: Diagnostic plots for generalised linear mixed effects model examining counts of major burrow openings with a *reader_year* random effect.

The random effects for *reader_year* (Figure 9) suggest that burrow counts from the reference set images were higher than expected in 2019, and this is accounted for by predicting burrow counts at the station level for a generic reader. Major burrow opening count data for the 2019 reference set images for each year that combinations of images have been read by each reader are provided in Appendix 2 and show that readers generally counted high in 2019.

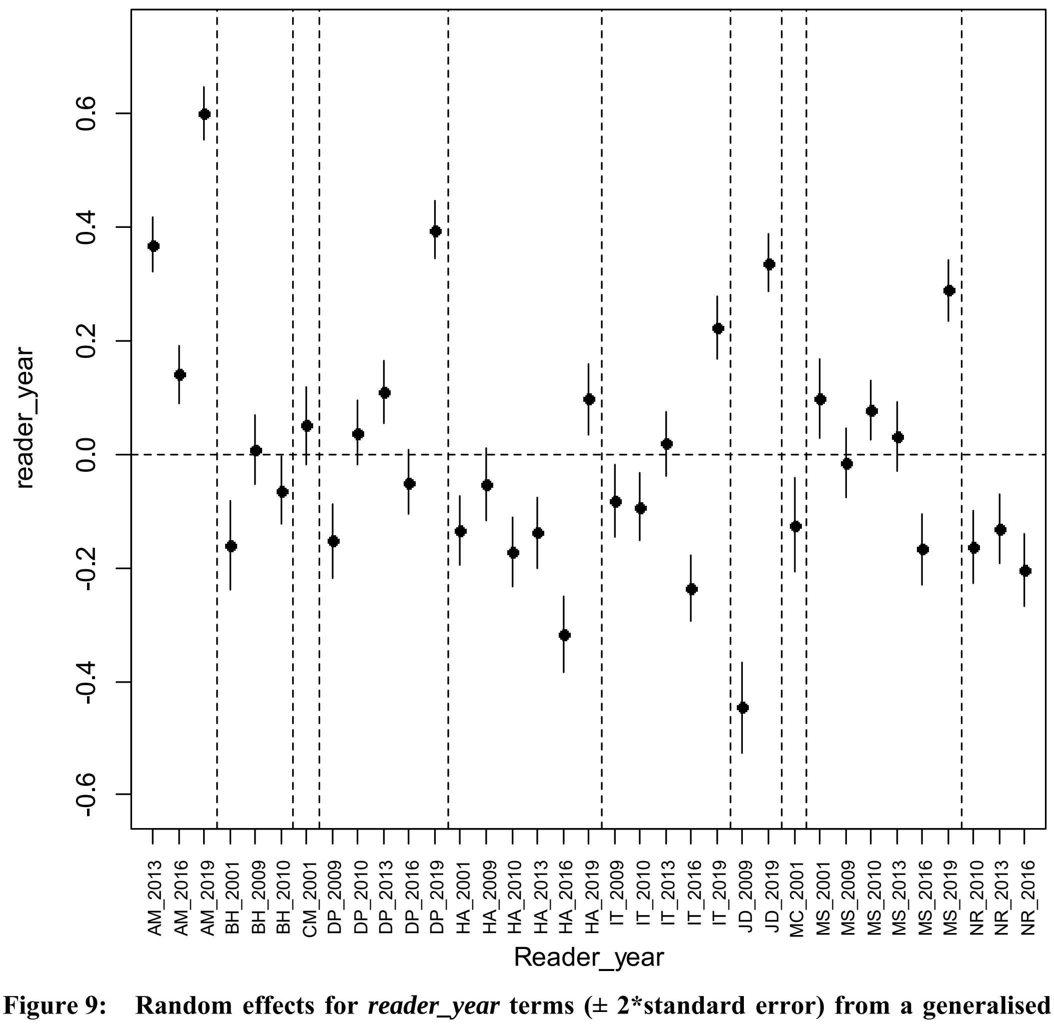

Figure 9: Random effects for *reader_year* terms (± 2*standard error) from a generalised linear mixed model relating the count of major burrow openings to *station_year*, and *readable area* (offset) for SCI 3.

For visible scampi, a Poisson error distribution provided the best initial fit to the data with the final model (Table 4) retaining the fixed effect *station_year* and the random effect *reader_year* (Table 5, diagnostic plots in Figure 10).

Table 4: AIC values for models considered examining visible scampi.

Fixed effects	Random effect	Offset	distribution	AIC
station_year	*reader_year*	Log(*readable area*)	Negative binomial	7 598.82
-	*reader_year*	Log(*readable area*)	Negative binomial	11 218.85
station_year	-	Log(*readable area*)	Negative binomial	7 605.84
station_year	*reader_year*	Log(*readable area*)	Poisson	7 596.74
-	*reader_year*	Log(*readable area*)	Poisson	12 796.44
station_year	-	Log(*readable area*)	Poisson	7 603.61
station_year	*reader*	Log(*readable area*)	Poisson	7 574.38

Table 5: Analysis of deviance for a generalised linear model relating the count of visible scampi to *station_year* and *readable area* (offset) with a *reader_year* random effect for SCI 3.

	Df	Sum sq	Mean Sq	F value
station_year	387	4 698.8	12.142	12.142

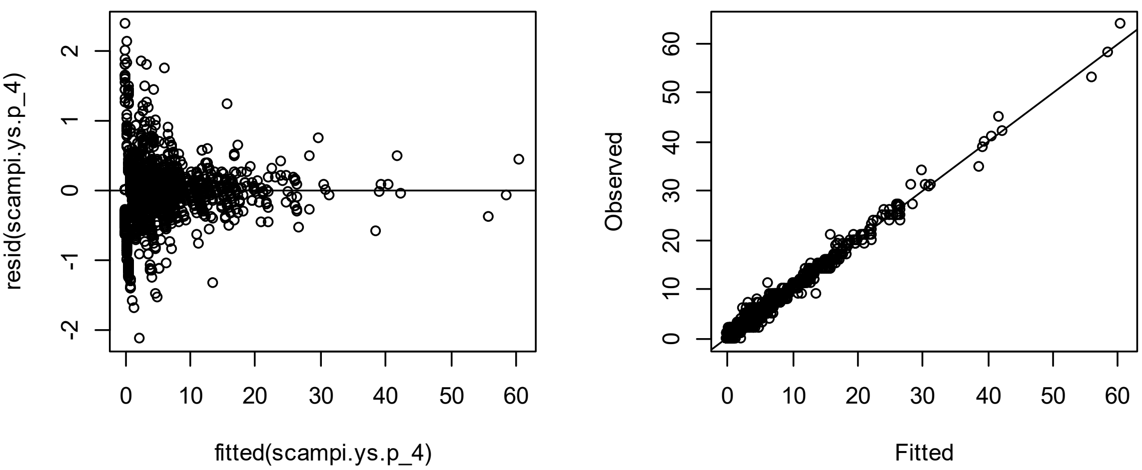

Figure 10: Diagnostic plots for a generalised linear mixed effects model examining effects on counts of visible scampi with a *reader_year* random effect.

Although the random effect for *reader_year* was retained in the model, the AIC improvement associated with the random effects model (7 AIC units, Table 4) was far smaller than for major burrow openings (over 900 AIC units, Table 2), and the scale of the reader effects was smaller (Figure 11) supporting our view that identification and counting of scampi is far less subjective than that of burrow openings. Although readers do differ in the counting of scampi (AM and DP tend to count higher than average, NR counts lower) there is less evidence of changes over time. Given the relative consistency within reader, a *reader* random effect term was offered rather than the *reader*_year term, resulting in a further reduction in AIC, and confirming that though there was a difference between readers, there was no significant *reader_year* interaction. The final model used to predict visible scampi counts retained the fixed effect *station_year* and the random effect *reader* (Table 6, diagnostic plots in Figure 12).

As with major burrow openings, differences are accounted for by predicting visible scampi counts for a generic reader.

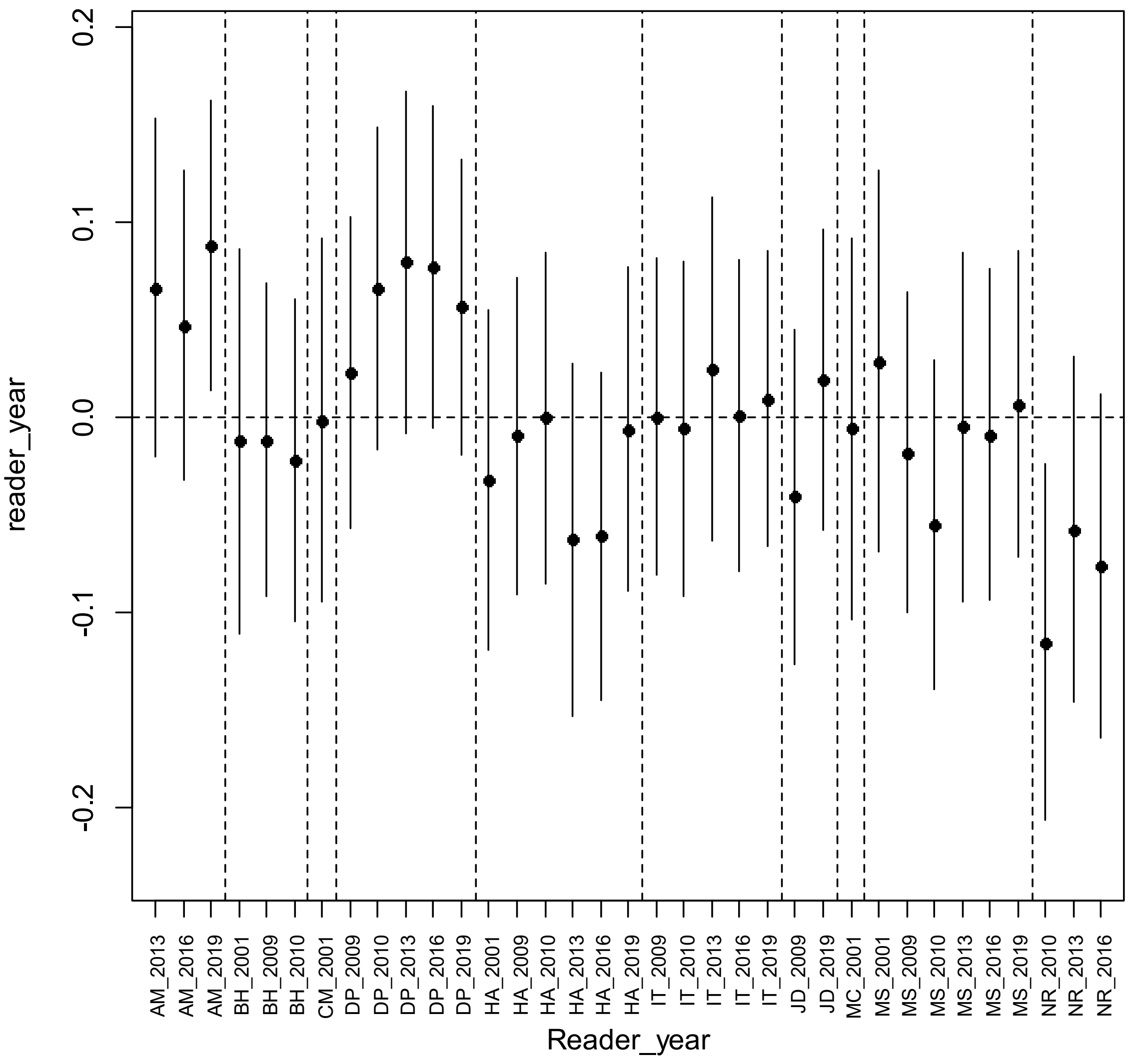

Figure 11: Random effects for *reader_year* terms (± 2*standard error) from a generalised linear mixed model relating the count of visible scampi to *station_year*, and *readable area* (offset) for SCI 3.

