Fisheries New Zealand
Tini a Tangaroa

CCSBT-ERS/2203/15
(ERSWG Agenda Item 5.1.4)

# Factors affecting Protected Species Captures in domestic surface longline fisheries

New Zealand Aquatic Environment and Biodiversity Report No.…..

Stefan Meyer, Darryl MacKenzie

ISSN 1176-9440 (print)
ISSN 1179-6480 (online)
ISBN XXXX (online)

**February 2022**

New Zealand Government

Requests for further copies should be directed to:

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

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

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

**TABLE OF CONTENTS**

## EXECUTIVE SUMMARY

**Meyer, S.; MacKenzie D. (2021). Factors affecting Protected Species Captures in domestic surface longline fisheries.**

***New Zealand Aquatic Environment and Biodiversity Report No. XX.* XX p.**

The overall objective of this study was to *Assess risk factors that influence the capture of protected species including seabirds, fur seals, sharks, and turtles by small SLL vessels to inform the development of potential mitigation strategies.*

For this study, the Protected Species Captures database (PSCDB) was expanded by utilizing additional variables that are stored in the centralised observer database (COD) but are not formally integrated into the PSCDB. Observed captures of seabirds, NZ fur seals, and marine turtles were then analysed. There were insufficient observed captures of dolphins and whales, and sharks and rays to enable meaningful analysis. This analysis focuses on small surface-longline (SSL) vessels operation between the 2006–07 and 2018–19 fishing years.

Negative binomial generalised linear models with varying level of complexity were fitted to observed captures of seabirds, NZ fur seals, and turtles. For seabird species, two alternate models were fitted: (1) a model for all seabird captures combined, (2) a multi-species captures model for the most frequently caught seabird species (black petrel, white-capped albatross, and Buller's albatross).

A two-phase model fitting process was used given the varying completeness of the variables. In Phase 1, models within the candidate set were fit separately to datasets with varying data completeness and (within each dataset) ranked by AIC. However, including many variables at once in the analysis would lead to substantial data pruning because of the heterogeneity of missing values across fishing events. Therefore, in Phase 2, additional variables that were incomplete for the dataset being considered were separately added to the top AIC-ranked model fitted to complete data from Phase 1, which should include the main variables for explaining variation in the observed captures.

The main effects identified in Phase 1 for the model with seabirds combined were fishing year, area (discrete areas along coastline), presence/absence of vessel freezer, moon phase, and start month. For the multi-species model fit to observed captures of black petrels, white-capped albatrosses, and Buller's albatrosses, the main effects were similar, and included presence/absence of vessel freezer, moon phase, start month, and an interaction term for area and species. Main effects identified in the NZ fur seal capture model were fishing year, area, start month, presence/absence of tori lines, and bathymetry. The model fitted to observed turtle captures showed poor predictive ability most likely due to insufficient observed captures.

Phase 2 model fitting indicated that several other vessel-configuration, fishing-behaviour, and environmental variables could affect the capture rates of seabirds and NZ fur seals. For example, seabird capture rates appeared to decrease with increased night hours, when the tori line was over the bait entry point, with increasing tori line attachment height (a proxy for aerial extent), and with increasing distance to shore. In contrast, capture rates increased with higher number of turns during setting, and fishing during higher sea surface temperatures. For fur seals, the presence/absence of light sticks, line setting height, use of light (short) streamers, seemed to increase capture rates, while increased night hours and increased distance between bait and tori line appeared to have a decreasing effect on capture rates.

A workshop was held to discuss the results and improvement of existing or new bycatch mitigation strategies. A main conclusion from the workshop was that a set of mandatory variables (e.g., whether tori line was placed over the bait entry point) are required to reduce the data sparseness that limits the assessment of mitigation measures and alternative options as done here. Further recommended was to

adjust instructions for variable collection to reduce the level of subjectivity that could arise otherwise (e.g., currently deck lighting which could attract birds is only recorded as to whether there existed unnecessary deck lighting). Further, it was recommended to focus data collection on variables that influence the sink rate of hooks, such as vessel speed and individual snood length.

# 1. INTRODUCTION

Surface longline (SLL) fishing in New Zealand (NZ) occurs predominantly off the west coast of the South Island and the east coast of the North Island, targeting tuna and swordfish. Incidental captures of non-target species occur within SLL fisheries, and these captures range from seabirds, marine mammals, marine turtles, to sharks and rays. Incidental seabird captures in NZ's SLL fisheries are mitigated through the following mandatory measures:

- Using hook-shielding device (hookpods) being introduced in 2020; and/or
- deploy a tori (streamer) line for the duration of all setting events; and
- either set lines at night, or weight lines.

The effectiveness of these measures, however, depends on the set-up of the vessel, conditions (e.g., weather) at the time of fishing, or the combination of different bycatch mitigation measures. For example, in South African pelagic longline fisheries the combined use of two bird-scaring lines, weighted branch lines and night setting is considered best practice to reduce seabird bycatch (Melvin et al., 2014). Bull (2007) also suggests that "a combination of BSL [bird scaring lines], line weighting, night setting (in some fisheries), and retention of offal during fishing operations is likely to be the most effective regime for mitigating seabird bycatch in NZ demersal and pelagic longline fisheries". The author further suggests that factors influencing the "effectiveness of a BSL include the seabird assemblage present, fishing grounds, target fish species, fishing method, vessel size, time of day/year, weather conditions, BSL quality, and mounting height". Other factors reducing bycatch (though not discussed in combination with bycatch mitigation devices) are the setting depth of hooks, hook type, presence/absence of light sticks (discussed for shark bycatch for NZ longline fisheries in Howard (2015)); setting depth of hooks (discussed for turtle bycatch for US Longline Fisheries in Swimmer et al. (2017)); dumping of offal (discussed for seabird bycatch mitigation for pelagic longline fisheries targeting tuna and related species in Melvin et la. (2014), and Middleton & Abraham (2007)); and distance to breeding site (discussed for seabird bycatch for New Zealand trawl and longline fisheries in Waugh et al. (2008)).

The overall objective of this study was to *Assess risk factors that influence the capture of protected species including seabirds, fur seals, sharks & rays, dolphins & whales, and turtles by small SLL vessels to inform the development of potential mitigation strategies.* The specific objectives of this study are:

1. *Conduct modelling analyses to examine the influence of factors that could potentially lead to the capture of protected species by domestic longline vessels.*
2. *Based on the outcome of Objective 1, summarise the results and organise a workshop to test potential mitigation strategies.*

For this study, the Protected Species Captures database (PSCDB; Abraham & Berkenbusch, 2019) was expanded by utilizing additional variables that are stored in the centralised observer database (COD; Sanders & Fisher 2010) but are not formally integrated into the PSCDB. Observed captures of seabirds, NZ fur seals, marine turtles, sharks and rays, and whales and dolphins were then analysed (where possible) to identify factors that potentially influence captures of protected species in SLL fisheries. This analysis focuses on small SLL vessels that operated between the 2006–07 and 2018–19 fishing years (i.e., hookpods were not integrated into this assessment). Hooks pods have not been assessed in this analysis as an updated COD including information on hook pods was not available at the time of this analysis.

## 2. METHODS

### 2.1 Data preparation

Groomed data from the PSCDB version 5 (Meyer, 2022, report in review) including the 2018–19 fishing year were combined with additional variables (i.e., those not being formerly integrated into the PSCDB) from the COD. The datasets were filtered for domestic and Australian-based small SLL vessels operating between the 2006–07 and 2018–19 fishing years, as this time period is considered to reflect the status quo of NZ's commercial SLL fishery (e.g., there are no Japanese vessels currently operating in NZ's SLL fisheries) and this project is aimed at identifying current risk factors so as to develop "new" mitigation strategies (personal communication with William Gibson and Ben Sharp, FNZ).

The PSCDB contains three tables: (1) fisher-reported catch effort data (*catch_effort_t*), observer-reported effort data (*observer_effort_t*), and reported protected species captures (*all_captures_t*). Records from *catch_effort_t* and *observer_effort_t* are linked as part of the PSCDB grooming by using several linking rules developed by Abraham & Berkenbusch (2019), which allows additional fields that are recorded in the observer data (e.g., mitigation methods) being appended to the catch effort data. Only observed fishing events were included in this analysis, hence only records from *catch_effort_t* that had been successfully linked to *observer_effort_t* (i.e., shared the same event key) were used.

Data was extracted from the PSCDB by applying the above filtering of records and joining the *catch_effort_t* and *observer_effort_t* tables on the event key column. Additional variables (see Table 1) taken from the COD were added to the filtered PSCDB extract by linking records via the *trip_number* (trip number allocated by the observer programme) and *station_number* (a sequential identifier for each fishing event, e.g., a tow or set) (Sanders & Fisher, 2018), which are preserved in both the COD and the *observer_effort_t* table of the PSC database.

New COD variables were obtained from the following tables (descriptions obtained directly from COD):

- *x_haul_effort*: Hourly information of observed tuna longline hauls (expanded by station number)
- *x_surface_lining_effort*: Profile information on all observed sets of tuna longlines (expanded by station number)
- *x_sll_baskets*: Surface long line gear, detail on baskets deployed for fishing events. From SLL gear form Version 3, August 2018.
- *x_sll_gear*: Surface long line gear data. From SLL gear form Version 3, August 2018.
- *x_surface_lining_bait*: Information on bait species used on observed sets of Tuna longline vessels (expanded by trip number)
- *x_tori_line*: Tori line details.
- *x_fishing_event_catch_specimen*: Description of catches of specimens (fish, birds, seals, etc) made by tuna longlines (expanded by station number)

The tables *x_fishing_event* (generic information associated with a set of fishing effort) and *x_trip* (header information common to a trip) were used to expand the different tables (if needed) by station numbers or trip numbers, respectively, so they can be sufficiently linked the PSCDB extract.

A total of 2 611 records of observed SLL fishing events on small vessels during the 2006–07 to 2018–19 fishing years were available in the PSCDB. 238 records were without a matching event key leading to remaining dataset with 2 373 fishing events available for this analysis. An initial data assessment of the completeness of each variable between the 2006–07 and 2018–19 fishing years was carried out and presented to the AEWG (Table 32 in Appendix A). Data were only fully available for variables that are already integrated into the PSCDB. The proportion of fishing events available for analysis diminished with the incorporation of variables from the COD, and the proportion varied substantially across variables, either because these were recorded sporadically or only in recent years (Table 32 in Appendix A).

Including all variables at once in the analysis would cause substantial data pruning because of the heterogeneity of missing values across fishing events and fishing years (see Table 32). Therefore, five datasets were created where variables were included based on different thresholds for data completeness. An unpruned dataset, containing 2 373 fishing events, was compiled that only included variables that were fully recorded (see Table 1) across all fishing events between 2006–07 and 2018–19. Next, a dataset was compiled that comprised variables for which at least 75% (on average between the 2006–07 and 2018–19 fishing years) had fishing events with available records (i.e., this also includes variables from the unpruned dataset) reducing the size of the dataset to 1 069 fishing events. Three additional pruned datasets were created with lower thresholds for data completes of ≥60%, ≥20%, and >0%. The corresponding size of these three datasets was 462, 336, and 0 fishing events, respectively. When including variables that had >0% of data completeness as lower threshold then the dataset was pruned to zero fishing events and was therefore not available for the analysis (but see Statistical modelling). Note, that not all variables shown in Table 32 were included as some variables appeared redundant (e.g., fishery seabirds vs. fishery), plus some additional variables were added to the analysis after consultation with the AEWG (e.g., *aerial_extent*). The final variables used here are described in Table 1.

**Table 1:** Variables included in model fitting; original data set size for small-vessel SLL catch effort was 2 611 fishing events but not all had event keys assigned that could be linked to observer data.

| **Variable** | **Description** |
|---|---|
| **100% data completeness across years (2373 fishing events)** | |
| species | Bird species |
| target | Target species |
| stats_area | Statistical area |
| fishing_year | Fishing year |
| area | Area (see Fig. 3), originally used to summarise estimated captures in Abraham & Richard (2019). Used here to coarsely divide the coastline into discrete sections. |
| vessel_size | Vessel size: 06-17 m, 17-28 m, 28-43 m |
| vessel_nation | Vessel nation: NZ, AUS |
| vessel_freezer | Use of vessel freezer: yes, no |
| moon_phase | Moon phase between 0 (new moon) and 1 (full moon) |
| start_month | Start month between 1 and 12 |
| season | Season: Summer (Jan, Feb, Mar), Autumn (Apr, May, Jun), Winter (Jul, Aug, Sep), Spring (Oct, Nov, Dec) |
| mitigation_tori | Use of tori line: yes, no |
| Dens | Bird species- and month-specific relative distribution layers provided by Charles Edwards (CESCAPE consultancy services) |
| time_of_day | Time of the day: Night (nautical dusk to nautical dawn), day (nautical dawn to nautical dusk); calculated from start_datetime column |
| bathymetry | Bathymetry (m) at start fishing location calculated from NZ 250m gridded bathymetric data set and imagery, Mitchell et al. (2012), released 2016. |
| moon_phase:species | Interaction between moon phase and species |
| mitigation_tori:species | Interaction between the use of tori line and species |
| **≥ 75% data completeness across years (1069 fishing events, or 45% of unpruned dataset)** | |
| wind | Low Beaufort scale 0 to 3<br>Medium 4 to 6<br>High Over 6 |
| baskets_number | Number of baskets [i.e., line sections] on the line |
| line_length | Length of line in kilometres. |
| distance_to_shore | Distance to shore in metres. |

