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Tini a Tangaroa

# Increased fisher-reporting of seabird captures during an electronic-monitoring trial

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L. Tremblay-Boyer
E. R. Abraham

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Seabirds are incidentally captured in New Zealand commercial fisheries, including bottom-longline fisheries targeting snapper and bluenose in northern North Island. Incidental captures of protected species, such as seabirds, are recorded by fishers and also by government fisheries observers when they are onboard commercial vessels. Nevertheless, the rates of these incidental captures are uncertain, as fisher-reported records may be incomplete and observer coverage of these bottom-longline fisheries is variable.

For this reason, a pilot electronic monitoring programme was implemented in October 2016 (the 2016–17 fishing year) in bottom-longline fisheries targeting snapper and bluenose in north-eastern North Island (the Hauraki Gulf and Bay of Plenty areas, Fisheries Management Area FMA 1). The fisheries in this area overlap with the spatial distribution of black petrel (*Procellaria parkinsoni*), which has been identified as the species most at risk from commercial fisheries in New Zealand. Black petrel breed on Little Barrier and Great Barrier islands in Hauraki Gulf during summer, and use the outer Hauraki Gulf area and pelagic waters for foraging during that time.

During the electronic monitoring programme, the haul of the catch was recorded using cameras onboard participating vessels, and the footage was subsequently reviewed. Here, we used a modelling approach to assess whether fisher-reported seabird captures were affected by the presence of onboard cameras.

We found that the rate of fisher-reported seabird captures increased from 0.0044 birds per thousand hooks before the trial to 0.0089 birds per thousand hooks during the trial for the vessels that participated in the camera trial for the snapper target fishery. This increase of around a factor of two was also supported by a statistical analysis. Key candidate model structures showed a positive effect of onboard cameras on the reporting of seabird capture rates: the model estimated that fisher reporting of seabird captures in the pilot programme fleet was around twice as high when vessels had onboard cameras than when they were without cameras (the median effect was 1.6 times higher when the analysis was restricted to vessels in the pilot programme, and 2.2 times higher when the whole fleet was included in the analysis). There was a 99.9% probability that the fisher-reporting rate increased during the trial for the analysis extended to the whole fleet.

To date, fisher-reported captures have not been used in the estimation of the impact of fishing on seabirds, due to the low reporting rates and potential limitations with species identification. Further data, both from observers and from an ongoing camera trial, will help to improve our understanding of variations in fisher-reporting rates in the bottom-longline fishery.

# 1. INTRODUCTION

Modern fisheries management relies on monitoring programmes to assess fishing activities, including the collection of data on effort, catch composition, and interactions with protected species (Food and Agriculture Organization of the United Nations 2002). Data from this monitoring include fisher-reported information and independently-collected data, including data from vessel-monitoring systems and fishery observers. Fishery observers are critical for obtaining detailed at-sea records, including the number and identity of protected species incidentally captured during fishing operations. These observer data form the basis of bycatch assessments, but observer effort frequently varies across fisheries and is generally low in comparison with total fishing effort (Lewison et al. 2004). For example, in New Zealand, observer coverage has been consistently low (frequently less than 5% of annual fishing effort) in small-vessel inshore fisheries (Abraham & Richard 2019a).

The limitations associated with placing observers on fishing vessels have led to the exploration of alternative monitoring approaches in New Zealand and elsewhere, including at-sea electronic monitoring through the use of cameras (Ames et al. 2007, McElderry et al. 2008, McElderry et al. 2010, Kindt-Larsen et al. 2012, Sylvia et al. 2016). In New Zealand, recent pilot studies have assessed the efficacy of electronic monitoring for the detection of black petrel (*Procellaria parkinsoni*) captures in bottom-longline fisheries in north-eastern North Island, with earlier research including electronic monitoring trials in longline, trawl, and set-net fisheries (McElderry et al. 2008, McElderry et al. 2011).

Black petrel has been identified as the species most at risk of population impacts from captures in commercial fisheries (Richard & Abraham 2015, Richard et al. 2017a). Black petrel breed on Little Barrier and Great Barrier islands in Hauraki Gulf during summer, residing in the Hauraki Gulf area and adjacent waters during that time (Bell et al. 2016). In order to monitor black petrel captures, a recent pilot electronic-monitoring (EM) programme was implemented in October 2016 (the 2016–17 fishing year) in bottom-longline fisheries targeting snapper and bluenose in the Hauraki Gulf and Bay of Plenty areas, Fisheries Management Area FMA 1. During electronic monitoring, the haul of the catch was filmed, and the footage was reviewed, allowing seabird captures to be identified. The electronic monitoring programme was a pilot project for the operation of camera systems on longline vessels, and is referred to here as the "EM-pilot". A key goal of the programme was to assess the feasibility of using cameras for monitoring seabird bycatch, including black petrel. Participating vessels were selected for the pilot study based on the spatial overlap of their fishing activity with the distribution of black petrel, as well as having had observer coverage in the past (D. Middleton, Trident Systems Limited, pers. comm.). Participation in the pilot program was voluntary.

In Australia, the introduction of EM led to an increase in the fisher-reporting of protected species captures (e.g., Emery et al. 2019). Here, we report on the impact of onboard cameras on fisher-reporting for seabird captures in bottom-longline fisheries targeting bluenose and snapper in FMA 1. The analysis spans the period when the catch forms allowed fishers to record seabird captures (i.e., from 2009–10 onwards), up to the first two years of the EM pilot programme (2016–17 and 2017–18). The analysis included a comparison of the fishing characteristics between bottom-longline vessels with EM equipment and the full fleets of snapper and bluenose target fisheries. To quantify the effect of electronic monitoring on seabird capture rates, Bayesian General Linearised Mixed Models (GLMMs) were fitted to the fisher-reported datasets of each target fishery. The statistical modelling also included other factors, such as observer presence, seasonal trends and spatial covariates (geographic coordinates, sea surface chlorophyll-*a* and bathymetry) that may relate to the distribution of seabirds, including black petrel.

# 2. METHODS

## 2.1 Data preparation

The analysis of fisher reported captures used catch and effort data recorded by fishers on LTCER (Lining Trip Catch Effort Return) forms that were submitted to Fisheries New Zealand. The analysis started in the 2009–10 fishing year, when the LTCER forms had been fully adopted across both target fisheries (see

Appendix A; Figure A-1), and ended in 2017–18, the last fishing year for which the observer data were available.

The analysis used data prepared for protected species capture estimation, up to the end of the 2017–18 fishing year (Abraham & Berkenbusch 2019). Fishing events were assigned to a fishery based on the fishing method and the fisher-declared target species. For this analysis, all trips in the bottom-longline fisheries targeting snapper and bluenose in FMA 1 were included, as these target fisheries were the focus of the electronic monitoring pilot programme (see Appendix B, Table B-1 and Figure B-2). Fisher-reported seabird captures for a fishing event were calculated by summing all capture records for species codes starting with an "X" from the non-fish capture tables.

Fisheries observers onboard commercial fishing vessels record the captures of protected species. These records provide an independent means of assessing incidental captures of protected species such as seabirds. An extract from the observer data was included in the present analysis using data from the snapper and bluenose target fisheries in FMA 1 to assign an observed status to each fishing trip (with or without observer).

Records from the electronic monitoring pilot programme were obtained from Trident Systems Limited, and covered the 2016–17 and 2017–18 fishing years. These records included information about fishing events with electronic monitoring, including a vessel identifier allowing a link to the fisher-reported data and additional information on the status of the recorded footage (e.g., percentage of footage reviewed). This dataset was used to assign a camera status (present or absent) to fishing events, and to identify an "EM-pilot fleet". The latter consisted of vessels that had participated in the electronic monitoring pilot programme, with at least one trip where a camera was present.

Analyses for the snapper and bluenose target fisheries were conducted independently. Once extracts were obtained from the relevant datasets, all subsequent data explorations and statistical analyses were conducted in R (R Core Team 2019).

### 2.2 Initial assessment of datasets

Changes in the temporal and spatial distribution of vessels in the EM-pilot fleet and the full fleet were compared, to assess whether any affect of electronic monitoring on the EM-pilot fleet could be extrapolated to fishing years when there was no electronic monitoring programme, or to vessels not belonging to the pilot programme.

For each vessel in the EM-pilot fleet, we compared the location of fishing activity when cameras were either present or absent. We also compared the location of fishing events and patterns of total and seasonal activities for individual vessels in the EM-pilot fleet with vessels in the rest of the fleet. All fishing events by EM-pilot vessels were considered, even when no camera was present, to identify vessel-specific behaviours.

### 2.3 Effect of on-board cameras on reported seabird captures

Captures reported by fishers were examined for the presence of a camera effect and an observer effect on seabird capture rates (all species). We also estimated baseline differences in fisher-reporting of seabird captures in the presence and absence of observers, prior to the commencement of the EM pilot programme (see Section 2.3.1).

The models were fitted to fisher-reported seabird capture data for the fishing years from 2009–10 to 2017–18. A covariate "camera present" was included with other covariates informed by the initial exploration of datasets. Models for the snapper and bluenose target fisheries were fitted independently. For each candidate model structure, the fitting procedure was conducted first on fishing events for vessels in the EM-pilot fleet only; it was then applied a second time on all fishing events including vessels not participating in the EM pilot programme.

Model fits were examined for the presence and statistical significance of camera and observer effects. Shifts in the position of the estimated effects under alternate model structures were also verified to ensure that the estimated camera and observer effects were not confounded with another covariate.

The models were fitted using Bayesian Markov chain Monte Carlo (MCMC) methods using the R package "brms" (Bürkner 2017). This package provides an efficient interface for fitting GLMMs in the Stan language (Carpenter et al. 2017, 1). A negative binomial error distribution was used, given the strong overdispersion in the seabird capture data, with most fishing events (more than 99%) reporting no captures. The impact of varying effort by fishing set on the probability of a positive capture event was accounted for by parameterising the negative binomial distribution by the number of trials, defined by the number of fishing hooks used in the fishing event (see Abraham et al. 2019 for the application of a similar model structure in trawl fisheries).

To improve model-fitting performance, the seabird captures and effort datasets were aggregated prior to fit over fishing year, month, vessel, 1-degree longitude and latitude, observer category and camera category. The model-fitting approach started with a basic model structure, gradually adding new covariates to assess changes to the estimates and improvement in model fit.

In the model, captures, $c_i$, in a bottom-longline set group, $i$, were modelled as samples from a negative-binomial distribution:

$$c_i \sim \text{NegativeBinomial}(\text{mean} = \mu_i n_i,\ \text{shape} = \theta n_i), \tag{1}$$

where $n_i$ is the number of hooks. The shape parameter, $\theta$, allows for extra dispersion in the number of captures, relative to a Poisson distribution. The negative-binomial distribution has the property that the mean of $n$ samples from a negative-binomial distribution (NegativeBinomial($\mu, \theta$)) is itself negative-binomially distributed, with mean $\mu n$ and shape $\theta n$. For this reason, while $c_i$ is the number of captures per group, $\mu_i$ needs to be interpreted as the mean capture rate per bottom-longline hook. The custom distribution facility of BRMS was used to code the negative binomial distribution for aggregated data. The mean capture rate within each group was then estimated as the exponential of the linear predictor, which was the sum of fixed and random effects.

A new parameter, $\nu$, was added to the parameterisation of the negative binomial distribution to allow more flexibility in the relationship between overdispersion and the mean catch rate (see also Abraham et al. 2019). Under the usual approach to fit a negative binomial GLM, overdispersion compared to mean catch rates $\mu$ is determined by the estimate of a single parameter $\theta$ assumed for all observations:

$$\psi = \mu + \frac{\mu^2}{\theta}. \tag{2}$$

This aspect can be challenging when combinations of covariate levels have considerably higher catch rates than others, as high $\mu$ combined with low $\theta$ can result in error distributions predicting implausibly high values (i.e., very long tails) at times. Although estimating covariate effects on $\theta$ as part of the model is possible, the results can be difficult to interpret as $\mu$ and $\theta$ are often correlated. For this reason, any covariate effect attributed to $\theta$ might otherwise be confounded with a covariate effect on $\mu$. We modified instead the definition of $\theta$, so that it includes a new parameter, $\nu$, scaling the extent of overdispersion as a function of $\mu$:

$$\theta \to \mu^\nu \theta, \tag{3}$$

so that overdispersion to the negative binomial distribution becomes:

$$\psi = \mu + \frac{\mu^2}{\mu^\nu \theta}. \tag{4}$$

This configuration allows for the overdispersion parameter to change as a function of $\mu$: as $\nu$ approaches 2, it cancels out $\mu^2$ in the numerator, so that the negative binomial distribution effectively becomes a Poisson distribution; as $\nu$ approaches 0, the additional $\mu^n$ term goes to 1 and the distribution converges back towards a standard negative binomial. Therefore, adding this new term in the model allows for additional flexibility in the realised error distribution between observations with the estimation of a single additional parameter. Upon initial testing all model diagnostics were improved with the inclusion of $\nu$ in the parameterisation of the negative binomial GLMMs, so we retained this formulation for all models.

We trialled four approaches to model the effect of having a camera and/or an observer present at a fishing event for the pilot fleet. The best approach was chosen based on model fit and relevance of the definition given the objective of the analysis, and used in all subsequent models. The approaches spanned different assumptions about the independence of the camera and observer effects:

1. the effects were treated as two independent variables (Camera + Observer);

2. the effects were independent but allowed an interaction (Camera + Observer + Camera:Observer), expecting that the presence of both camera and observer would have an additional effect;

3. the effects were treated as two variables, but fishing events with both a camera and observer were assumed to be observer-only (CameraMod + Observer), with the expectation that the camera effect was irrelevant when an observer was onboard, such that sets with both camera and observers were classified as observed-only (‘Observer‘);

4. the effects were treated as a single variable (ObserverCameraCombined) with three levels: unobserved, camera-only or observer-only. Similar to assumption (3), this approach assumed that the camera effect was irrelevant when an observer was onboard.

Using the model formula notation of BRMS, the basic model structure was:

captures | trials(hooks) $\sim$ CameraObserver + s(Month, bs=‘cc’) + (1|year) + (1|vessel).

In this formula, “captures” is the number of fisher-reported seabird captures ($c$); “trials(hooks)” indicates that the total number of hooks in a group is to be treated as a number of trials when parameterising the distribution; “CameraObserver“ is the chosen approach to model the camera and observer effects based on the options outlined above; “s(Month, bs=‘cc’)” specifies a seasonal effect via a cyclical spline fitted on month (allowing consistency between the effects for December and January), “(1|year)” is a random effect on the fishing year and “(1|vessel)” is a random effect on the vessel, accounting for operational differences across vessels that could result in different capture rates per vessel, and vessel-specific distributions of spatial activity.