Table 6: Analysis of deviance for a generalised linear model relating the count of visible scampi to *station_year* and *readable area* (offset) with a *reader* random effect for SCI 3.

	Df	Sum sq	Mean Sq	F value
station_year	387	5 172.6	13.366	13.366

To further explore the *reader_year* or *reader* effect on visible scampi counts, the same modelling process was applied to the counts of scampi emerged from burrows (Table 7). For emerged scampi, a Poisson error distribution provided the best fit to the data with the final model retaining only the fixed effect *station_year* and not the random effect *reader_year* or *reader* (Table 8, diagnostic plots in Figure 13). This would imply that the *reader* effect of the visible scampi count is associated with the doorkeeping component of the population, and not the emerged component.

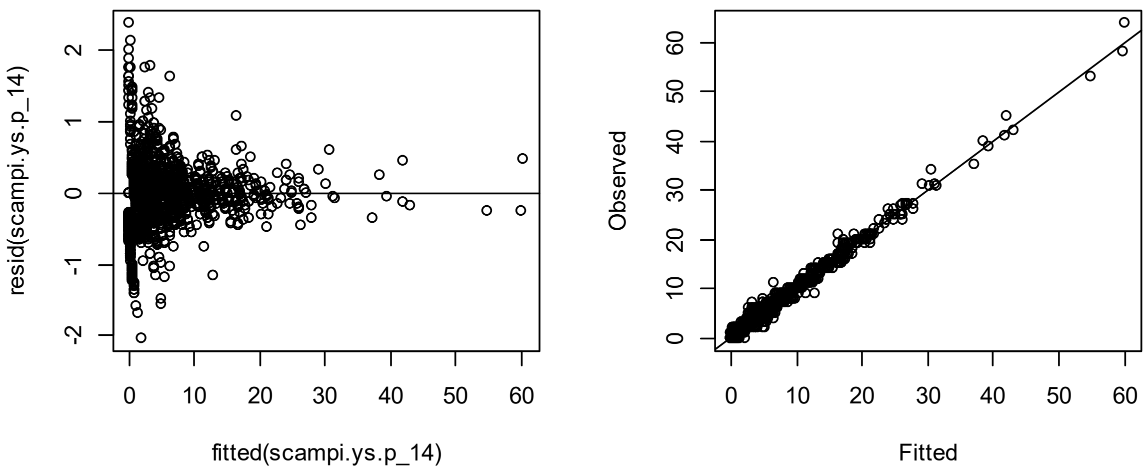

Figure 12: Diagnostic plots for generalised linear mixed effects model examining effects on counts of visible scampi with a *reader* random effect.

Table 7: AIC values for models considered examining scampi emerged from burrows.

Fixed effects	Random effect	Offset	distribution	AIC
station_year	*reader_year*	Log(*readable area*)	Negative binomial	3 494.58
-	*reader_year*	Log(*readable area*)	Negative binomial	5 954.85
station_year	*reader*	Log(*readable area*)	Negative binomial	3 494.58
station_year	-	Log(*readable area*)	Negative binomial	3 492.62
station_year	*reader_year*	Log(*readable area*)	Poisson	3 492.55
-	*reader_year*	Log(*readable area*)	Poisson	6 541.53
station_year	*reader*	Log(*readable area*)	Poisson	3 492.55
station_year	-	Log(*readable area*)	Poisson	3 490.55

Table 8: Analysis of deviance for a generalised linear model relating the count of scampi emerged from burrows to *station_year* and *readable area* (offset) for SCI 3.

	Df	Deviance	Resid. Df	Resid. Dev	Pr (>Chi)
NULL			2 433	4 078.1	
station_year	387	3 867	2 046	211.1	<0.00001

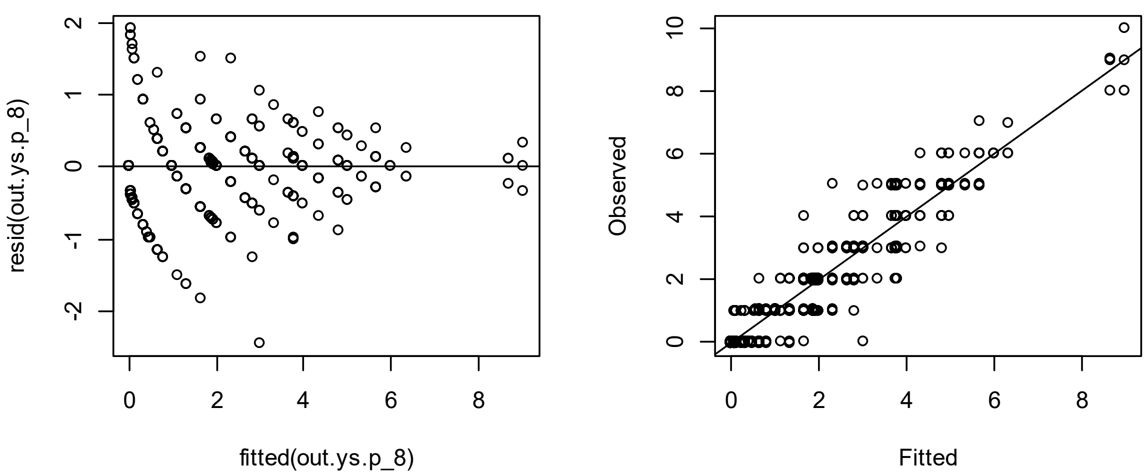

Figure 13: Diagnostic plots for generalised linear mixed effects model examining effects on counts of emerged scampi.

The locations of photographic stations and relative burrow densities are shown in Figure 14. The uncorrected burrow density estimates at the station level varied from 0.06 to 0.45 m^{-2}, and reader correction factors reduced these (median density reduced from 0.24 m^{-2} to 0.18 m^{-2}). Densities of visible scampi ranged from 0.02 to 0.02 m^{-2} (Figure 15), and reader correction factors slightly reduced these. Densities of scampi emerged from burrows ranged from 0 to 0.02 m^{-2}. Scaling the densities to the combined area of the strata (5022 km^2) leads to an abundance estimate of 871 million burrows (6% CV) or, assuming 100% occupancy, a maximum abundance estimate of the same number of animals (Table 9). Analyses of all SCI 3 surveys (with and without *reader_year* corrections) are presented in Appendix 3.

Overall, the corrected density of major scampi burrow openings was estimated to be 0.17 m^{-2}. The density was lowest in strata 903 and 902A1 and 902A2 (within the more western area of the fishery) (Table 9). The estimated mean density of all visible scampi was 0.07 m^{-2}, with the lowest density observed in the same strata as the lowest burrow densities. Scaling the observed density of visible scampi by the area in each stratum leads to a minimum abundance estimate of 360 million animals (7% CV) for the surveyed area (Table 10). Counting animals out of burrows and walking free on the surface reduced this estimate to 35 million animals (13% CV) (Table 11).

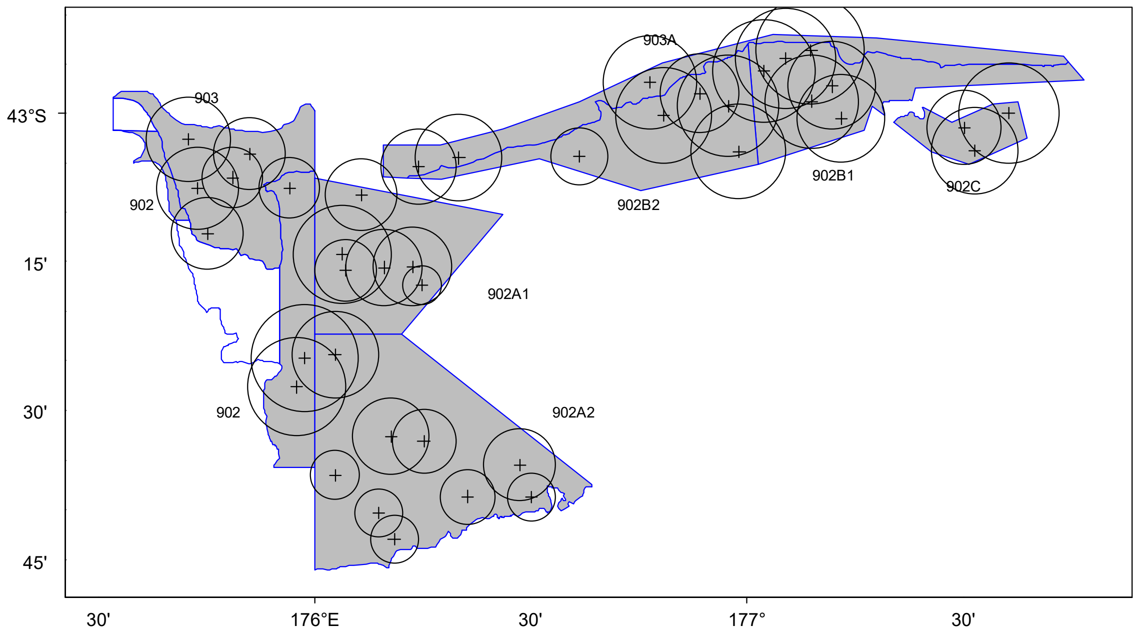

Figure 14: Station locations for the 2019 photographic survey of SCI 3 (area of symbol represents relative burrow density). Largest circle represents 0.45 burrows m^{-2} (uncorrected for *reader_year*).

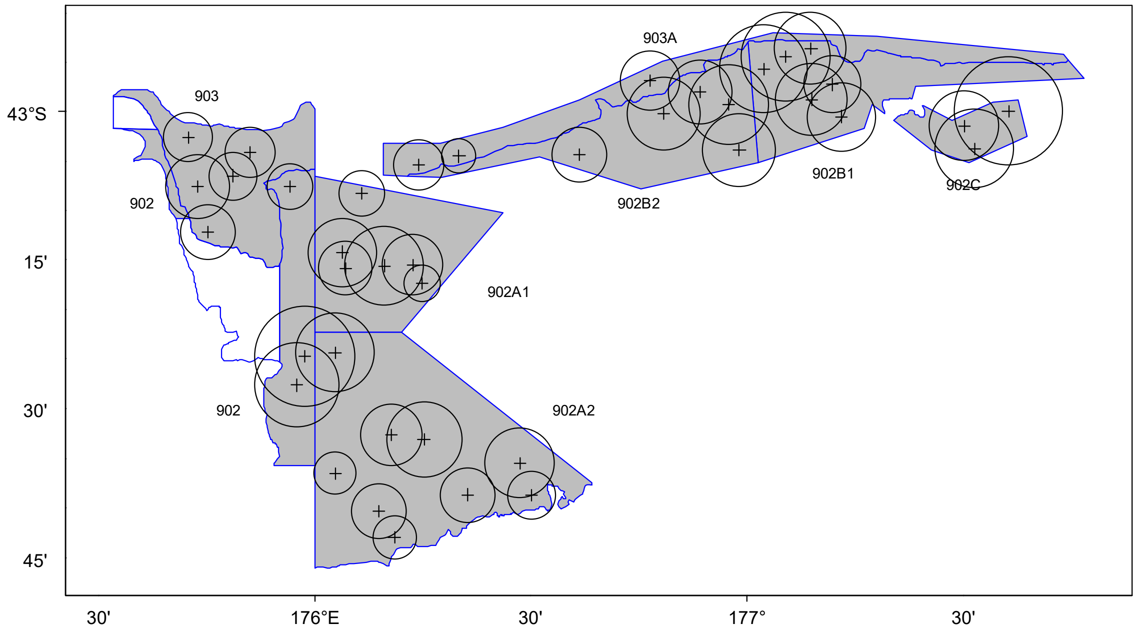

Figure 15: Station locations for the 2019 photographic survey of SCI 3 (area of symbol represents relative visible scampi density). Largest circle represents 0.20 visible scampi m^{-2} (uncorrected for *reader_year*).