| | |
|---|---|
| night_hours | Hours of fishing at night |
| min_depth | On current 2018+ set logs this is the minimum hook depth (m). The pre-2018 Set logs, is the expected minimum depth of the line when set in metres. |
| max_depth | On current 2018+ set logs this is the maximum hook depth (m). The pre-2018 Set logs, is the expected maximum depth of the line when set in metres. |
| bait_thrower_used_yn | Use of a bait thrower: yes, no |
| wind_beaufortscale | Wind strength in Beaufort scale |
| number_of_vessels | The number of vessels within a 24 nautical mile radius. |
| cloud_cover | Percentage of cloud cover at start of the set. |
| snood_signal_time | The snood signal time in seconds. |
| start_wind_direction | Wind direction at start of the set (0 to 359 degrees). |
| **≥ 60% data completeness across years (462 fishing events or 19% of unpruned dataset)** | |
| wind | Low Beaufort scale 0 to 3<br>Medium 4 to 6<br>High Over 6 |
| vessel_speed | Speed of the vessel during the haul in knots. |
| vessel heading | Vessels heading at time of observation in degrees (0 to 359). |
| surface_temperature | Sea surface temperature (decimal degrees C). |
| **≥ 20% data completeness across years (336 fishing events or 14% of unpruned dataset)** | |
| tori_length | Length of tori line (metres). |
| tori_height | Height of attachment of tori line above the water (metres). |
| line_entry_yn | Whether the tori line was over bait entry point. (Yes or no). |
| bait_stream | Distance between bait landing point and tori line in metres. |
| **> 0% data completeness across years (0 fishing events or 0% of unpruned dataset)** | |
| dist_stern_to_bait_min | Minimum distance from stern to bait entry point (m). |
| float_line_length | Length of the float/drop line (m). |
| attach1_height | Height of attachment point above water (m). |
| attach1_distance | Lateral distance (m) from centre of stern to attachment point. |
| setting_turns | Number of turns during setting |
| dist_bait_to_tori | Lateral distance from bait entry point to tori line (m). |
| float_line_diameter | Diameter of the float/drop line (mm). |
| aerial_extent | Aerial extent of tori line (m). |
| distance_weight_to_hook | Distance between the hook and the closest weight (cm). |
| snood_signal_time | The snood signal time in seconds. |
| long_streamer_distance | The maximum distance between any long streamers, in metres. For pre-2018 forms, this is maximum distance between any streamers. |
| mitigation_none | |
| bottom_depth | |
| light_sticks_yn | Presence of light sticks on line (Y/N). |
| acoustic_bird_deterrent_yn | Whether acoustic bird deterrents were used as a mitigation strategy for Protected Species Captures (Y/N/U). |
| deck_light_yn | Whether there was unnecessary deck lighting while setting (Y/N/U). |
| fishing_gear_discard_yn | Whether fishing gear was discarded (Y/N/U). |
| setting_path | 3-part code for path of vessel while setting. Code detail on back of setting form. |
| discards_during_setting | Whether there was any offal, bait or whole fish discarded during setting. |
| line_setting_height | Line setting height (m). |
| hook_type | Hook type and size, as referred to by retailers. |
| number_snoods | Number of snoods in the basket. |
| long_streamer_yn | Presence of long streamers (Y/N). |
| light_streamer_yn | Presence of light streamers (Y/N). |

| | |
|---|---|
| setting_strategy | Part one of setting path code - denotes strategy for the path of set. |
| surface_float_diameter | Diameter of the surface floats (cm) |
| snood_length | Length of snoods (m). |
| long_streamer_aerial_yn | Whether long streamers cover aerial extent (Y/N). |
| weight | Mass of the weight closest to hook (g). |
| weighting_type | Weighting type:<br>H = Hook pods,<br>S = Sliding weight,<br>W = Weighted swivel,<br>F = Fixed weights,<br>~~C = shark Clip,~~<br>O = Other (described in comments). |

## 2.2 Species grouping

Datasets were compiled for seabirds, NZ fur seals, turtles, dolphins and whales, and shark and rays. Seabird species were grouped according to Abraham & Richard (2020), with 10 specific species (note, Buller's albatrosses contained Buller's albatross and Pacific albatross, and Southern Buller's albatross) and all remaining bird species were grouped into other albatrosses and other birds. For non-bird species the groups were turtles (leatherback turtle, green turtle, loggerhead turtle, turtle; names as per PSCDB), dolphins and whales (long-beaked common dolphin, Hector's dolphin, Dusky dolphin, bottlenose dolphin, beaked whales, orca, common dolphin, pilot whale long-finned, dolphins and toothed whales ; names as per PSCDB), and shark and rays (oceanic whitetip shark, spine-tailed devil ray, basking shark, porbeagle shark, white pointer shark ; names as per PSCDB). More fine-scaled grouping was not considered due to the small number of observed captures. NZ fur seals were treated as a separate group. The effect of data pruning on the observed number of captures for each group is shown in Table 2.

**Table 2:** Effect of data pruning on number of observed captures between the 2006–07 and 2017–19 fishing years in small-vessel SLL fisheries. Shown are number of observed captures for datasets that include variables with different lower threshold for data completeness (see column header); when all variable with data completeness >0% were included then all fishing events were removed from the dataset.

| **Species** | **100%** | **≥75%** | **≥60%** | **≥20%** | **>0%** |
|---|---|---|---|---|---|
| Black petrel | 29 | 21 | 15 | 14 | - |
| Buller's albatross | 154 | 48 | 24 | 16 | - |
| Flesh-footed shearwater | 9 | 2 | 2 | 0 | - |
| Grey petrel | 16 | 11 | 2 | 1 | - |
| Salvin's albatross | 5 | 3 | 2 | 2 | - |
| Sooty shearwater | 1 | 0 | 0 | 0 | - |
| White-capped albatross | 141 | 44 | 21 | 16 | - |
| White-chinned petrel | 18 | 8 | 5 | 0 | - |
| Other birds | 50 | 14 | 5 | 5 | - |
| Other albatrosses | 155 | 62 | 28 | 18 | - |
| | | | | | |
| NZ fur seal | 149 | 56 | 34 | 16 | - |
| Turtles | 19 | 12 | 8 | 4 | - |
| Dolphins and whales | 9 | 4 | 2 | 1 | - |
| Sharks and rays | 3 | 2 | 1 | 1 | - |

## 2.3 Observed effort and captures in small-vessel surface-longline fisheries between 2006–07 and 2018–19

A total of 758 observed captures were recorded in the PSCDB extract for small-vessel SSL fisheries between the 2006–07 and 2018–19 fishing years. These captures predominantly contained seabirds and NZ fur seals (Table 2). Observed captures varied considerably between fishing years, ranging between 19 (2007–08 fishing year) and 143 (2015–16 fishing year) captures (Fig. 1). The mean annually observed effort for data used in this analysis was 171 123 hooks, with annually observed effort ranging between 72 963 (2012–13 fishing year) and 341 272 (2016–17 fishing year) hooks (Fig. 2). Most effort occurred within the areas Northland and Hauraki (NOHA), East Coast North Island (ECNI), West Coast North Island (WCNI), and West Coast South Island (WCSI) (Figs. 2 and 3). The two main target species were Southern bluefin tuna (*Thunnus maccoyii*) and Bigeye tuna (*Thunnus obesus*).

Seabird captures (for all seabird species combined) predominantly occurred along the West Coast of the South Island and the northern regions of the North Island (Fig. 3). The three most frequently caught bird species (not including the groups other birds and other albatrosses) were black petrel, Buller's albatross, and white-capped albatross, with 29, 154, and 141 birds, respectively, caught between the 2006–07 and 2018–19 fishing years (Table 2). Black petrel captures were constrained to the areas Northland and Hauraki, and Bay of Plenty, whereas Buller's albatross albatrosses were observed being captured in the areas Northland and Hauraki, and Bay of Plenty, and East Coast North Island. White-capped albatross captures occurred in most areas but predominantly off the West Coast of South Island (Fig. 3).

Observed captures of NZ fur seals mostly occurred off the West Coast of South Island, and in the areas Bay of Plenty, and East of North Island (Fig. 3). Observed captures of turtles, dolphins and whales, sharks and rays were rare and predominantly occurred in areas of the North Island.

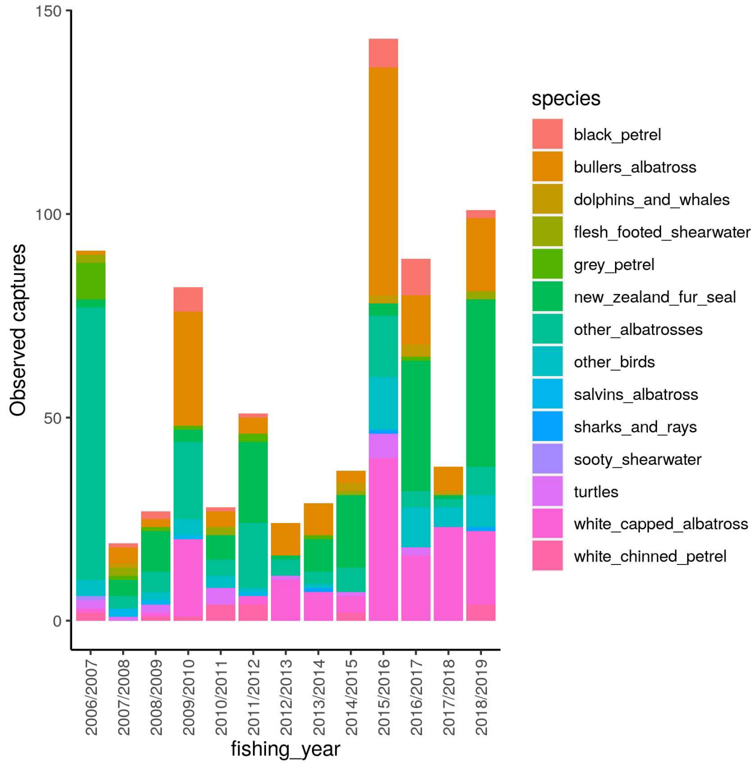



**Figure 1:** Observed captures of seabirds, NZ fur seals, turtles, dolphins and whales, and sharks and rays in small-vessel SLL fisheries between the 2006–07 and 2018–19 fishing years.

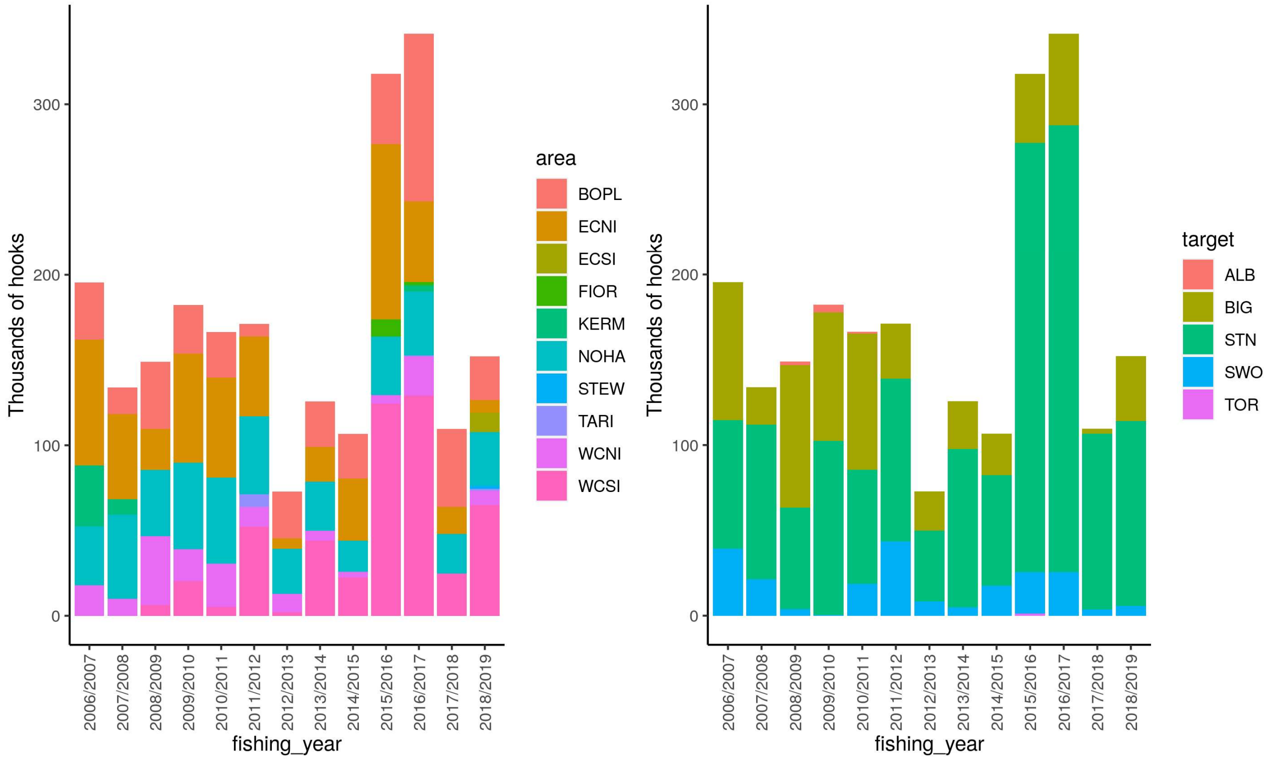



**Figure 2:** SLL effort (small-vessels) in thousands of hooks between the 2006–07 and 2018–19 fishing years by area (left panel) and target species (right panel); Areas are BOPL: Bay of Plenty; ECNI: East Coast Nort Island; ECSI: East Coast South Island; FIOR: Fjordland; KERM: Kermadec Islands; NOHA: Northland and Hauraki; STEW: Stewart-Snares shelf; TARI: Taranaki; WCNI: West Coast North Island; WCSI: West Coast South Island. Target species are ALB: Albacore tuna (*Thunnus alalunga*); BIG: Bigeye tuna (*Thunnus obesus*); STN: Southern bluefin tuna (*Thunnus maccoyii*); SWO: Swordfish, and TOR: Pacific bluefin tuna (*Thunnus orientalis*).