From this basic structure, we tested the inclusion of spatial covariates, as we would expect the probability of seabird capture to be influenced by local abundance, and key seabird species (e.g., black petrel) are unevenly distributed across the Hauraki Gulf region. We tested three types of spatial covariates: a random effect for the longitude-latitude cell at the 1°resolution, a non-linear relationship (spline) for the mean chlorophyll-*a* by month and 1°cell, and a non-linear relationship (spline) for the bathymetry (these alternative model structures are outlined in Table 1). Each candidate structure was fitted independently to the snapper and bluenose target fisheries using the EM-pilot fleet in the first instance and the full fleet dataset second.

Bayesian GLMMs were fitted by MCMC methods with four chains over 2000 iterations and a burn-in period of 1000 iterations. Model performance was assessed with diagnostics comparing key trends in estimated and observed capture rates, including model prediction of total seabird captures by fishing year, the proportion of zero captures per fishing year and month, and the distribution of positive capture events (median and tails), to ensure that the overdispersion in the capture data is accurately represented by the model.

Alternative model structures were compared based on the leave-one-out information criterion (Vehtari et al. 2016a, 2016b). Like the Akaike Information Criterion (AIC), this metric balances additional model complexity with improvement in the fit, and can be used to test whether the addition of model covariates is warranted by the resulting changes in model fit. A smaller LOOIC value indicates an improved model.

Assuming that electronic monitoring was present on all fishing events, seabird capture rates were extrapolated by using the same dataset as in the model-fit scenario but switching the value of "camera" to present for all events. Predictions were made by drawing from each MCMC trace of the model (i.e., 4000 draws).

Diagnostics and estimated effects for key models are shown in Appendices C and D.

**Table 1: Model structures used to assess the impact of onboard cameras on the fisher-reporting of seabird captures in bottom-longline fisheries in northeastern New Zealand. Model covariates included: ObserverCameraCombined, a three-level variable indicating whether sets were unobserved, had an observer, or were recorded by a camera; s(Month, bs='cc'), season; (1|year), random effect on the fishing year; (1|vessel), random effect on the vessel; (1|Cell), random effect on the 1° cell; s(bathymetry), bathymetry; s(chlorophyll-a), sea surface chlorophyll-*a* concentration.**

| Model | Model structure |
|---|---|
| Response variable | captures \| trials(hooks) $\sim$ |
| Baseline | ObserverCameraCombined + s(Month, bs='cc') + (1\|year) + (1\|vessel) |
| + Cell | ObserverCameraCombined + s(Month, bs='cc') + (1\|year) + (1\|vessel) + (1\|Cell) |
| + Cell (No vessel) | ObserverCameraCombined + s(Month, bs='cc') + (1\|year) + (1\|Cell) |
| + Cell + chlorophyll-a | ObserverCameraCombined + s(Month, bs='cc') + (1\|year) + (1\|vessel) + (1\|Cell) + s(chlorophyll-a) |
| + Cell + bathymetry | ObserverCameraCombined + s(Month, bs='cc') + (1\|year) + (1\|vessel) + (1\|Cell) + s(bathymetry) |

### 2.3.1 Assessing the observer effect for vessels within and outside of the pilot fleet before the EM pilot started

To inform the interpretation and extrapolation of camera effects from the pilot fleet to other vessels, we also estimated baseline differences in fisher-reporting of seabird captures in the presence and absence of observers, prior to the commencement of the EM pilot programme. We used the modelling framework described above and applied the following model structure to the full dataset, filtered to remove 2016–17 and 2017–18, the two years when the EM pilot was active:

captures | trials(hooks) $\sim$
s(Month, bs='cc') + (1|year) + InPilotFleet + Observer + InPilotFleet:Observer,

where "InPilotFleet" is a binary variable, indicating whether the vessel participated in the EM pilot or not. The interaction term "InPilotFleet:Observer" allowed testing whether there was a different effect of having an observer on-board on reported capture rates for the pilot fleet versus other vessels.

**Table 2: Observer coverage, fishing effort and seabird captures for bottom-longline vessels targeting snapper in northern North Island, Fisheries Management Area 1. Data are for vessels participating in the electronic monitoring pilot programme using cameras (EM pilot) and other vessels, for the period 2009–10 to 2015–16 (before the camera trial) and for the 2016–17 and 2017–18 fishing years (during the camera trial). Included are the number of vessels with some fishing in each fleet, the number of sets, the number of hooks set (thousand hooks), the number of fisher-report seabird captures, and the bird captures per unit effort (BPUE; per thousand hooks).**

| Period | Observed | Fleet | Vessels | Sets | Hooks | Captures | BPUE |
|---|---|---|---|---|---|---|---|
| 2009–16, before trial | No | EM pilot | 8 | 9 149 | 28 709 | 126 | 0.0044 |
| | | Others | 68 | 29 369 | 45 033 | 103 | 0.0023 |
| | Yes | EM pilot | 8 | 322 | 1 036 | 11 | 0.0106 |
| | | Others | 37 | 660 | 1 000 | 76 | 0.0760 |
| 2016–18, during trial | No | EM pilot | 9 | 2 587 | 8 275 | 74 | 0.0089 |
| | | Others | 32 | 6 010 | 11 730 | 18 | 0.0015 |
| | Yes | EM pilot | 9 | 164 | 512 | 5 | 0.0098 |
| | | Others | 12 | 126 | 207 | 2 | 0.0097 |
| All | All | All | 85 | 48 387 | 96 502 | 415 | 0.0043 |

# 3. RESULTS

## 3.1 The snapper target fishery

There were nine vessels in the EM-pilot fleet that targeted snapper in FMA1, out of a total of 41 that targeted snapper in FMA 1 during the period of the trial (Table 2). The vessels that were included in the trial tended to set more hooks than the other vessels, and over the two year period of the trial, 42.1% of the hooks set by bottom longline vessels targeting snapper were on vessels that were participating in the EM-pilot. Observer coverage in the snapper bottom-longline fishery was low, with observer coverage of 2.9% over the period 2009–10 to 2017–18 and of 3.5% during the two year period of the camera trial.

Across the entire period used for the analysis, 2009–10 to 2017–18, a total of 415 seabird captures were reported by fishers in FMA 1 snapper bottom-longline fisheries (Table 2). When restricted to the vessels that participated in the camera trial, the fisher-reported seabird capture rate on unobserved fishing increased from 0.0044 to 0.0089 birds per 1000 hooks, an increase of a factor of around two. At the same time, on observed fishing the seabird capture rate remained steady, at a rate of 0.0106 birds per 1000 hooks before the trial, and 0.0098 birds per 1000 hooks during the trial (although because of the low observer coverage, these raw figures should be treated with caution). Fisher-reported captures during unobserved fishing on the vessels that did not participate in the trial were lower, with rates of 0.0023 and 0.0015 birds per 1000 hooks, before and during the trial, respectively.

Most of the records identified at the species level were either flesh-footed shearwater (*Puffinus carneipes*; 235 captures) or black petrel (*Procellaria parkinsoni*; 90 captures). Other species with more than five fisher-reported captures were Buller's shearwater, sooty shearwater, Cape petrel, and fluttering shearwater (Table 3). During the 2016–17 and 2017–18 fishing years, a total of 99 seabird captures were reported by fishers, and 79 of these captures were from vessels that were part of the EM-pilot.

These patterns in the fisher-reported bycatch rate were consistent across years (Figure 1). In the bottom-longline fleet targeting snapper, EM-pilot vessels generally had greater observer coverage. In four of the six years with observed fishing events, fisher-reported seabird capture rates were higher for the observed than for the unobserved component of the non-EM-pilot fleet. On unobserved fishing, fisher-reported captures were typically higher in the EM-pilot fleet than in the other-vessel fleet.

Across all years, the spatial distribution of fishing effort by vessels that were part of the EM-fleet was closer to the shelf edge than was typical for the fleet as a whole (Figure 2). During the year of the camera

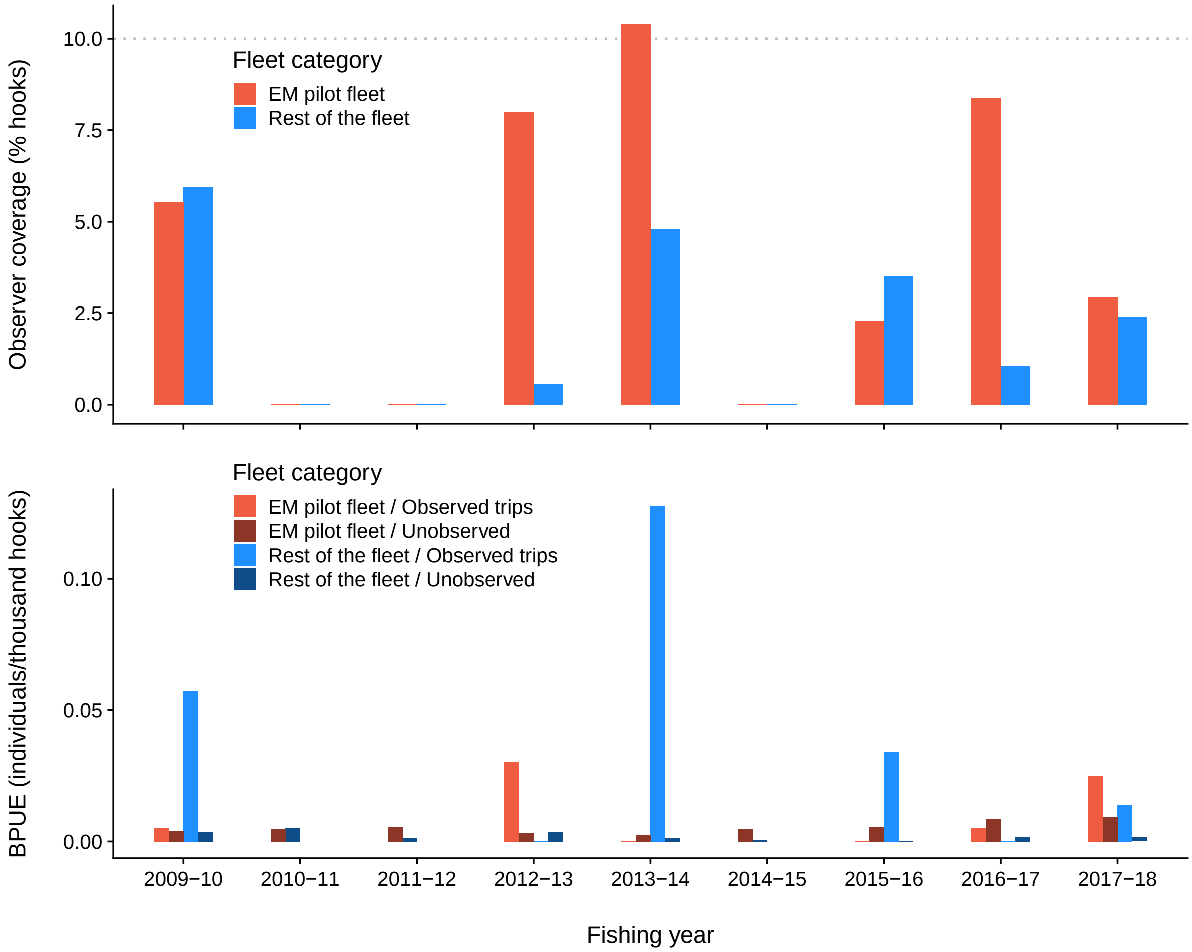


**Figure 1: Comparison of observer effort (top) and of fisher-reported seabird capture rates for the observed and unobserved components (bottom) between the electronic-monitoring (EM) pilot fleet and the remaining fleet of bottom-longline vessels targeting snapper in northeastern New Zealand. The top graph shows annual observer coverage (percentage of hooks set that were observed), with the dotted line indicating 10% observer coverage. The bottom graph shows the BPUE (bird capture per unit effort, i.e., per 1000 hooks).**

**Table 3: Fisher-reported captures of seabirds in Fisheries Management Area (FMA) 1 snapper bottom-longline fisheries, from 2009–10 to 2017–18. The identification of these captures is as reported by the fishers, and has not been independently checked.**

| Common name | Scientific name | Captures |
|---|---|---|
| Flesh-footed shearwater | *Puffinus carneipes* | 235 |
| Black petrel | *Procellaria parkinsoni* | 90 |
| Petrels, prions, and shearwaters | Hydrobatidae, Procellariidae & Pelecanoididae | 41 |
| Buller's shearwater | *Puffinus bulleri* | 9 |
| Sooty shearwater | *Puffinus griseus* | 8 |
| Cape petrel | *Daption capense* | 7 |
| Shearwaters | *Puffinus* spp. | 6 |
| Fluttering shearwater | *Puffinus gavia* | 6 |
| Australasian gannet | *Morus serrator* | 2 |
| Gannets and boobies | Sulidae | 2 |
| Buller's albatross | *Thalassarche bulleri* | 1 |
| Westland petrel | *Procellaria westlandica* | 1 |
| Cape petrels | *Daption* spp. | 1 |
| Common diving petrel | *Pelecanoides urinatrix* | 1 |
| White-bellied storm petrel | *Fregetta grallaria grallaria* | 1 |
| Gulls | Laridae | 1 |
| Penguins | Spheniscidae | 1 |
| Short-tailed shearwater | *Puffinus tenuirostris* | 1 |
| Southern black-backed gull | *Larus dominicanus dominicanus* | 1 |

trial, however, the spatial distribution of fishing by the EM-fleet was more representative of the entire fleet, including within Hauraki Gulf.

In general, there was lower fishing effort in winter than in summer by the snapper bottom longline vessels (Figure 3). The seasonal pattern of fishing by the EM-pilot vessels was similar to the seasonal fishing patterns of the whole fleet for most vessels.

## 3.2 The bluenose target fishery

There were five vessels in the EM-pilot fleet that targeted bluenose in FMA 1, out of a total of 17 that targeted bluenose in FMA 1 during the period of the trial (Table 4). Over the two year period of the trial, 75.1% of the hooks set by bottom longline vessels targeting bluenose were on vessels that were participating in the EM-pilot. In general, observer coverage in the bluenose bottom-longline fishery was low, with observer coverage of 2.4% over the period 2009–10 to 2017–18, but with an increase to 11.4% during the two year period of the camera trial.

There was a total of 73 fisher-reported seabird captures over the entire period, of which 35 captures were reported by vessels within the EM-pilot fleet, all during the 2016–17 and 2017–18 fishing years (Table 4). It is striking that, on unobserved fishing by vessels that participated in the trial, the only fisher-reported seabird captures (26 captures) occurred during the period of the trial (even though the number of hooks set by these vessels during the trial was only 21.7% of the number set in the years before the trial). Although the number of observed hooks was low, the highest fisher-reported capture rates were during observed fishing events.