Table 9: Estimates of the density and abundance of major burrow openings from the SCI 3 survey for 2019, by stratum, based on predicted counts by a generic reader. Fishery estimates of density and abundance represent the combined stratum estimates.

								Stratum	
Strata	902	903	902A1	902A2	902B1	902B2	902C	903A	Total
Area (km^2)	439.84	552.08	700.41	1 432.38	605.42	660.97	172.45	459.18	5 022.73
N. stations	3	5	6	9	6	5	3	3	40
Mean density (m^{-2})	0.21	0.16	0.15	0.11	0.26	0.22	0.21	0.21	0.17
CV	0.25	0.13	0.18	0.16	0.07	0.15	0.14	0.13	0.06
Abundance (Millions)	92.83	86.59	102.07	150.92	158.6	148.6	36.05	95.43	871.1

Table 10: Estimates of the density and abundance of visible scampi from the SCI 3 survey for 2019, by stratum, based on predicted counts by a generic reader. Fishery estimates of density and abundance represent the combined stratum estimates.

								Stratum	
Strata	902	903	902A1	902A2	902B1	902B2	902C	903A	Total
Area (km^2)	439.84	552.08	700.41	1 432.38	605.42	660.97	172.45	459.18	5 022.73
N. stations	3	5	6	9	6	5	3	3	40
Mean density (m^{-2})	0.11	0.05	0.06	0.06	0.1	0.08	0.13	0.04	0.07
CV	0.35	0.11	0.21	0.15	0.13	0.12	0.26	0.28	0.07
Abundance (Millions)	47.25	27.47	41.91	88.51	58.57	55.41	22.24	19.3	360.66

Table 11: Estimates of the density and abundance of scampi out of burrows from the SCI 3 survey for 2019, by stratum. Scampi "out" were defined as those for which the telson was not obscured by the burrow. Fishery estimates of density and abundance represent the combined stratum estimates.

	Stratum								
Strata	902	903	902A1	902A2	902B1	902B2	902C	903A	Total
Area (km^2)	439.84	552.08	700.41	1 432.38	605.42	660.97	172.45	459.18	5 022.73
N. stations	3	5	6	9	6	5	3	3	40
Mean density (m^{-2})	0.01	0	0.01	0.01	0.01	0.01	0	0	0.01
CV	0.5	0.58	0.6	0.16	0.21	0.29	0.13	1	0.13
Abundance (Millions)	3.77	2.09	3.93	12.17	5.8	5.25	0.81	1.61	35.43

The trend in abundance in major burrow openings is shown in Figure 16. The calibration to account for *reader_year* effects slightly increased the estimated abundance in 2016 and reduced the estimate to a greater extent in 2019, but does not change the overall increasing trend in the data since 2009 (Figure 16). The estimated abundance of major burrow openings shows a consistent increase between 2009 and 2016, with a further but slower increase between 2016 and 2019. For the combined 902 and 903 strata (surveyed since 2001), the abundance shows a considerable decline between 2001 and 2009 (to about 25% of the 2001 estimated abundance), but an increase between 2009 and 2013 (to about 70% of the 2001 estimate), and a slight increase to 2019 (at just over 80% of the 2001 estimated abundance). The indices of scampi abundance (visible scampi and scampi out of burrows) are presented in Figure 17. These show a similar decline between 2001 and 2009 (for the 902 and 903 strata). Since 2009, the abundance estimates of scampi have increased, although the overall SCI 3 survey area estimate of visible scampi declined between 2009 and 2010.

Overall survey mean densities for the current and previous surveys in SCI 3 are provided in Table 12. The count of visible scampi as a percentage of burrows (which could be considered a minimum estimate of occupancy) was 41% in 2019 (mean of 28% for survey series). The range observed (Table 12) is comparable with the SCI 1 and SCI 2 survey series (Tuck et al. 2016; Tuck et al. 2013), but slightly lower than that observed in SCI 6A (Tuck et al. 2020). The proportion of scampi seen out of their burrows (scampi out as a proportion of all visible scampi) was 10% in 2019 (mean of 16% for survey series), which is also comparable with SCI 1 and SCI 2, but lower than SCI 6A. It has been hypothesised that the seabed sediment in SCI 6A is not cohesive enough to maintain large burrows, and large scampi are often observed in narrow trenches (possibly collapsed burrows), which may explain the increased proportion of animals being categorised as "out". Limited sediment particle size composition data presented here (see below) confirms that sediment from SCI 6A contains more sand and less silt and clay than samples from other scampi areas (as shown in Figure 27).

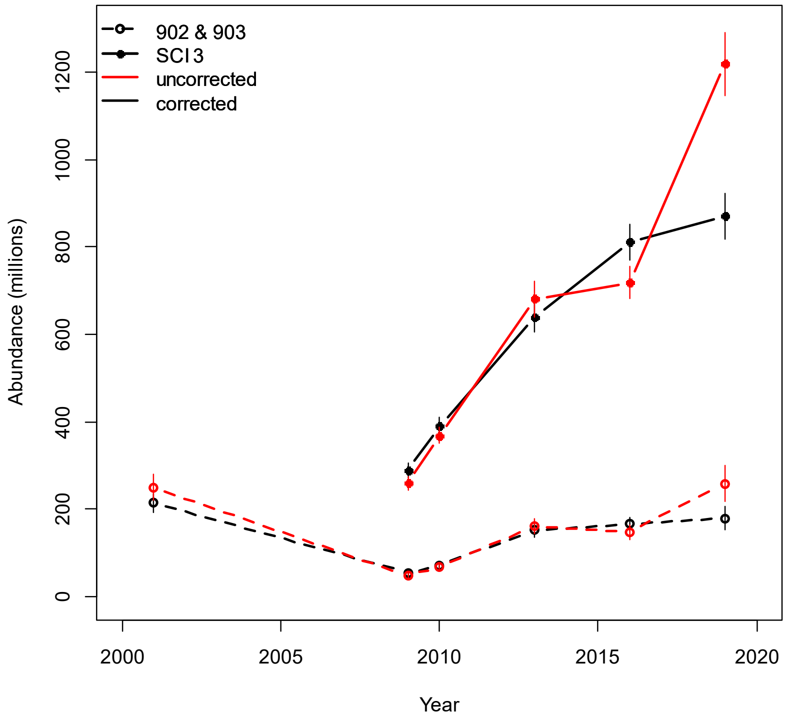

Figure 16: Estimated abundance of scampi major burrow openings (± CV) for SCI 3 for combined 902 and 903 strata, and whole SCI 3 survey area. The 2001 estimate is based on the October/November survey.

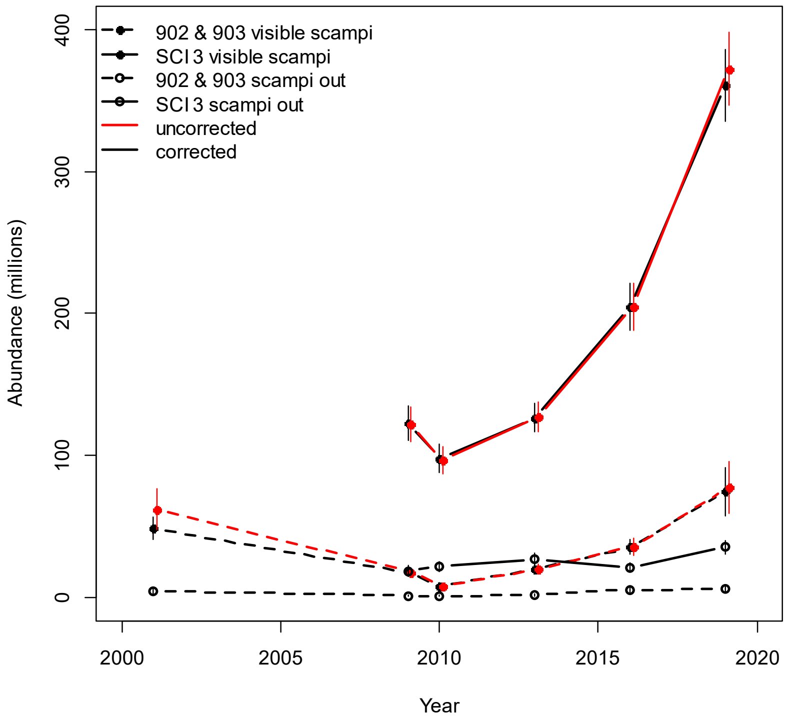

Figure 17: Estimated abundance of all visible scampi and those seen outside the burrow (± CV) for SCI 3 for combined 902 and 903 strata, and whole SCI 3 survey area. The 2001 estimates are based on the October/November survey.

Table 12: 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	0.2160	0.0492	0.0046	22.78	9.35
2009	0.0552	0.0183	0.0013	33.15	7.10
2010	0.0731	0.0085	0.0014	11.63	16.47
2013	0.1538	0.0203	0.0022	13.20	10.84
2016	0.1674	0.0358	0.0058	21.39	16.20
2019	0.1809	0.0753	0.0059	41.63	7.84
SCI 3					
2009	0.0575	0.0245	0.0038	42.61	15.51
2010	0.0776	0.0195	0.0044	25.13	22.56
2013	0.1273	0.0252	0.0054	19.80	21.43
2016	0.1616	0.0408	0.0043	25.25	10.54
2019	0.1734	0.0718	0.0071	41.41	9.89

3.2 Trawl survey

The locations of trawl survey stations and relative scampi catch rates are shown in Figure 18. Biomass estimates are provided by stratum for the 2019 survey in Table 13 and are compared with previous surveys in Table 15, Table 16, and Figure 19. Equivalent abundance estimates (i.e., by number) are provided for the 2019 survey in Table 14 and are compared with previous surveys in Table 17, Table 18, and Figure 20.

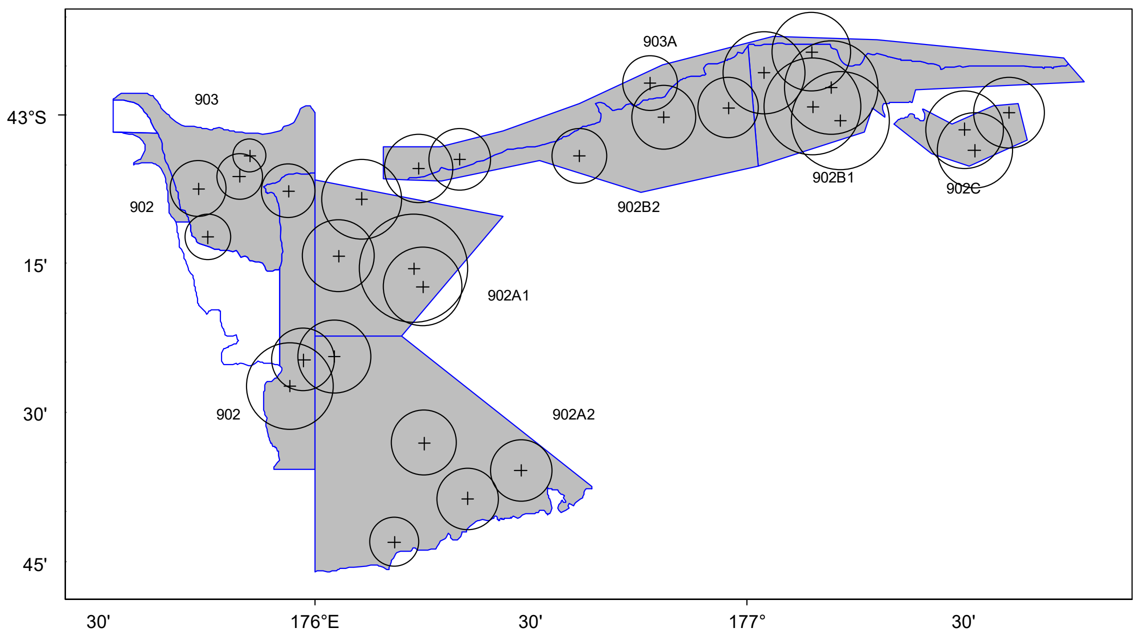

Figure 18: Trawl station locations for the 2019 photographic survey of SCI 3 (area of symbol represents relative scampi catch rate). Largest circle represents 27 kg nm^{-1}.

