Fisheries New Zealand
Tini a Tangaroa

Developments in scampi surveys: 2023–24

New Zealand Fisheries Assessment Report 2025/02

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ISSN 1179-5352 (online)
ISBN 978-1-991330-78-9 (online)

January 2025

Te Kāwanatanga o Aotearoa
New Zealand Government

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Please cite this report as:

Holmes, S.J.; McGregor, V.L.; Underwood, M.J.; Wieczorek, A.M. (2025). Developments in scampi surveys: 2023–24. *New Zealand Fisheries Assessment Report 2025/02.* 19 p.

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PLAIN LANGUAGE SUMMARY

This report describes two separate pieces of work done in 2023–24 to improve the way scampi surveys are included in stock assessment models.

Scampi build and live in burrows made from the sediment in their environment. One of the ways scampi stocks have been assessed historically is with a series of photo surveys where the number of burrow entrances in a series of photos are counted by photo ‘readers’. There can be variability between readers in interpretation of bottom features as burrows. An individual reader’s interpretation can also ‘drift’ over time. A way to test for differences in interpretation between readers and for ‘reader drift’ was developed so that the burrow count indices could be properly calibrated.

In 2019, this calibration methodology was updated but when it was applied to later surveys there were large and unexpected adjustments which undermined confidence in the method. This report outlines the design for a simulation framework that could test whether the calibration method is performing as intended.

When an abundance index is used in a stock assessment model a catchability (labelled *q*) converts the numbers in the index to numbers in the population. These *q* values are estimated within the model, but the model uses ‘prior’ information about what values of *q* are considered reasonable. These prior distributions have historically been estimated by combining survey results with results from acoustic tag experiments. These have been used to estimate what proportion of the time scampi spend outside of their burrows and can therefore be caught by a trawl or seen in a photograph.

It has been found that the assessment results are sensitive to the specification of the *q* priors. A workshop was held to document how the *q*-priors had been calculated in the past and to agree on the best practise going forward. This report documents the results of this workshop.

EXECUTIVE SUMMARY

Holmes, S.J.[1]; McGregor, V.L.; Underwood, M.J.; Wieczorek, A.M. (2025). Developments in scampi surveys: 2023–24.
***New Zealand Fisheries Assessment Report 2025/02.* 19 p.**

This report describes two separate pieces of work done in 2023–24 to improve the way scampi (*Metanephrops challenger)* surveys are included in stock assessment models.

Burrow counts from photo surveys are subject to variability in reader interpretation of bottom features as burrows. A methodology was therefore developed to test for differences in interpretation between readers and for ‘reader drift’; i.e., differences in interpretation by an individual reader over time. In 2019, the reader count standardisation methodology for burrow count calibration was updated, but the application of the new methodology to the subsequent three surveys led to large and unprecedented downward adjustments which undermined confidence in the method. This report outlines the design for a simulation framework that could test whether the calibration methodology performs as intended.

Stock assessments require a catchability q for each index and in previous assessments informed priors were necessary. Those same assessments have demonstrated that assessment results, especially for initial biomass B_0 estimates, are sensitive to the specification of the q priors. Their derivation has evolved over time and the precise derivations and rationale behind them had become unclear to the Fisheries New Zealand Deepwater Working Group. In response, under this project a workshop was held to set out the evolution of the q-prior calculation methodology and arrive at a consensus for best practise going forward. This report reproduces the outline of the q-prior evolution and details the outcomes from the workshop.

The main conclusions from the workshop were that:

- The currently used equations to estimate the q for major burrow count, visible scampi and emerged scampi were found to be appropriate using the current methodology.
- A scampi emergence rate based on data from daylight hours should be used because the photo survey and trawl survey are both conducted in daylight hours.
- It is appropriate to use the emerged scampi index instead of the major burrow count index for the SCI 6A assessment.
- In the first instance, the trawl survey catchability prior should be based on that of visible scampi or emerged scampi and the final model estimate for the trawl survey catchability assessed as to whether it is reasonable.
- If the methodology to calculate a prior distribution remains unchanged, there is no need to re-estimate the distribution for each new assessment.
- The same priors can be used for the SCI 1, SCI 2 and SCI 3 assessments. Data from the surveys of all three areas should be used to derive best estimates for major burrow count, visible scampi and emerged scampi q.
- A single emergence rate for SCI 1, SCI 2 and SCI 3 grounds is reasonable, but because of the different nature of emergence in SCI 6A, the emergence rate specific to this area should be maintained.

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1. INTRODUCTION

Scampi (*Metanephrops challengeri*) was introduced into the Quota Management System (QMS) in 2004 and has been commercially targeted since the late 1980s. The commercial scampi fishery is a low volume, high value fishery which operates in four main areas: SCI 1 and SCI 2 around the north and east of the North Island; SCI 3 off the east coast of the South Island; and SCI 6A around the Auckland Islands (Figure 1, Fisheries New Zealand 2024).