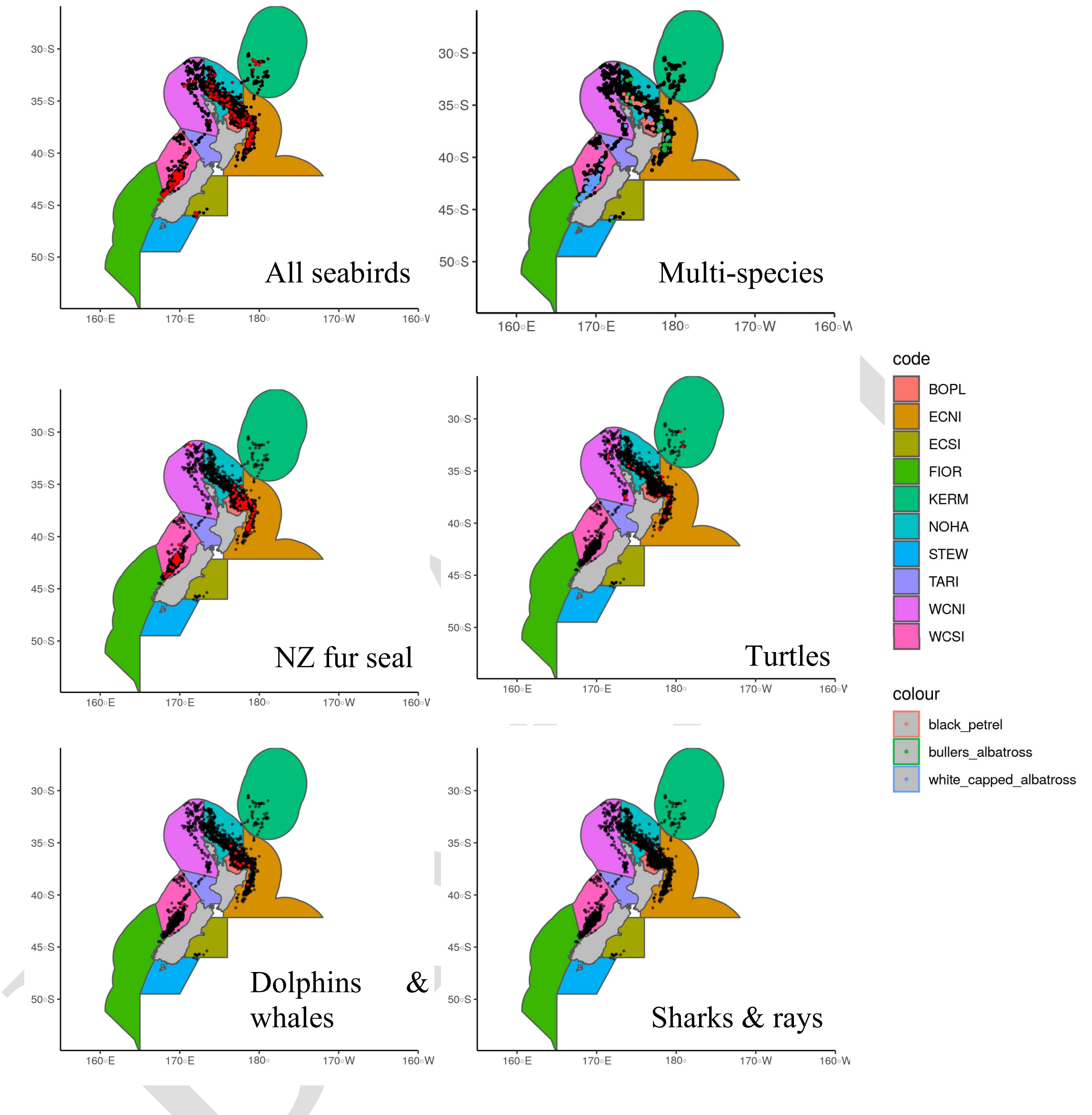



**Figure 3:** Area-variable used in captures modelling. BOPL: Bay of Plenty; ECNI: East Coast Nort Island; ECSI: East Coast South Island; FIOR: Fjordland; KERM: Kermadec Islands; NOHA: Northland and Hauraki; STEW: Stewart-Snares shelf; TARI: Taranaki; WCNI: West Coast North Island; WCSI: West Coast South Island. Also shown are observed fishing events (black dots); observed captures (red dots; and differently coloured dots for dataset used in multi-species model).

## 2.4 Variable correlations

Variables were assessed for potential correlations prior to model fitting as highly correlated variables may lead to confounding of estimated effect size parameters (due to the large number of variables a separate file is provided for pairwise correlations: pairwise_correlations_sll_study.png). A list of potentially confounded parameters due to variable correlation is provided in Table 3. Potentially correlated variables were not necessarily excluded from the analyses, but the potential correlation was considered when interpreting and refining model fits.

**Table 3:** List of potentially correlated variable pairs that may lead to parameter confounding.

| Variable 1 | Variable 2 |
|---|---|
| fishery_seabird | fishery |
| target | fishery |
| | start_month |
| vessel_nation | fishing_year |
| | mitigation_tori |
| start_solar_altitude | start_month |
| season | start_month |
| area_seabirds | area |
| vessel_size | vessel_freezer |
| | vessel_nation |
| | mitigation_tori |
| tori_length | min_depth |
| snood_signal | max_depth |
| vessel_speed | line length |
| sea_surface_temperature | cloud_cover |
| float_line_length | snood_length |
| total_hook_number | basket_number |
| | line length |
| | night_hours |
| | sea_surface_temperature |
| basket_number | night_hours |
| bait_thrower_used_yn | start_month |
| moon_phase | start_month |
| start_solar_altitude | number_of_vessels |
| | sea_surface_temperature |
| | start_month |
| start_month | bird densities |
| season | bird densities |
| tori_length | basket_number |
| | line length |
| | sea_surface_temperature |
| long_streamer_aerial_yn | weight |
| | mainline_diameter |
| | float_line_diameter |
| | surface_float_diameter |
| dist_bait_to_tori | snood_length |

| | |
|---|---|
| | long_streamer_aerial_yn |
| vessel_length | float_line_length |
| | weight |
| | basket_number |
| distance_weight_to_hook | line length |
| float_line_length | basket_number |
| weight | basket_number |

## 2.5 Statistical modelling

Negative binomial generalised linear models (to account for zero-inflated data and potential variation in the capture rate, due to a lack of independence of the capture events within a fishing event) with varying level of complexity were fitted to each of the 4 datasets with records (see Table 1) using the glm.nb-function in R (Venables & Ripley, 2002). The base model structure was:

$$captures_i \sim offset(total\_hook\_num_i/1000) + \boldsymbol{X}_i \qquad (1)$$

where *captures* are the reported captures on observed fishing event *i, total_hook_num* are the total number of hooks reported on observed fishing event *i*, and $\boldsymbol{X}_i$ denote fixed effects for up to 5 variables recorded on observed fishing event *i*. An offset term for the total number of hooks was included in the model because each fishing event is associated with a different number of deployed hooks. The total number of hooks was divided by 1 000, such that the estimated capture rates can be interpreted as captures per 1 000 hooks.

For each dataset, a candidate set of models was defined where each model contained no more than five predictor variables that were complete for the data set being considered. A maximum of five variables was included to reduce potential overfitting of the data given the relative rarity of observed captures. The particular set of variables included in a model defines the set of predictors included in $\boldsymbol{X}$ defined in Equation 1. All possible combinations of the complete variables were allowed in the candidate set.

A two-phase model fitting process was used given the varying completeness of the datasets. In Phase 1, all models within the candidate set were fit to the data (separately for all datasets with varying data completeness) and compared using AIC. Top models (i.e., with lowest AIC) were assessed for potentially confounded parameters and fine-tuned if required. In Phase 2, additional variables that were incomplete for the dataset being considered (i.e., variables that contained missing values and would therefore reduce the number of observations used to estimate parameters) were added to the top AIC-ranked model, and the expanded model fit to the reduced dataset to estimate the effect of the incomplete variable on capture rates. Only a single incomplete variable was added to the top model each time to restrict the degree of data pruning (i.e., adding two incomplete variables to the top model would likely reduce the amount of available data than adding only one incomplete variable). A possible shortcoming of this two-phase approach is that it only estimates the effect of the additional variables given the structure of the top-ranked model, and other base model structures are not considered. However, this is a pragmatic approach given the extremely large possible number of models that would have to be considered otherwise and given that the top AIC-ranked model should include the main variables for explaining variation in the observed captures. The top-ranked model was re-fit to the reduced dataset (as well as the expanded model) to allow valid comparison of the two models using AIC, which must be based on the same data set.

Models were only fit to observed captures of seabirds, NZ fur seals, and turtles. There were insufficient observed captures of dolphins and whales, and sharks and rays to enable meaningful analysis (Table 2).

Seabird captures were analysed using two different general approaches. First, captures for all species where combined (including “other birds” and “other albatrosses”), hence the response variable considered is the total number of seabirds captured on an event. An aggregated seabird relative density layer (see Table 1 for variable descriptions) was developed by summing the species-specific relative monthly distribution layers and re-scaling the new layer, so it sums to one (i.e., there were 12 separate layers with aggregated densities). Second, a multi-species analysis was conducted for the most frequently observed species captures: black petrel, Buller’s albatross, and white-capped albatross (Table 2). Datasets for each of these species were stacked and *species* was used as a variable during the model fitting to allow for a different mean capture rate for each species. This multi-species approach allows the effect of some variables to be consistent across the three species. Further, species- and month-specific relative distributions were used as a covariate. Initial model exploration showed that observed captures for all other species were too rare to obtain species-specific estimates of capture rates. The coarse species groups “other birds” and “other albatrosses” were also excluded here, because these reflect groups of mixed species.

To diagnose model fits, standardized residuals from each top model (i.e., for each species or group of species) were plotted against predictors. Additionally, the average predicted captures per area (see Fig. 3 for areas) were plotted against the average observed captures per area.

Initially, Bayesian model fitting was attempted for modelling the seabird captures (as proposed, following Abraham & Richard, 2020), but was deemed to be impractical for fitting large numbers of models (i.e., > 1 000) within a reasonable time frame. To assess consistency of results based on the initially proposed Bayesian model framework and the final approach used here, a simple set of models has been fitted in both frameworks and results were compared against each other (Appendix B).

# 3. RESULTS

## 3.1 All seabirds captures model

Tables 4 to 7 show the top-10 models (based on AIC) and the Null model (i.e., intercept model) fitted to observed captures of all seabirds combined. For the different datasets between 2 379 and 331 211 models were fitted. Model fitting to all seabird captures suggests a relationship between observed seabird captures and moon phase as well as the start month or season. This result was consistent for all datasets analysed here (Tables 4 to 7). When fitting models to data with ≥75% and 100% data completeness for each variable, then the inclusion of the area variable was also supported (Tables 4 and 5).

Good predictive ability (i.e., the mean number of predicted captures on observed fishing per area compared against the mean number of actual observed captures per area were well correlated) was observed for all top-10 models fitted to data with ≥75% and 100% data completeness per variable (see Figs. 15 and 17 in Appendix C). When fitting models to datasets with ≥60% and ≥20% data completeness per variable, then the top-10 models also included gear configuration-specific variables such as the line length (Tables 6 and 7), and the predictive ability of these models was acceptable (see Figs. 19 and 21 in Appendix C).

The best-supported model (model 1) fitted to the dataset for variables with 100% data completeness, included the variables fishing year, area, presence/absence of a vessel freezer, moon phase, and start month (Table 4). There existed a decreasing trend in standardized residuals with increasing moon phase (Fig. 4), implying that the relationship between observed captures and moon phase could be non-linear. However, re-fitting the model with log-transformed moon phase (i.e., to model an asymptotic relationship between the observed capture rate and moon phase) has not resulted in an improved model fit (results not shown here).



**Table 4**: Top-10 models fitted to all seabirds captures where model fits included variables with 100% data completeness (unpruned dataset with 2 373 fishing events); the total number of explored models was 2 379.

| Model | Description | df | logLik | AIC | Δ AIC |
|---|---|---|---|---|---|
| 1 | fishing_year+area+vessel_freezer+moon_phase+start_month | 36 | -1023.254 | 2118.508 | 0 |
| 2 | area+vessel_size+vessel_freezer+moon_phase+start_month | 26 | -1035.393 | 2122.786 | 4.278 |
| 3 | area+vessel_freezer+moon_phase+start_month+dens | 25 | -1037.134 | 2124.268 | 5.76 |
| 4 | stats_area+fishing_year+vessel_freezer+moon_phase+start_month | 68 | -994.632 | 2125.263 | 6.755 |
| 5 | area+vessel_nation+vessel_freezer+moon_phase+start_month | 25 | -1039.107 | 2128.214 | 9.706 |
| 6 | target+area+vessel_freezer+moon_phase+start_month | 28 | -1036.252 | 2128.505 | 9.997 |
| 7 | area+vessel_freezer+moon_phase+start_month | 24 | -1040.274 | 2128.547 | 10.039 |
| 8 | area+vessel_freezer+moon_phase+start_month+season | 24 | -1040.274 | 2128.547 | 10.039 |
| 9 | area+vessel_freezer+moon_phase+start_month+mitigation_tori | 25 | -1039.489 | 2128.979 | 10.471 |
| 10 | area+vessel_freezer+moon_phase+start_month+time_of_day | 25 | -1040.023 | 2130.046 | 11.538 |
| Null model | Intercept | 2 | -1212.683 | 2429.366 | 310.858 |

**Table 5:** Top-10 models fitted to all seabirds captures where model fits included variables with >75% data completeness (1 069 fishing events or 45% of unpruned dataset); the total number of explored models was 83 681.

| Model | Description | df | logLik | AIC | Δ AIC |
|---|---|---|---|---|---|
| 1 | area+vessel_size+moon_phase+start_month+time_of_day | 24 | -438.7038 | 925.408 | 0 |
| 2 | area+vessel_size+moon_phase+start_month+min_depth | 24 | -439.3688 | 926.738 | 1.33 |
| 3 | area+vessel_size+moon_phase+start_month+baskets_number | 24 | -440.0381 | 928.076 | 2.668 |
| 4 | area+vessel_size+vessel_freezer+moon_phase+start_month | 24 | -440.0645 | 928.129 | 2.721 |
| 5 | area+vessel_freezer+moon_phase+start_month+min_depth | 25 | -441.3773 | 928.755 | 3.347 |
| 6 | area+vessel_nation+moon_phase+start_month+min_depth | 23 | -441.403 | 928.806 | 3.398 |
| 7 | area+moon_phase+start_month+min_depth | 22 | -442.4893 | 928.979 | 3.571 |
| 8 | area+moon_phase+start_month+season+min_depth | 22 | -442.4893 | 928.979 | 3.571 |
| 9 | area+moon_phase+start_month+night_hours+min_depth | 23 | -441.4898 | 928.980 | 3.572 |
| 10 | target+area+moon_phase+start_month+min_depth | 25 | -439.6559 | 929.312 | 3.904 |
| Null model | Intercept | 2 | -512.3364 | 1028.673 | 103.265 |

**Table 6:** Top-10 models fitted to all seabirds captures where model fits included variables with >60% data completeness (462 fishing events or 19% of unpruned dataset); the total number of explored models was 174 436.

| Model | Description | df | logLik | AIC | Δ AIC |
|---|---|---|---|---|---|
| 1 | moon_phase+start_month+start_wind_direction+bait_thrower_used_yn+surface_temperature | 17 | -205.093 | 444.1868 | 0 |
| 2 | moon_phase+start_month+bait_thrower_used_yn+wind_beaufortscale+surface_temperature | 17 | -205.739 | 445.4788 | 1.292 |
| 3 | target+moon_phase+start_month+bait_thrower_used_yn+surface_temperature | 19 | -203.967 | 445.9343 | 1.7475 |
| 4 | moon_phase+start_month+bait_thrower_used_yn+cloud_cover+surface_temperature | 17 | -206.029 | 446.0584 | 1.8716 |
| 5 | moon_phase+start_month+wind+bait_thrower_used_yn+surface_temperature | 18 | -205.085 | 446.1701 | 1.9833 |
| 6 | moon_phase+start_month+mitigation_tori+bait_thrower_used_yn+surface_temperature | 17 | -206.127 | 446.2538 | 2.067 |
| 7 | target+area+moon_phase+start_month+bait_thrower_used_yn | 23 | -200.208 | 446.4167 | 2.2299 |
| 8 | vessel_size+moon_phase+start_month+bait_thrower_used_yn+surface_temperature | 17 | -206.209 | 446.4179 | 2.2311 |
| 9 | moon_phase+start_month+baskets_number+bait_thrower_used_yn+surface_temperature | 17 | -206.256 | 446.5113 | 2.3245 |
| 10 | moon_phase+start_month+bait_thrower_used_yn+surface_temperature | 16 | -207.449 | 446.8981 | 2.7113 |
| Null model | Intercept | 2 | -257.661 | 519.322 | 75.1352 |