The overall raised trawl survey estimate was 1220 t (6% CV) (Table 13), or 16.4 million individuals (6% CV) (Table 14). Given that scampi live in burrows and are only available to trawl gear when emerged on the seabed, this is likely to be (as with all the trawl surveys) a considerable underestimate of the stock biomass. Trends in biomass (by stratum Table 15, and subarea Table 16 and Figure 19) and abundance (by stratum Table 17, and subarea Table 18 and Figure 20) show a similar pattern, with the 2019 estimate continuing the overall increase observed since the 2009 survey (although biomass and abundance remained stable between 2010 and 2013). The 2019 biomass and abundance estimates are almost 3 times those from 2009. Of the current survey coverage, only the core area of the original QMA 3 (strata 902 and 903, defined as MO – Mernoo original in SCI 3 stock assessments) was surveyed in 2001, and the 2019 estimate for this subarea is about 62% of the 2001 estimate.

Relative changes over time in the trawl survey series (Figure 20) are very similar to those observed in the photographic abundance indices (see Figure 16 and Figure 17).

Table 13: Trawl survey biomass estimates (tonnes) by stratum for SCI 3. Mean values are expressed as kilograms per nautical mile (using the *Kaharoa* scampi trawl gear).

	Stratum								
Strata	902	903	902A1	902A2	902B1	902B2	902C	903A	Total
Area (km^2)	439.84	552.08	700.41	1 432.38	605.42	660.97	172.45	459.18	5 022.73
N. stations	3	4	4	5	5	3	3	3	30
Mean (kg.nm^{-1})	10.49	4.86	16.75	9.80	18.42	8.33	12.83	9.91	11.24
CV	0.28	0.20	0.21	0.13	0.09	0.09	0.05	0.15	0.06
Biomass (t)	99.63	57.90	253.38	303.17	240.86	118.89	47.78	98.25	1219.85

Table 14: Trawl survey abundance estimates (millions) by stratum for SCI 3. Mean values are expressed as numbers per nautical mile (using the *Kaharoa* scampi trawl gear).

	Stratum								
Strata	902	903	902A1	902A2	902B1	902B2	902C	903A	Total
Area (km^2)	439.84	552.08	700.41	1 432.38	605.42	660.97	172.45	459.18	5 022.73
N. stations	3	4	4	5	5	3	3	3	30
Mean (No. nm^{-1})	120.01	88.97	194.22	131.33	274.62	131.96	164.54	120.00	151.91
CV	0.28	0.23	0.22	0.12	0.09	0.07	0.10	0.10	0.06
Abundance (millions)	1.14	1.06	2.94	4.06	3.55	1.88	0.61	1.19	16.44

Table 15: Time series of raised trawl survey scampi stock biomass estimates (tonnes) by survey and stratum for SCI 3.

	Stratum										Total
Year	902	903	902A	902A1	902A2	902B	902B1	902B2	902C	903A	
2001	63.4	190.9									
2009	31.8	8.4	295.5			49.7			24.2	8.5	418.1
2010	22.6	26.4	347.7			123.3			37.7	38.4	596.1
2013	72.1	54.4		90.1	87.9	163.8			38.4	44.7	551.3
2016	51.5	88.1		83.0	235.8		183.9	138.3	32.3	100.2	913.1
2019	99.6	57.9		253.4	303.2		240.9	118.9	47.8	98.2	1 219.9

Table 16: Time series of raised trawl survey scampi stock estimates (tonnes) by survey and subarea for SCI 3. Subarea MO contains stratum 902 and 903, subarea MW contains stratum 902A or its subcomponents (902A1 and 902A2) and subarea MN contains stratum 902B (or subcomponents 902B1 and 902B2), 902C and 903A.

	Subarea			
Year	MO	MW	MN	Total
2001	254.4			
2009	40.2	295.0	82.3	418.1
2010	49.0	347.0	199.1	596.1
2013	126.5	178.0	246.6	551.3
2016	139.6	318.8	454.7	913.1
2019	158.3	572.7	505.7	1 219.9

Table 17: Time series of raised trawl survey scampi stock abundance estimates (millions) by survey and stratum for SCI 3.

	Stratum										Total
Year	902	903	902A	902A1	902A2	902B	902B1	902B2	902C	903A	
2001	0.8	2.9									
2009	0.3	0.1	3.9			0.7			0.3	0.1	5.5
2010	0.2	0.4	4.8			2.1			0.5	0.6	8.6
2013	0.9	0.9		0.4	1.8	3.0			0.5	0.6	8.2
2016	0.7	1.6		1.1	3.7		3.0	2.3	0.4	1.4	14.2
2019	1.1	1.1		2.9	4.1		3.6	1.9	0.6	1.2	16.4

Table 18: Time series of raised trawl survey scampi stock estimates (millions) by survey and subarea for SCI 3. Subarea MO contains stratum 902 and 903; subarea MW contains stratum 902A or its subcomponents (902A1 and 902A2); and subarea MN contains stratum 902B (or subcomponents 902B1 and 902B2), 902C, and 903A.

	Subarea			
Year	MO	MW	MN	Total
2001	3.7			
2009	0.4	3.9	1.1	5.5
2010	0.6	4.8	3.2	8.6
2013	1.8	1.8	4.1	8.2
2016	2.3	4.8	7.2	14.2
2019	2.2	7.0	7.2	16.4

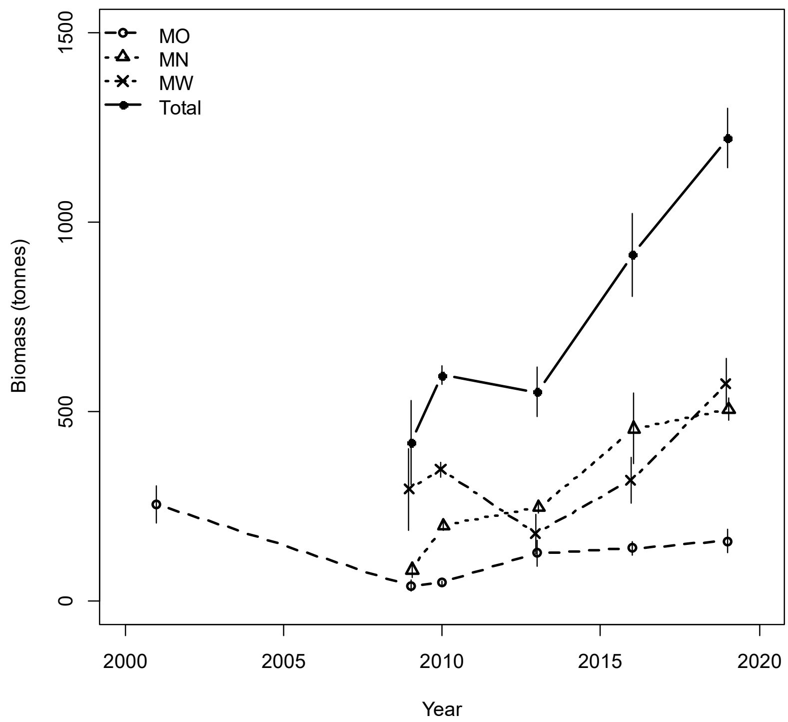

Figure 19: Plot of time series of trawl survey biomass estimates (± CV) for SCI 3. Subarea MO contains stratum 902 and 903; subarea MW contains stratum 902A or its subcomponents (902A1 and 902A2); and subarea MN contains stratum 902B (or subcomponents 902B1 and 902B2), 902C, and 903A.

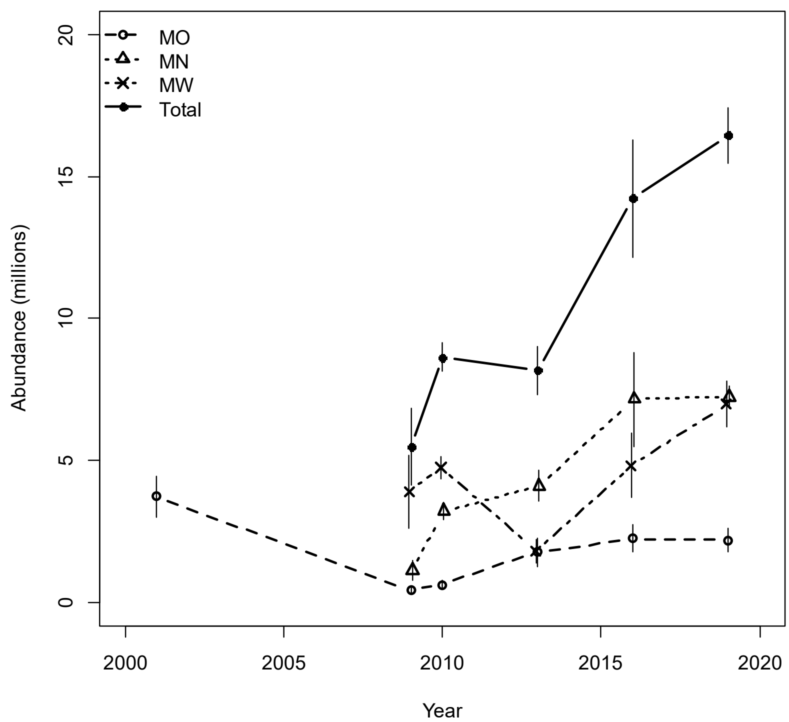

Figure 20: Plot of time series of trawl survey abundance estimates (± CV) for SCI 3. Subarea MO contains stratum 902 and 903; subarea MW contains stratum 902A or its subcomponents (902A1 and 902A2); and subarea MN contains stratum 902B (or subcomponents 902B1 and 902B2), 902C, and 903A.

Over the whole SCI 3 trawl survey, 1037 kg of scampi were caught, accounting for almost 7% of the total catch. Scampi were the fourth most abundant species. By weight, the most dominant species in the catches were javelinfish (20%) and sea perch (18%). Within commercial fishing activities, scampi form a greater proportion of the total catch, as bycatch mitigation approaches reduce finfish catches.

3.3 Tagging

Undamaged lively scampi were tagged from each trawl catch and released to investigate growth. The next scheduled research sampling in SCI 3 will be in 2022, and it is anticipated that all recoveries of scampi tagged in 2019 will come from commercial fishing activity. During the trawling component of the survey, 2748 scampi were tagged with streamer or T-bar tags and then released. The length distributions of the tagged scampi are presented in Figure 21. Tagging did not target specific size ranges, and the length distribution of tagged animals reflects the size distribution of suitable animals from the catches (Figure 22). The sex ratio in catches from previous surveys in SCI 3 at this time of year (September) have been male dominated (Tuck et al. 2018), but were roughly even in 2019, which may reflect a slight change in the timing of moulting. Tagged scampi were released at 28 separate locations (Figure 23). No scampi were released while the vessel was in the process of trawling, and no recaptures were made by the RV *Kaharoa* during the survey. Tagging mortality has not been investigated in this area, but, when examined previously elsewhere, no tagging effect has been detected, and short-term (up to seven days) survival has been estimated at 88% in SCI 6A (Tuck et al. 2015b) and 76% in SCI 2 (Tuck et al. 2013). The difference was assumed to be related to higher release mortality caused by warmer surface water temperatures in SCI 2.