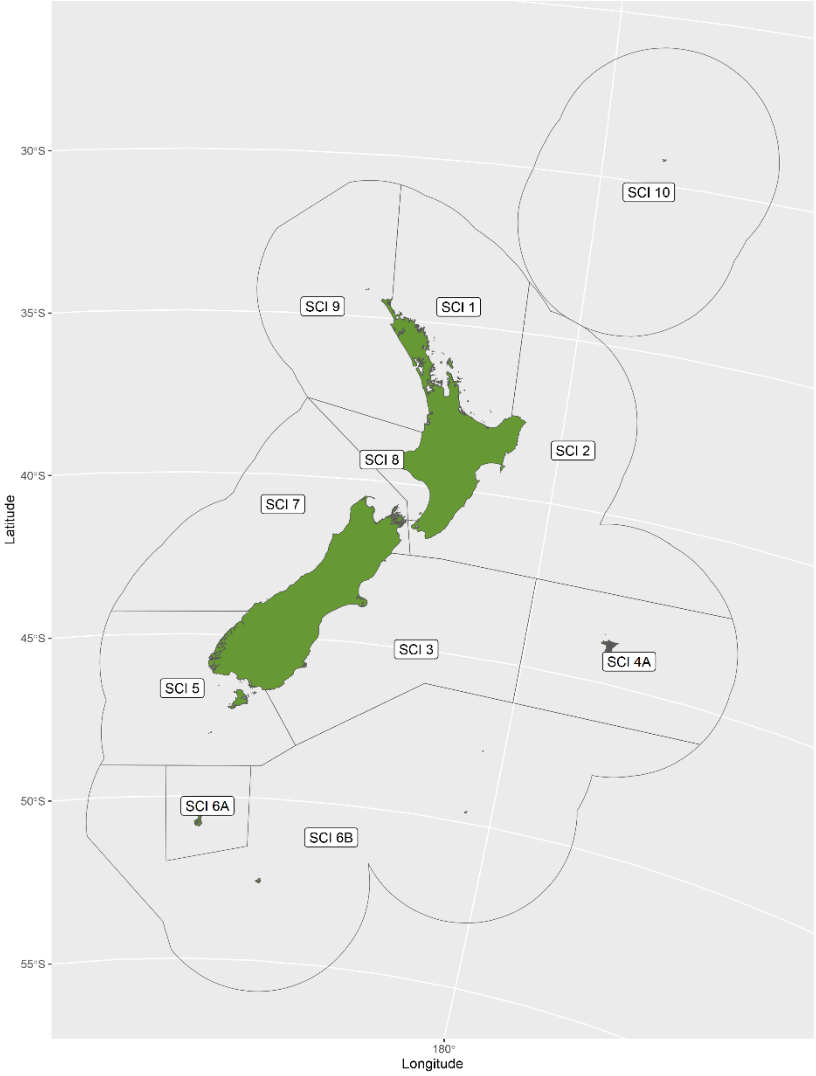

Figure 1: Quota Management Areas (QMAs) for scampi in New Zealand. SCI 10 is an administrative stock only, with no catch.

Scampi stocks are assessed with three main abundance indices: CPUE (catch per unit effort); trawl surveys; and photo surveys. Scampi are known to have temporal and moult related emergence rate patterns that may affect interpretation of CPUE and trawl surveys.

The photo burrow count index is not affected by emergence rate behaviour but is affected by variability in reader interpretation of bottom features as burrows. A methodology was therefore developed to test for differences in interpretation between readers and for 'reader drift'; i.e., differences in interpretation by an individual reader over time. This testing and correction methodology was initially a two-stage process with each stage utilising a generalised linear model (GLM). The first stage was to estimate reference set standardised coefficients to correct for reader drift between survey years, and the second stage was to apply these year effect correction coefficients for each reader to the original survey reads, and then standardise these adjusted counts to correct for differences between readers (Tuck & Dunn 2009, Tuck et al. 2009). For surveys conducted from 2019 the methodology was updated to a single stage generalised linear mixed model (GLMM).

In the scampi surveys in SCI 3 (2019), SCI 1 (2021) and SCI 2 (2021) the raw estimates of burrow counts were higher than any previous years, but the application of the GLMM led to large downward adjustments (Hartill et al. 2022, Tuck et al. 2021). In 2022, the scampi photo survey indices, and subsequently the SCI 1 stock assessment, were rejected by the Deepwater Working Group, and the SCI 2 assessment was given a lower quality rating than the previous SCI 2 assessment (Fisheries New Zealand 2024).

To re-establish confidence in the burrow count indices, two experienced readers read all images from stratum 402 of SCI 1 from the four most recent surveys (2012, 2015, 2018, and 2021) in a randomised year/station order, within a one-month time span to minimise any drift in their reading ability. Stratum 402 in SCI 1 was selected as there was a strong correction applied to the 2021 survey burrow count, with the 2021 raw index being higher than the earlier surveys, and the corrected estimate for 2021 being lower than the 2018 survey. The results from the re-read process supported the previous downward adjustment to the 2021 SCI 1 survey abundance estimate, i.e., the burrow count for 2021 was determined to be lower than the count for 2018 (McGregor et al. 2024).

Using the full SCI 1 data, the single stage GLMM ‘calibration’ process was tested for data compilation or coding errors, but none were found. The calibration was also repeated using the previous two stage methodology, producing very similar adjustments to the previously calculated indices for each of the survey strata for the final 2021 survey year (McGregor et al. 2024).

This report outlines work conducted under Fisheries New Zealand project SCI2023-03 “Developments in scampi surveys”, detailing the essential elements required of any simulation study to test the calibration methodology. This work was conducted to address remaining concerns about the appropriateness of the methodology, even after a review of the GLMM approach that focused on the statistical theory of this approach was conducted by a non-fisheries statistician, as part of a separate project (Gray in prep). The simulation method development was conducted under objective one of the project. Support to the independent statistician review was also provided under this objective:

Objective one: “To review scampi surveys to evaluate the merits of trawl and photographic surveys for scampi and document the outcome.”

The abundance index of major burrow counts, together with the index from the accompanying trawl survey, are used in the SCI 1, SCI 2 and SCI 3 stock assessments. For the SCI 6A assessment, the index of visible scampi, or most recently fully emerged scampi, is used in combination with the trawl survey index. Stock assessments require a catchability q for each index to scale the relative abundances of the indices to the estimated population size and, in previous assessments, informed priors were necessary. Tuck et al. (2015a) noted that integrated assessments attempted before the availability of the informed q priors “provided highly unrealistic biomass estimates, provided poor fits to abundance indices, and failed to converge.” Subsequent assessments have demonstrated that assessment results, especially initial biomass B_0, are sensitive to the specification of the q priors (see e.g., Tuck 2021). Their derivation has evolved over time and had become unclear to the Fisheries New Zealand Deepwater Working Group.

In response Objective 2 of project SCI2023-03 was:
“To review, coordinate, and document a workshop, and document the catchability (q) priors used for trawl and photo surveys for all New Zealand scampi stock assessments.”

This report outlines the evolution of the q-prior calculation methodology and details the outcomes from the workshop dedicated to their review.

2. PHOTO SURVEY CALIBRATION

2.1 Count protocols and GLMM specification

2.1.1 Photo survey design and reading protocols

Up to 2023, the photographic surveys followed a random stratified design in which strata were partially defined by depth. Stations were pre-allocated to strata to minimise the overall CV of the survey. The number of stations in each stratum was based on previous survey estimates of scampi burrow densities. In the 2021 surveys of SCI 1 and SCI 2, the number of stations in a stratum varied from 4 to 21 (Hartill et al. 2022) and in the 2023 SCI 3 survey they varied from 3 to 9 stations (Wieczorek et al. 2024). At each station, the target was to expose 30–40 images as the ship drifted along a transect, using a time delay sufficient to ensure that adjacent photographs did not overlap. Images were examined for usability, with the main criteria being the ability to discern fine seabed detail and the visibility of more than 50% of the frame (i.e., 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).

Burrow openings were defined as either ‘Major’ or ‘Minor’ (Hartill et al. 2022; Wieczorek et al. 2024). ‘Major’ burrow openings were identified using a definition characteristic of burrows that were often associated with scampi. ‘Minor’ burrow openings were often smaller rear openings associated with a ‘Major’ burrow opening. Each opening (whether major or minor) was further classed as ‘highly characteristic’ or ‘probable’ based on the extent to which each was of a type typically observed to be used by scampi. Most of the bioturbation observed in the images were not counted as burrows, as they were not considered to be characteristic of scampi burrowing. An investigation into mud burrowing megafauna on scampi grounds concluded that it was unlikely that other species present would generate burrows that would be confused with those generated by scampi (Tuck & Spong 2013).