**Table 7:** Top-10 models fitted to all seabirds captures where model fits included variables with >20% data completeness (336 fishing events or 14% of unpruned dataset); the total number of explored models was 331 211.

| Model | Description | df | logLik | AIC | Δ AIC |
|---|---|---|---|---|---|
| 1 | moon_phase+season+line_length+cloud_cover+surface_temperature | 9 | -144.024 | 306.0471 | 0 |
| 2 | moon_phase+season+line_length+wind_beaufortscale+surface_temperature | 9 | -145.933 | 309.8658 | 3.8187 |
| 3 | moon_phase+season+line_length+surface_temperature+bait_stream | 9 | -146.146 | 310.2927 | 4.2456 |
| 4 | moon_phase+season+line_length+surface_temperature+tori_height | 9 | -146.156 | 310.3122 | 4.2651 |
| 5 | moon_phase+season+night_hours+cloud_cover+surface_temperature | 9 | -146.429 | 310.8574 | 4.8103 |
| 6 | moon_phase+season+line_length+surface_temperature | 8 | -147.789 | 311.5778 | 5.5307 |
| 7 | moon_phase+season+mitigation_tori+line_length+surface_temperature | 8 | -147.789 | 311.5778 | 5.5307 |
| 8 | moon_phase+season+line_length+surface_temperature+tori_length | 9 | -146.843 | 311.6859 | 5.6388 |
| 9 | moon_phase+season+time_of_day+line_length+surface_temperature | 9 | -146.931 | 311.8629 | 5.8158 |
| 10 | moon_phase+season+time_of_day+line_length+tori_height | 9 | -146.997 | 311.9931 | 5.946 |
| Null model | Intercept | 2 | -179.5254 | 363.0508 | 57.0037 |

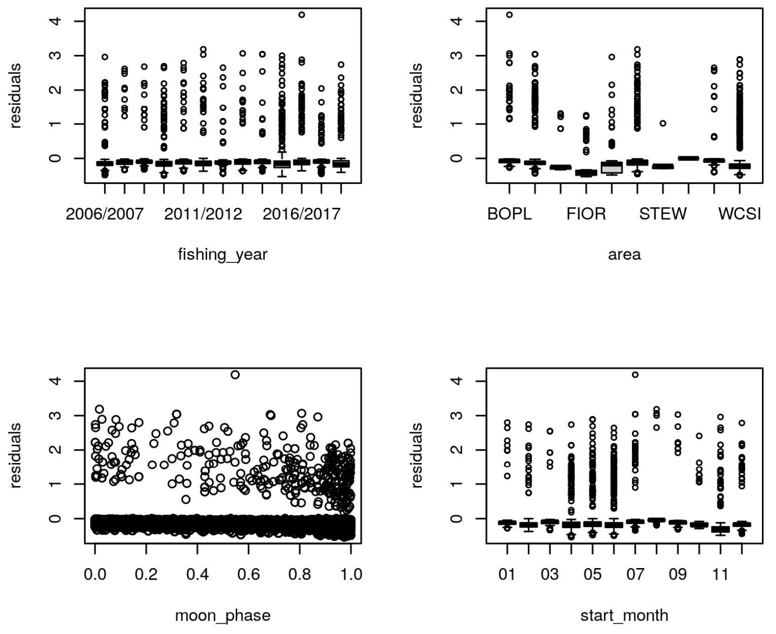



**Figure 4:** Residuals vs predictors from top all seabirds captures model (model 1) where model fits included variables with 100% data completeness (Table 4).

Model estimates from model 1 (Table 4) are shown in Table 8. The estimated mean capture rate (on log-scale) per 1 000 hooks was -3.875 (standard error: 0.535), which converts to approximately 0.021 captures per 1 000 hooks on actual scale. This intercept relates to the case when fishing year is 2006–07, in the Bay of Plenty (BOPL) area, for vessels without vessel freezer, and operating in January during new moon (moon phase = 0). Model strata-specific estimates are further described on back-transformed effects by taking the exponential, hence the effects become multiplicative and can be interpreted as the proportional change of the capture rate by one unit change of the predictor variable.

The model suggests interannual variability in capture rates, with proportional changes ranging between 0.22 and 1.1 (Table 8). Further some areas had significantly higher capture rates, such as the east coast South Island (ECSI) were the proportional change in the capture rate was 38.78 (95% CI: 8.117–185.319) but note that only a few seabird captures were observed in this area (see Fig. 3). The significant effects for start month suggest that higher capture rates were observed during late spring/early summer months (e.g., a proportional increase of 6.4 (95% CI: 2.529–16.217) for captures rate in November) as opposed to lower captures rates over winter (e.g., proportional change of 0.1 (95% CI: 0.028–0.347) or 90% reduced capture rate during August). Capture rates also increased proportionally with moon phase by factor 5.71 (95% CI: 3.731–8.735) per unit change in moon phase (Table 8). The results imply that vessels with vessel freezer on board had captures rates about three times higher (2.86 (95% CI: 1.975–4.143)) compared to vessel without freezer on board.

**Table 8:** Model estimates from top all seabirds captures model (model 1) where model fits included variables with 100% data completeness (Table 4). Base cases for categorical fixed effects were 2006–07 for fishing_year, BOPL for area, FALSE for vessel_freezer and 1 for start_month.

| | Estimate | SE | 95% CI | exp(estimate) incl. 95% CI | z-value | p-value |
|---|---|---|---|---|---|---|
| (Intercept) | -3.875 | 0.535 | -4.924; -2.826 | 0.02 (0.007; 0.059) | -7.238 | <0.001*** |
| fishing_year2007–08 | -0.879 | 0.452 | -1.765; 0.007 | 0.42 (0.171; 1.007) | -1.944 | 0.052 |
| fishing_year2008–09 | -0.880 | 0.445 | -1.752; -0.008 | 0.41 (0.173; 0.992) | -1.979 | 0.048* |
| fishing_year2009–10 | -0.264 | 0.361 | -0.972; 0.444 | 0.77 (0.378; 1.558) | -0.733 | 0.463 |
| fishing_year2010–11 | -0.999 | 0.411 | -1.805; -0.193 | 0.37 (0.165; 0.824) | -2.430 | 0.015* |
| fishing_year2011–12 | -1.055 | 0.380 | -1.8; -0.31 | 0.35 (0.165; 0.733) | -2.778 | 0.005** |
| fishing_year2012–13 | 0.094 | 0.509 | -0.904; 1.092 | 1.1 (0.405; 2.979) | 0.185 | 0.853 |
| fishing_year2013–14 | -1.285 | 0.437 | -2.142; -0.428 | 0.28 (0.117; 0.651) | -2.941 | 0.003** |
| fishing_year2014–15 | -1.052 | 0.453 | -1.94; -0.164 | 0.35 (0.144; 0.849) | -2.321 | 0.020* |
| fishing_year2015–16 | -0.826 | 0.350 | -1.512; -0.14 | 0.44 (0.22; 0.869) | -2.356 | 0.018* |
| fishing_year2016–17 | -1.508 | 0.366 | -2.225; -0.791 | 0.22 (0.108; 0.454) | -4.117 | <0.001*** |
| fishing_year2017–18 | -0.483 | 0.458 | -1.381; 0.415 | 0.62 (0.251; 1.514) | -1.055 | 0.292 |
| fishing_year2018–19 | -0.726 | 0.389 | -1.488; 0.036 | 0.48 (0.226; 1.037) | -1.865 | 0.062 |
| areaECNI | 0.926 | 0.323 | 0.293; 1.559 | 2.52 (1.34; 4.754) | 2.864 | 0.004** |
| areaECSI | 3.658 | 0.798 | 2.094; 5.222 | 38.78 (8.117; 185.319) | 4.587 | <0.001*** |
| areaFIOR | 3.707 | 0.660 | 2.413; 5.001 | 40.73 (11.172; 148.502) | 5.618 | <0.001*** |
| areaKERM | 0.310 | 0.527 | -0.723; 1.343 | 1.36 (0.485; 3.83) | 0.588 | 0.556 |
| areaNOHA | 0.303 | 0.319 | -0.322; 0.928 | 1.35 (0.725; 2.53) | 0.952 | 0.341 |
| areaSTEW | 3.614 | 1.725 | 0.233; 6.995 | 37.11 (1.262; 1091.164) | 2.095 | 0.036* |
| areaTARI | -33.800 | 21220000.000 | -41591234; 41591166 | 0 (0,0) | 0 | 1.000 |
| areaWCNI | -0.364 | 0.488 | -1.32; 0.592 | 0.69 (0.267; 1.808) | -0.746 | 0.456 |
| areaWCSI | 2.644 | 0.337 | 1.983; 3.305 | 14.07 (7.268; 27.235) | 7.844 | <0.001*** |
| vessel_freezerTRUE | 1.051 | 0.189 | 0.681; 1.421 | 2.86 (1.975; 4.143) | 5.573 | <0.001*** |
| moon_phase | 1.742 | 0.217 | 1.317; 2.167 | 5.71 (3.731; 8.735) | 8.02 | <0.001*** |
| start_month02 | -0.260 | 0.536 | -1.311; 0.791 | 0.77 (0.27; 2.205) | -0.486 | 0.627 |

| | | | | | | |
|---|---|---|---|---|---|---|
| start_month03 | -0.852 | 0.640 | -2.106; 0.402 | 0.43 (0.122; 1.495) | -1.332 | 0.183 |
| start_month04 | -1.184 | 0.513 | -2.189; -0.179 | 0.31 (0.112; 0.837) | -2.309 | 0.021* |
| start_month05 | -0.857 | 0.489 | -1.815; 0.101 | 0.42 (0.163; 1.107) | -1.752 | 0.080 |
| start_month06 | -0.228 | 0.478 | -1.165; 0.709 | 0.8 (0.312; 2.032) | -0.477 | 0.634 |
| start_month07 | -1.247 | 0.474 | -2.176; -0.318 | 0.29 (0.113; 0.728) | -2.629 | 0.009** |
| start_month08 | -2.322 | 0.644 | -3.584; -1.06 | 0.1 (0.028; 0.347) | -3.605 | <0.001*** |
| start_month09 | 0.055 | 0.548 | -1.019; 1.129 | 1.06 (0.361; 3.093) | 0.101 | 0.920 |
| start_month10 | 0.786 | 0.580 | -0.351; 1.923 | 2.19 (0.704; 6.84) | 1.357 | 0.175 |
| start_month11 | 1.857 | 0.474 | 0.928; 2.786 | 6.4 (2.529; 16.217) | 3.917 | <0.001*** |
| start_month12 | 0.989 | 0.474 | 0.06; 1.918 | 2.69 (1.062; 6.808) | 2.089 | 0.037* |

In Phase 2, the top model (model 1) originally fitted to the unpruned dataset was repeatedly re-fitted with one additional variable that was not already assessed at this stage (i.e., the model was re-fitted repeatedly but each time with another additional variable). Variables with a significant slope are shown in Table 9 (non-significant parameters are provided in Table 10). Based on the AIC difference between the expanded model and the original model 1 (but re-fitted to account for altered data structure), all parameters received some support for being included in the model. However, note that most variables were only recorded recently between the 2017–18 and 2018–19 fishing years, hence only being recorded on between 272 to 302 fishing events. A pairwise comparison between each additional predictor implies that parameters are not strongly correlated meaning that each variable could potentially have an independent effect on the estimated capture rate (however, consider the low sample size for some variables) (Fig. 5). Plots showing standardized residuals vs. each fitted additional variable are shown in Appendix K.

Most estimated effects pointed into the anticipated direction (Table 9). Mandatory bycatch mitigation measures seemed reducing seabird bycatch if employed effectively. For example, tori lines reduced seabird captures when the tori line was over the bait entry point (variable: line_entry_yn) with a proportional change of 0.61 (95% CI: 0.385–0.964) or 51% reduction compared to tori lines not being set over the bait entry point. Aerial extent (expected to reduce the capture rate) had a positive effect on the capture rate but note that the aerial extent of the tori line is estimated by the observer and thus might be inaccurate. In contrast, an increasing attachment height of the tori line (variable: attach1_height), which influences the aerial extent, resulted in a proportional change of the capture rate of 0.37 (95% CI:0.191–0.731) or 63% decrease per unit change in attachment height (range 3 to 17 m). There existed also a small decrease in capture rates (1% or proportional change of 0.99 (95% CI: 0.983–0.999)) per unit (cm) increase in the distance to the weight to the hook. Increasing the number of night hours also resulted in a proportional change of the capture rate by 0.82 (95% CI: 0.671–0.997) or 18% reduction of capture rate per additional night hour.

Gear configuration and vessel behaviour variables also affected the capture rate of seabirds. For example, capture rates decreased by about 5% for every additional 10 km off the shore (i.e., proportional change per 10 km is 0.95 (95% CI: 0.915–0.979)). Further, an increasing number of turns (range 0 to 2) during setting increased capture rates by 94% (or proportional change of 1.94 (95% CI: 1.145–3.301)). Increasing float line length resulted in reduced seabird capture rates (proportional change per meter float line: 0.76 (95% CI: 0.611–0.937)). A higher risk of seabird captures was observed for fishing during higher sea surface temperatures (proportional increase of 1.27 (95% CI: 1.076–1.49) in capture rates per additional degree Celsius). Histograms for significant predictors are shown in Appendix O.