For the bluenose target fleet, seabird captures were only recorded in three fishing years; for those years, the capture rate was higher for observed trips (Figure 4). Because of the sporadic nature of the reported captures within the bluenose fleet, the limited number of total captures, and the relatively low number of hooks set by vessels participating in the trial (less than 1 000 000), it is difficult to make inferences about variation in the reported capture rates between fishing with and without cameras. For this reason,

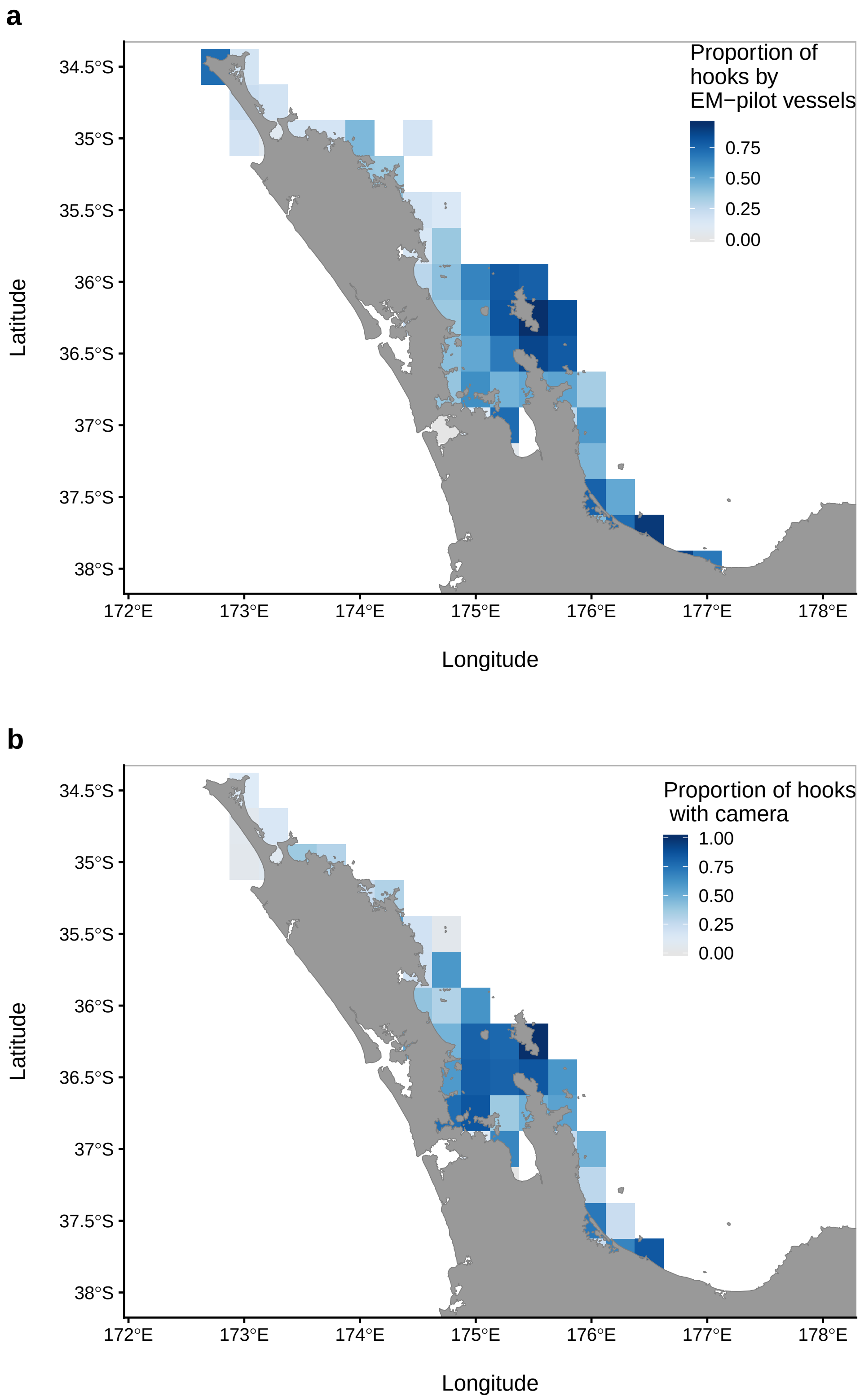


**Figure 2: Fishing effort (proportion of hooks set) by bottom-longline vessels targeting snapper that participated in the electronic monitoring pilot programme (EM-pilot) in northern North Island. Effort is shown within each 0.25-degree cell for cells with more than 20 sets, over the period 2008–09 to 2017–18 (a), and for the 2016–17 and 2017–18 fishing years only (b), i.e. while the EM pilot programme was ongoing.**

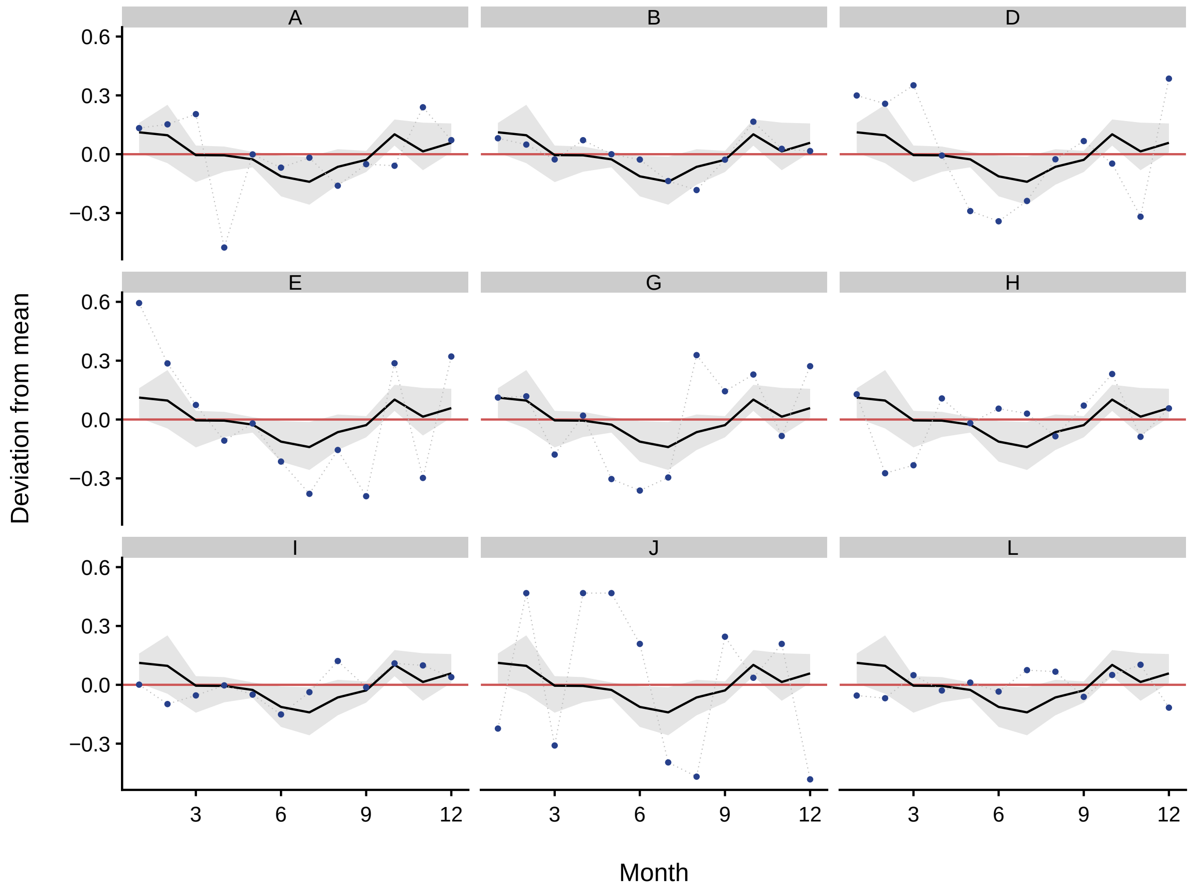


**Figure 3: Comparison of seasonality in fishing activity by individual bottom-longline vessels with onboard cameras targeting snapper, compared with the remainder of snapper bottom-longline fleet. Grey band shows the interquartile range for the deviation from the annual activity by vessel for the full fleet, overlaid line indicates the average deviation for vessels with cameras over their entire fishing period. Individual vessels with cameras are identified by different letters.**

**Table 4: Observer coverage, fishing effort and seabird captures for bottom-longline vessels targeting bluenose in northern North Island, Fisheries Management Area 1. Data are for vessels participating in the electronic monitoring pilot programme using cameras (EM pilot) and other vessels, for the period 2008–09 to 2015–16 (before the camera trial) and for the 2016–17 and 2017–18 fishing years (during the camera trial). Included are the number of vessels with some fishing in each fleet, the number of sets, the number of hooks set (thousand hooks), the number of fisher-report seabird captures, and the bird captures per unit effort (BPUE; per thousand hooks).**

| Period | Observed | Fleet | Vessels | Sets | Hooks | Captures | BPUE |
|---|---|---|---|---|---|---|---|
| 2009–16, before trial | No | EM pilot | 5 | 1 806 | 3 059 | 0 | 0.0000 |
| | | Others | 94 | 9 326 | 15 049 | 25 | 0.0017 |
| | Yes | EM pilot | 2 | 20 | 34 | 0 | 0.0000 |
| | | Others | 13 | 78 | 142 | 17 | 0.1200 |
| 2016–18, during trial | No | EM pilot | 5 | 477 | 664 | 26 | 0.0392 |
| | | Others | 12 | 171 | 205 | 0 | 0.0000 |
| | Yes | EM pilot | 4 | 66 | 109 | 9 | 0.0828 |
| | | Others | 1 | 1 | 3 | 0 | 0.0000 |
| All | All | All | 104 | 11 945 | 19 263 | 77 | 0.0040 |

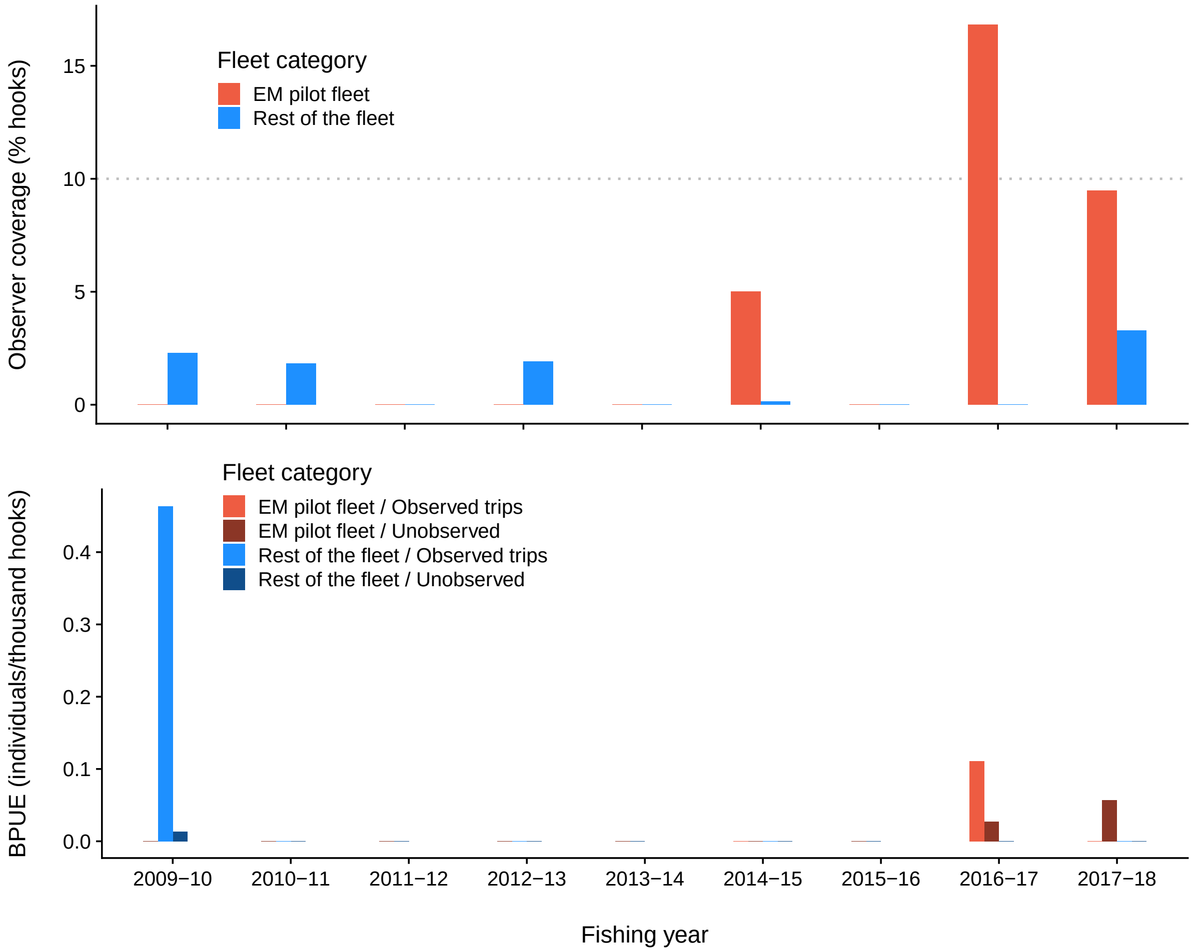


**Figure 4: Comparison of observer effort (top) and of fisher-reported seabird capture rates for the observed and unobserved components (bottom) between the electronic-monitoring (EM) pilot fleet and the remaining fleet of bottom-longline vessels targeting bluenose in northeastern New Zealand. The top graph shows annual observer coverage (percentage of hooks set that were observed), with the dotted line indicating 10% observer coverage. The bottom graph shows the BPUE (bird capture per unit effort, i.e., per 1000 hooks).**

fisher-reported captures in the bluenose fisheries are not considered further in the current analysis.

### 3.3 Statistical modelling of the camera effect

We fitted Bayesian GLMs to the fisher-reported data to assess the presence of a camera effect on the fisher-reported seabird captures. Only results for the snapper target fishery are presented, as model fits for the dataset of the bluenose target fishery were deemed unreliable.

A seasonal effect was included in the baseline model structure by using a cyclical spline. The cyclical spline constrains the start and end of the fitted relationship to meet at the same value, which is appropriate for a covariate like month, where 1 (January) follows 12 (December). The fitted spline successfully captured the expected smooth annual variation in seabird abundance during the year, with lower values during winter months (Figure 5) (both flesh-footed shearwater and black petrel migrate away from New Zealand outside of the breeding season which is September to May for flesh-footed shearwater and October to July for black petrel; Richard et al. 2017b).