The burrow count index used only major burrow counts as there can be more than one minor opening associated with each major burrow opening. The indices were based on counts of burrow openings rather than assumed burrow systems, because systems were relatively large compared with the image size and accepting all burrows totally or partly within each photograph is positively biased by edge effects (Marrs et al. 1996; Marrs et al. 1998).

Once the images from the survey had been scored by three readers, any images for which there was disagreement by more than 1 in burrow count (combined for ‘highly characteristic’ and ‘probable’) were re-examined by all readers without conferring. All images where there were any differences between readers on the count of visible scampi (including difference of interpretation as to whether a scampi was “in” or “out” of a burrow) were also re-examined by all readers. After re-assessing their own interpretation against the original image, readers were encouraged to compare their readings with the interpretations of other readers (but were free to change or not change their score considering observations from other readers). This re-reading process was used to maintain consistency among readers as well as to refine the count for a given image.

Reference set images from previous surveys were reread half-way through the reading of the current survey, so that the counts could be recalibrated to correct for changes in reader interpretation over time. Each image in each reference set was read by all six readers following the standard image scoring and re-reading procedure described above. The reference sets were extended over time to include reference set images from each survey. This progressive extension of the reference set resulted in an image reference set that was excessively large, requiring some thinning of images from the reference. The reference sets that were read alongside the 2021 and 2023 surveys were therefore restricted to those collected during the five previous surveys, with 30–36 images taken from both high and low burrow density stations in each year. Further details on the reading protocols are described in Wieczorek et al. (2024).

2.1.2 GLMM specification

To calibrate the major burrow count, two composite factors were created. The first, *year_stn*, was a combination of the image year and station number. The second, *reader_yr*, was a combination of reader and the year in which that reader read the images. The response variable was the sum of major burrow counts identified across all the images read, per survey station and survey year combination. The *year_stn* covariate was offered as a fixed effect and the *reader_yr* covariate was offered as a random effect (random intercept). Each image had a different readable area, which was accommodated by entering the sum of the readable areas across all images read for each *year_stn*, as an offset to the model (Equation 1).

$$major \sim year\_stn + (1 \,|\, reader\_yr\,) + offset(\ln\,(readable)) \tag{1}$$

The model was fitted assuming either a Poisson or negative binomial distribution, both of which were appropriate for a response variable consisting of count data.

Predictions from GLMMs cannot be made to fixed effect factors not included in the original fitting process. As the *year_stn* combinations were included as fixed factors to predict counts across the survey stations, including year-station combinations from the most recent survey, those stations needed to be included in the original fitting process. The GLMM was therefore fit to a combination of the original survey station data and the reference set data.

Once a model fit was made, the reference set data were discarded and a prediction dataset was created from the remaining mean burrow counts for each *year_stn*. The fitted model was used to predict burrow counts from these data, omitting the random effects for *reader_yr*. By not using the random effects, the prediction was of a population mean from the distribution of the *reader_yr* factor. The purpose of this was to obtain burrow counts made by an ‘average’ reader in an ‘average’ year.

Correction for both reader effects and reader drift was only necessary for the estimates of major burrow counts. Images of emerged scampi were considered unambiguous (Wieczorek et al. 2024). Differences between readers of counts of semi-emerged or ‘door-keeping’ scampi exist but counts of door keeping scampi appear very consistent over time (different surveys) for a given reader.

2.2 Outline for a simulation study

Notation used in describing the simulation study is given in Table 1.

Table 1: Notation used in describing the photo survey calibration simulation exercise.

Notation	Description
$pB_{,r,y}$	The probability a reader r identifies a burrow as a burrow in year y
$pF_{,r,y}$	The probability a reader r identifies a non-burrow feature as a burrow in year y
y	Survey year

2.2.1 Simplifying assumptions

The large corrections seen in the SCI 1 burrow counts were seen across all strata (McGregor et al. 2024), therefore simplifying the simulation to a single stratum should still adequately capture the variability. In the first instance it seems reasonable for the number of survey stations and the number of images per station to remain the same in all years. All images can be assigned the same readable area. The dependent variable in the GLMM fit was burrow count, but the final desired output was burrow density (burrows m^{-2}); the log of the combined readable area (*readable*) of all images across a station was included as an offset in the fit. It is also the case that surveys to date have groomed images to exclude those with readable areas that are too small.

2.2.2 Model features

Years simulated

Whether the length of the survey series affected the ability of the calibration algorithm to detect and correct for reader bias is unclear. Large corrections occurred for a series with five years of data. Current protocol includes images from the five previous surveys in the reference set. It is therefore recommended to simulate six years of data, the minimum number required to incorporate five years of reference set images.

Readers

The total number of readers and the allocation of images to readers has been consistent throughout the photo surveys. To replicate this:

- Generate six readers.
- Allocate half of all stations from each ‘current’ survey to three readers.
- The combination of readers per station should vary, i.e., to mimic reality a random allocation of readers to stations is desired to achieve an overlap between readers.
- All images from a given station must be read by the same 3 readers because the calibration method uses burrow count per station as the response variable.

Distribution of features across images

‘Burrows’ are spread unevenly, with many images receiving zero counts (Middleton 2025, figure 1). It is not clear what distribution would best replicate the distribution of features across images. Gray (in prep) tested whether burrow count means by survey station were roughly equal to the burrow count variances, which would suggest that scampi burrows per image were Poisson distributed within a station. He concluded that the agreement between means and variances was sufficiently good for this assumption to be reasonable. Non-burrow features could also be assumed to be distributed according to a separate Poisson distribution.

It is assumed that for both burrow and non-burrow feature counts, images within a station are unlikely to be fully independent. It is also assumed that different stations will have different per image means. For each station therefore, the mean to be supplied to the Poisson distributions for image generation should come from a distribution. In the first instance it is suggested these also come from Poisson distributions.

In previous studies involving simulation of count data, 1000 repetitions of simulated data were generated to minimize the impact of simulation error (e.g., Fernandez & Vatcheva 2022).

Ratio between burrows and overall number of features

In surveys conducted to date, the ratio between burrows and features varied depending on the area and substrate. Some areas are biodiverse with holes and burrows from different species, while other areas are less complex and easier to interpret. Within a station, substrate is generally similar, but within a stratum, substrate may vary between stations. Features not included in the burrow counts included ‘small’ burrows and collapsed burrows. From previous readings of surveys, the ratio between burrows and the overall number of features was estimated as between 1:2 and 1:7 (i.e., out of seven features, only one was included in the burrow counts).