**Table 9:** Estimated effect size and AIC for models with significant effect for additional parameter $X_i$ (i.e., variable that was not already assessed using the unpruned dataset) being added to top all seabirds captures model (model 1; Table 4); *Model 1*: model 1 in Table 4 but re-fitted with fishing events removed that had additional parameter $X_i$ missing; *Model 1 + Xi*: Model 1 from Table 4 plus additional parameter; *Δ AIC*: AIC difference between AICs of *Model 1* and *Model 1 + $X_i$*; *Estimate* and *SE*: Estimated effect size and standard error of additional parameter $X_i$; *Prop. events left* and *N events left*: proportion and total fishing events left compared to unpruned dataset; *N captures*: Number of observed captures; *Year range*: Range of fishing years (January year shown) with available records for additional parameter $X_i$. Variables are ordered by the number of available fishing events.

| | AIC | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **Model 1** | **Model 1 + $X_i$** | **Δ AIC** | **Estimate** | **SE** | 95% CI | **exp(estimate) incl. 95% CI** | **Prop. events left** | **N events left** | **N captures** | **Year range** |
| distance_to_shore | 2026.827 | 2017.765 | -9.062 | -0.0000055 | 0.0000017 | 0–0 | 0.95 (0.915–0.979) per 10 km | 0.973 | 2 309 | 518 | 2007–2019 |
| night_hours | 2026.697 | 2024.858 | -1.838 | -0.201 | 0.101 | -0.399–-0.003 | 0.82 (0.671–0.997) | 0.971 | 2 308 | 518 | 2007–2019 |
| min_depth | 2045.462 | 2041.005 | -4.457 | -0.023 | 0.009 | -0.041–-0.005 | 0.98 (0.96–0.995) | 0.952 | 2 260 | 570 | 2007–2019 |
| surface_temperature | 1375.791 | 1369.878 | -5.913 | 0.236 | 0.083 | 0.073–0.399 | 1.27 (1.076–1.49) | 0.646 | 1 534 | 351 | 2007–2018 |
| tori_length | 1151.762 | 1141.913 | -9.849 | -0.007 | 0.002 | -0.011–-0.003 | 0.99 (0.989–0.997) | 0.575 | 1 365 | 300 | 2007–2018 |
| line_entry_yn | 1148.016 | 1145.400 | -2.616 | | | | | 0.574 | 1 362 | 299 | 2007–2018 |
| line_entry_ynY | | | | -0.495 | 0.234 | -0.954–-0.036 | 0.61 (0.385–0.964) | | | | |
| dist_stern_to_bait_min | 294.293 | 291.590 | -2.703 | 0.042 | 0.019 | 0.005–0.079 | 1.04 (1.005–1.082) | 0.127 | 302 | 95 | 2018–2019 |
| float_line_length | 294.293 | 287.875 | -6.418 | -0.279 | 0.109 | -0.493–-0.065 | 0.76 (0.611–0.937) | 0.127 | 302 | 95 | 2018–2019 |
| dist_bait_to_tori | 294.293 | 291.380 | -2.914 | 0.047 | 0.022 | 0.004–0.09 | 1.05 (1.004–1.094) | 0.127 | 301 | 95 | 2018–2019 |
| attach1_height | 294.293 | 286.692 | -7.601 | -0.984 | 0.342 | -1.654–-0.314 | 0.37 (0.191–0.731) | 0.126 | 300 | 95 | 2018–2019 |
| attach1_distance | 294.293 | 289.332 | -4.961 | 0.080 | 0.030 | 0.021–0.139 | 1.08 (1.021–1.149) | 0.126 | 300 | 95 | 2018–2019 |
| setting_turns | 293.496 | 290.271 | -3.225 | 0.665 | 0.270 | 0.136–1.194 | 1.94 (1.145–3.301) | 0.125 | 297 | 95 | 2018–2019 |
| float_line_diameter | 234.251 | 231.967 | -2.283 | -0.309 | 0.141 | -0.585–-0.033 | 0.73 (0.557–0.968) | 0.120 | 284 | 95 | 2018–2019 |
| aerial_extent | 294.293 | 292.367 | -1.926 | 0.079 | 0.039 | 0.003–0.155 | 1.08 (1.003–1.168) | 0.117 | 278 | 95 | 2018–2019 |
| distance_weight_to_hook | 294.293 | 290.771 | -3.522 | -0.009 | 0.004 | -0.017–-0.001 | 0.99 (0.983–0.999) | 0.115 | 272 | 95 | 2018–2019 |

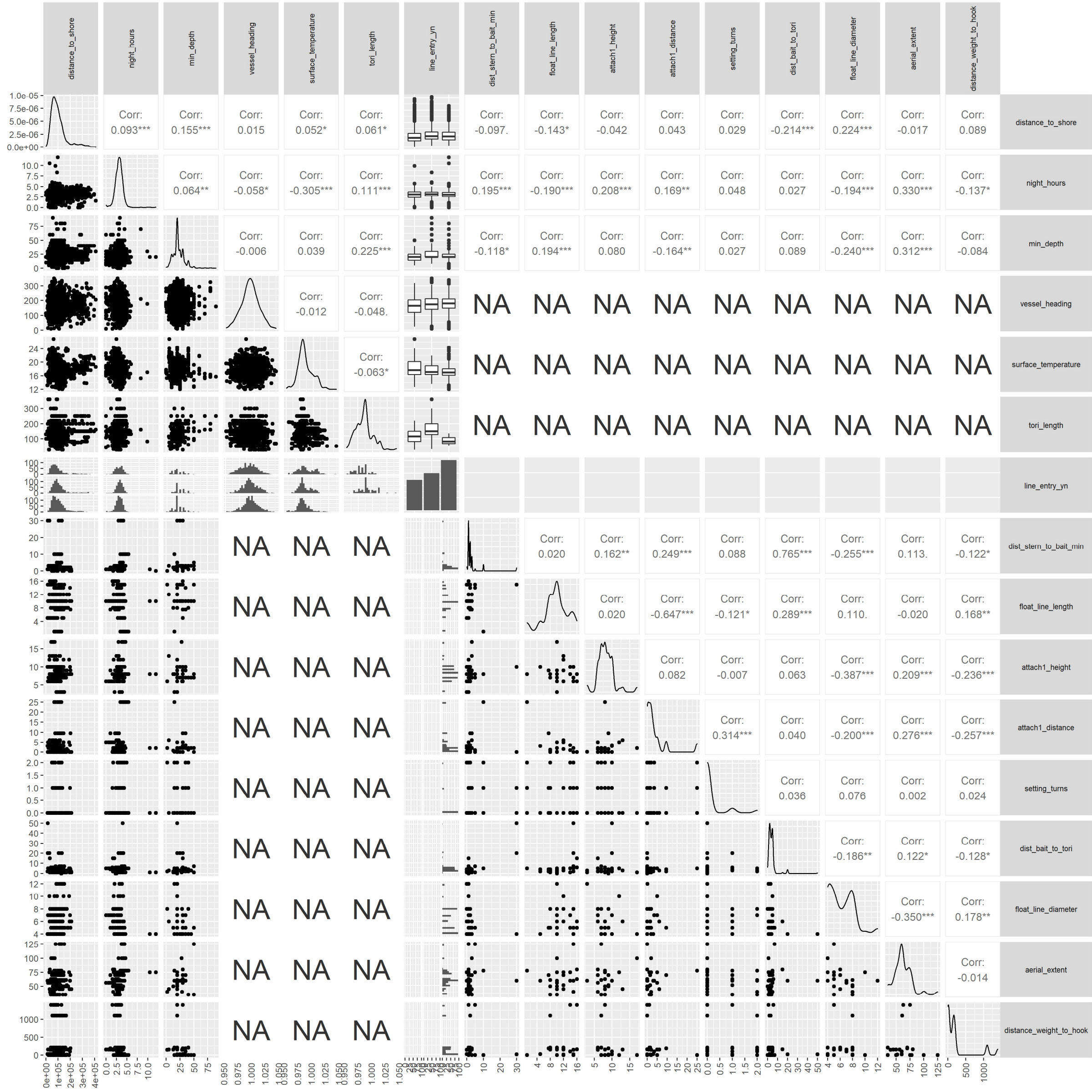



**Figure 5:** Pairwise comparison of significant additional parameters (Table 9) that were added to top all seabirds captures model (model 1; Table 4).

**Table 10:** Estimated effect size and AIC for models with non-significant effect for additional parameter Xi (i.e., variable that was not already assessed using the unpruned dataset) being added to top all seabirds captures model (model 1; Table 4); Model 1: model 1 in Table 4 but re-fitted with fishing events removed that had additional parameter Xi missing; Model 1 + Xi: Model 1 from Table 4 plus additional parameter; Δ AIC: AIC difference between AICs of Model 1 and Model 1 + Xi; Estimate and SE: Estimated effect size and standard error of additional parameter Xi; Prop. events left and N events left: proportion and total fishing events left compared to unpruned dataset; *N captures*: Number of observed captures; Year range: Range of fishing year (January year shown) with available records for additional parameter Xi. Variables are ordered by the number of available fishing events. Blank field for estimates: model failed.

| | AIC | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **Model 1** | **Model 1 + $X_i$** | **Δ AIC** | **Estimate** | **SE** | **95% CI** | **exp(estimate) incl. 95% CI** | **Prop events left** | **N events left** | **N captures** | **Year range** |
| baskets_number | 2116.790 | 2118.679 | 1.889 | -0.001 | 0.003 | -0.007–0.005 | 1 (0.993–1.005) | 0.99 | 2 358 | 578 | 2007–2019 |
| line_length | 2103.319 | 2104.897 | 1.578 | -0.006 | 0.009 | -0.024–0.012 | 0.99 (0.977–1.012) | 0.99 | 2 354 | 578 | 2007–2019 |
| max_depth | 2011.905 | 2013.868 | 1.963 | 0.000 | 0.002 | -0.004–0.004 | 1 (0.996–1.004) | 0.93 | 2 216 | 566 | 2007–2019 |
| start_wind_direction | 1971.143 | 1971.260 | 0.117 | -0.001 | 0.001 | -0.003–0.001 | 1 (0.997–1.001) | 0.92 | 2 204 | 534 | 2007–2019 |
| bait_thrower_used_yn | 1811.520 | 1811.518 | -0.002 | | | | | 0.87 | 2 062 | 484 | 2007–2018 |
| *bait_thrower_used_ynY* | | | | 0.647 | 0.403 | -0.143–1.437 | 1.91 (0.867–4.208) | | | | |
| wind_beaufortscale | 1768.439 | 1770.416 | 1.977 | -0.007 | 0.048 | -0.101–0.087 | 0.99 (0.904–1.091) | 0.85 | 2 006 | 475 | 2007–2018 |
| number_of_vessels | 1766.770 | 1768.740 | 1.970 | 0.008 | 0.043 | -0.076–0.092 | 1.01 (0.927–1.097) | 0.84 | 2 003 | 477 | 2007–2018 |
| cloud_cover | 1615.879 | 1617.879 | 2.000 | 0.000 | 0.002 | -0.004–0.004 | 1 (0.996–1.004) | 0.82 | 1 944 | 418 | 2007–2019 |
| snood_signal_time | 1817.884 | 1819.195 | 1.311 | -0.026 | 0.033 | -0.091–0.039 | 0.97 (0.913–1.039) | 0.81 | 1 942 | 515 | 2007–2019 |
| vessel_speed | 1604.664 | 1604.440 | -0.223 | -0.141 | 0.093 | -0.323–0.041 | 0.87 (0.724–1.042) | 0.76 | 1 801 | 444 | 2007–2018 |
| long_streamer_distance | 1647.798 | 1649.265 | 1.467 | -0.020 | 0.025 | -0.069–0.029 | 0.98 (0.933–1.029) | 0.73 | 1 725 | 453 | 2008–2018 |
| tori_height | 1151.758 | 1153.374 | 1.615 | -0.029 | 0.048 | -0.123–0.065 | 0.97 (0.884–1.067) | 0.58 | 1 364 | 300 | 2007–2018 |
| bait_stream | 1108.039 | 1109.887 | 1.847 | -0.019 | 0.049 | -0.115–0.077 | 0.98 (0.891–1.08) | 0.55 | 1 294 | 288 | 2007–2018 |
| mitigation_none | 542.988 | 542.988 | 0.000 | | | | | 0.24 | 573 | 165 | 2007–2018 |
| bottom_depth | | | | | | | | 0.15 | 355 | 112 | 2007–2018 |
| light_sticks_yn | 294.293 | 296.181 | 1.888 | | | | | 0.13 | 302 | 95 | 2018–2019 |
| *light_sticks_ynY* | | | | -0.126 | 0.378 | -0.867–0.615 | 0.88 (0.42–1.849) | | | | |
| acoustic_bird_deterrent_yn | 294.293 | | | | | | | 0.13 | 302 | 95 | 2018–2019 |
| deck_light_yn | 294.293 | 296.293 | 2.000 | | | | | 0.13 | 302 | 95 | 2018–2019 |
| *deck_light_ynY* | | | | 5.782 | 9575210.253 | -18767406.314–18767417.878 | | | | | |
| fishing_gear_discard_yn | 294.293 | 296.293 | 2.000 | | | | | 0.13 | 302 | 95 | 2018–2019 |
| *fishing_gear_discard_ynU* | | | | -1.514 | 4640629.833 | -9095635.987–9095632.959 | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| hook_type | 294.293 | | | | | | | 0.13 | 302 | 95 | 2018–2019 |
| number_snoods | 294.293 | 296.170 | 1.876 | -0.038 | 0.099 | -0.232–0.156 | 0.96 (0.793–1.169) | 0.13 | 302 | 95 | 2018–2019 |
| setting_path | 293.496 | 323.077 | 29.581 | | | | | 0.13 | 301 | 95 | 2018–2019 |
| *setting_path1A0* | | | | -8.410 | 16104918.120 | -31565647.925–31565631.105 | | | | | |
| *setting_path1A1* | | | | -5.294 | 16104918.120 | -31565644.809–31565634.221 | | | | | |
| *setting_path1A2* | | | | -5.836 | 16104918.120 | -31565645.351–31565633.679 | | | | | |
| *setting_path1B0* | | | | -12.606 | 69319931.110 | -135867077.582–135867052.37 | | | | | |
| *setting_path1C0* | | | | -42.872 | 37219191.411 | -72949658.038–72949572.294 | | | | | |
| *setting_path1C1* | | | | -7.910 | 16104918.120 | -31565647.425–31565631.605 | | | | | |
| *setting_path2A0* | | | | -8.057 | 68908170.998 | -135060023.213–135060007.099 | | | | | |
| *setting_path3* | | | | -8.929 | 16104918.120 | -31565648.444–31565630.586 | | | | | |
| *setting_path3A0* | | | | -8.433 | 16104918.120 | -31565647.948–31565631.082 | | | | | |
| *setting_path3B2* | | | | -4.308 | 48580967.229 | -95218700.077–95218691.461 | | | | | |
| *setting_path3C0* | | | | -4.127 | 67911046.218 | -133105654.714–133105646.46 | | | | | |
| *setting_path3C1* | | | | -9.810 | 16104918.120 | -31565649.325–31565629.705 | | | | | |
| *setting_path4A0* | | | | -8.071 | 16104918.120 | -31565647.586–31565631.444 | | | | | |
| *setting_path5* | | | | -3.925 | 67911046.163 | -133105654.404–133105646.554 | | | | | |
| *setting_path5A* | | | | -3.914 | 67911046.129 | -133105654.327–133105646.499 | | | | | |
| *setting_path5A0* | | | | -7.609 | 16104918.120 | -31565647.124–31565631.906 | | | | | |
| *setting_path5B1* | | | | 15.077 | 69104127.639 | -135444075.095–135444105.249 | | | | | |
| *setting_path5B2* | | | | -9.009 | 68908170.882 | -135060023.938–135060005.92 | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *setting_path5C1* | | | | -38.409 | 17345159.198 | -33996550.437–33996473.619 | | | | | |
| *setting_path5D2* | | | | -7.584 | 68908170.872 | -135060022.493–135060007.325 | | | | | |
| *setting_path5U2* | | | | -4.293 | 67911046.044 | -133105654.539–133105645.953 | | | | | |
| *setting_path6A* | | | | -4.082 | 67911046.159 | -133105654.554–133105646.39 | | | | | |
| *setting_path6A0* | | | | -6.450 | 16104918.120 | -31565645.965–31565633.065 | | | | | |
| *setting_path6B* | | | | -3.560 | 67911046.147 | -133105654.008–133105646.888 | | | | | |
| *setting_path6C1* | | | | -8.199 | 16104918.120 | -31565647.714–31565631.316 | | | | | |
| *setting_path6C2* | | | | -6.153 | 16104918.120 | -31565645.668–31565633.362 | | | | | |
| *setting_path6E0* | | | | -8.496 | 16104918.120 | -31565648.011–31565631.019 | | | | | |
| discards_during_setting | 284.309 | 288.308 | 4.000 | | | | | 0.13 | 301 | 94 | 2018–2019 |
| *discards_during_settingU* | | | | 27.370 | 16499039.615 | -32338090.275–32338145.015 | | | | | |
| *discards_during_settingY* | | | | -0.031 | 1.406 | -2.787–2.725 | 0.97 (0.062–15.253) | | | | |
| line_setting_height | 294.293 | 295.363 | 1.070 | -0.401 | 0.370 | -1.126–0.324 | 0.67 (0.324–1.383) | 0.13 | 301 | 95 | 2018–2019 |
| long_streamer_yn | 294.293 | 296.293 | 2.000 | | | | | 0.13 | 300 | 95 | 2018–2019 |
| *long_streamer_yn* | | | | -4.465 | 10569122.468 | -20715484.502–20715475.572 | | | | | |
| light_streamer_yn | 294.293 | 293.251 | -1.042 | | | | | 0.13 | 300 | 95 | 2018–2019 |
| *light_streamer_yn* | | | | -1.357 | 0.850 | -3.023–0.309 | 0.26 (0.049–1.362) | | | | |
| setting_strategy | 263.909 | 269.418 | 5.508 | | | | | 0.12 | 286 | 88 | 2018–2019 |
| *setting_strategy2* | | | | -2.064 | 67396558.112 | -132097255.964–132097251.836 | | | | | |
| *setting_strategy3* | | | | -2.358 | 1.340 | -4.984–0.268 | 0.09 (0.007–1.308) | | | | |
| *setting_strategy4* | | | | -1.511 | 0.891 | -3.257–0.235 | 0.22 (0.038–1.265) | | | | |
| *setting_strategy5* | | | | -1.198 | 1.007 | -3.172–0.776 | 0.3 (0.042–2.172) | | | | |
| *setting_strategy6* | | | | -1.202 | 1.098 | -3.354–0.95 | 0.3 (0.035–2.586) | | | | |
| surface_float_diameter | 234.251 | 236.251 | 2.000 | -0.572 | 304917.132 | -597638.151–597637.007 | | 0.12 | 284 | 70 | 2018–2019 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| snood_length | 234.251 | 234.617 | 0.366 | 0.107 | 0.077 | -0.044–0.258 | 1.11 (0.957–1.294) | 0.12 | 284 | 70 | 2018–2019 |
| weight | 294.293 | 291.920 | -2.373 | -0.024 | 0.014 | -0.051–0.003 | 0.98 (0.95–1.003) | 0.12 | 272 | 95 | 2018–2019 |
| weighting_type | 294.293 | 295.967 | 1.674 | | | | | 0.12 | 272 | 95 | 2018–2019 |
| *long_streamer_aerial_yn* | | | | -0.802 | 0.549 | -1.878–0.274 | 0.45 (0.153–1.315) | | | | |
| *weighting_typeF* | | | | -13.379 | 34748477.641 | -68107029.555–68107002.797 | | | | | |
| *weighting_typeOW* | | | | 20.256 | 23340677.409 | -45747707.466–45747747.978 | | | | | |
| *weighting_typeS* | | | | 22.153 | 17513902.051 | -34327225.867–34327270.173 | | | | | |
| *weighting_typeSW* | | | | 23.989 | 17513902.051 | -34327224.031–34327272.009 | | | | | |
| *weighting_typeW* | | | | 22.692 | 17513902.051 | -34327225.328–34327270.712 | | | | | |
| *weighting_typeWC* | | | | 23.568 | 22990701.479 | -45061751.331–45061798.467 | | | | | |
| long_streamer_aerial_yn | 294.293 | 294.430 | 0.136 | | | | | 0.11 | 258 | 95 | 2018–2019 |
| *long_streamer_aerial_yn* | | | | -0.802 | 0.549 | -1.878–0.274 | 0.45 (0.153–1.315) | | | | |