There were no large differences in model performance between the candidate approaches to model the camera and observer effects (Table 5). The effects from a single variable with three levels (option 4, with

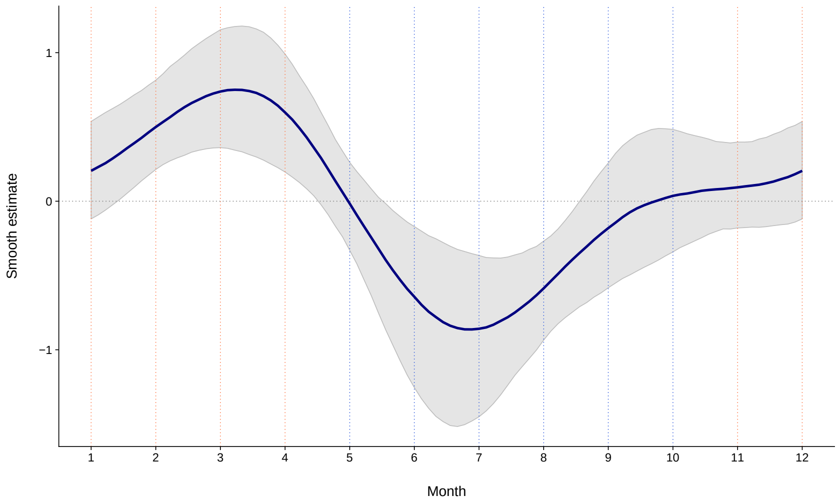


**Figure 5: Estimated effects for the cyclical spline fitted to month for the baseline + 1° cell model of the bottom-longline fishery targeting snapper in northern North Island. A higher value indicates that larger capture rates are to be expected during those months compared with the baseline (dotted line). The grey band shows the 95% confidence interval. The vertical lines highlight the six coldest and warmest months of the year, in blue and red respectively.**

**Table 5: Values for the leave-one-out information criterion for different model structures used to select the best approach to include camera and observer covariates in a model to measure the effect of electronic monitoring (EM) on the fisher-reporting of seabird capture rates. Models were based on data from the bottom-longline fishery targeting snapper in northeastern New Zealand for vessels that were part of a pilot fleet trialling onboard cameras.**

| Model | LOOIC |
|---|---|
| (1) Observer + Camera | 917.4 |
| (2) Observer + Camera + Observer:Camera | 918.8 |
| (3) Observer + CameraMod | 917.6 |
| (4) ObserverCameraCombined | 917.8 |

**Table 6: Values for the leave-one-out information criterion (LOOIC) for different model structures used to estimate the effect of electronic monitoring (EM) on the fisher-reporting of seabird capture rates. Models were based on data from the bottom-longline fishery targeting snapper in northeastern New Zealand, including vessels that were part of a pilot fleet, trialling onboard cameras. Model structures were the baseline model, plus covariates such as observer, bathymetry and sea surface chlorophyll-*a* concentration.**

| Model | LOOIC | |
|---|---|---|
| | EM pilot fleet | All vessels |
| Baseline | 917.8 | 1 729.0 |
| Baseline + Cell | 909.1 | 1 726.1 |
| Baseline + Cell (No vessel) | 923.9 | 1 953.2 |
| Baseline + Cell + chl-a | 911.2 | 1 726.9 |
| Baseline + Cell + bathymetry | 910.3 | 1 721.3 |

levels “unobserved”, “camera-only”, “observer”) allow direct comparison between the effect strengths, so we retained this structure for all subsequent models.

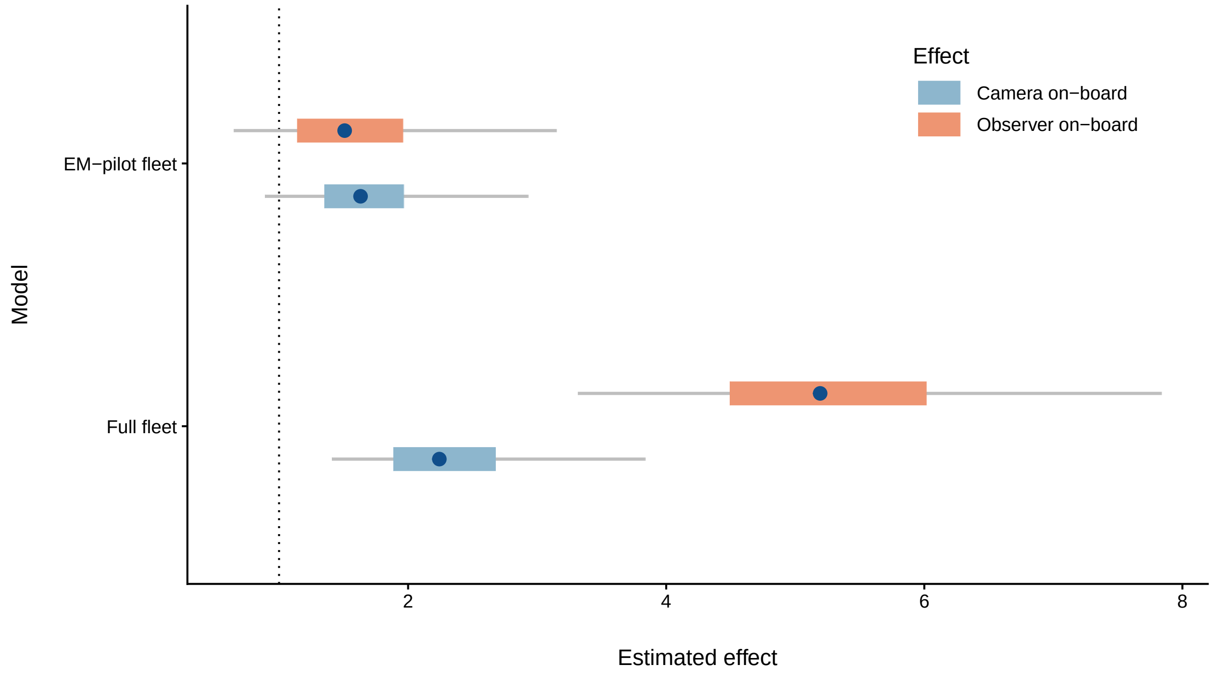


**Figure 6: Comparison of the estimated camera versus observer effect on seabird capture rates between different model structures. The effect is multiplicative on a baseline rate for unobserved sets without cameras (the intercept). The vertical dotted line indicates no effect (multiplicative effect of 1). Effects were estimated for the full fleet of bottom-longline vessels targeting snapper in northern North Island, and for vessels participating in the electronic monitoring pilot programme (EM-pilot). The 95% probable interval is shown in grey, the 50% probable interval in the darker band, and the median estimate in blue.**

For the EM-pilot fleet in the snapper target fishery, the smallest LOOIC value, indicating the best model structure, was the baseline model (see Section 2.3) with a cell effect (i.e., without an observer effect) (Table 6). The models not including a cell or a vessel effect ("Baseline" and "Baseline + Cell (No vessel)") performed less well; the inclusion of explicit spatial covariates (chlorophyll-*a*, bathymetry) did not improve the model. For the full snapper target fishery including all vessels, the baseline model with a cell effect and a non-linear effect for bathymetry performed the best, but the confidence bounds around the estimated bathymetry relationship were large. The second best-performing model was the baseline model with the cell effect; we used this model ("Baseline + Cell") for subsequent analyses for both the EM-pilot and the full fleet.

Positive camera effects were evident for both the EM-pilot fleet and the entire snapper target fishery across different model structures, accounting for the observer effect and also for spatial covariates (bathymetry and chlorophyll-*a*) (Figure 6 and Appendix C, Figure C-4 comparing key model structures). In the model applied to the EM-pilot fleet only, the camera effect was 1.63 (95% c.i.: 0.89–2.93), indicating that the fisher-reporting rate of seabird captures was estimated to be 1.6 times higher during the camera trial than before it. The lower bound overlaps the no-effect value of one, but within this model there is a 94.7% probability that the multiplicative camera effect is larger than one. When the analysis was expanded to the full fleet, the camera effect was slightly higher (2.24; 95% c.i.: 1.41–3.84), with a 95% credible interval that no longer includes one and a 99.9% probability that the camera effect is larger than one.

In the model applied to the EM-pilot fleet only, the observer effect was a multiplicative effect of 1.51 (95% c.i.: 0.65–3.15), and also overlapped with the camera effect. In contrast, for the dataset spanning the entire snapper target fishery, the observer effect was considerably more important than the camera effect, but estimated with higher uncertainty (5.19; 95% c.i.: 3.32–7.84).

### 3.4 Differences before the electronic monitoring pilot

A Bayesian GLMM was fitted to the full fleet dataset for years prior to the commencement of the EM pilot programme, to assess whether the presence of an onboard observer had a different effect on pilot vessels compared with full fleet vessels.

The presence of an onboard observer had a slight positive multiplicative effect on fisher-reported seabird capture rates for the pilot fleet (median: 1.65; 95% c.i.: 0.58–4) and a large positive effect for vessels in the remainder of the fleet (median: 12.67; 95% c.i.: 4.26–41.73).

## 4. DISCUSSION

Fishers are required to report the capture of protected species when they occur; however, in New Zealand, fisher-reported rates of seabird captures have historically been lower than captures rates derived from observer data (Abraham & Thompson 2011). In Australia, the introduction of video monitoring on surface-longline vessels resulted in an increase in the fisher reporting of seabird, marine mammal, and turtle captures (Emery et al. 2019). In that study, the fisher-reported capture rates of seabird captures in the eastern tuna and billfish longline fishery increased from 0.0006 to 0.0054 birds per 1000 hooks, an increase by a factor of nine.

In the 2016–17 fishing year, a pilot programme using electronic (video) monitoring was initiated in bottom-longline fisheries in the Hauraki Gulf area (FMA 1); this programme was prompted by discussions by the Black Petrel Working Group, and had the purpose of trialling the use of camera footage for monitoring protected species bycatch. In this study, we analysed data from this pilot programme to explore the influence of onboard cameras on the fisher-reporting of seabird bycatch. In particular, we assessed fisher-reported records of seabird captures in the bottom-longline fleet targeting snapper in FMA 1. The analysis included the first two years (2016–17 and 2017–18); it also included earlier data from 2009–10 onwards, when a change in reporting form facilitated the self-reporting of seabird captures by fishers in bottom-longline fisheries. The analysis included all records of seabird captures, and most of the records identified at the species level were either flesh-footed shearwater (*Puffinus carneipes*) or black petrel (*Procellaria parkinsoni*).

For the snapper target fishery, for the vessels that participated in the camera trial, the rate of fisher-reported seabird captures increased from 0.0044 birds per thousand hooks before the trial to 0.0089 birds per thousand hooks during the trial. The data from the trial included all fishing when the cameras were installed, irrespective of whether they were collecting footage, or whether footage was subsequently reviewed. This increase of around a factor of two was supported by statistical analysis. Key candidate model structures showed a positive effect of onboard cameras on the reporting of seabird capture rates: the model estimated that fisher-reporting of seabird captures on the pilot programme fleet was around twice as high when the vessels had cameras on board than when they were without cameras (the median effect was 1.6 times higher when the analysis was restricted to vessels in the pilot programme, and 2.2 times higher when the whole fleet was included in the analysis). When the analysis was restricted to the pilot fleet, there was a 94.7% probability that the fisher-reporting rate increased during the trial. This probability increased to 99.9% when the analysis extended to the whole fleet. Within the pilot fleet, the effect of cameras on fisher-reporting was similar to the effect of having an observer on board.

One aspect that potentially confounds the analysis is that fisher-reported seabird capture rates on the vessels selected for the electronic monitoring pilot programme were higher than for other vessels (even in the years before the camera trial began). This finding was somewhat expected, as pilot vessels were chosen for the trial in part based on their tendency to fish in areas with high black petrel abundance (David Middleton, Trident Systems Limited, pers. comm.). This aspect was controlled for by carrying out an analysis that was restricted to the pilot fleet only, and also for the full fleet.

While the fisher-reporting appears to have increased during the trial, an analysis of the data did not provide information on why this change occurred. The presence of a camera on the vessel, with the prospect that any capture could be found during review, may have led to increased fisher reporting. In contrast, participating in the trial would have led to the fishers being exposed to the issue of seabird bycatch, as well as an increase in the fishers engagement with fisheries management. This involvement may have led to an improvement in the reporting practices of the fishers.

Although we did not carry out a formal analysis of changes in reporting in the bluenose fishery, the only fisher-reported seabird captures on unobserved fishing by the vessels that participated in the trial occurred when cameras were installed. Further data, both from observers and from an ongoing camera trial, would help to understand variation in fisher-reporting rates in this fishery.

Analysing the impacts of fishing on seabird populations is challenging given the low observer coverage in small-vessel bottom longline fisheries. When considering all seabirds and commercial fisheries within New Zealand waters, black petrel is the New Zealand seabird species that is most at risk from the impact of commercial fishing, and flesh footed shearwater is the species with the third highest risk (Richard & Abraham 2017). Both of these species are caught in bottom-longline fisheries in northern New Zealand. To date, fisher-reported captures have not been used in the estimation of the impact of fishing on seabirds, due to the low reporting rates and potential limitations of species identification (e.g., Abraham & Richard 2019b). Improved reporting rates could increase the reliability of fisher-reported captures for use in future analyses of fishing impact on seabird populations.