Reference set images

The simulation needs to distinguish between when an image is read for the first time (the survey year) and when it is read as a reference set image. Once an image is selected as being in the reference set it remains in the reference set. The recent development of dropping the oldest reference set images is not required for the simulation. The number of burrows and overall features in the reference set images does not change irrespective of the year the image is read.

Reference set stations are primarily chosen from to obtain “a good balance” of images showcasing a range of burrows and scampi densities. One approach for the simulation exercise could be to partition images from a given survey, as generated by the operating model, into categories with a given number of burrows (e.g., zero burrows, one burrow, two burrows), and then select an image at random and without replacement from each category until a target number of images have been selected. Categories would then drop out of the selection process if all their available images were used. This selection would, of course, be based on the ‘true’ number of burrows rather than a burrow count. The current target number of reference images from a single survey is 30 and in the first instance this would be the number suggested for the simulation.

Probabilities for identifying burrows and for false positives

Two terms were considered necessary to represent the probability of a reader identifying a feature as a burrow: the probability that a reader identifies a true burrow as a burrow, and the probability that a reader identifies a non-burrow feature as a burrow. This is for two reasons:

1. We assume that a trained reader is more likely to correctly identify a true burrow than falsely identify a non-burrow.
2. Use of a separate term lends itself to scenarios where the probability of false positives varies in time or between readers relative to the probability of correctly identifying a burrow. Example scenarios include the probability of false positives increasing with an increasing density of features in images, or the probability of false positives increasing with an increasing proportion of features being true burrows. The latter could occur when the scampi population is increasing and collapsed burrows have become re-occupied. Both possibilities have been suggested as explaining the large reader-year effects seen from the recent scampi surveys (Ian Tuck pers. comm.).

The distributions used when determining reader outcomes can be different to those used to spread burrows and features between images (and each other). For example, both the probability a reader r identifies a burrow as a burrow in year y, $pB_{,r,y}$ and the probability a reader r identifies a non-burrow feature as a burrow in year y, $pF_{,r,y}$ can be passed to a binomial distribution to receive a binary outcome for each burrow or feature in an image, where 1 = counted as a major burrow and 0 = dismissed as not a major burrow.

If the $pB_{,r,y}$ and $pF_{,r,y}$ values are set up as a matrix (with one value for each reader-year combination), at what point in the simulation process images are read has no effect because the matrix of values allows $pB_{,r,y}$ and/or $pF_{,r,y}$ to change between survey years while keeping them the same for the images from that year’s survey and the reference set images read in that year. If $pB_{,r,y}$ and/or $pF_{,r,y}$ values need to be different between the survey year images and the reference set images read in that year, a second matrix of $pB_{,r,y}$ and $pF_{,r,y}$ values specific to the reference set would be required.

Modular design and nested looping

Code to generate a set of images and code to emulate the reading process should be set up as separate functions with the ability to read in a variable declaring the type of distribution to be used (to distribute burrows/features or read images) and all parameters relevant to the chosen distribution. Six distributions were envisaged for the simulation, which would:

1. Generate the mean number of major burrows for each station.
2. Generate the mean number of non-burrow features for each station.
3. Generate the number of major burrows per image (with mean taken from the major burrow station level distribution).
4. Generate the number of non-burrow features per image (with mean taken from the non-burrow feature station level distribution).
5. Determine whether a reader counts a major burrow as a burrow.
6. Determine whether a reader counts a non-burrow feature as a burrow.

When generating images, it is suggested to loop through survey years so that reference set images can be established at the same time as the survey images are created. The reference set images are a subset of the full set of survey images and need to be retained over all subsequent surveys.

When simulating reading it is suggested to:

1. loop through survey years;
2. in each survey year loop through images;
3. for each image, loop through readers assigned to that image; and
4. for each reader, process actual burrows (if present) followed by non-burrow features (if present).

Test statistics
To determine whether the calibration method produces a major burrow count closer to the true value than the uncorrected count, the metrics of mean square error (MSE), root mean square error (RMSE) and mean absolute error (MAE) between uncorrected counts against true burrow numbers and corrected counts against true burrow numbers could be used. The exception to this is when the structure of the code is being tested with uncorrected count data equalling true burrow numbers (see below).

Size, sign (over or under-estimation), and consistency of differences between true numbers and counts are important. For example, a time series of counts with a consistent bias could potentially be accommodated in an assessment through a catchability term. In a scenario where $pB_{,r,y}$ had been consistent between readers and years but low, and then, in a later year, increased across readers to a value that brought the uncorrected count closer to the true number of burrows, the GLMM may 'correct' the later count to be more in line with counts from earlier years, i.e., to be more compatible with the old $pB_{,r,y}$ value. Measures like MSE may increase for the corrected count, but the time series may have become more useful to an assessment.

For further insights, the distributions across the repetitions of simulated data, of both the uncorrected and corrected counts, could be analysed, such as testing how closely they approximate a normal distribution. Deviations from a normal distribution would suggest that the number of iterations in the simulation was insufficient. Distributions of the *reader_yr* effects estimated from the GLMM could also be considered to determine how they reflect the changes in $pB_{,r,y}$ and/or $pF_{,r,y}$ instigated in the operational model.

2.2.3 Test scenarios

An initial test should simply be a structural test of the code, i.e., to ensure that the uncorrected major burrow count is identical to the generated number of burrows if the simulation is set up with burrows perfectly identified, and the probability of false positives is zero. The suggested structure of the code allows for many potential subsequent scenarios, including where the:

- Probability a reader *r* identifies a burrow as a burrow in year y, $pB_{,r,y}$, is high and the probability a reader *r* identifies a non-burrow feature as a burrow in year *y*, $pF_{,r,y}$, is low. Both $pB_{,r,y}$ and $pF_{,r,y}$ are the same for all readers and across all survey years.
- Probability $pB_{,r,y}$ is high and consistent across readers and years, $pF_{,r,y}$ becomes higher in the final year but is consistent across readers.
- Probability $pB_{,r,y}$ is high and consistent across readers and years, $pF_{,r,y}$ becomes higher in the final year but varies across readers.
- Probability $pB_{,r,y}$ is high and consistent across readers and years, $pF_{,r,y}$ rises steadily over survey years but is consistent across readers.
- Probability $pB_{,r,y}$ is high and consistent across readers and years, $pF_{,r,y}$ rises over survey years and varies across readers.
- Probability $pB_{,r,y}$ rises steadily over survey years, $pF_{,r,y}$ stays consistent between readers and across years.

In the scenarios described above, a high value of $pB_{,r,y}$ is suggested when kept consistent across readers and years, but in terms of the performance of the calibration method, whether the value is high or low should be unimportant. Changes in estimated major burrow densities relative to true scampi abundance should be compensated for within the assessment model by a change in the catchability term, *q* for the burrow count index. Changes in estimated major burrow densities from the photo survey relative to estimated visible scampi densities from the photo survey does alter the catchability prior (see Section 3).