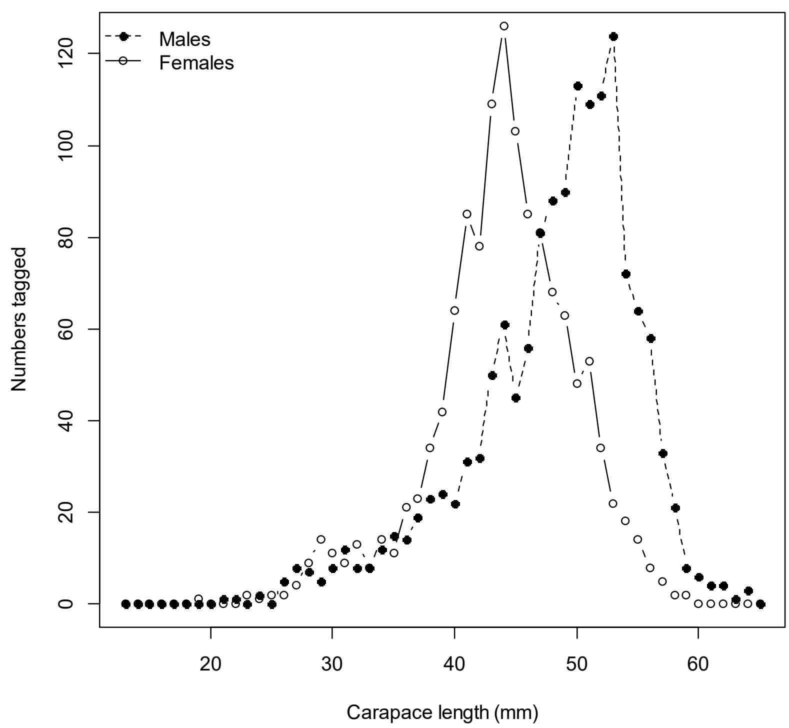

Figure 21: Length distribution of scampi tagged and released in SCI 3 during the 2019 survey voyage.

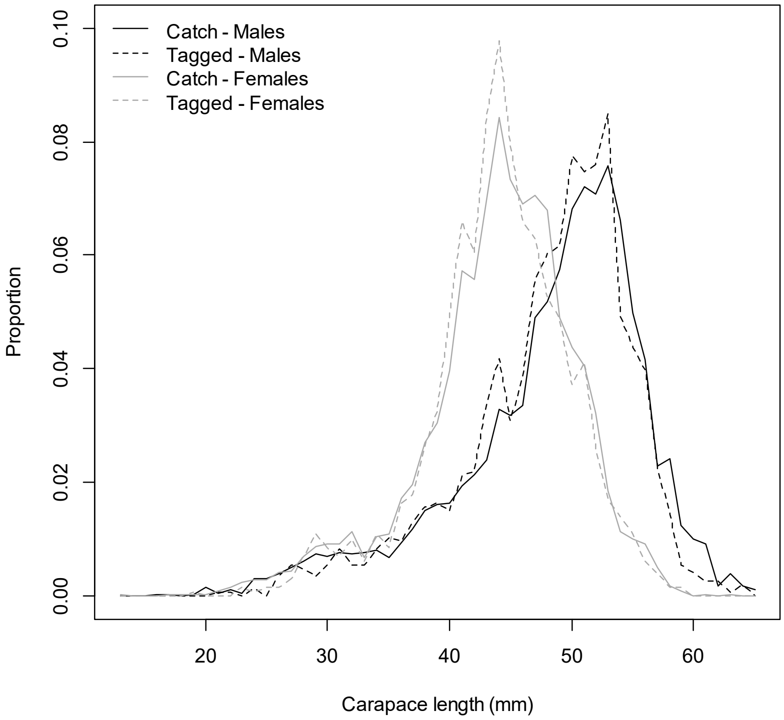

Figure 22: Proportion at length by sex in the scampi survey catches and tagged sample during the 2019 SCI 3 survey voyage.

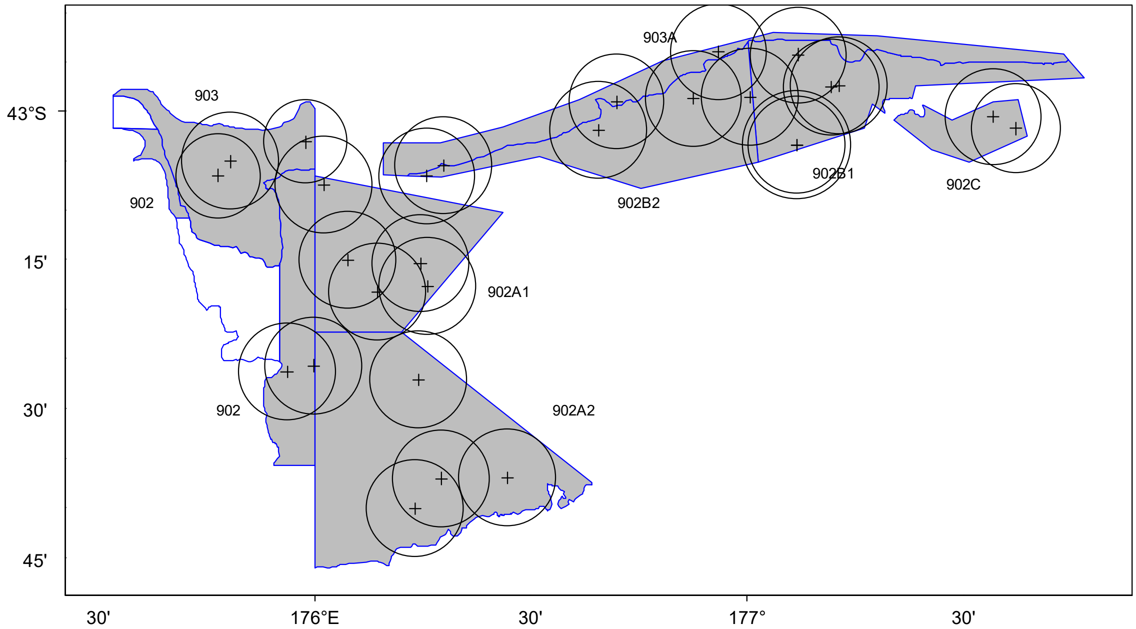

Figure 23: Map showing distribution of 2019 scampi release locations in SCI 3 and relative numbers released at each location. Largest circles represent 125 animals. The smallest release batch was 74 animals, and the average release batch was 98 animals.

To date (September 2020) no recoveries have been reported to NIWA of scampi tagged in SCI 3 in 2019. Tag recovery rates from SCI 3 have generally been very low. The same tagging approach is used in all areas, and it is unclear why recovery rates are so different, although, as discussed above, the colder surface waters in SCI 6A may contribute to increased survival.

3.4 Other sampling

Microsporidian infection of scampi

All measured scampi were examined for visual signs of *Microsporidian* infection on the basis of diagnostic features identified in Figure 6. The maximum estimated infection rate was 2.9% at the individual station level, and overall infection rate was 0.2% (Table 19). These rates appear comparable with the rates anecdotally estimated in SCI 6A in the late 2000s (although infection rates were not specifically recorded at this time). No previous estimates are available for SCI 3.

The spatial distribution of samples, and relative infection rates is presented in Figure 24. Infected animals were only detected in the north eastern part of the fishery, and only at low levels. Samples were collected at the request of the MPI Aquatic Diseases Team.

Table 19: Details of scampi examined and visually detected with signs of microsporidian infection.

Station	Stratum	Scampi examined	Not infected	Infected	% Infected
41	903	110	110		0.00%
42	903	205	205		0.00%
43	903	127	127		0.00%
44	902C	116	116		0.00%
45	902C	121	121		0.00%
46	902C	146	146		0.00%
47	902B1	110	110		0.00%
48	902A2	124	124		0.00%
49	902A2	103	103		0.00%
50	902A1	153	153		0.00%
51	902B1	136	136		0.00%
52	902B1	132	132		0.00%
53	902B2	185	185		0.00%
54	902B2	144	140	4	2.86%
55	902	148	148		0.00%
56	902A1	168	168		0.00%
57	903A	178	178		0.00%
58	903A	203	202	1	0.50%
59	902A1	195	195		0.00%
60	902	191	191		0.00%
61	902	191	191		0.00%
62	902A2	186	186		0.00%
63	902A1	160	160		0.00%
64	902B2	172	172		0.00%
65	903A	133	132	1	0.76%
66	902B1	126	124	2	1.61%
67	902B1	160	159	1	0.63%
68	902A2	175	175		0.00%
69	902A2	126	126		0.00%
70	903	160	160		0.00%
Total		4 584	4 575	9	0.20%

Confidence in the visual diagnosis was provided by the MPI Aquatic Diseases Team's analysis. Scampi visually diagnosed as infected showed moderate to marked multifocal to diffuse areas of microsporidiosis in the skeletal and cardiac muscle consistent with *Myospora* species, but no abnormalities were detected using histology in the control "healthy" scampi collected at the same time (Cara Brosnahan, MPI, pers. comm.).

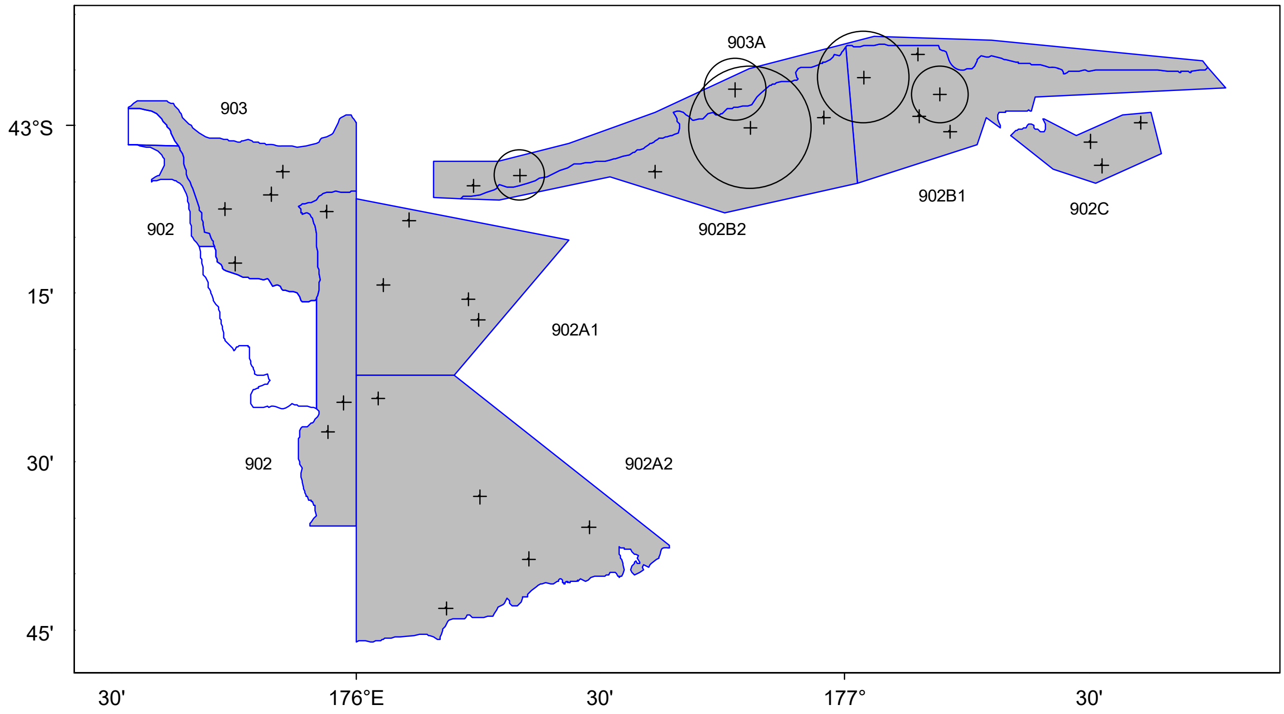

Figure 24: Relative *Microsporidian* infection rates detected visually from trawl survey catches in SCI 3 in 2019. The highest infection rate (indicated by the size of the largest bubble) was 2.8%.