## 3.2 Multi-species captures model: black petrel, white-capped albatross, Buller's albatross

Tables 11 to 14 show the top-10 (and top-11 in table 11) and intercept models when fitting a multi-species captures model to observed captures of black petrels, white-capped albatrosses, and Buller's albatrosses. For the different datasets between 6 884 and 510 415 models were fitted. Models 1 to 10 in each table show that very similar results were obtained compared to the model being fitted to all seabird captures combined (i.e., when ignoring the actual species), with consistent support to include the parameters area, start month or season and moon phase (Tables 11 to 14). The top models fitted to the full data set were not including fishing year (as opposed to the top model in the all seabird captures model), but note that less captures were available for this model fit (i.e., only three species were included). Standardized residuals vs. predictor plots (Figs. 6 and 7) showed a similar trend for moon phase as also observed in the all seabirds model. Further, some obvious pattern existed when assessing residuals against bird density (Fig. 6). Initial model exploration (not shown here) showed that the species density effect (*dens*, e.g., in model 1, Table 11) was only significant if an area term was included, implying that both terms are confounded. The non-significant effect for species density could be due to inaccurate species distribution layers or that recorded fishing start positions do not match with areas of high bird densities were captures might have occurred. The coarse *area* variable seems therefore being a sufficient and preferred proxy to reflect the species distribution as indicated by the top model in Table 11. Further, it seemed reasonable to include an interaction between area and species, because each of the modelled species have very localised distributions (e.g., black petrel in Hauraki Gulf region). Another post-hoc adjustment was to remove the initially moon phase-species interaction as the difference in AICs between the two top model's (model 11 without, and model 12 with moon phase-species interaction) was only 1.405. The post-hoc adjusted model (model 11) received the strongest support. Model 11 was further support by the good alignment between mean predicted captures per area and the actual mean observed capture per area (Figs. 22 to 24 in Appendix D). Models 1 to 10 showed poor predictive ability.



**Table 11**: Top-13 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with 100% data completeness (unpruned dataset with 2 373 fishing events); the total number of explored models was 6 884 plus 3 post-hoc adjusted models (11 to 13).

| Model | Description | df | logLik | AIC | Δ AIC |
|---|---|---|---|---|---|
| 11 | area:species + vessel_freezer + start_month + moon_phase | 44 | -799.1226 | 1686.245 | 0 |
| 12 | area:species + vessel_freezer + start_month + moon_phase:species | 46 | -797.8248 | 1687.65 | 1.405 |
| 13 | area:species + vessel_freezer + start_month + dens + moon_phase:species | 47 | -797.6347 | 1689.269 | 3.024 |
| 1 | area+vessel_freezer+start_month+dens+moon_phase:species | 27 | -853.937 | 1761.874 | 75.629 |
| 2 | area+vessel_size+start_month+dens+moon_phase:species | 28 | -853.05 | 1762.1 | 75.855 |
| 3 | stats_area+vessel_size+start_month+dens+moon_phase:species | 60 | -822.758 | 1765.516 | 79.271 |
| 4 | fishing_year+area+vessel_freezer+start_month+moon_phase:species | 38 | -844.78 | 1765.561 | 79.316 |
| 5 | stats_area+vessel_freezer+start_month+dens+moon_phase:species | 59 | -823.896 | 1765.792 | 79.547 |
| 6 | area+vessel_size+vessel_freezer+start_month+moon_phase:species | 28 | -856.393 | 1768.785 | 82.54 |
| 7 | area+vessel_size+season+dens+moon_phase:species | 20 | -864.81 | 1769.621 | 83.376 |
| 8 | fishing_year+area+start_month+dens+moon_phase:species | 38 | -848.769 | 1773.538 | 87.293 |
| 9 | stats_area+fishing_year+vessel_freezer+start_month+moon_phase:species | 70 | -816.815 | 1773.63 | 87.385 |
| 10 | fishing_year+area+vessel_size+start_month+moon_phase:species | 39 | -848.299 | 1774.597 | 88.352 |
| Null model | intercept | 2 | -1070.998 | 2145.996 | 459.751 |

**Table 12:** Top-10 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with >75% data completeness (1 069 fishing events or 45% of unpruned dataset); the total number of explored models was 146 595.

| Model | Description | df | logLik | AIC | Δ AIC |
|---|---|---|---|---|---|
| 1 | area+moon_phase+season+time_of_day+baskets_number | 15 | -345.247 | 720.4934 | 0.00 |
| 2 | fishing_year+area+start_month+dens+moon_phase:species | 34 | -326.372 | 720.7443 | 0.25 |
| 3 | fishing_year+area+moon_phase+season+baskets_number | 24 | -336.618 | 721.2362 | 0.74 |
| 4 | area+moon_phase+season+baskets_number+distance_to_shore | 15 | -346.041 | 722.0821 | 1.59 |
| 5 | area+season+dens+moon_phase:species+baskets_number | 17 | -344.28 | 722.5607 | 2.07 |
| 6 | area+start_month+dens+moon_phase:species+distance_to_shore | 25 | -336.563 | 723.1262 | 2.63 |
| 7 | area+start_month+dens+time_of_day+moon_phase:species | 25 | -336.61 | 723.2193 | 2.73 |
| 8 | area+season+time_of_day+moon_phase:species+baskets_number | 17 | -344.66 | 723.32 | 2.83 |
| 9 | fishing_year+area+moon_phase+start_month+time_of_day | 32 | -329.727 | 723.453 | 2.96 |
| 10 | fishing_year+area+season+moon_phase:species+baskets_number | 26 | -335.737 | 723.4744 | 2.98 |
| Null model | Intercept | 2 | -418.5183 | 841.0366 | 120.54 |

**Table 13:** Top-10 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with >60% data completeness (462 fishing events or 19% of unpruned dataset); the total number of explored models was 284 273.

| Model | Description | df | logLik | AIC | Δ AIC |
|---|---|---|---|---|---|
| 1 | fishing_year+moon_phase+season+time_of_day+surface_temperature | 17 | -178.698 | 391.3958 | 0.00 |
| 2 | fishing_year+moon_phase+season+mitigation_tori+time_of_day | 17 | -178.835 | 391.6706 | 0.27 |
| 3 | fishing_year+moon_phase+season+dens+time_of_day | 17 | -178.907 | 391.8143 | 0.42 |
| 4 | fishing_year+area+season+dens+long_streamer_distance | 21 | -174.949 | 391.8983 | 0.50 |
| 5 | fishing_year+moon_phase+season+time_of_day+wind_beaufortscale | 17 | -179.113 | 392.2261 | 0.83 |
| 6 | fishing_year+area+moon_phase+season+dens | 21 | -175.155 | 392.3104 | 0.91 |
| 7 | fishing_year+season+mitigation_tori+dens+time_of_day | 17 | -179.193 | 392.3863 | 0.99 |
| 8 | start_month+dens+moon_phase:species+wind_beaufortscale+surface_temperature | 19 | -177.218 | 392.4358 | 1.04 |
| 9 | moon_phase+start_month+dens+wind_beaufortscale+surface_temperature | 17 | -179.253 | 392.5064 | 1.11 |
| 10 | fishing_year+area+moon_phase+season+long_streamer_distance | 21 | -175.308 | 392.6154 | 1.22 |
| Null model | Intercept | | -230.0593 | 464.1186 | 72.72 |

**Table 14:** Top-10 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with >20% data completeness (336 fishing events or 14% of unpruned dataset); the total number of explored models was 510 415.

| Model | Description | df | logLik | AIC | Δ AIC |
|---|---|---|---|---|---|
| 1 | fishing_year+moon_phase+season+time_of_day+surface_temperature | 17 | -178.698 | 391.3958 | 0 |
| 2 | fishing_year+moon_phase+season+mitigation_tori+time_of_day | 16 | -178.835 | 391.6706 | 0.2748 |
| 3 | fishing_year+moon_phase+season+dens+time_of_day | 17 | -178.907 | 391.8143 | 0.4185 |
| 4 | fishing_year+area+season+dens+long_streamer_distance | 21 | -174.949 | 391.8983 | 0.5025 |
| 5 | fishing_year+moon_phase+season+time_of_day+wind_beaufortscale | 17 | -179.113 | 392.2261 | 0.8303 |
| 6 | fishing_year+area+moon_phase+season+dens | 21 | -175.155 | 392.3104 | 0.9146 |
| 7 | fishing_year+season+mitigation_tori+dens+time_of_day | 16 | -179.193 | 392.3863 | 0.9905 |
| 8 | start_month+dens+moon_phase:species+wind_beaufortscale+surface_temperature | 19 | -177.218 | 392.4358 | 1.04 |
| 9 | moon_phase+start_month+dens+wind_beaufortscale+surface_temperature | 17 | -179.253 | 392.5064 | 1.1106 |
| 10 | fishing_year+area+moon_phase+season+long_streamer_distance | 21 | -175.308 | 392.6154 | 1.2196 |
| Null model | Intercept | 2 | | | |

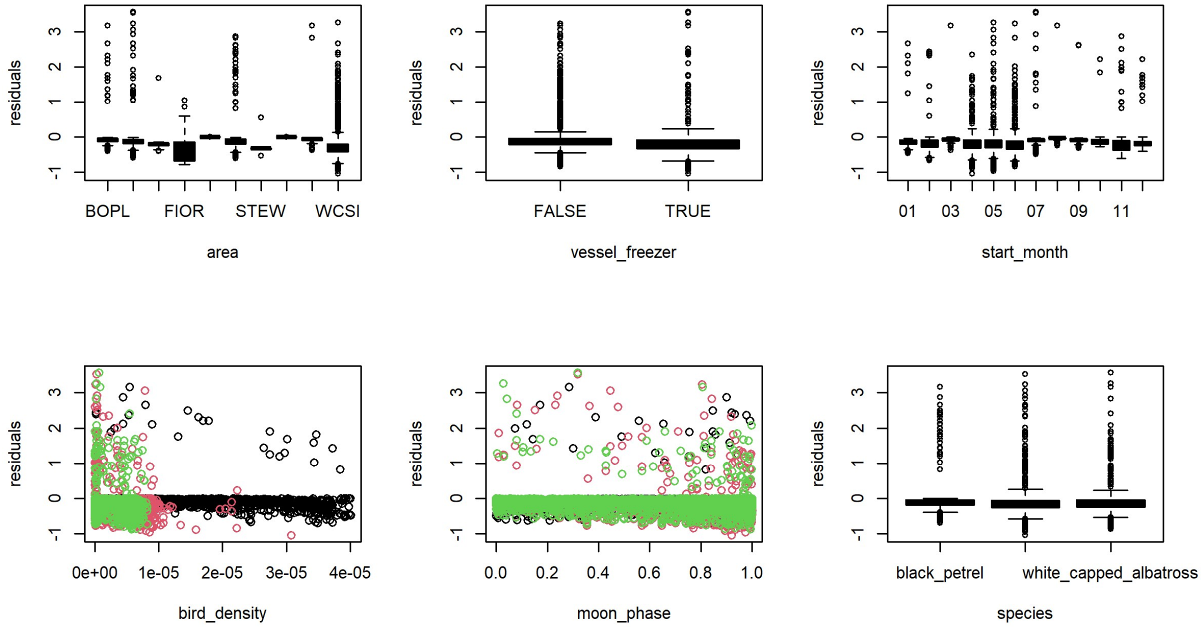



**Figure 6:** Residuals vs predictors from second top multi-species seabird captures model (model 1) where model fits included variables with 100% data completeness (Table 11).