3. CATCHABILITY PRIORS

The first informed priors for scampi survey catchability for New Zealand stocks used a formula based on a combination of attributes taken from the literature and consideration of photo survey calibration results (Tuck & Dunn 2012). Starting in 2010 at the Mernoo Bank (SCI 3), acoustic tagging experiments were conducted alongside the photo and trawl surveys of scampi grounds. These experiments tagged and released animals caught in the survey area with tags capable of transmitting at regular intervals and with a unique frequency per tag. Moorings with hydrophones positioned 20 and 40 m above the seabed were left to detect the tag signals, possible only when the animals were not in burrows. The proportion of time that an animal was detected, averaged over all animals that were detectable over the full mooring duration, was used to infer the emergence rate of the scampi. For further details of the tagging experiments see Tuck et al. (2015a). Results from these acoustic tagging experiments and the references describing them are given in Table 2.

Table 2: Summary of acoustic tagging experiments conducted on scampi grounds. Information not available indicated by “–”.

Year	Area	Mooring sites	Scampi tagged (used for detection rate)	Mooring duration (days)	Detection rate best estimate (%)	Reference	Notes
2010	SCI 3	–	–	–	38.9	Tuck 2013	Detection “varied from 20–80%”
2012	SCI 1	3	40 (18)	46.6	52 (24 hr mean) 46 (daylight hrs)	Tuck et al. 2013, Tuck et al. 2015a	24 hr 5 & 95% quantiles 33.3 and 72.2% Daylight 95% CI (41.7, 50.7)
2012	SCI 2	3	39 (4)	62	67	Tuck et al. 2013, Tuck et al. 2015a	Detection 5 & 95% quantiles 25 & 100%
2013	SCI 3	3	40 (5)	–	51.7	Tuck et al. 2015b	Detection 5 & 95% quantiles 20 & 80%
2013	SCI 6A	3	60 (15)	21	66	Tuck et al. 2015c	95% CI (40, 86)

With the availability of acoustic tagging results, the catchability priors for the indices of major burrow counts, visible scampi, emerged scampi and the trawl surveys were estimated in two stages.

Stage one

- Estimates of major burrow opening density (burrows m^{-2}), visible scampi density (animals m^{-2}) and emerged scampi density (animals m^{-2}) were obtained from the latest survey.
- An emergence rate for scampi was obtained from acoustic tagging data.
- Photo survey estimates of major burrow count and emergence rate data were combined to obtain the best estimate for the major burrow count catchability $\widehat{q_{photo}}$.
- For the best estimate of trawl survey catchability, $\widehat{q_{trawl}}$, emergence rate data were combined with the photo survey estimate of emerged scampi.
- Bootstrapping one or more of the constituent variables was performed to derive estimates of the 2.5th, 50th and 97.5th percentiles for $\widehat{q_{photo}}$ and $\widehat{q_{trawl}}$.

Note that for the best estimate of visible scampi catchability, $\widehat{q_{scampi}}$, only the emergence rate data was initially considered (see Section 3.1.1).

Stage two

- Catchabilities were assumed to follow a lognormal distribution.
- The mean and standard deviation of the lognormal function was gained by:
    - ➢ A GLM fitted to the 2.5th, 50th and 97.5th percentiles of the q obtained from stage 1, assuming a binomial distribution and using a probit link function, i.e., $\Pr(Y=1|X) = \Phi(\beta_0 + \beta_1 X)$, where Φ is the cumulative distribution function (CDF) of the standard normal distribution.
    - ➢ From the relationship between a probit link and the CDF of the standard normal, the standard deviation, σ, of the normal distribution is given by $1/\beta_1$.
    - ➢ The mean, μ, of the normal distribution is given by $-\beta_0/\beta_1$.
    - ➢ The mean of the lognormal is given by $exp(\mu + \sigma^2/2)$ and the CV of the lognormal is given by $\sqrt{\exp(\sigma^2) - 1}$.

3.1 Key stages in catchability prior development

3.1.1 Equations used in assessments from 2010–11 to 2015–16

The best estimate for the major burrow count catchability, $\widehat{q_{photo}}$ was calculated as

$$\widehat{q_{photo}} = \frac{B}{P} = \frac{B}{V/E} = \frac{B \times E}{V} \qquad (2)$$

where
B = major burrow opening density (burrows m^{-2}),
P = estimated population density (animals m^{-2}),
V = visible scampi density (emerged + door-keeping) (animals m^{-2}), and
E = emergence rate.

In SCI 6A, scampi appeared to spend less time in burrows, with animals frequently observed associated with ‘trench features’ (possibly collapsed burrows) (Tuck et al. 2007). On this basis, the index of visible scampi was used in assessments in place of the major burrow index with the catchability prior given by

$$\widehat{q_{scampi}} = \frac{V}{P} = \frac{V}{V/E} = E \qquad (3)$$

To find the best estimate of q for the trawl survey, the estimate for emerged scampi was divided by the estimate for population density

$$\widehat{q_{trawl}} = \frac{\varepsilon}{P} = \frac{\varepsilon}{V/E} = \frac{\varepsilon \times E}{V} \qquad (4)$$

Where ε was the estimate for emerged scampi from the photo survey.

3.1.2 Equations used in assessments from 2016–17 to present

In the assessments up to the 2015–16 SCI 6A assessment, all visible scampi “ranging from those walking free on the surface to those within burrows, where only the tips of claws can be seen” were scaled by emergence (Tuck 2019). In 2010 the proportion of visible scampi acoustically detectable were determined by placing activated acoustic tags in burrows in shallow waters to confirm when they became undetectable. Tags were detected on the surface of the seabed and in the entrance to burrows, but not within a burrow (Tuck et al. 2015a).

Starting with the 2016–17 SCI 3 assessment, photo survey images were re-examined to determine which of the door-keeping scampi would be acoustically detectable using the above criteria (Figure 2). This proportion k of door-keeping scampi considered acoustically detectable was calculated independently for SCI 1–2, SCI 3, and SCI 6A.
SCI 1 and SCI 2: all observed door-keepers in the 2018 survey.
SCI 3: all observed door-keepers in the 2018 survey.
SCI 6A: all observed door-keepers from all SCI 6A surveys to 2019.

Figure 2: Examples of scampi observed within the entrance to burrows (door keeping). Only the tips of the claws can be seen in the right hand image. Notations indicate animal judged acoustically detectable (left), uncertain as to acoustically detectable (middle) and judged not detectable (right).