CTD profiles

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

Acoustic seabed measurements and sediment sampling

Data from the vessel's ES60 scientific echosounder (set at a range sufficient to observe the double echo of the seabed) were recorded throughout the voyage except during periods when finer resolution detail of the seabed was required (e.g., running trawl lines overnight in advance of fishing). These data have been archived for future analysis in the Fisheries New Zealand *acoustic* database.

Sediment samples were collected at 25 survey stations (Figure 25) and have been analysed for particle size and percentage organic content, along with a further 20 samples collected from previous scampi surveys (6 samples from SCI 1, 4 samples from SCI 2, and 10 samples from SCI 6A). Particle size analysis data have been archived in NIWA's *Marine Sediments* database.

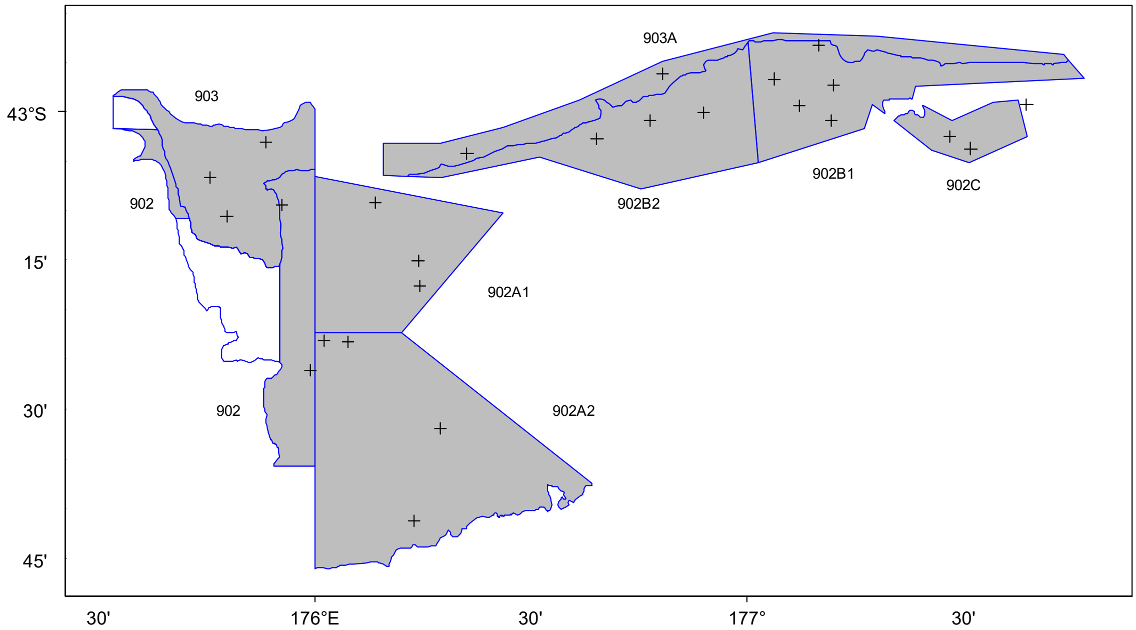

Figure 25: Locations of sediment samples collected during the SCI 3 survey.

A Shepard diagram of sand, silt, and clay content of the sediment (Figure 26) shows that though there is clearly variability between sites within region, there are also some differences between regions. The samples from SCI 1 and SCI 2 were categorised as silty sand and sandy silt, whereas those from SCI 6A were sand and silty sand, and SCI 3 samples generally had a higher clay content, with most samples categorised as clayey sand.

Preliminary analysis of the SCI 3 data (25 stations) suggested that there were correlations between sediment composition and depth, and also evidence of correlations between environmental parameters and scampi catch parameters (Figure 27). There is considerable evidence that such relationships exist for other scampi species (e.g., Bell et al. 2006; Tuck et al. 1997).

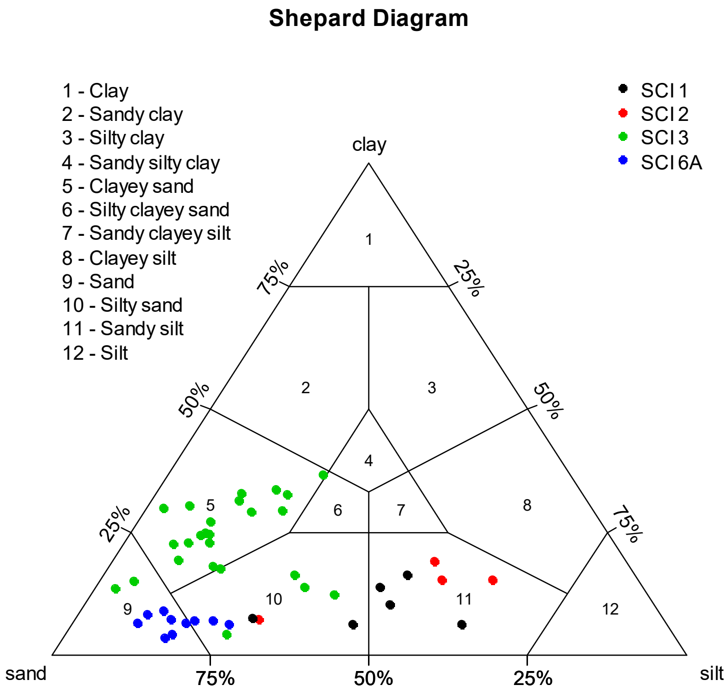

Figure 26: Shepard diagram of sediment composition (aggregated to sand, silt, and clay).

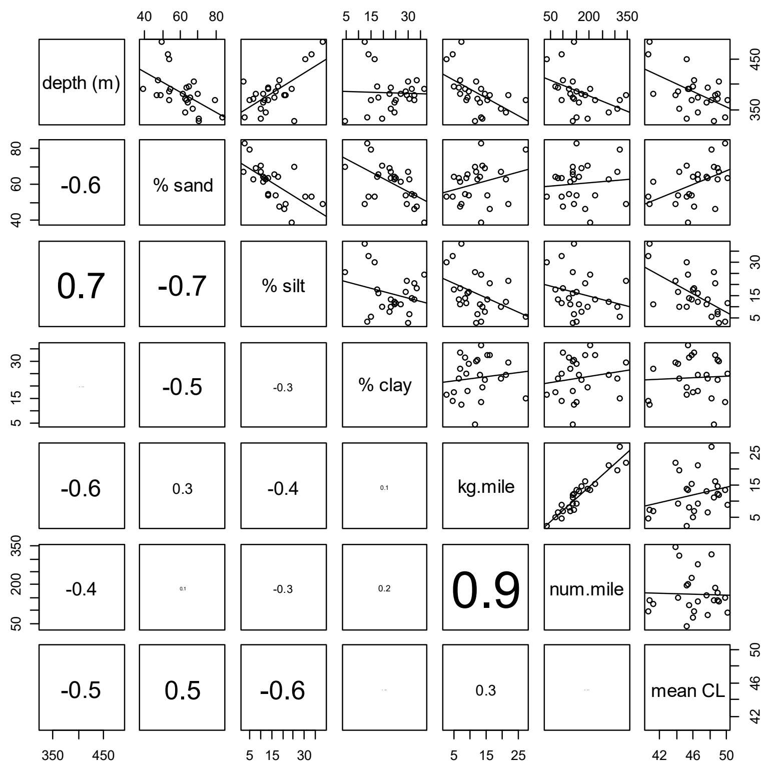

Figure 27: Pairs plot (scatterplots on upper right, correlation coefficients of lower left) for sediment composition parameters, scampi catch rate (kg per nautical mile and numbers per nautical mile), and mean size of scampi caught.

Predation on scampi

Limited opportunistic analysis of fish stomach contents was conducted when time allowed during routine catch sampling of the fish catch. The measuring and tagging of scampi dominates the time spent processing research trawl catches, and a greater focus on fish stomachs would require additional survey staff and/or a change in priorities. A total of 96 individual fish were examined (63 ling, 15 sea perch, 12 stargazer, and 6 pale ghost sharks). Of the 96 stomachs examined, 71 were classed as empty or regurgitated (Table 20). Of the remaining 25 stomachs, scampi remains (sometimes from more than one individual) were identified from 8 fish stomachs (excluding very fresh material considered to have been consumed in the trawl). Scampi remains were identified within the stomachs of pale ghost shark (GSP), ling (LIN), and sea perch (SPE). Although very preliminary in nature, this work supports the conclusions of the recent analysis from the SCI 6A survey (Tuck et al. 2020) suggesting that ling in particular may be a significant predator of scampi.

Scampi remains detected in fish stomachs were in a range of digested states, and it was rare to find an intact carapace to measure. Scampi remains have been retained for future analysis if required. Various measurements of components available could be used to estimate the carapace length of the original scampi prey, to examine the relationship between predator and prey.

Table 20: Summary of stomach contents analysis conducted during SCI 3 survey.

Species	Common name	Empty / regurgitated	Not empty	Containing scampi	Total	% of not empty stomachs containing scampi
GIZ	Stargazer	9	3	0	12	0
GSP	Pale ghost shark	0	6	2	6	33.3
LIN	Ling	53	10	5	63	50
SPE	Sea perch	9	6	1	15	16.7
Total		71	25	8	96	

4. CONCLUSIONS

A photographic and trawl survey of scampi in SCI 3 was conducted in September 2019, replicating the coverage of previous surveys since 2009 in the region. The photographic survey estimated a scampi burrow abundance of 871 million over the whole area, continuing the increase observed since the 2009 survey. The indices of emerged and visible scampi have also increased since the 2009 survey. The trawl survey estimated a biomass of 1220 t, which continued the overall increase in biomass observed since 2009. Given that scampi live in burrows and are only available to trawl gear when they emerge on the seabed, trawl survey estimates are likely to be considerable underestimates of the stock biomass.

Almost 2750 scampi were tagged and released as part of an investigation into growth, but no scampi recaptures by fishers had been reported to NIWA by September 2020. Any future recaptures will be incorporated into the existing tag recapture dataset for this stock and used to estimate growth rates within the stock assessment model.

A range of additional data were collected during the survey, including visually detected *Microsporidian* infection rates in scampi, CTD profiles, sediment samples, acoustic seabed measurements, and stomach contents of potential scampi predators. *Microsporidian* infection rates were very low (0.2%) across the whole survey, and infected animals were only recorded in one area of the fishery. Histological examination of visually detected healthy and infected scampi provided confidence in the visual detections. Limited stomach content analysis identified pale ghost shark, ling, and sea perch as predators of scampi.

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. We thank the Environmental Protection Agency and the NIWA Activity Notifications team for their help in complying with the requirements of the Exclusive Economic Zone and Continental Shelf Regulations 2013, in relation to returning tagged scampi to the sea. The voyage was funded within Fisheries New Zealand project SCI2019-01. This report was reviewed by Bruce Hartill.