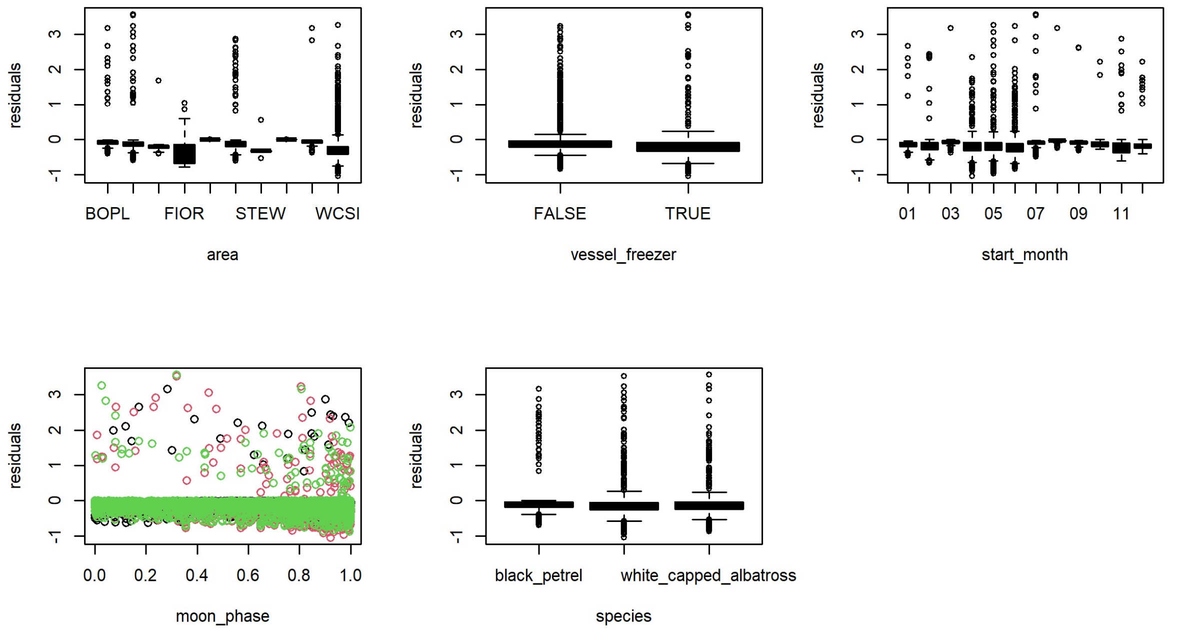



**Figure 7:** Residuals vs predictors from top multi-species seabird captures model (model 11) where model fits included variables with 100% data completeness (Table 11).

Model estimates from model 11 (Table 11) are shown in Table 15. The estimated mean capture (on log-scale) per thousand hooks was -3.606 (standard error: 0.656), which converts to approximately 0.027 captures per 1 000 hooks on actual scale. Similar to the all seabirds model, there was a significant positive relationship between the presence/absence of a vessel freezer, a significant start month effect with higher capture rates being observed during late spring/early summer months and lower captures rates over the winter. Increasing moon phase also resulted in significantly higher capture rates with a proportional increase of 10.84 (95% CI: 6.372–18.433) per unit change in moon phase.

**Table 15:** Model estimates from top multi-species seabirds captures model (model 11) where model fits included variables with 100% data completeness (Table 11).

| | Estimate | SE | 95% CI | exp(estimate) incl. 95% CI | z-value | p-value |
|---|---|---|---|---|---|---|
| (Intercept) | -3.606 | 0.656 | -4.892–-2.32 | 0.03 (0.008–0.098) | -5.495 | <0.001*** |
| vessel_freezerTRUE | 1.246 | 0.203 | 0.848–1.644 | 3.48 (2.335–5.175) | 6.139 | <0.001*** |
| start_month02 | -0.800 | 0.692 | -2.156–0.556 | 0.45 (0.116–1.744) | -1.156 | 0.248 |
| start_month03 | -1.516 | 1.164 | -3.797–0.765 | 0.22 (0.022–2.15) | -1.302 | 0.193 |
| start_month04 | -1.164 | 0.657 | -2.452–0.124 | 0.31 (0.086–1.132) | -1.770 | 0.077 |
| start_month05 | -0.583 | 0.639 | -1.835–0.669 | 0.56 (0.16–1.953) | -0.913 | 0.361 |
| start_month06 | 0.212 | 0.625 | -1.013–1.437 | 1.24 (0.363–4.208) | 0.340 | 0.734 |
| start_month07 | -1.616 | 0.645 | -2.88–-0.352 | 0.2 (0.056–0.703) | -2.504 | 0.012* |
| start_month08 | -3.033 | 1.120 | -5.228–-0.838 | 0.05 (0.005–0.433) | -2.707 | 0.007** |
| start_month09 | -0.841 | 0.868 | -2.542–0.86 | 0.43 (0.079–2.364) | -0.969 | 0.333 |
| start_month10 | -0.055 | 0.908 | -1.835–1.725 | 0.95 (0.16–5.611) | -0.060 | 0.952 |
| start_month11 | 1.213 | 0.611 | 0.015–2.411 | 3.36 (1.016–11.14) | 1.984 | 0.047* |
| start_month12 | 0.592 | 0.645 | -0.672–1.856 | 1.81 (0.511–6.399) | 0.917 | 0.359 |
| moon_phase | 2.383 | 0.271 | 1.852–2.914 | 10.84 (6.372–18.433) | 8.781 | <0.001*** |
| areaBOPL:speciesblack_petrel | -2.641 | 0.511 | -3.643–-1.639 | 0.07 (0.026–0.194) | -5.166 | <0.001*** |
| areaECNI:speciesblack_petrel | -5.204 | 1.025 | -7.213–-3.195 | 0.01 (0.001–0.041) | -5.076 | <0.001*** |
| areaECSI:speciesblack_petrel | -31.550 | 6174000 | -12101072–12101008 | 0 () | 0.000 | 1.000 |
| areaFIOR:speciesblack_petrel | -33.820 | 6097000 | -11950154–11950086 | 0 () | 0.000 | 1.000 |
| areaKERM:speciesblack_petrel | -34.540 | 2729000 | -5348875–5348805 | 0 () | 0.000 | 1.000 |
| areaNOHA:speciesblack_petrel | -2.371 | 0.490 | -3.331–-1.411 | 0.09 (0.036–0.244) | -4.835 | <0.001*** |
| areaSTEW:speciesblack_petrel | -31.480 | 15150000 | -29694031–29693969 | 0 () | 0.000 | 1.000 |
| areaTARI:speciesblack_petrel | -33.700 | 6485000 | -12710634–12710566 | 0 () | 0.000 | 1.000 |
| areaWCNI:speciesblack_petrel | -3.724 | 1.075 | -5.831–-1.617 | 0.02 (0.003–0.198) | -3.464 | <0.001*** |
| areaWCSI:speciesblack_petrel | -33.140 | 876800 | -1718561–1718495 | 0 () | 0.000 | 1.000 |
| areaBOPL:speciesbullers_albatross | -4.055 | 0.815 | -5.652–-2.458 | 0.02 (0.004–0.086) | -4.976 | <0.001*** |
| areaECNI:speciesbullers_albatross | -1.892 | 0.290 | -2.46–-1.324 | 0.15 (0.085–0.266) | -6.531 | <0.001*** |
| areaECSI:speciesbullers_albatross | -31.550 | 6174000 | -12101072–12101008 | 0 () | 0.000 | 1.000 |
| areaFIOR:speciesbullers_albatross | 1.015 | 0.717 | -0.39–2.42 | 2.76 (0.677–11.249) | 1.416 | 0.157 |

| | | | | | | |
|---|---|---|---|---|---|---|
| areaKERM:speciesbullers_albatross | -34.540 | 2729000 | -5348875–5348806 | 0 () | 0.000 | 1.000 |
| areaNOHA:speciesbullers_albatross | -3.313 | 0.575 | -4.44–-2.186 | 0.04 (0.012–0.112) | -5.757 | <0.001*** |
| areaSTEW:speciesbullers_albatross | 2.382 | 1.928 | -1.397–6.161 | 10.83 (0.247–473.845) | 1.236 | 0.217 |
| areaTARI:speciesbullers_albatross | -33.700 | 6485000 | -12710634–12710566 | 0 () | 0.000 | 1.000 |
| areaWCNI:speciesbullers_albatross | -33.030 | 1329000 | -2604873–2604807 | 0 () | 0.000 | 1.000 |
| areaWCSI:speciesbullers_albatross | -0.192 | 0.215 | -0.613–0.229 | 0.83 (0.542–1.258) | -0.893 | 0.372 |
| areaBOPL:specieswhite_capped_albatross | -3.991 | 0.795 | -5.549–-2.433 | 0.02 (0.004–0.088) | -5.022 | <0.001*** |
| areaECNI:specieswhite_capped_albatross | -3.780 | 0.542 | -4.842–-2.718 | 0.02 (0.008–0.066) | -6.974 | <0.001*** |
| areaECSI:specieswhite_capped_albatross | 0.824 | 1.210 | -1.548–3.196 | 2.28 (0.213–24.425) | 0.681 | 0.496 |
| areaFIOR:specieswhite_capped_albatross | 0.652 | 0.744 | -0.806–2.11 | 1.92 (0.447–8.25) | 0.876 | 0.381 |
| areaKERM:specieswhite_capped_albatross | -34.540 | 2729000 | -5348874.54–5348805.46 | 0 () | 0.000 | 1.000 |
| areaNOHA:specieswhite_capped_albatross | -5.296 | 1.089 | -7.43–-3.162 | 0.01 (0.001–0.042) | -4.861 | <0.001*** |
| areaSTEW:specieswhite_capped_albatross | -31.480 | 15150000 | -29694031.48–29693968.52 | 0 () | 0.000 | 1.000 |
| areaTARI:specieswhite_capped_albatross | -33.700 | 6485000 | -12710633.7–12710566.3 | 0 () | 0.000 | 1.000 |
| areaWCNI:specieswhite_capped_albatross | -3.732 | 1.078 | -5.845–-1.619 | 0.02 (0.003–0.198) | -3.460 | <0.001*** |
| areaWCSI:specieswhite_capped_albatross | NA | NA | | | NA | NA |

As for the models fitted to all seabird captures combined, Phase 2 model fitting implied that the configuration of tori lines is important for their effectiveness to reduce seabird captures (Table 16). Whilst variables such as tori length, and distance between weight and hook had only modest effects, the strong negative relationship between capture rates and tori line attachment height (attach1_height; 0.54 (95% CI: 0.327–0.878) on actual scale; or 46% decrease in capture rate per unit (m) increase in attachment height), suggests that the aerial extent of the tori line is strong factor influencing the effectiveness of tori lines.

Gear configuration and vessel behaviour variables that had a strong effect on capture rates were vessel speed, mainline diameter, floatline diameter, number of turns during line setting, and snood length (Table 16). The model results suggest a proportional change of capture rates of 0.78 (95% CI: 0.625–0.969) for every additional knot in vessel speed. Increasing mainline diameter resulted increased in capture rates (1.5 (95% CI: 1.096–2.06) change per unit change on mainline diameter), whereas increases in floatline diameter led to decreasing capture rates (0.74 (0.548–0.994) change per unit change in floatline diameter). Further, for every increase in the number of turns (range 0 to 2), the capture rate proportionally increased by 1.91 (95% CI: 1.138–3.217) or 91%. Longer snoods also increased capture rates (1.18 (95% CI: 1.065–1.301) proportional change per unit change in snood length). Capture rates decreased by about 5% for every additional 10 km off the shore (i.e., proportional change per 10 km is 0.52 (95% CI: 0.357–0.754)). Histograms for significant predictors are shown in Appendix P.