In the assessments up to the 2015–16 SCI 6A assessment, all emerged scampi were assumed to be caught by the trawl gear during a trawl survey. Starting with the 2016–17 SCI 3 assessment, a new term T was introduced to represent the proportion of emerged scampi caught by the trawl. Examination of the relationship between estimates of emerged scampi abundance from photographic surveys and trawl sampling during the same survey (albeit at a later date) indicated that, on average, trawl catch estimates were a half to a third of the emerged scampi estimates, with the pattern reasonably consistent between stocks (Tuck 2020).

Equations for $q_{\widehat{photo}}$, $q_{\widehat{scampi}}$, $q_{\widehat{emerged}}$ and $q_{\widehat{trawl}}$ became

$$q_{\widehat{photo}} = \frac{B}{P} = \frac{B}{D/E} = \frac{B \times E}{\varepsilon + k\delta} \tag{5}$$

$$q_{\widehat{scampi}} = \frac{V}{P} = \frac{V}{D/E} = \frac{V \times E}{\varepsilon + k\delta} \tag{6}$$

$$q_{\widehat{emerged}} = \frac{\varepsilon}{P} = \frac{\varepsilon}{D/E} = \frac{\varepsilon \times E}{\varepsilon + k\delta} \tag{7}$$

$$q_{\widehat{trawl}} = \frac{\varepsilon}{P} \times T = \frac{\varepsilon}{D/E} \times T = \frac{\varepsilon \times E}{\varepsilon + k\delta} \times T \tag{8}$$

where
$D = \varepsilon + k\delta$ = detectable scampi,
ε = emerged (or 'out') scampi density (animals m^{-2}),
δ = door-keeping scampi density (animals m^{-2}),
k = proportion of door-keeping scampi acoustically detectable, and
T = proportion of emerged scampi caught by the trawl.

3.1.3 Developments in most recent SCI 1 and 2, SCI 3 and SCI 6A assessments

The same data should not be used to form a prior and as input data to the assessment because this is likely to give a higher degree of certainty in the posterior than should be accepted. Therefore, the prior distributions for q_{photo} in the most recent assessments were based on the distributions calculated for the previous assessment. Therefore, the prior distribution for q_{photo} calculated from the 2019–2020 SCI 3 data was not used but rather the distribution calculated for the 2017–18 SCI 1 and SCI 2 assessment (Tuck 2020, McGregor et al. 2022). Similarly, the q_{photo} prior distribution for SCI 3 used the major burrow index from the 2020–21 SCI 1 and SCI 2 assessments, although the major burrow index was not used in the assessment because of concerns over the photo survey calibration results (McGregor 2023).

In the 2018–19 SCI 6A assessment, the trend of the visible scampi index was considered to contradict the trend in the CPUE data (Tuck 2021). Although the CPUE index declined slightly from 2016 to 2019, the photo index of visible animals increased markedly from 2013 to 2019. Further examination of the photo survey data identified that much of the large increase in abundance between 2016 and 2019 was accounted for by an increase in the number of door-keeper scampi observed. Although all sizes of scampi were observed door keeping, the smallest (recruit) animals were generally only seen in burrow entrances. The Deepwater Working Group concluded that the emerged scampi index was more representative of the population available to the commercial fishery or trawl surveys and should be used, rather than the visible scampi index (Tuck 2021). The emerged scampi index was retained for the 2022–23 SCI 6A assessment.

The SCI 6A trawl survey had been conducted by two vessels, the F.V. *San Tongariro* for the surveys in 2007–09 and 2013 and the R.V. *Kaharoa* for the surveys in 2016, 2019 and 2023. Tuck (2021) compared the photographic survey (which was expected to be independent of vessel) and trawl survey abundance estimates to provide estimates of the relative catchabilities (qs) of the *San Tongariro* and *Kaharoa* scampi trawl gear. This analysis suggested that the *San Tongariro* had a catchability roughly double that of the *Kaharoa*. This relative catchability was explored as a potential q-ratio prior for the *San Tongariro* and *Kaharoa* surveys, but after initial assessment runs, the DWWG concluded that a q-ratio prior was unnecessary because the model was able to estimate the catchabilities for the two vessels if provided with a common prior. That prior was made equal to the emerged scampi prior. The same approach was applied for the assessment to 2022–23 (Holmes & McGregor 2024).

3.2 Incorporation of uncertainty and consistency of priors between assessments

In theory, any of the components of the equations outlined in Section 3.1.2 could be included as a distribution of values, either generated from the assumed distribution and calculated mean and variance or through bootstrapping of the raw data. In practice, in 2017 and 2018, an assumed CI for k, the proportion of door-keeping scampi acoustically detectable, was used to derive the quantiles for $\widehat{q_{photo}}$ with best estimate (median) values used for the other terms. For $\widehat{q_{trawl}}$, the confidence interval for the term T was also employed. For the following round of assessments, the 95% CI for k was obtained from bootstrapping the original data. The CI was considerably narrower than that assumed before and the resulting priors were considered too 'tight'. The CI for E (emergence rate) was therefore also incorporated. The approaches used for each assessment are given in Table **3** and a comparison of the resulting priors are shown in Figure 3 and Figure 4.

Table 3: Quantities contributing to the estimation of major burrow count catchability prior $\widehat{q_{photo}}$ and trawl survey catchability prior $\widehat{q_{trawl}}$ and indication whether variation in the quantity was considered when estimating the 2.5% and 97.5% quantiles for $\widehat{q_{photo}}$ and $\widehat{q_{trawl}}$. B = major burrow opening density (burrows m^{-2}); E = emergence rate; ε = emerged (or 'out') scampi density (animals m^{-2}); δ = door-keeping scampi density (animals m^{-2}); k = proportion of door-keeping scampi acoustically detectable; T = proportion of emerged scampi caught by the trawl.

Assessment	B	E	ε	δ	k	T
SCI 1 & 2 (to 2017–18)	median	median	median	median	95% CI (2018 SCI 1 photo survey)	95% CI Trawl survey catches vs photo survey estimates of ε (data from all surveys to 2016 SCI 3)
SCI 1 & 2 (to 2020–21)[1]	median	95% CI	median	median	95% CI (2018 SCI 1 photo survey)	95% CI Trawl survey catches vs photo survey estimates of ε (data from all surveys to 2016 SCI 3)
SCI 3 (to 2016–17)	median	median	median	median	95% CI assumed (0.05, 0.95)	95% CI Trawl survey catches vs photo survey estimates of ε (data from all surveys to 2016 SCI 3)
SCI 3 (to 2019–20)[2]	median	95% CI	median	median	95% CI (2019 SCI 3 photo survey)	95% CI Trawl survey catches vs photo survey estimates of ε (data from all surveys to 2016 SCI 3)
SCI 6A (to 2018–19)	n.a.[3]	median	median	median	95% CI (all SCI 6A photo surveys)	95% CI Trawl survey catches vs photo survey estimates of ε (surveys by *F.V. San Tongariro*)

1. The prior was developed but not used. The prior developed for SCI 3 (to 2019–20) was selected, but the major burrow count index was dropped from the assessment model (see Section 3.1.3).
2. The prior was developed but not used. The prior developed for SCI 1 & 2 (to 2017–18) was selected (see Section 3.1.3).
3. Not relevant because B is used in the calculation of $\widehat{q_{photo}}$ which is not used in the SCI 6A assessment.