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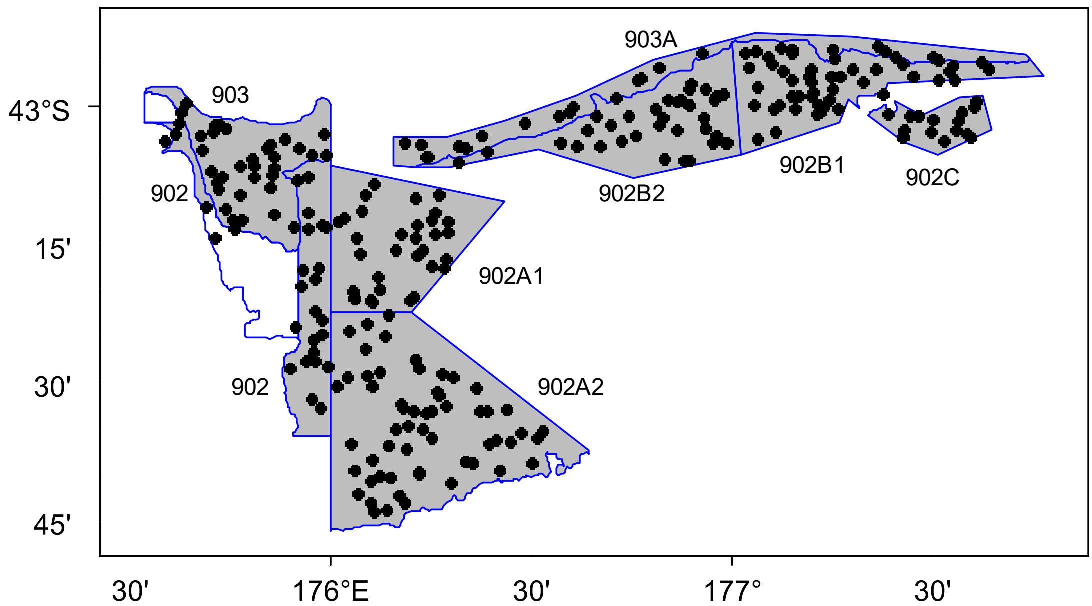
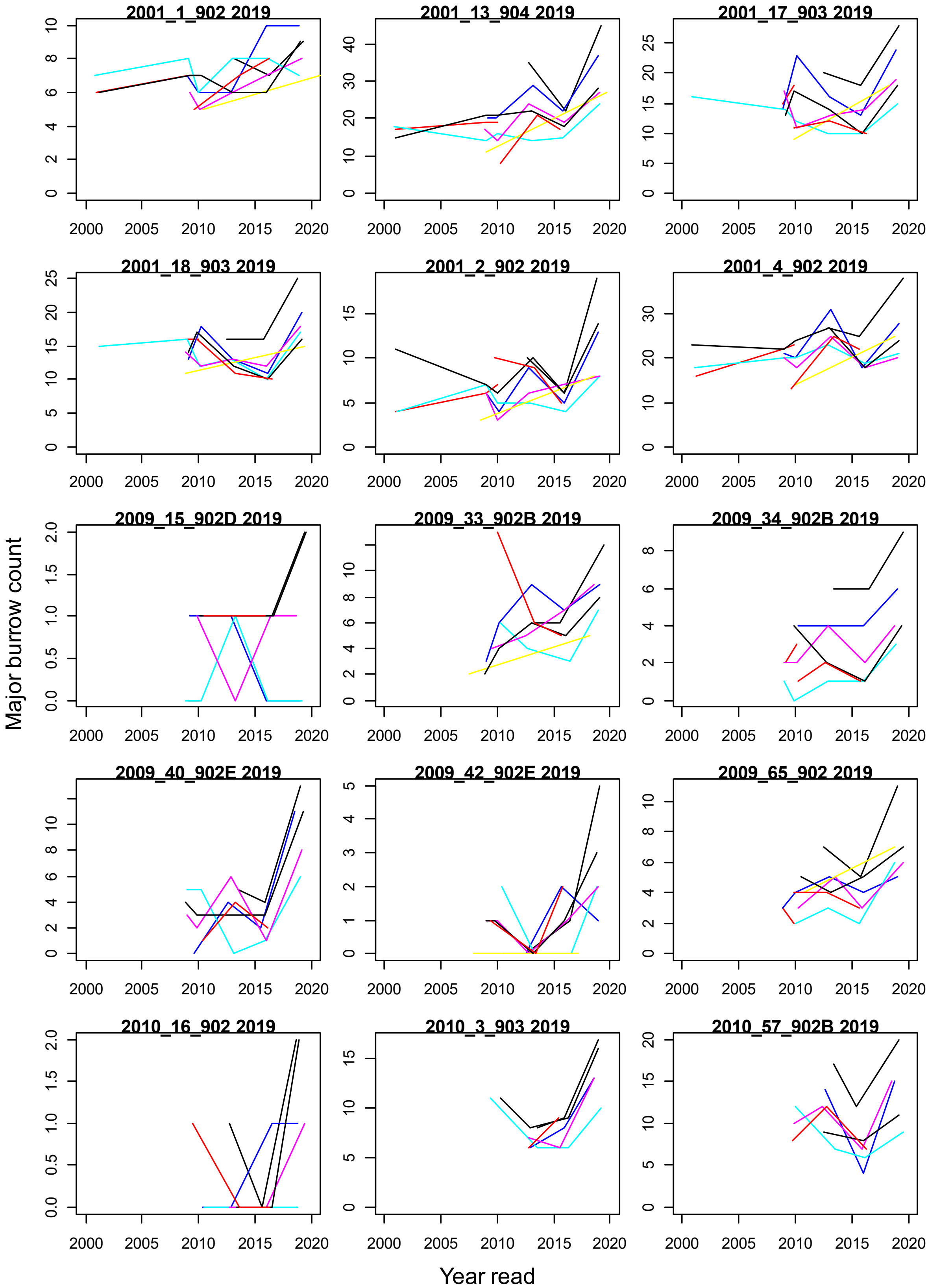
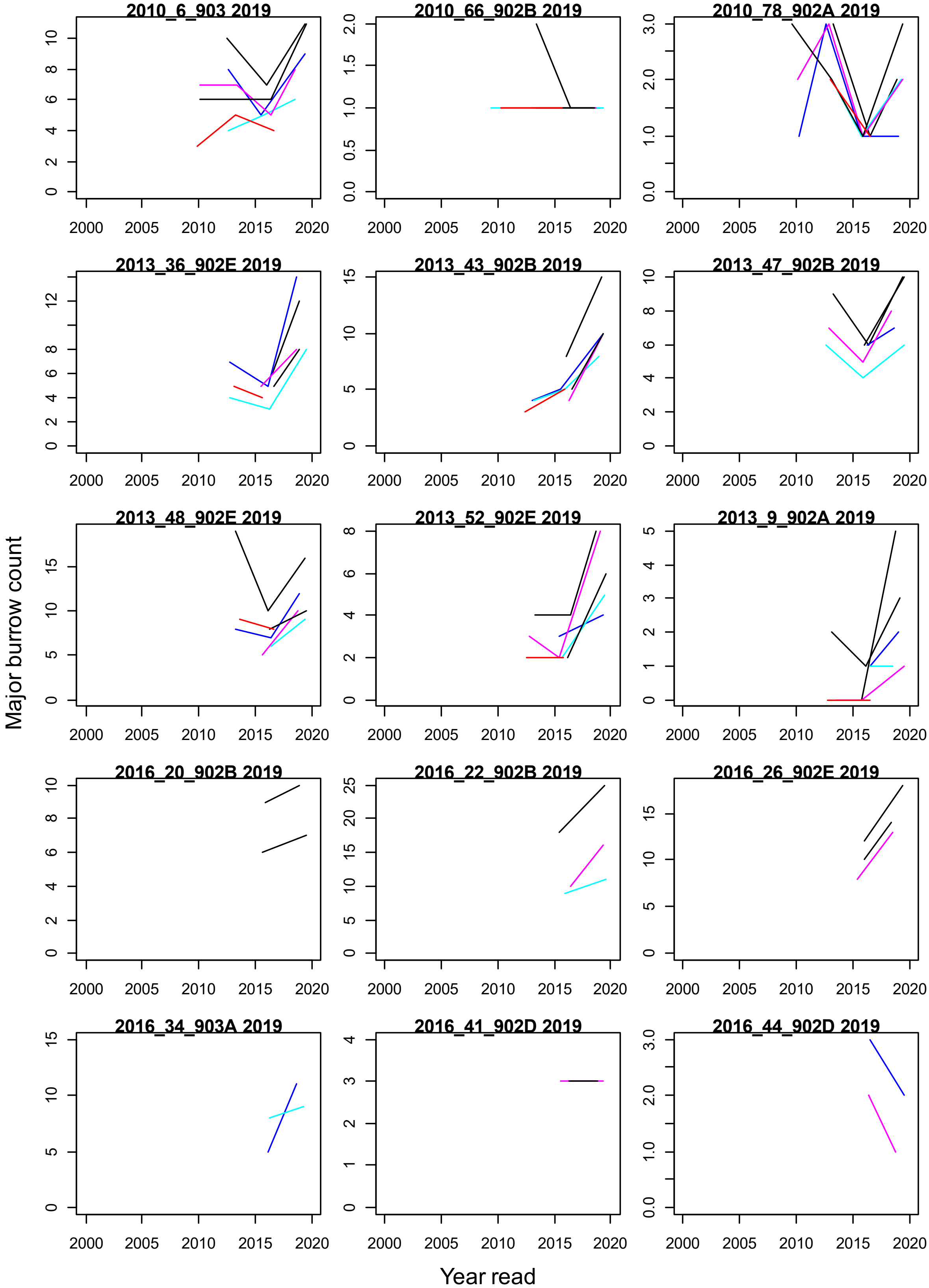
APPENDIX 1: DISTRIBUTION OF SCI 3 PHOTOGRAPHIC STATIONS (2009–2019)



APPENDIX 2: BURROW COUNT DATA FOR 2019 REFERENCE SETS

Comparison over time by reader of Major burrow counts for sets of images read as reference sets in 2019. Set labels (e.g., 2001_1_902_2019) relate to original survey year _ original station _ stratum _ year in which that combination of images was defined. Each line on the plots represents a different reader.




2010_6_903 2019
2010_66_902B 2019
2010_78_902A 2019
2013_36_902E 2019
2013_43_902B 2019
2013_47_902B 2019
2013_48_902E 2019
2013_52_902E 2019
2013_9_902A 2019
2016_20_902B 2019
2016_22_902B 2019
2016_26_902E 2019
2016_34_903A 2019
2016_41_902D 2019
2016_44_902D 2019
Major burrow count
Year read

APPENDIX 3: 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})	0.1335	0.3473	0.2525
CV	0.2	0.15	0.12
Abundance (Millions)	58.72	191.73	250.44

Visible scampi	902	903	902&903
Area (km^2)	440	553	993
Stations	7	9	16
Mean density (m^{-2})	0.0213	0.0957	0.0627
CV	0.38	0.26	0.23
Abundance (Millions)	9.39	52.84	62.23

Scampi out	902	903	902&903
Area (km^2)	440	553	993
Stations	7	9	16
Mean density (m^{-2})	0.0004	0.008	0.0046
CV	1	0.49	0.47
Abundance (Millions)	0.18	4.41	4.59

Uncorrected analysis
2009

Major burrows	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	7	9	8	12	11	8	3	5	63	
Mean density (m^{-2})	0.0534	0.0457	0.0376	0.0601	0.0572	0.0532	0.0453	0.0468	0.0518	0.0492
CV	0.26	0.14	0.13	0.14	0.13	0.16	0.15	0.05	0.06	0.14
Abundance (Millions)	23.51	25.25	26.31	86.09	34.65	35.15	7.81	21.48	260.23	48.75

Visible scampi	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	7	9	8	12	11	8	3	5	63	
Mean density (m^{-2})	0.0183	0.018	0.0134	0.0394	0.0269	0.023	0.0172	0.0089	0.0243	0.0181
CV	0.28	0.22	0.21	0.17	0.15	0.3	0.39	0.24	0.1	0.18
Abundance (Millions)	8.05	9.91	9.4	56.42	16.27	15.19	2.96	4.07	122.28	17.97