## 5. ACKNOWLEDGMENTS

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## APPENDIX A: TYPES OF FORMS USED IN BOTTOM-LONGLINE FISHERIES

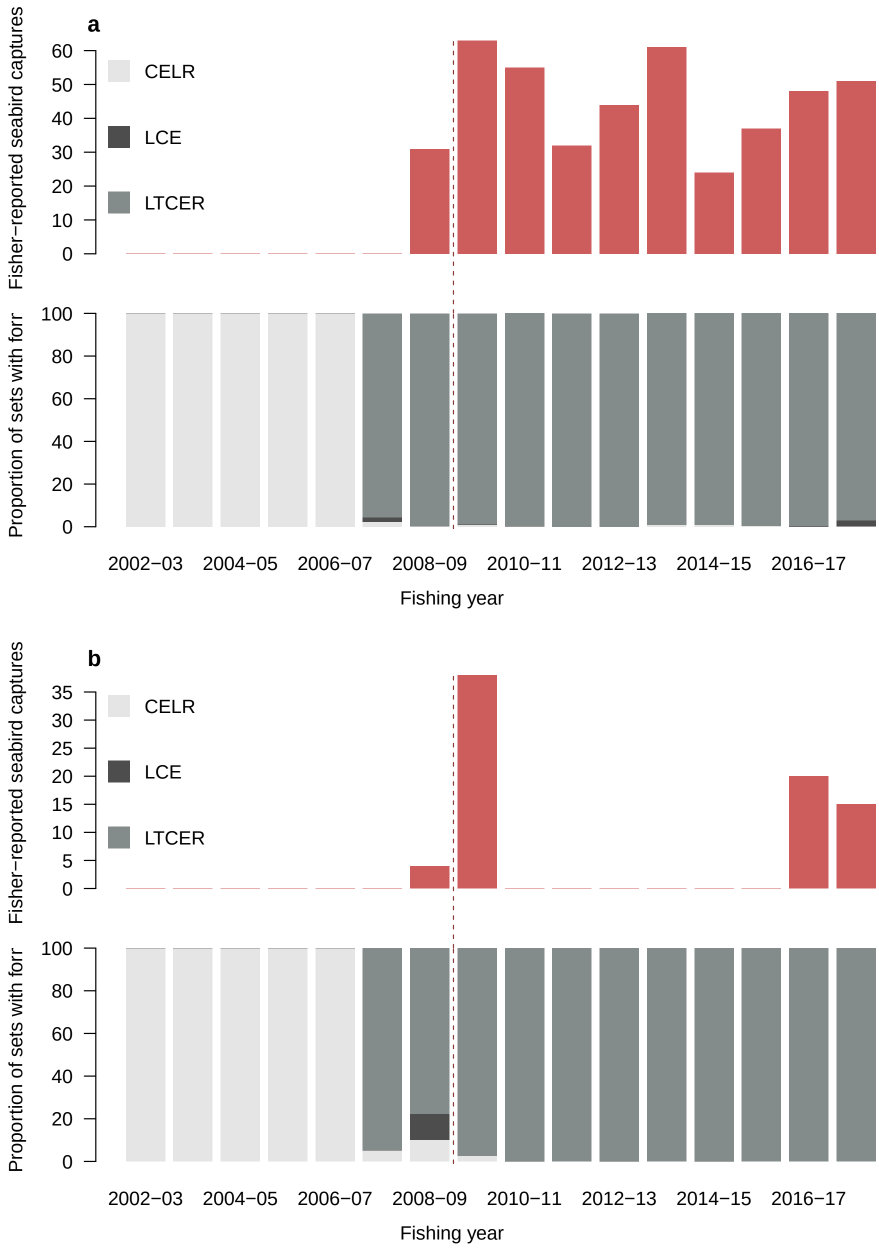


**Figure A-1: Total number of fisher-reported seabird captures (red) and proportion of fisher-reporting forms (grey) in the bottom-longline fishery targeting snapper (a) and bluenose (b), by fishing year, showing the transition to form types enabling the reporting of seabird captures. Forms were: CEL, Catch Effort Landing; LCE, Lining Catch Effort; LTC, Lining Trip Catch. Dashed red line indicates the start of the current reporting period.**

## APPENDIX B: ELECTRONIC MONITORING OF BOTTOM-LONGLINE FISHERIES

### B.1 Electronic monitoring data

There was a total of 4656 bottom-longline sets with a camera onboard. Of this total number of sets, 812 sets had footage reviewed. Most sets (77.1%) were in bottom-longline fisheries targeting snapper and bluenose (Figure B-2 and Table B-1). Although not all sets on vessels with a camera had associated footage, most sets had a relatively continuous time-series of footage covering the haul; reviewed footage usually spanned a series of contiguous sets (Figure B-3).

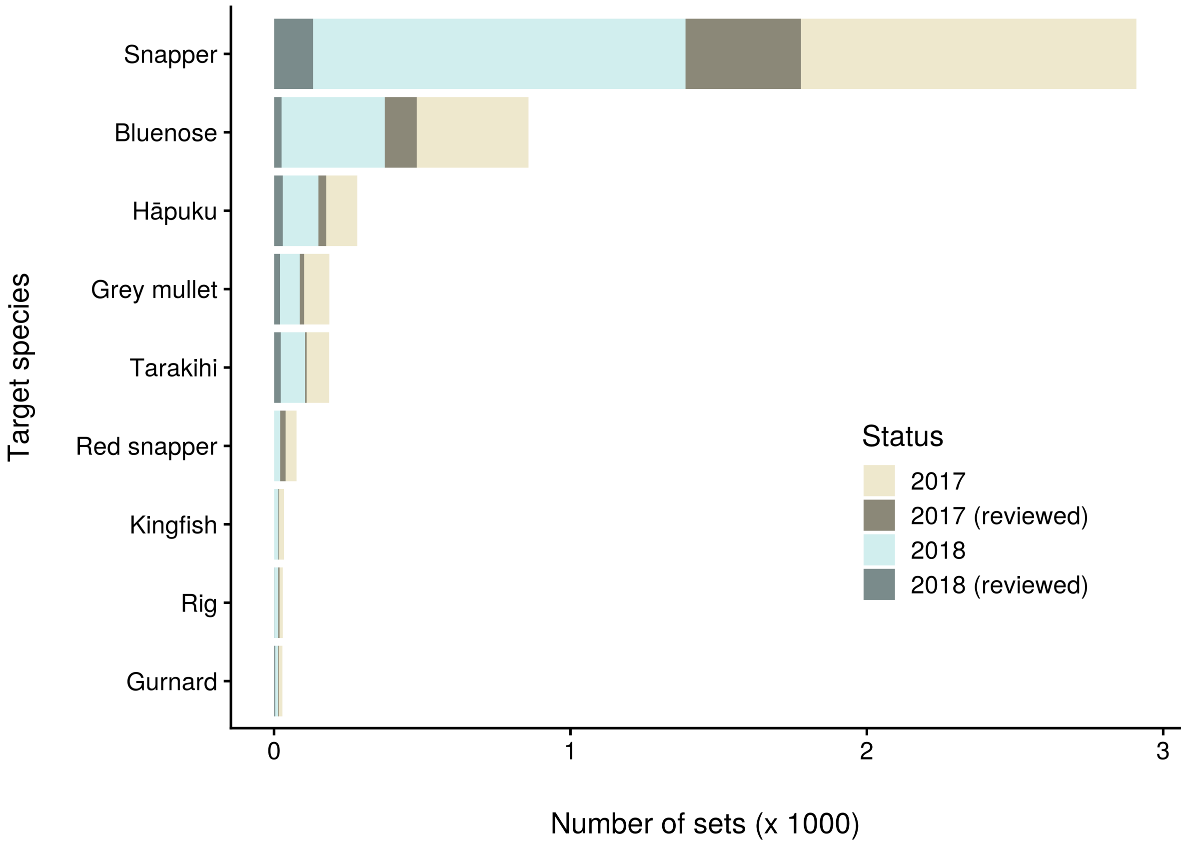


**Figure B-2: Number of sets in bottom-longline fisheries that had electronic monitoring with onboard cameras in 2016–17 (2017) and 2017–18 (2018). Data are shown by target species, and include the number of sets with reviewed footage for each fishing year. Target species were: SNA, snapper; BNS, bluenose; HPB, hāpuku; GMU, grey mullet; TAR, tarakihi; RSN, red snapper; KIN, kingfish; SPO, rig; GUR, gurnard.**

**Table B-1: Summary of number of sets per target species and fishing year for bottom-longline target fisheries with at least ten sets with an onboard camera. Target species were: SNA, snapper; BNS, bluenose; HPB, hāpuku; GMU, grey mullet; TAR, tarakihi; RSN, red snapper; KIN, kingfish; SPO, rig; GUR, gurnard.**

| Fishing year | Target species | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | BNS | GMU | GUR | HPB | KIN | LIN | RSN | SNA | SPO | TAR |
| 2016–17 | 486 | 100 | 15 | 131 | 18 | 12 | 55 | 1522 | 15 | 82 |
| 2017–18 | 373 | 87 | 13 | 150 | 15 | 11 | 21 | 1388 | 14 | 104 |
| Total | 859 | 187 | 28 | 281 | 33 | 23 | 76 | 2910 | 29 | 186 |


**Figure B-3: Status of electronic monitoring footage on bottom-longline sets that had cameras deployed in the bluenose and snapper target fisheries. Data are shown by set date for vessels with at least five declared trips in the respective target fishery. High footage percentage is defined as sets with at least 7.2 hours of footage following the start of the haul.**

## APPENDIX C: MODEL COEFFICIENTS

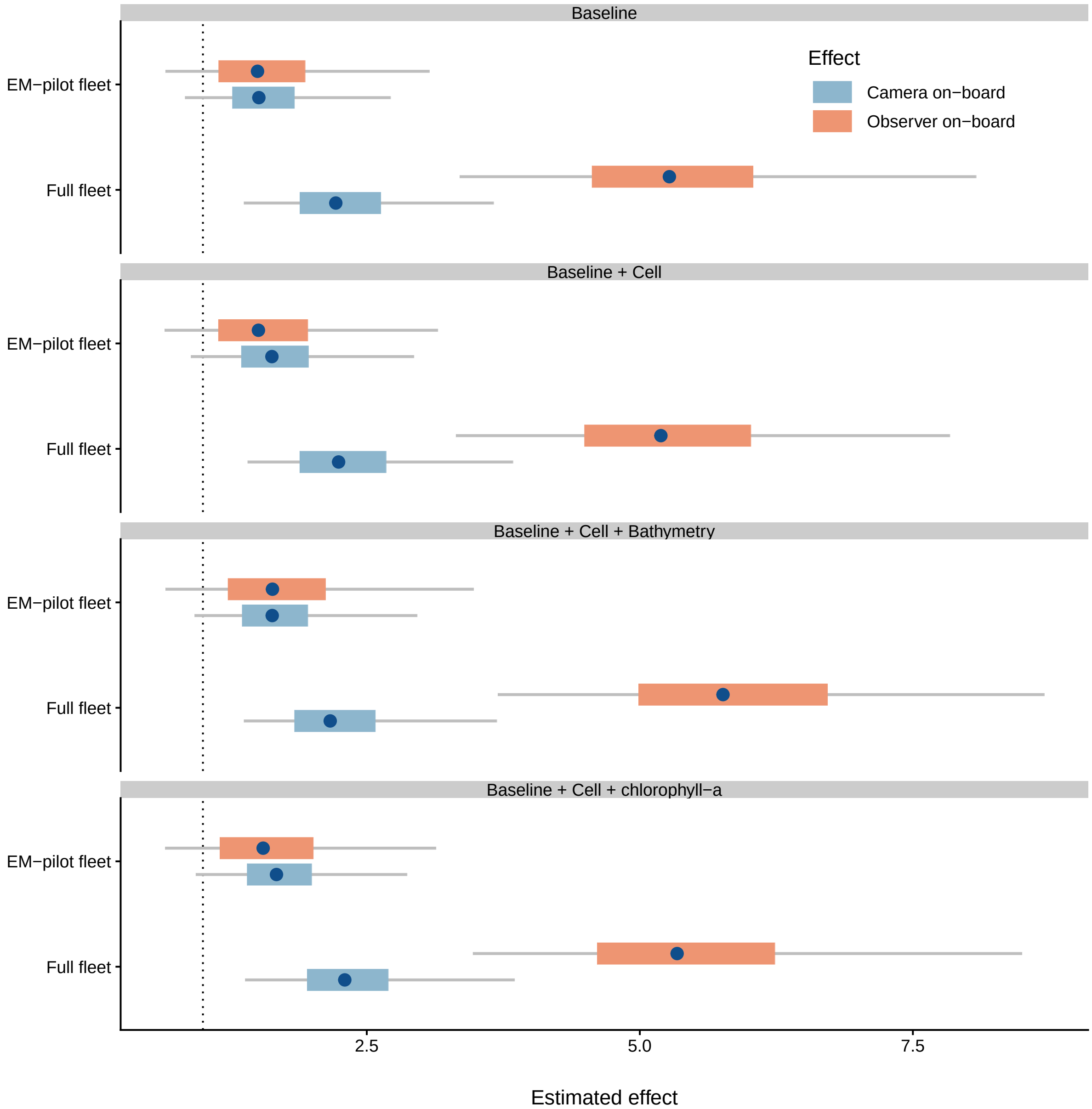


**Figure C-4: Comparison of the estimated camera versus observer effect on seabird capture rates for different model structures. The effect is multiplicative on a baseline rate for unobserved sets without cameras (the intercept). The vertical dotted line indicates no effect (multiplicative effect of 1). Models were for bottom-longline vessels participating in an electronic monitoring pilot programme (EM-pilot) and for all vessels in northern North Island. Median estimate in blue, grey lines show 95% credible interval, dark bands indicate the 50% credible interval.**

**Table C-2: Summary of model parameters estimated for the electronic monitoring pilot fleet of the bottom-longline fishery targeting snapper. Shown are for each parameter the summary statistics of the posterior distribution (mean, median, and 95% credible interval, based on the 2.5% and 97.5% quantiles), $\hat{R}$ diagnostics, and the reduction in the effective length of the chains due to autocorrelation. Trace plots of the chains are also shown.**

| Parameter | Statistic | | | Diagnostics | | |
|---|---|---|---|---|---|---|
| | Mean | Median | 95% c.i. | $\hat{R}$ | Loss (%) | Trace |
| **Model intercept** | | | | | | |
| Baseline | 0.000002 | 0.000002 | 0.000000 – 0.000006 | 1.002814 | 64.0 | |
| **Observation effects** | | | | | | |
| Observer effect | 1.61 | 1.51 | 0.65 – 3.15 | 1.00 | | |
| Camera effect | 1.70 | 1.63 | 0.89 – 2.93 | 1.00 | 39.9 | |
| **Random effects (sd)** | | | | | | |
| Fishing year | 0.18 | 0.15 | 0.01 – 0.55 | 1.00 | 51.8 | |
| Vessel | 0.96 | 0.89 | 0.37 – 2.04 | 1.00 | 65.0 | |
| 1°cell | 1.08 | 0.94 | 0.17 – 2.75 | 1.00 | 70.2 | |
| **Overdispersion** | | | | | | |
| $1/\phi$ | 0.41 | 0.14 | 0.00 – 2.02 | 1.00 | 21.6 | |
| $\nu$ | 0.82 | 0.88 | 0.29 – 1.11 | 1.01 | 67.9 | |
| **Effect compared to base rate** | | | | | | |
| 2009–10 | 0.99 | 1.00 | 0.63 – 1.39 | 1.00 | 1.1 | |
| 2010–11 | 1.05 | 1.01 | 0.72 – 1.57 | 1.00 | 1.5 | |
| 2011–12 | 1.07 | 1.02 | 0.77 – 1.65 | 1.00 | 4.8 | |
| 2012–13 | 1.02 | 1.00 | 0.71 – 1.48 | 1.00 | | |
| 2013–14 | 0.89 | 0.93 | 0.48 – 1.17 | 1.00 | 30.3 | |
| 2014–15 | 1.01 | 1.00 | 0.68 – 1.44 | 1.00 | | |
| 2015–16 | 1.06 | 1.02 | 0.75 – 1.53 | 1.00 | | |
| 2016–17 | 0.97 | 0.98 | 0.62 – 1.34 | 1.00 | 27.2 | |
| 2017–18 | 1.09 | 1.03 | 0.76 – 1.72 | 1.00 | 29.1 | |