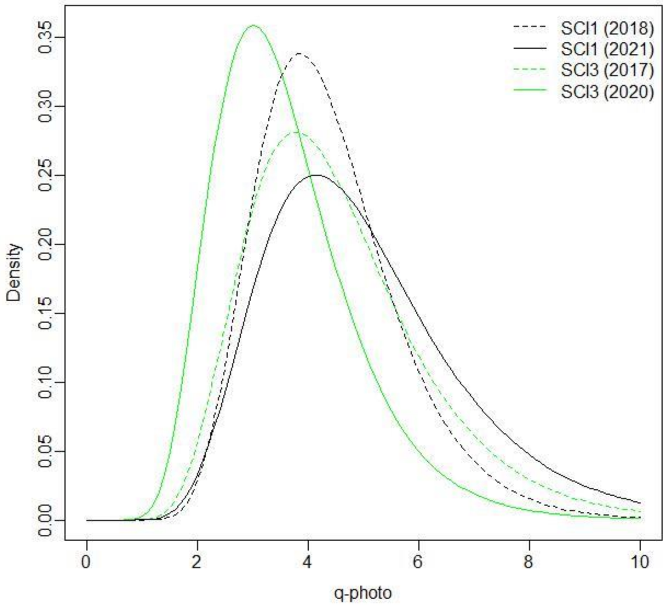

Figure 3: Prior distributions used for the major burrow count catchability (q-photo) for the SCI 1 and SCI 2 assessments to 2017–18 (SCI1 2018); developed but not used for the SCI 1 and SCI 2 assessments to 2020–21 (SCI1 2021); SCI 3 assessment to 2016–17 (SCI3 2017); developed but not used for the SCI 3 assessment to 2019–20 (SCI3 2020).

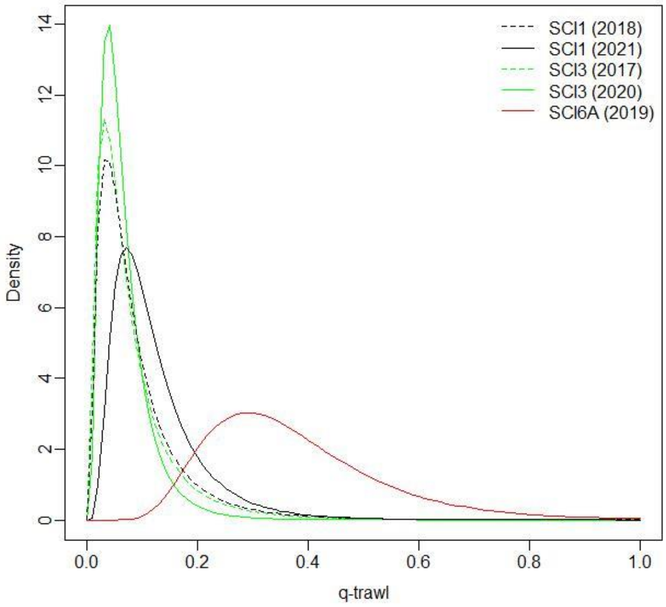

Figure 4: Prior distributions used for the trawl survey catchability (q-trawl) for the SCI 1 and SCI 2 assessments to 2017–18 (SCI1 2018); SCI 1 and SCI 2 assessments to 2020–21 (SCI1 2021); SCI 3 assessment to 2016–17 (SCI3 2017); SCI 3 assessment to 2019–20 (SCI3 2020); SCI 6A assessment to 2018–19 (SCI6A 2019).

3.3 Catchability prior workshop

A workshop to review the developments in catchability prior formulation and their latest form was held on 15 February 2024. Conclusions from the workshop were as follows:

Equations used for the priors

- The currently used equations for $\widehat{q_{photo}}$, $\widehat{q_{scampi}}$ and $\widehat{q_{emerged}}$ were found to be appropriate.
- The emergence rate based on data from daylight hours should be used because the photo survey and trawl survey are both conducted in daylight hours.
- It was considered appropriate to use the emerged scampi index instead of the major burrow index for the SCI 6A assessment.
- There was low confidence in the derivation of the T term in the $\widehat{q_{trawl}}$ equation. It was recommended that, in the first instance, the trawl survey catchability prior be based on $\widehat{q_{scampi}}$ or $\widehat{q_{emerged}}$ and the final model estimate for the trawl survey catchability be assessed as to whether it was reasonable.

Generality of prior and frequency of calculation

- If the methodology to calculate a prior distribution remains unchanged, there is no need to re-estimate the distribution for each new assessment.
- The same priors can be used for SCI 1, SCI 2 and SCI 3 assessments. To that end, it was recommended to use the distributions of B (major burrow opening density), δ (door-keeping scampi density), and ε (emerged scampi density) from the most recent SCI 1, SCI 2 and SCI 3 assessments to form combined-area inputs for calculation of $\widehat{q_{photo}}$, $\widehat{q_{scampi}}$ and $\widehat{q_{emerged}}$.
- A single emergence rate for SCI 1, SCI 2 and SCI 3 grounds is reasonable, but because of the different nature of emergence in SCI 6A, the emergence rate specific to this area should be maintained.

3.3.1 Change of survey vessel

The R.V. *Kaharoa* will be replaced by the R.V. *Kaharoa II* in mid-2025. For scampi surveys, the new vessel will deploy the same gear as before but will have self-tensioning winches which may influence catchability. The workshop considered the options available:

- Conduct back-to-back tows during a scampi survey with the *Kaharoa II*, alternating between tows using self-tensioning and tows without. Derive a *q*-ratio penalty.
- Compare catch rates of the trawl survey to the density of emerged scampi observed in the photo survey separately for *Kaharoa* and *Kaharoa II*, i.e., make use of the T term in the $\widehat{q_{trawl}}$ equation with separate T terms for *Kaharoa* and *Kaharoa II*. This is equivalent to the initial approach investigated when the *F.V. San Tongariro* was replaced by the *R.V. Kaharoa* (Tuck 2021).
- Do not use the trawl survey abundance index from the first *Kaharoa II* survey. When SCI 6A changed from *F.V. San Tongariro* to *R.V. Kaharoa*, the data from the first *Kaharoa* survey was not used; q_{trawl} was estimated within the model on the second *Kaharoa* survey.