Scampi out	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	7	9	8	12	11	8	3	5	63	
Mean density (m^{-2})	0.0013	0.0014	0.001	0.0048	0.0082	0.006	0.0013	0.0019	0.0038	0.0013
CV	0.48	0.58	0.69	0.43	0.24	0.59	1	0.51	0.21	0.39
Abundance (Millions)	0.58	0.76	0.69	6.82	4.95	3.98	0.23	0.85	18.86	1.34

Uncorrected analysis
2010

Major burrows	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	6	9	10	9	11	9	3	5	62	
Mean density (m^{-2})	0.0467	0.0866	0.0608	0.0557	0.0932	0.0847	0.0545	0.1215	0.0733	0.0689
CV	0.24	0.08	0.1	0.15	0.11	0.09	0.14	0.15	0.05	0.09
Abundance (Millions)	20.56	47.8	42.6	79.84	56.41	55.98	9.39	55.81	368.39	68.35

Visible scampi	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	6	9	10	9	11	9	3	5	62	
Mean density(m^{-2})	0.009	0.0077	0.0128	0.0217	0.0237	0.0322	0.0179	0.0208	0.0192	0.0083
CV	0.36	0.24	0.19	0.23	0.27	0.15	0.49	0.36	0.1	0.21
Abundance (Millions)	3.98	4.24	8.93	31.13	14.36	21.29	3.08	9.54	96.55	8.22

Scampi out	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	6	9	10	9	11	9	3	5	62	
Mean density (m^{-2})	0.0025	0.0005	0.0045	0.0041	0.0053	0.007	0.0056	0.0063	0.0044	0.0014
CV	0.53	1	0.38	0.4	0.45	0.32	0.6	0.39	0.16	0.47
Abundance (Millions)	1.09	0.25	3.13	5.92	3.19	4.6	0.96	2.9	22.04	1.34

Uncorrected analysis
2013

Major burrows	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	6	5	5	16	6	6	3	3	50	
Mean density (m^{-2})	0.1088	0.2063	0.0563	0.0875	0.2058	0.1929	0.1633	0.1626	0.1357	0.1631
CV	0.13	0.14	0.13	0.12	0.2	0.11	0.18	0.28	0.06	0.11
Abundance (Millions)	47.84	113.92	39.46	125.35	124.62	127.51	28.16	74.67	681.53	161.76

Visible scampi	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	6	5	5	16	6	6	3	3	50	
Mean density (m^{-2})	0.0198	0.0208	0.0115	0.0162	0.0422	0.0501	0.0442	0.021	0.0254	0.0203
CV	0.37	0.1	0.56	0.16	0.17	0.18	0.18	0.26	0.08	0.17
Abundance (Millions)	8.7	11.49	8.07	23.24	25.54	33.11	7.62	9.65	127.42	20.18

Scampi out	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	6	5	5	16	6	6	3	3	50	
Mean density (m^{-2})	0.0029	0.0016	0.0052	0.0038	0.011	0.0076	0.0071	0.0067	0.0054	0.0022
CV	0.69	0.51	0.84	0.31	0.24	0.21	0.36	0.28	0.15	0.46
Abundance (Millions)	1.29	0.87	3.62	5.38	6.64	5.04	1.22	3.07	27.13	2.16

Uncorrected analysis 2016

Major burrows	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	3	7	3	11	11	6	3	7	51	
Mean density (m^{-2})	0.1014	0.1877	0.0781	0.1085	0.208	0.1901	0.1432	0.1833	0.1431	0.1494
CV	0.21	0.13	0.43	0.11	0.1	0.1	0.07	0.06	0.05	0.11
Abundance (Millions)	44.6	103.61	54.68	155.4	125.95	125.67	24.69	84.19	718.78	148.21

Visible scampi	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	3	7	3	11	11	6	3	7	51	
Mean density (m^{-2})	0.0327	0.0388	0.0184	0.0349	0.0651	0.0555	0.0541	0.0454	0.0408	0.0361
CV	0.24	0.21	0.39	0.26	0.13	0.11	0.01	0.15	0.08	0.16
Abundance (Millions)	14.37	21.41	12.87	49.98	39.4	36.66	9.32	20.82	204.85	35.79

Scampi out	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	3	7	3	11	11	6	3	7	51	
Mean density (m^{-2})	0.0038	0.0075	0.0009	0.0022	0.009	0.0047	0.0077	0.0045	0.0043	0.0058
CV	1	0.42	1	0.38	0.24	0.25	0.24	0.41	0.15	0.42
Abundance (Millions)	1.66	4.12	0.65	3.08	5.45	3.13	1.33	2.07	21.49	5.78

Uncorrected analysis 2019

Major burrows	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	3	5	6	9	6	5	3	3	40	
Mean density (m^{-2})	0.3169	0.2156	0.2086	0.1513	0.3645	0.2944	0.2967	0.2844	0.2426	0.2605
CV	0.28	0.11	0.2	0.16	0.07	0.16	0.17	0.13	0.06	0.16
Abundance (Millions)	139.41	119.04	146.13	216.68	220.7	194.57	51.17	130.59	1218.28	258.44

Visible scampi	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	3	5	6	9	6	5	3	3	40	
Mean density (m^{-2})	0.1123	0.0512	0.0619	0.0641	0.0996	0.0851	0.1337	0.0432	0.0741	0.0783
CV	0.36	0.11	0.21	0.15	0.13	0.12	0.27	0.28	0.07	0.23
Abundance (Millions)	49.37	28.25	43.32	91.78	60.33	56.26	23.06	19.85	372.22	77.63

Scampi out	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	3	5	6	9	6	5	3	3	40	
Mean density (m^{-2})	0.0086	0.0038	0.0056	0.0085	0.0096	0.0079	0.0047	0.0035	0.0071	0.0059
CV	0.5	0.58	0.6	0.16	0.21	0.29	0.13	1	0.13	0.39
Abundance (Millions)	3.77	2.09	3.93	12.17	5.8	5.25	0.81	1.61	35.43	5.85

Reader_year corrected analysis for burrow counts
2001

Major burrows	902	903	902&903
Area (km^2)	440	553	993
Stations	7	9	16
Mean density (m^{-2})	0.1413	0.2755	0.216
CV	0.21	0.11	0.1
Abundance (Millions)	62.14	152.09	214.23

Reader_year corrected analysis for visible scampi
2001

Visible scampi	902	903	902&903
Area (km^2)	440	553	993
Stations	7	9	16
Mean density (m^{-2})	0.0215	0.0713	0.0492
CV	0.38	0.18	0.16
Abundance (Millions)	9.45	39.37	48.83

Reader_year corrected analysis for burrow counts
2009

Major burrows	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	7	9	8	12	11	8	3	5	63	
Mean density (m^{-2})	0.0594	0.0519	0.0422	0.065	0.0632	0.06	0.0505	0.0535	0.0575	0.0552
CV	0.26	0.13	0.12	0.14	0.12	0.15	0.18	0.06	0.06	0.14
Abundance (Millions)	26.13	28.65	29.53	93.17	38.26	39.68	8.72	24.55	288.68	54.78

Reader_year corrected analysis for visible scampi
2009

Visible scampi	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	7	9	8	12	11	8	3	5	63	
Mean density(m^{-2})	0.0184	0.0182	0.0135	0.0396	0.027	0.0232	0.0175	0.009	0.0245	0.0183
CV	0.28	0.22	0.21	0.17	0.15	0.3	0.38	0.24	0.1	0.17
Abundance (Millions)	8.11	10.03	9.44	56.79	16.33	15.34	3.01	4.11	123.17	18.14

Reader_year corrected analysis for burrow counts
2010

Major burrows	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	6	9	10	9	11	9	3	5	62	
Mean density (m^{-2})	0.0497	0.0917	0.0625	0.0598	0.0985	0.0898	0.0575	0.1285	0.0776	0.0731
CV	0.22	0.08	0.09	0.15	0.11	0.09	0.15	0.14	0.05	0.09
Abundance (Millions)	21.86	50.65	43.75	85.72	59.64	59.37	9.91	59	389.89	72.52

Reader_year corrected analysis for visible scampi
2010

Visible scampi	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	6	9	10	9	11	9	3	5	62	
Mean density (m^{-2})	0.0093	0.0078	0.0129	0.0219	0.0239	0.0331	0.0179	0.0211	0.0195	0.0085
CV	0.36	0.24	0.18	0.23	0.26	0.15	0.48	0.35	0.1	0.22
Abundance (Millions)	4.1	4.32	9.05	31.42	14.48	21.89	3.09	9.69	98.05	8.42

Reader_year corrected analysis for burrow counts
2013

Major burrows	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	6	5	5	16	6	6	3	3	50	
Mean density (m^{-2})	0.1068	0.1912	0.0541	0.0797	0.189	0.1882	0.1496	0.1524	0.1273	0.1538
CV	0.14	0.13	0.14	0.11	0.18	0.08	0.16	0.21	0.05	0.1
Abundance (Millions)	46.97	105.55	37.87	114.17	114.42	124.42	25.79	70	639.2	152.52

Reader_year corrected analysis for visible scampi
2013

Visible scampi	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	6	5	5	16	6	6	3	3	50	
Mean density (m^{-2})	0.0198	0.0206	0.0114	0.016	0.0415	0.0501	0.0441	0.0211	0.0252	0.0203
CV	0.38	0.1	0.56	0.16	0.17	0.18	0.18	0.28	0.08	0.17
Abundance (Millions)	8.71	11.4	8.01	22.88	25.11	33.11	7.6	9.68	126.5	20.11

Reader_year corrected analysis for burrow counts
2016

Major burrows	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	3	7	3	11	11	6	3	7	51	
Mean density (m^{-2})	0.1104	0.2128	0.088	0.1231	0.234	0.2117	0.1643	0.2127	0.1616	0.1674
CV	0.17	0.12	0.42	0.1	0.1	0.1	0.04	0.05	0.05	0.1
Abundance (Millions)	48.54	117.5	61.64	176.33	141.66	139.94	28.34	97.69	811.64	166.05

Reader_year corrected analysis for visible scampi
2016

Visible scampi	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	3	7	3	11	11	6	3	7	51	
Mean density (m^{-2})	0.0321	0.0388	0.0187	0.0348	0.065	0.0554	0.0541	0.0455	0.0408	0.0358
CV	0.22	0.21	0.39	0.26	0.13	0.12	0.02	0.15	0.08	0.15
Abundance (Millions)	14.11	21.44	13.09	49.84	39.36	36.64	9.33	20.88	204.69	35.55

Reader_year corrected analysis for burrow counts
2019

Major burrows	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	3	5	6	9	6	5	3	3	40	
Mean density (m^{-2})	0.2111	0.1568	0.1457	0.1054	0.262	0.2248	0.2091	0.2078	0.1734	0.1809
CV	0.25	0.13	0.18	0.16	0.07	0.15	0.14	0.13	0.06	0.15
Abundance (Millions)	92.83	86.59	102.07	150.92	158.6	148.6	36.05	95.43	871.1	179.42

Reader_year corrected analysis for visible scampi
2019

Visible scampi	902	903	902A1	902A2	902B1	902B2	902C	903A	Fishery	902&903
Area (km^2)	440	553	700	1 432	605	661	172	459	5 022	
Stations	3	5	6	9	6	5	3	3	40	
Mean density (m^{-2})	0.1074	0.0498	0.0598	0.0618	0.0967	0.0838	0.129	0.042	0.0718	0.0753
CV	0.35	0.11	0.21	0.15	0.13	0.12	0.26	0.28	0.07	0.23
Abundance (Millions)	47.25	27.47	41.91	88.51	58.57	55.41	22.24	19.3	360.66	74.72