**Table C-3: Summary of model parameters estimated for the full fleet of the bottom-longline fishery targeting snapper. Shown are for each parameter the summary statistics of the posterior distribution (mean, median, and 95% credible interval, based on the 2.5% and 97.5% quantiles), $\hat{R}$ diagnostics, and the reduction in the effective length of the chains due to autocorrelation. Trace plots of the chains are also shown.**

| Parameter | Statistic | | | Diagnostics | | |
|---|---|---|---|---|---|---|
| | Mean | Median | 95% c.i. | $\hat{R}$ | Loss (%) | Trace |
| Model intercept | | | | | | |
| Baseline | 0.000001 | 0.000001 | 0.000000 – 0.000001 | 1.001002 | 63.5 | |
| Observation effects | | | | | | |
| Observer effect | 5.30 | 5.19 | 3.32 – 7.84 | 1.00 | 19.0 | |
| Camera effect | 2.34 | 2.24 | 1.41 – 3.84 | 1.00 | 8.6 | |
| Random effects (sd) | | | | | | |
| Fishing year | 0.15 | 0.13 | 0.01 – 0.43 | 1.00 | 62.8 | |
| Vessel | 1.91 | 1.88 | 1.33 – 2.76 | 1.00 | 72.9 | |
| 1°cell | 0.61 | 0.55 | 0.06 – 1.52 | 1.01 | 69.1 | |
| Overdispersion | | | | | | |
| $1/\phi$ | 1.05 | 0.96 | 0.05 – 2.72 | 1.00 | 39.7 | |
| $\nu$ | 1.05 | 1.07 | 0.80 – 1.16 | 1.01 | 75.4 | |
| Effect compared to base rate | | | | | | |
| 2009–10 | 1.10 | 1.05 | 0.87 – 1.58 | 1.00 | 22.0 | |
| 2010–11 | 1.07 | 1.02 | 0.82 – 1.51 | 1.00 | 1.6 | |
| 2011–12 | 1.05 | 1.02 | 0.81 – 1.50 | 1.00 | | |
| 2012–13 | 0.97 | 0.98 | 0.70 – 1.26 | 1.00 | | |
| 2013–14 | 0.96 | 0.98 | 0.68 – 1.19 | 1.00 | 10.8 | |
| 2014–15 | 0.98 | 0.99 | 0.70 – 1.29 | 1.00 | | |
| 2015–16 | 1.08 | 1.03 | 0.84 – 1.55 | 1.00 | | |
| 2016–17 | 0.90 | 0.93 | 0.59 – 1.11 | 1.00 | 45.0 | |
| 2017–18 | 1.01 | 1.00 | 0.72 – 1.32 | 1.00 | | |

## APPENDIX D: MODEL DIAGNOSTICS

### D.1 EM-pilot fleet for the snapper fishery

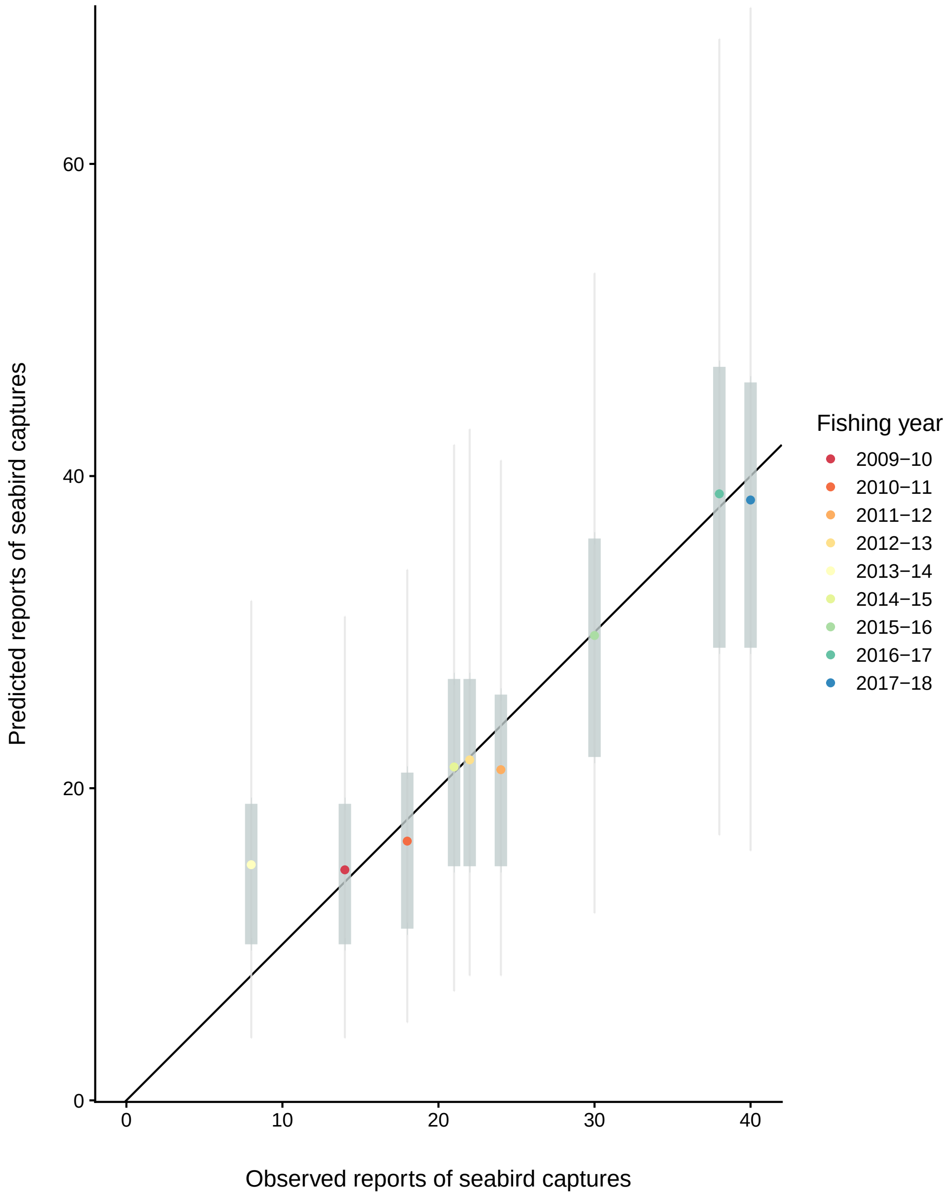


**Figure D-5: Observed versus predicted (mean) reported seabird captures per fishing year for the model of the electronic monitoring pilot fleet. The 25-75$^{th}$ quantile for the predictions is shown in grey; the whiskers cover the 2.5-97.5$^{th}$ quantile range.**

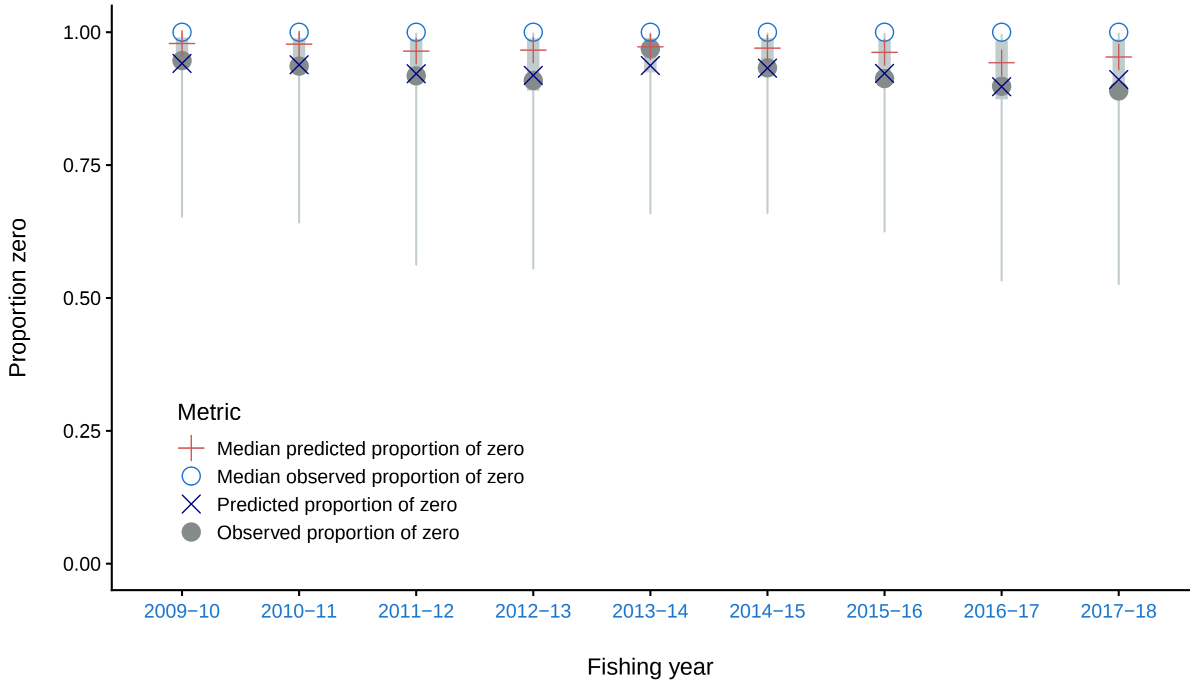


**Figure D-6: Mean and median proportion of zero observed versus predicted for those observations for the EM pilot fleet model, by fishing year. The median $\pm$ 25th quantiles for the predictions is shown in grey; the whiskers cover the 2.5-97.5th quantile range.**

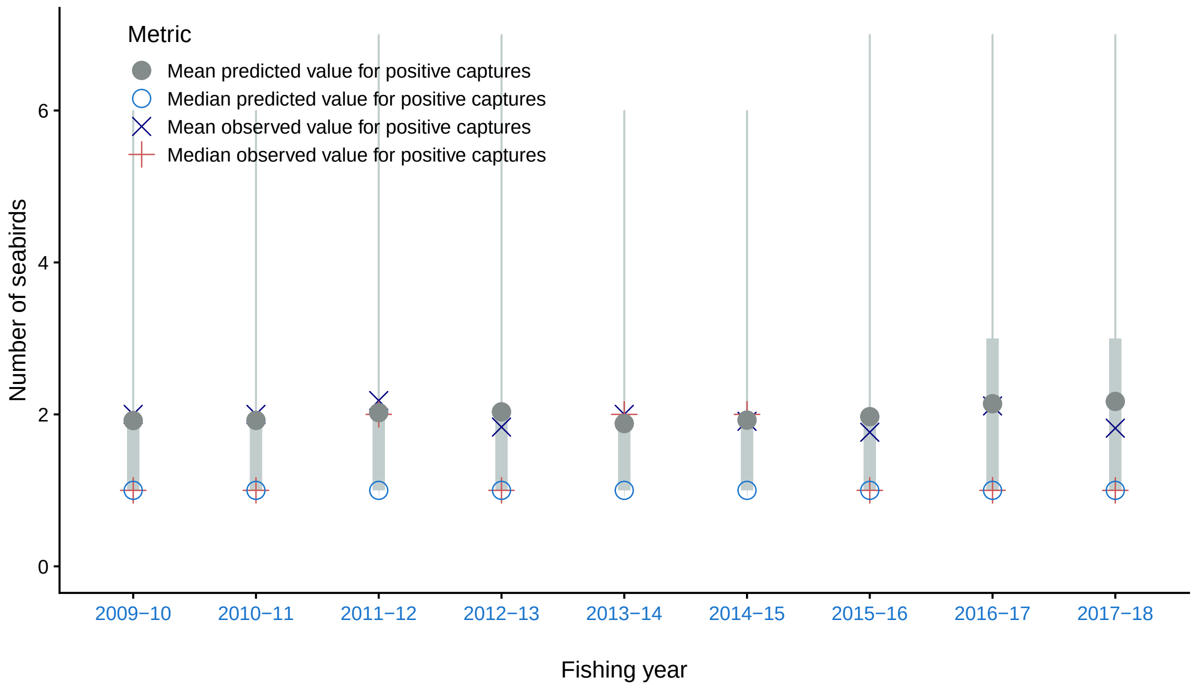


**Figure D-7: Mean and median number of seabirds caught over positive capture events by fishing year versus predicted for those observations for the EM pilot fleet model. The median $\pm$ 25th quantiles for the predictions is shown in grey; the whiskers cover the 2.5-97.5th quantile range.**

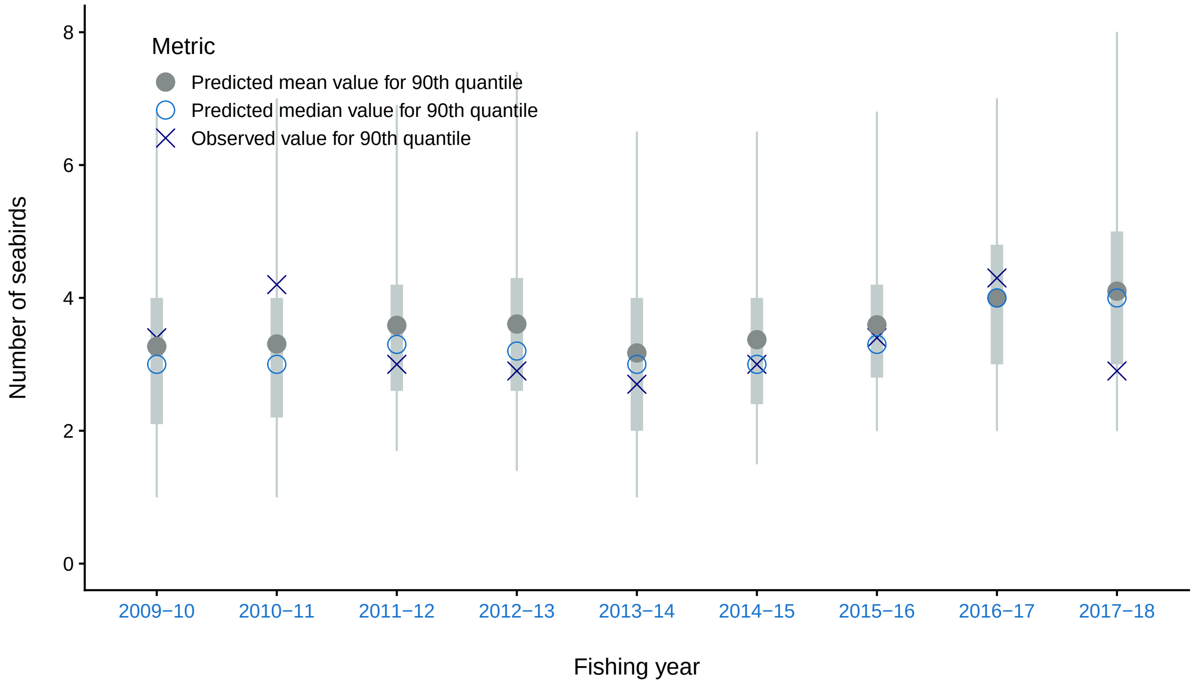


**Figure D-8: Mean and median position of the 90th quantile of positive capture events by fishing year versus predicted for those observations for the EM pilot fleet model. The median ± 25th quantiles for the predictions is shown in grey; the whiskers cover the 2.5-97.5th quantile range.**