3.3.2 Recommendations from the workshop for future work

Recommendations from the workshop for future work were centred on the re-analysis of the acoustic survey data. In the original analyses, only animals detected consistently throughout the duration of the experiment were included in the calculation of emergence rate. This was done to remove the risk that animals that had: a) died in a burrow; b) been eaten; or c) moved outside of detection range were interpreted as alive in a burrow. Additional data are potentially available using animals that were consistently detected for ‘a good portion’ of the experiment, using the information from the period for which they were detected. In the original analyses, acoustic data collected during the first 48 hours following release were excluded from the analyses to reduce the possible influence of capture/release on behaviour. This protocol would be maintained.

The workshop recommended to consider, for SCI 1, SCI 2 and SCI 3, pooling data across surveys to gain a single emergence rate. Because of the hierarchical nature of the combined data, bootstrap procedures would need to take account of which results came from which survey.

It was questioned at the workshop whether emergence data gathered in one survey should be used for priors in later years, i.e., whether long term patterns in emergence are missed because of the assumption of a constant emergence rate. The workshop suggested that analyses of time series of ε/B and k/B estimates might indicate whether emergence rates vary over time.

4. DISCUSSION

Large downward revisions to the major burrow count estimates occurred after the significant change to the scampi photo survey calibration methodology (Hartill et al. 2022, Tuck et al. 2021), which resulted in a lack of confidence in the photo survey calibration method. The rejection of the SCI 1 (to 2020–21) stock assessment (and the downgrading of the SCI 2 assessment) after rejection of the major burrow count index demonstrates the importance of a trusted calibration method. As noted above, burrow count indices are important because both commercial CPUE series and trawl surveys may be affected by unknown patterns of scampi emergence from burrows.

Since the 2020–21 SCI 1 and SCI 2 assessments, data compilation or other coding errors have been ruled out as causing the issue, and the current GLMM results were comparable to the older two-stage calibration method (McGregor et al. 2024). Consideration of the approach from a statistical theory approach has also failed to find fault with the current calibration method (Gray in prep.). Re-reads of images from SCI 1 surveys resulted in counts across survey years being higher than the estimates obtained at the time of the surveys suggesting the presence of reader drift. The re-reads also resulted in lower major burrow estimates for the 2021 survey than for the 2018 survey, compared to record high estimates of burrow counts for the 2021 survey when the 2021 survey was first read (McGregor et al. 2024). The latter result suggests a greater than normal drift at the time of reading the 2021 survey. Photo survey results from the SCI 3 area in 2023 are now available (see Wieczorek et al. 2024). Application of the GLMM as described above may indicate that the 2019 and 2021 reads were outliers, however, whether the scale of correction of the survey reads in 2019 and 2021 was appropriate remains uncertain.

The simulation study outlined would allow for characterisation of the behaviour of the calibration method in response to known traits in reader performance, either between readers or for a given reader. The proposed simulation should provide the flexibility to test for any scenario; e.g., new readers counting higher or lower could simply be accommodated by altering the $pB_{,r,y}$ and/or $pF_{,r,y}$ values for one or more of the simulation readers at the appropriate stage in the time series of surveys. An additional advantage of the simulation would be the ability to test whether the size of the reference set affects the ability of the GLMM to detect reader drift or reader bias relative to other readers.

The values of the scampi survey catchability priors are, to an extent, a less serious issue than acceptance of the photo survey calibration. The chosen prior is immaterial if the abundance index has been omitted from the assessment model. Different choices of prior mean values have been shown to considerably affect initial biomass estimates, but to have a much smaller impact on estimates of current status as a percentage of B_0 (e.g., Tuck 2021). However, oversensitivity to the choice of prior for the trawl survey catchability was one factor cited for the rejection of the 2020–21 SCI 1 assessment (Fisheries New Zealand 2024). Combining information over scampi areas SCI 1–3 and possibly SCI 4 to form the major burrow count catchability prior, as recommended at the *q*-prior workshop, should guard against biases caused by the results of a given photo survey or acoustic survey. This would also help alleviate concerns with respect to using the same data in both prior and assessment input data, conforming better to best practices for priors in Bayesian stock assessments (Romakkaniemi 2015).

The *q*-priors workshop also concluded that the priors do not need updating if the methodology for their derivation has remained unchanged. Further recommendations include revisiting their calculation after a few surveys to ensure that they remain valid given more recent data, and to test whether informed priors are still necessary when conducting a new assessment.

It was recommended that a re-analysis of the scampi acoustic tagging data be completed. Scampi emergence (examined through the analysis of catch rates) has been shown to vary seasonally in relation to moult and reproductive cycles (which vary with sex), and over shorter timescales in relation to diel cycles (Ward & Davis 1987, Tuck 2010). Emergence related to tidal cycles has been found for the similarly burrowing Norway lobster (*Nephrops norvegicus*) (Bell et al. 2008, Sbragaglia et al. 2013). The results of the New Zealand acoustic tagging experiments showed cyclical patterns in detectability, with scampi apparently responding to water current direction at one site (increased detection when currents flowed across the shelf, heading inshore) and time of day (increased detection around dawn), but not tidal periodicity (Tuck et al. 2015a). The acoustic tagging study durations were too short to investigate longer term cycles. It may be possible to investigate longer-term variation in emergence by looking at the relationship between estimated detectable scampi density and major burrow density of the scampi survey series, as suggested by the *q*-priors workshop.

5. POTENTIAL RESEARCH

Section 2.2 outlines a simulation study to verify the photo survey calibration methodology.

Section 3.3.2 lists potential future research resulting from the catchability priors workshop.

6. FULFILMENT OF BROADER OUTCOMES

As required under Government Procurement rules[2], Fisheries New Zealand considered broader outcomes (secondary benefits such as environmental, social, economic or cultural benefits) that would be generated by this project. The following broader outcomes were delivered:

Supporting women in science
Three out of the four researchers of the project were women.

Building capacity and capability in the research sector
The team working on the project brought together a diverse range of skill sets and experience levels.

7. ACKNOWLEDGEMENTS

This work was completed under Fisheries New Zealand project SCI2023-03. We thank members of the Fisheries New Zealand Deepwater Working Group and Alistair Gray for suggestions and feedback and the participants in the catchability priors workshop. Thank you to Samik Datta, Jennifer Devine and Richard O’Driscoll (NIWA) and Gretchan Skea and Bruce Hartill (Fisheries New Zealand) for reviewing the manuscript.

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[2] https://www.procurement.govt.nz/procurement/principles-charter-and-rules/government-procurement-rules/planning-your-procurement/broader-outcomes/

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