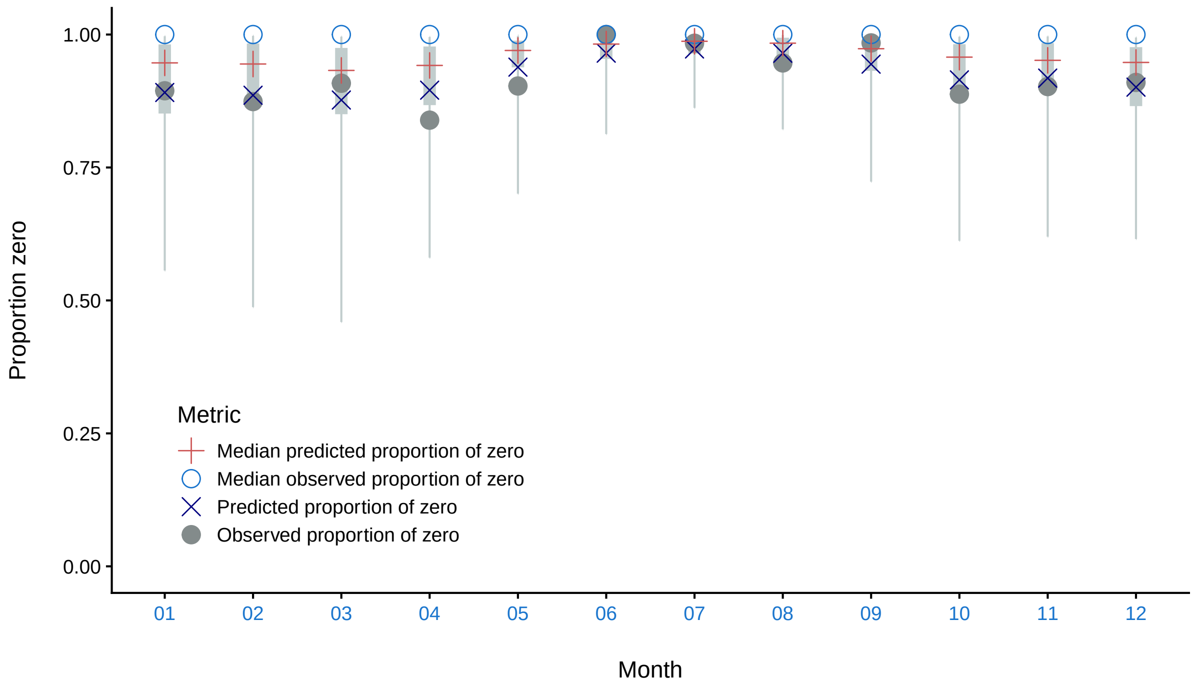


**Figure D-9: Mean and median proportion of zero observed by month versus predicted for those observations for the EM pilot fleet model. The median ± 25th quantiles for the predictions is shown in grey; the whiskers cover the 2.5-97.5th quantile range.**

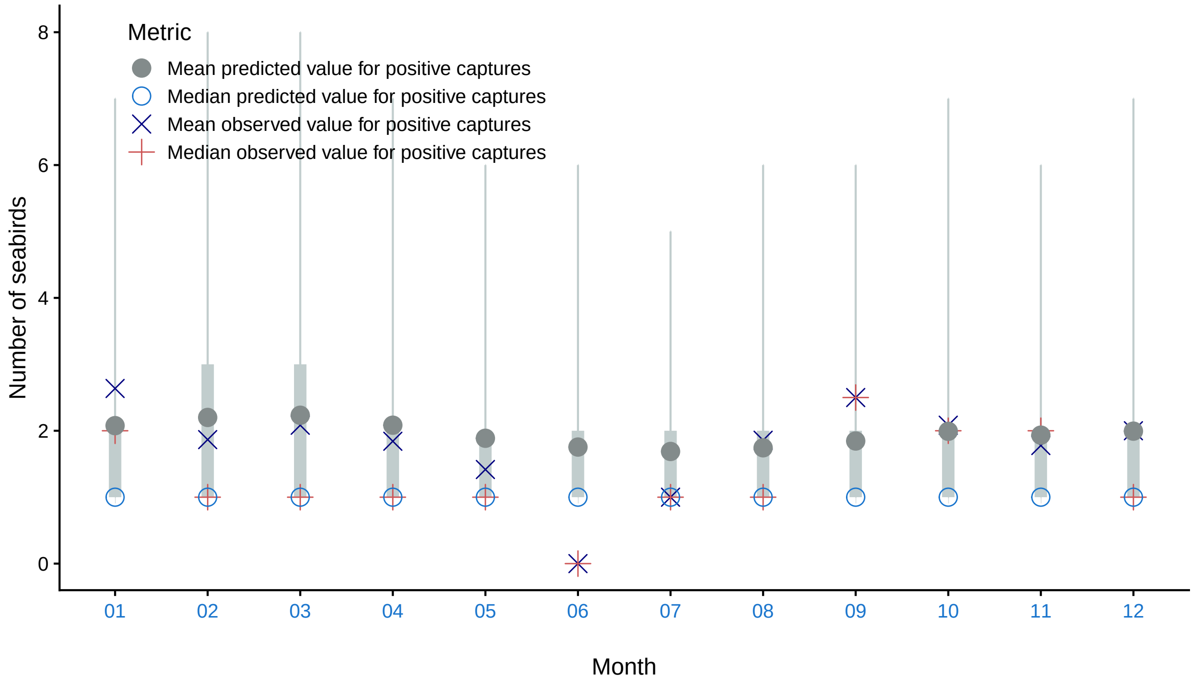


**Figure D-10: Mean and median number of seabirds caught over positive capture events by month versus predicted for those observations for the EM pilot fleet model. The median ± 25$^{th}$ quantiles for the predictions is shown in grey; the whiskers cover the 2.5-97.5$^{th}$ quantile range.**

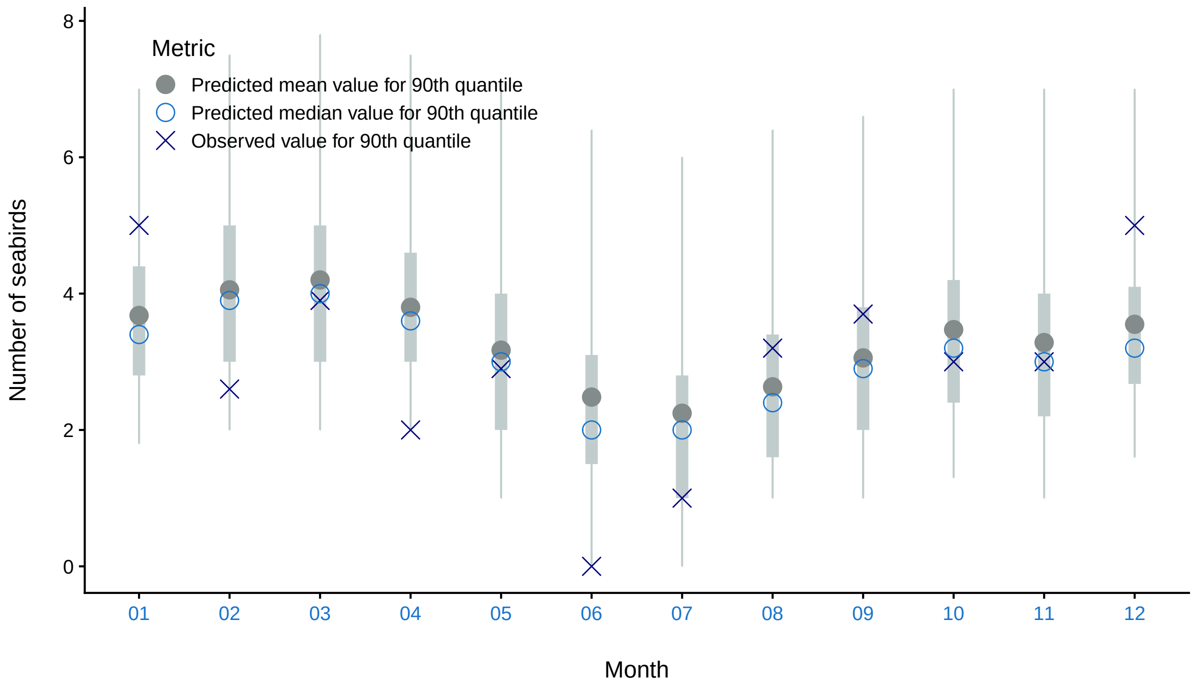


**Figure D-11: Mean and median position of the 90$^{th}$ quantile of positive capture events by month versus predicted for those observations for the EM pilot fleet model. The median ± 25$^{th}$ quantiles for the predictions is shown in grey; the whiskers cover the 2.5-97.5$^{th}$ quantile range.**

## D.2 Full fleet for the snapper fishery

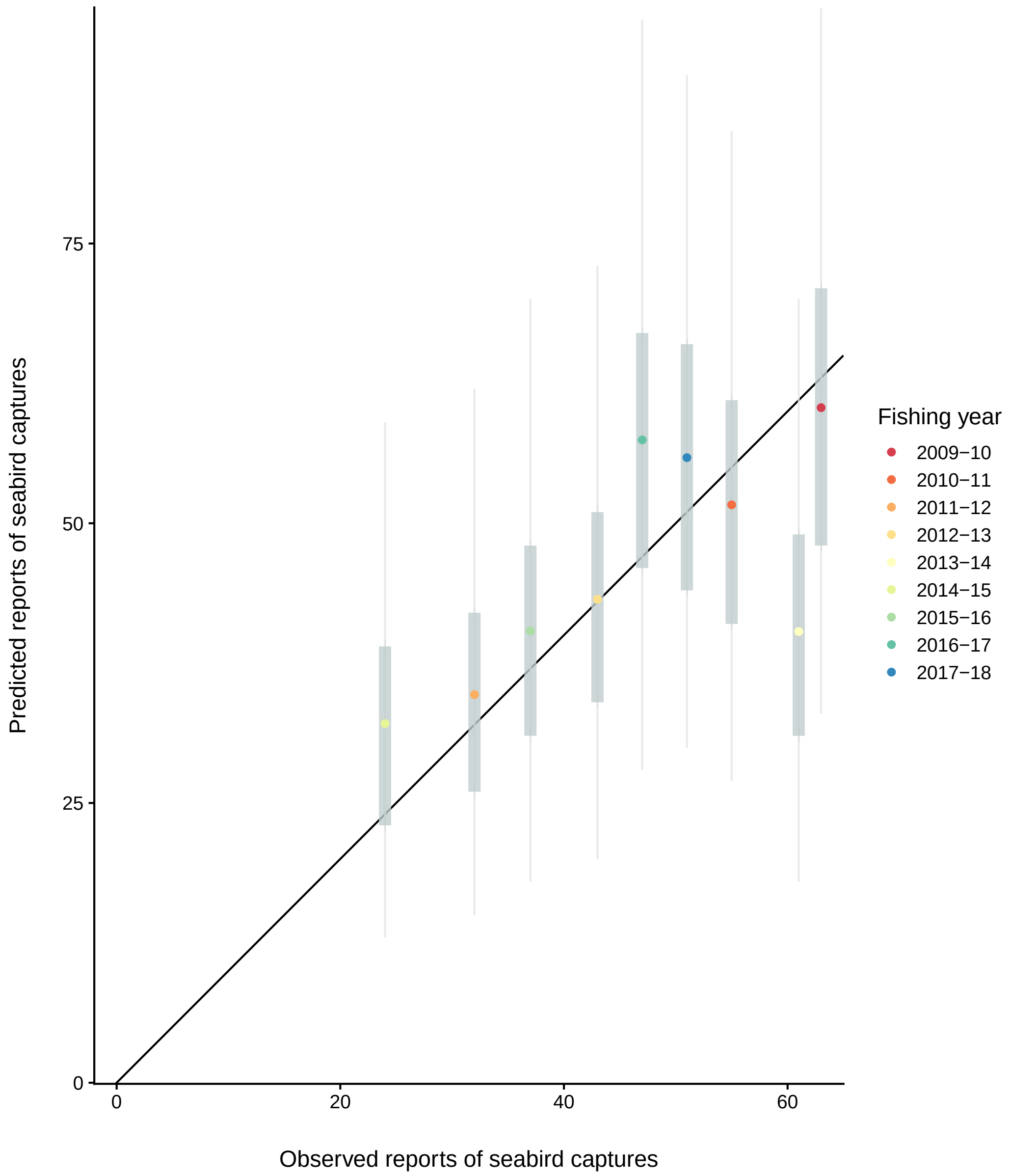


**Figure D-12: Observed versus predicted (mean) reported seabird captures per fishing year for the model of the full fleet. The 25-75$^{th}$ quantile for the predictions is shown in grey; the whiskers cover the 2.5-97.5$^{th}$ quantile range.**

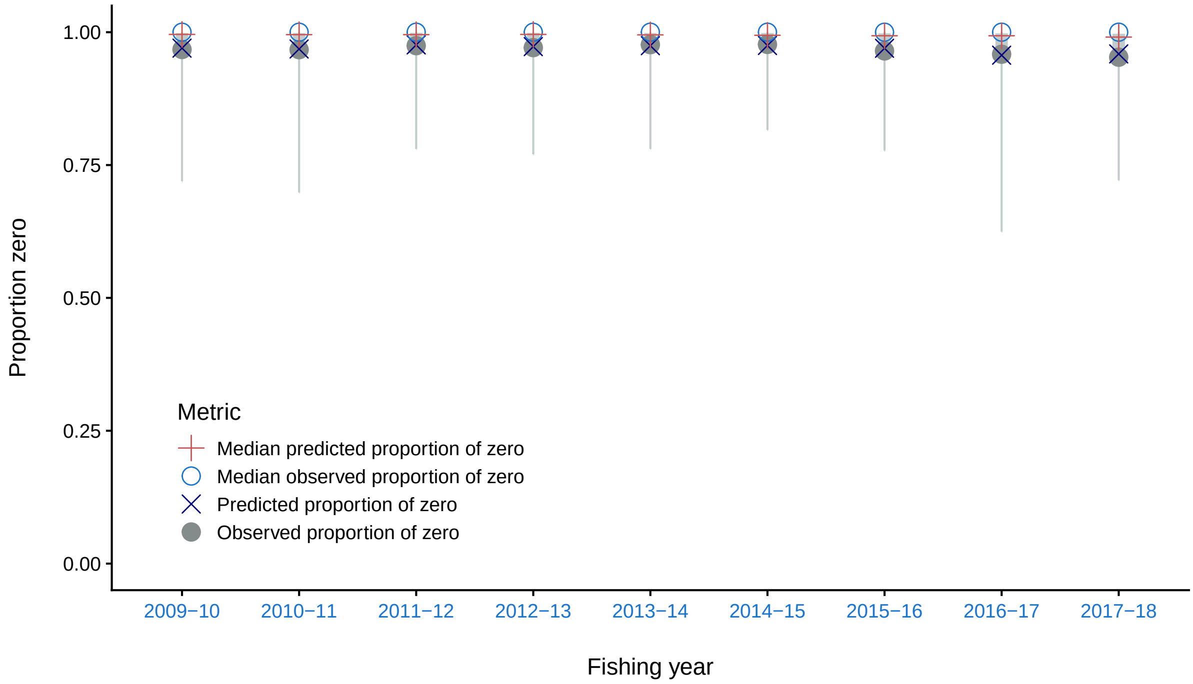


**Figure D-13: Mean and median proportion of zero observed versus predicted for those observations for the full fleet model, by fishing year. The median $\pm$ 25$^{th}$ quantiles for the predictions is shown in grey; the whiskers cover the 2.5-97.5$^{th}$ quantile range.**

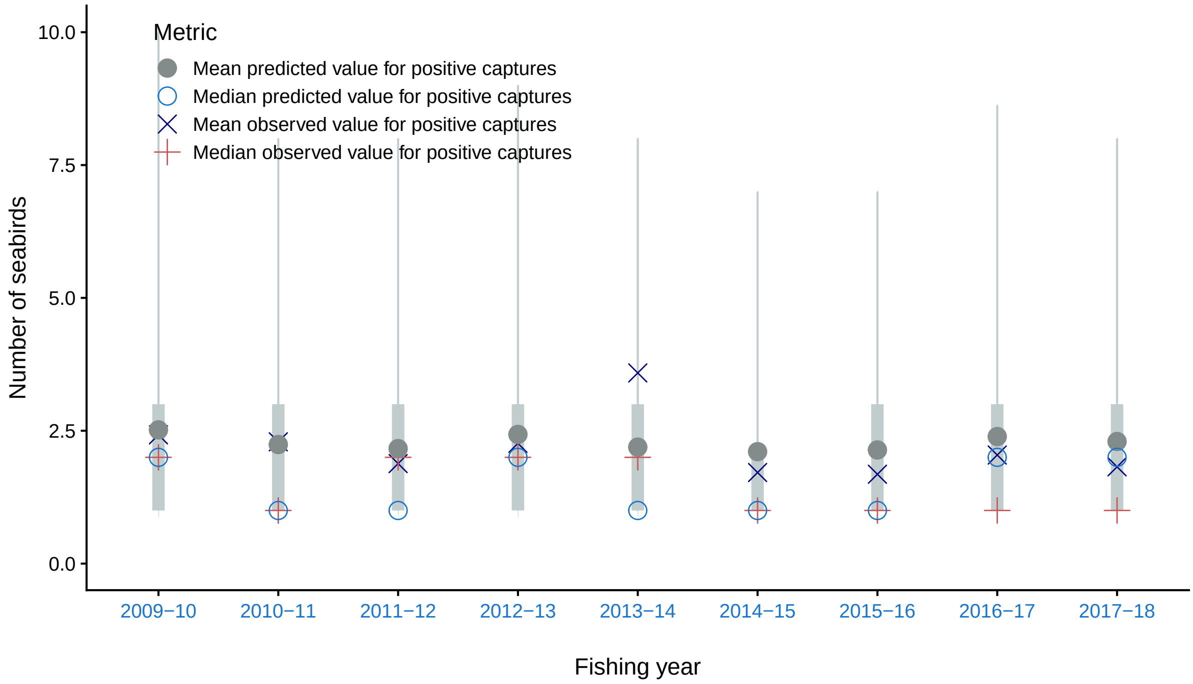


**Figure D-14: Mean and median number of seabirds caught over positive capture events by fishing year versus predicted for those observations for the full fleet model. The median ± 25$^{\text{th}}$ quantiles for the predictions is shown in grey; the whiskers cover the 2.5-97.5$^{\text{th}}$ quantile range.**

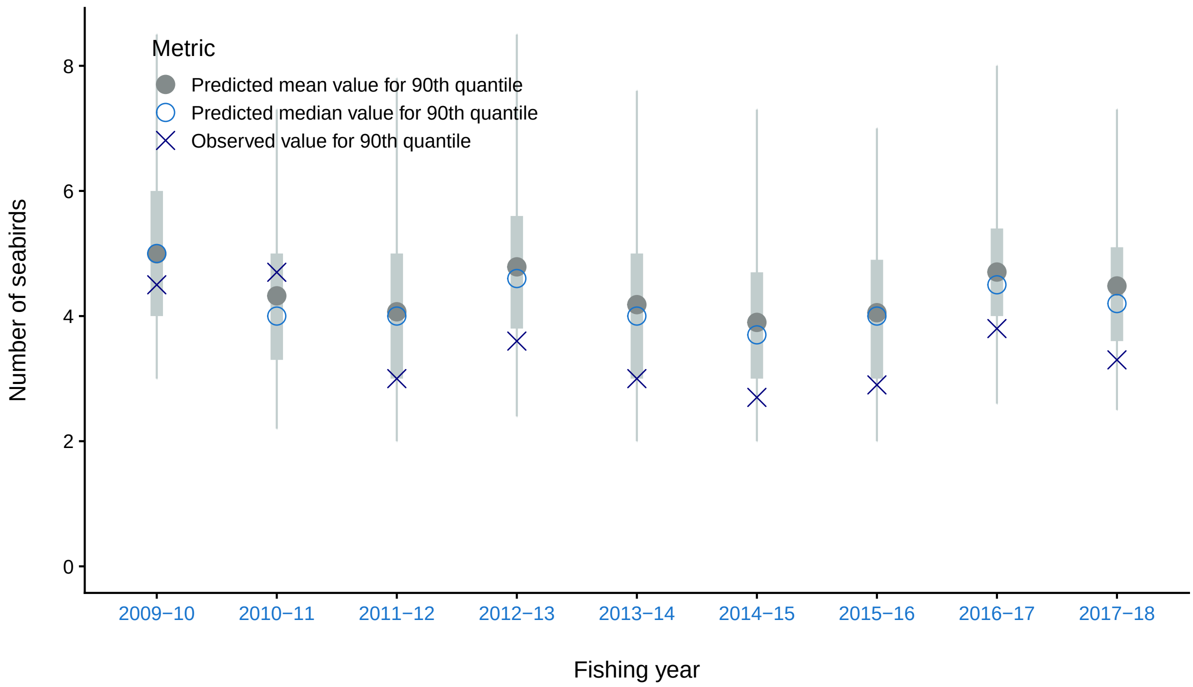


**Figure D-15: Mean and median position of the 90$^{\text{th}}$ quantile of positive capture events by fishing year versus predicted for those observations for the full fleet model. The median ± 25$^{\text{th}}$ quantiles for the predictions is shown in grey; the whiskers cover the 2.5-97.5$^{\text{th}}$ quantile range.**

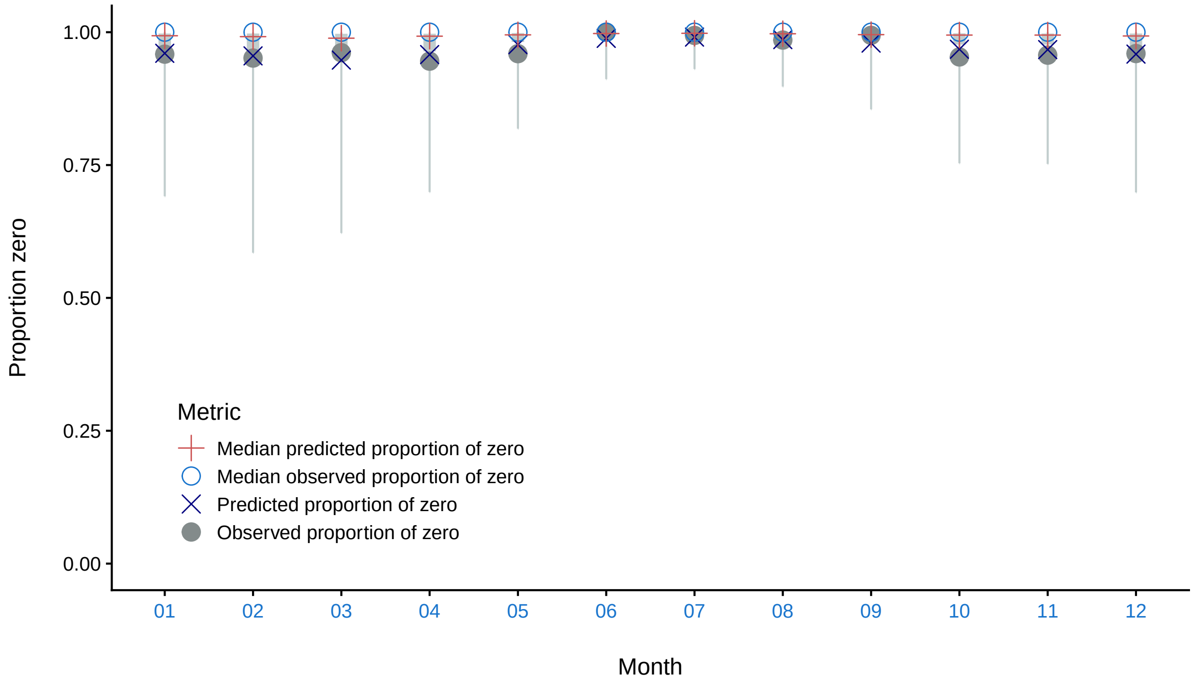


**Figure D-16: Mean and median proportion of zero observed by month versus predicted for those observations for the full fleet model. The median $\pm$ 25th quantiles for the predictions is shown in grey; the whiskers cover the 2.5-97.5th quantile range.**

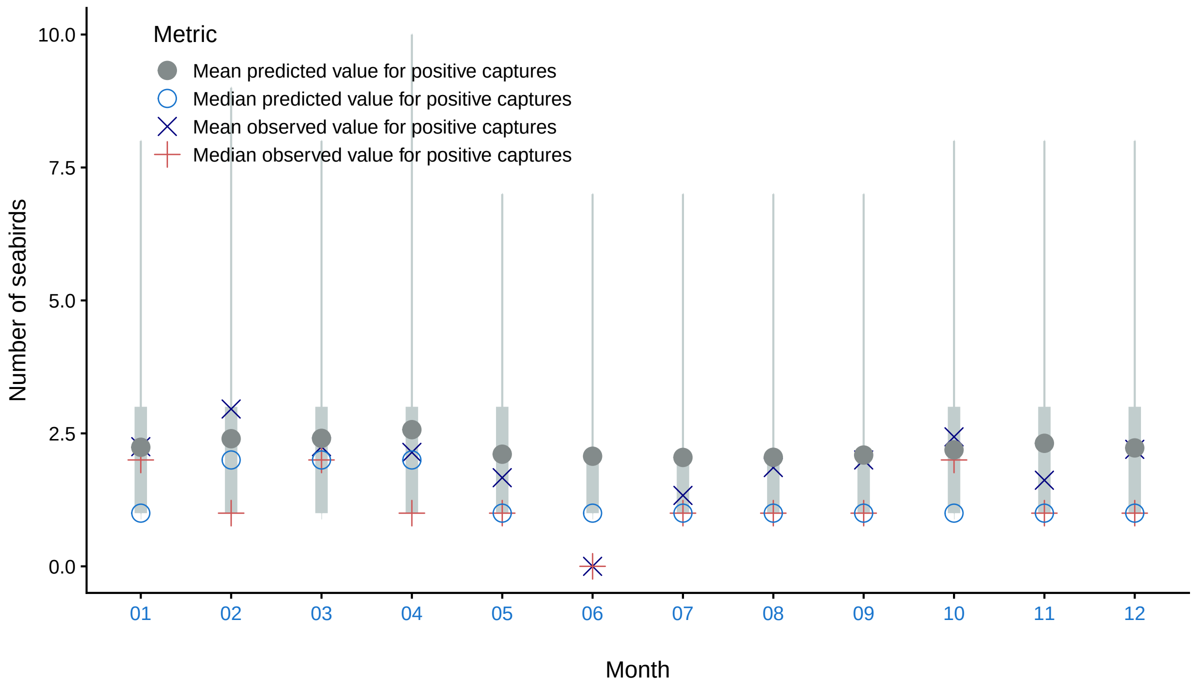


**Figure D-17: Mean and median number of seabirds caught over positive capture events by month versus predicted for those observations for the full fleet model. The median $\pm$ 25th quantiles for the predictions is shown in grey; the whiskers cover the 2.5-97.5th quantile range.**

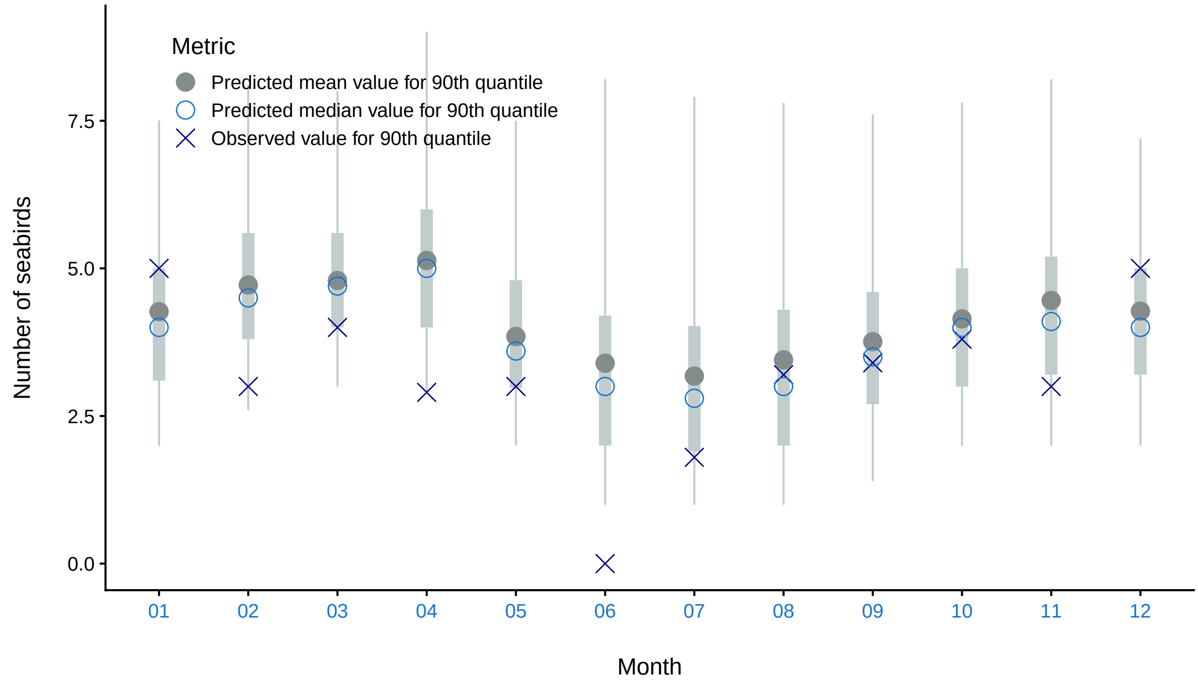


**Figure D-18: Mean and median position of the 90$^{th}$ quantile of positive capture events by month versus predicted for those observations for the full fleet model. The median $\pm$ 25$^{th}$ quantiles for the predictions is shown in grey; the whiskers cover the 2.5-97.5$^{th}$ quantile range.**