**Table 16:** Estimated effect size and AIC for models with significant effect for additional parameter $X_i$ (i.e., variable that was not already assessed using the unpruned dataset) being added to top multi-species seabird captures model (model 11; Table 11); *Model 1*: model 11 in Table 14 but re-fitted with fishing events removed that had additional parameter $X_i$ missing; *Model 11 + Xi*: Model 11 from Table 11 plus additional parameter; *Δ AIC*: AIC difference between AICs of *Model 11* and *Model 11 +* $X_i$; *Estimate* and *SE*: Estimated effect size and standard error of additional parameter $X_i$; *Prop. events left* and *N events left*: proportion and total fishing events left compared to unpruned dataset; *N captures*: Number of observed captures; *Year range*: Range of fishing year (January year shown) with available records for additional parameter $X_i$. Variables are ordered by the number of available fishing events.

| | AIC | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **variable** | **Model 11** | **Model 11 + $X_i$** | **Δ AIC** | **Estimate** | **SE** | **95% CI** | **exp(estimate) incl. 95% CI** | **Prop events left** | **N events left** | **N captures** | **Year range** |
| line_length | 1682.88 | 1680.27 | -2.61 | -0.023 | 0.011 | -0.045–-0.001 | 0.98 (0.956–0.999) | 0.99 | 2 354 | | 2007–2019 |
| distance_to_shore | 1677.15 | 1660.71 | -16.44 | -6.57E-06 | 1.91E-06 | 0; 0 | 0.52 (0.357–0.754) per 10 km | 0.97 | 2 309 | | 2007–2019 |
| min_depth | 1624.37 | 1622.25 | -2.12 | -0.021 | 0.010 | -0.041–-0.001 | 0.98 (0.96–0.999) | 0.95 | 2 260 | | 2007–2019 |
| cloud_cover | 1179.10 | 1176.57 | -2.53 | -0.006 | 0.003 | -0.012–0 | 0.99 (0.988–1) | 0.82 | 1 944 | | 2007–2019 |
| snood_signal_time | 1502.52 | 1498.74 | -3.78 | -0.078 | 0.036 | -0.149–-0.007 | 0.92 (0.862–0.993) | 0.82 | 1 942 | | 2007–2019 |
| vessel_speed | 1241.25 | 1237.96 | -3.29 | -0.251 | 0.112 | -0.471–-0.031 | 0.78 (0.625–0.969) | 0.76 | 1 801 | | 2007–2018 |
| tori_length | 998.96 | 994.06 | -4.90 | -0.006 | 0.002 | -0.01–-0.002 | 0.99 (0.99–0.998) | 0.57 | 1 364 | | 2007–2018 |
| tori_height | 998.96 | 995.92 | -3.04 | -0.110 | 0.054 | -0.216–-0.004 | 0.9 (0.806–0.996) | 0.59 | 1527 | | 2007–2018 |
| dist_stern_to_bait_min | 318.80 | 316.74 | -2.06 | 0.034 | 0.016 | 0.003–0.065 | 1.03 (1.003–1.068) | 0.14 | 366 | | 2018–2019 |
| mainline_diameter | 318.80 | 314.61 | -4.19 | 0.407 | 0.161 | 0.091–0.723 | 1.5 (1.096–2.06) | 0.14 | 362 | | 2018–2019 |
| attach1_height | 318.80 | 314.60 | -4.20 | -0.624 | 0.252 | -1.118–-0.13 | 0.54 (0.327–0.878) | 0.14 | 360 | | 2018–2019 |
| attach1_distance | 318.80 | 316.50 | -2.30 | 0.047 | 0.023 | 0.002–0.092 | 1.05 (1.002–1.096) | 0.14 | 360 | | 2018–2019 |
| setting_turns | 318.32 | 314.54 | -3.78 | 0.649 | 0.265 | 0.13–1.168 | 1.91 (1.138–3.217) | 0.14 | 356 | | 2018–2019 |
| float_line_diameter | 245.10 | 242.89 | -2.21 | -0.304 | 0.152 | -0.602–-0.006 | 0.74 (0.548–0.994) | 0.13 | 344 | | 2018–2019 |
| snood_length | 245.10 | 239.04 | -6.06 | 0.163 | 0.051 | 0.063–0.263 | 1.18 (1.065–1.301) | 0.13 | 344 | | 2018–2019 |
| distance_weight_to_hook | 318.80 | 314.05 | -4.75 | -0.010 | 0.004 | -0.018–-0.002 | 0.99 (0.982–0.998) | 0.10 | 273 | | 2018–2019 |

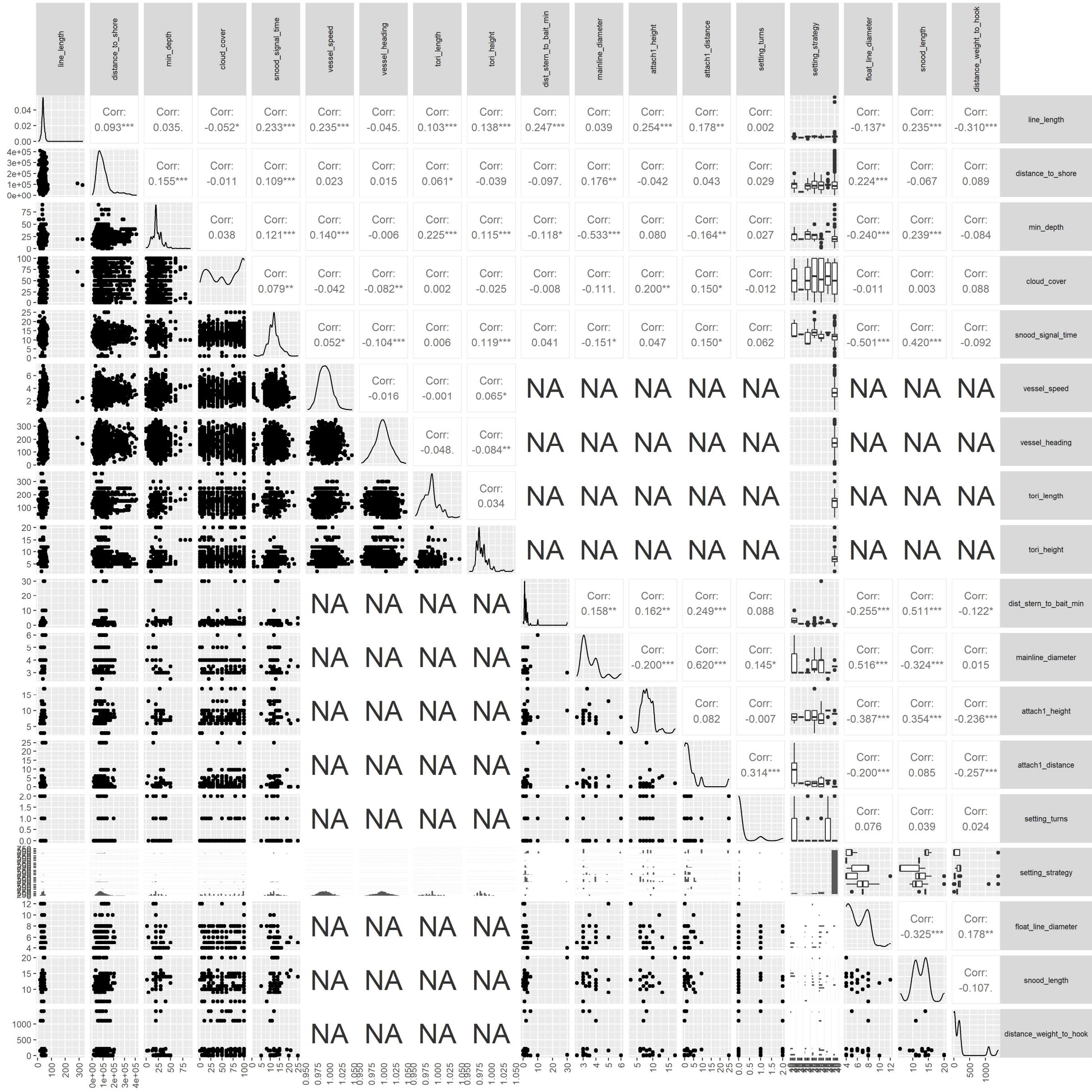



**Figure 8:** Pairwise comparison of significant additional parameters (Table 19) that were added to top multi-species captures model (model 11; Table 11).

**Table 17:** Estimated effect size and AIC for models with non-significant effect for additional parameter Xi (i.e., variable that was not already assessed using the unpruned dataset) being added to top multi-species captures model (model 11; Table 11); Model 11: model 11 in Table 11 but re-fitted with fishing events removed that had additional parameter Xi missing; Model 11 + Xi: Model 11 from Table 11 plus additional parameter; Δ AIC: AIC difference between AICs of Model 11 and Model 11 + Xi; Estimate and SE: Estimated effect size and standard error of additional parameter Xi; Prop. events left and N events left: proportion and total fishing events left compared to unpruned dataset; Year range: Range of fishing year (January year shown) with available records for additional parameter Xi. Variables are ordered by the number of available fishing events. Blank field for estimates: model failed.

| | AIC | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **Model 11** | **Model 11 + $X_i$** | **Δ AIC** | **Estimate** | **SE** | **95% CI** | **exp(estimate) incl. 95% CI** | **Prop events left** | **N events left** | **N captures** | **Year range** |
| baskets_number | 1685.33 | 1687.30 | 1.97 | -0.001 | 0.003 | -0.007–0.005 | 0.03 (0.008–0.098) | 0.99 | 2 358 | | 2007–2019 |
| night_hours | 1677.13 | 1676.13 | -1.00 | -0.221 | 0.124 | -0.464–0.022 | 3.48 (2.335–5.175) | 0.97 | 2 308 | | 2007–2019 |
| max_depth | 1587.84 | 1589.84 | 2.00 | 0.000 | 0.002 | -0.004–0.004 | 0.45 (0.116–1.744) | 0.93 | 2 216 | | 2007–2019 |
| start_wind_direction | 1555.94 | 1556.98 | 1.04 | 0.001 | 0.001 | -0.001–0.003 | 0.22 (0.022–2.15) | 0.93 | 2 204 | | 2007–2019 |
| bait_thrower_used_yn | 1392.67 | 1394.29 | 1.63 | | | | 0.56 (0.16–1.953) | 0.87 | 2 062 | | 2007–2018 |
| *bait_thrower_used_ynY* | | | | -0.477 | 0.786 | -2.018–1.064 | 1.24 (0.363–4.208) | | | | |
| wind_beaufortscale | 1364.05 | 1365.42 | 1.37 | -0.047 | 0.058 | -0.161–0.067 | 0.2 (0.056–0.703) | 0.85 | 2 006 | | 2007–2018 |
| number_of_vessels | 1360.77 | 1362.77 | 2.00 | -0.002 | 0.053 | -0.106–0.102 | 0.05 (0.005–0.433) | 0.84 | 2 003 | | 2007–2018 |
| long_streamer_distance | 1507.42 | 1508.53 | 1.12 | 0.026 | 0.025 | -0.023–0.075 | 0.43 (0.079–2.364) | 0.73 | 1 725 | | 2008–2019 |
| surface_temperature | 955.67 | 956.56 | 0.89 | 0.110 | 0.098 | -0.082–0.302 | 0.95 (0.16–5.611) | 0.65 | 1 534 | | 2007–2018 |
| line_entry_yn | 987.71 | 989.65 | 1.95 | | | | 3.36 (1.016–11.14) | 0.57 | 1 362 | | 2007–2018 |
| *line_entry_ynY* | | | | -0.057 | 0.246 | -0.539–0.425 | 1.81 (0.511–6.399) | | | | |
| bait_stream | 951.22 | 953.18 | 1.96 | -0.012 | 0.059 | -0.128–0.104 | 10.84 (6.372–18.433) | 0.55 | 1 294 | | 2007–2018 |
| mitigation_none | 396.22 | 396.22 | 0.00 | | | | 0.07 (0.026–0.194) | 0.24 | 573 | | 2007–2018 |
| bottom_depth | 392.53 | 394.51 | 1.98 | 0.000 | 0.001 | -0.002–0.002 | 0.01 (0.001–0.041) | 0.15 | 355 | | 2007–2018 |
| light_sticks_yn | 318.80 | 320.69 | 1.89 | -0.132 | 0.401 | -0.918–0.654 | 0 () | 0.13 | 302 | | 2018–2019 |
| acoustic_bird_deterrent_yn | 318.80 | | | | | | 0 () | 0.13 | 302 | | 2018–2019 |
| deck_light_yn | 318.80 | 320.80 | 2 | | | | 0 () | 0.13 | 302 | | 2018–2019 |
| *deck_light_ynY* | | | | 2.565 | 2866541.777 | -5618419–5618424 | 0.09 (0.036–0.244) | | | | |
| fishing_gear_discard_yn | 318.80 | 320.80 | 2 | | | | 0 () | 0.13 | 302 | | 2018–2019 |
| *fishing_gear_discard_ynU* | | | | -1.838 | 2173472.408 | -4260008–4260004 | 0 () | | | | |
| setting_path | 318.32 | | | | | | 0.02 (0.003–0.198) | 0.13 | 301 | | 2018–2019 |
| discards_during_setting | 310.68 | 314.42 | 3.747 | | | | 0 () | 0.13 | 301 | | 2018–2019 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *discards_during_settingU* | | | | 27.347 | 4301311.169 | -8430543–8430597 | 0.02 (0.004–0.086) | | | |
| *discards_during_settingY* | | | | -29.578 | 6789369.979 | -13307195–13307136 | 0.15 (0.085–0.266) | | | |
| hook_type | 318.80 | | | | | | 0 () | 0.13 | 302 | 2018–2019 |
| mainline_material | 318.80 | | | | | | 2.76 (0.677–11.249) | 0.13 | 302 | 2018–2019 |
| float_line_length | 318.80 | 318.95 | 0.147 | -0.047 | 0.036 | -0.118–0.024 | 0 () | 0.13 | 302 | 2018–2019 |
| number_snoods | 318.80 | 320.79 | 1.985 | -0.011 | 0.089 | -0.185–0.163 | 0.04 (0.012–0.112) | 0.13 | 302 | 2018–2019 |
| line_setting_height | 318.80 | 318.85 | 0.051 | -0.531 | 0.354 | -1.225–0.163 | 10.83 (0.247–473.845) | 0.13 | 301 | 2018–2019 |
| long_streamer_yn | 318.80 | 320.80 | 2 | | | | 0 () | 0.13 | 300 | 2018–2019 |
| *long_streamer_yn* | | | | -1.166 | 2454346.699 | -4810521–4810518 | 0 () | | | |
| light_streamer_yn | 318.80 | 319.26 | 0.458 | | | | 0.83 (0.542–1.258) | 0.13 | 300 | 2018–2019 |
| *light_streamer_yn* | | | | -0.482 | 0.403 | -1.272–0.308 | 0.02 (0.004–0.088) | | | |
| dist_bait_to_tori | 318.80 | 317.48 | -1.325 | 0.032 | 0.019 | -0.005–0.069 | 0.02 (0.008–0.066) | 0.13 | 301 | 2018–2019 |
| surface_float_diameter | 245.10 | 247.10 | 2 | -0.517 | 72585.433 | -142268–142267 | 2.28 (0.213–24.425) | 0.12 | 284 | 2018–2019 |
| aerial_extent | 318.80 | 317.26 | -1.539 | 0.055 | 0.029 | -0.002–0.112 | 1.92 (0.447–8.25) | 0.12 | 278 | 2018–2019 |
| long_streamer_aerial_yn | 318.80 | 319.37 | 0.565 | | | | 0 () | 0.11 | 258 | 2018–2019 |
| *long_streamer_aerial_yn* | | | | -0.555 | 0.459 | -1.455–0.345 | 0.01 (0.001–0.042) | | | |
| weight | 318.80 | 317.38 | -1.425 | -0.022 | 0.014 | -0.049–0.005 | 0 () | 0.11 | 272 | 2018–2019 |
| weighting_type | 318.80 | 321.04 | 2.243 | | | | 0 () | 0.11 | 272 | 2018–2019 |
| *weighting_typeF* | | | | -7.139 | 11327367.093 | -22201647–2220163 | 0.02 (0.003–0.198) | | | |
| *weighting_typeOW* | | | | 23.906 | 10299724.770 | -20187437–20187484 | | | | |
| *weighting_typeS* | | | | 23.387 | 9951583.960 | -19505082–19505128 | 0.98 (0.956–0.999) | | | |
| *weighting_typeSW* | | | | 25.145 | 9951583.960 | -19505079–19505130 | 0.52 (0.357–0.754) | | | |
| *weighting_typeW* | | | | 24.293 | 9951583.960 | -19505081–19505129 | 0.98 (0.96–0.999) | | | |
| *weighting_typeWC* | | | | 25.562 | 10224600.253 | -20040191–20040242 | 0.99 (0.988–1) | | | |
| *weighting_typeWS* | | | | 25.205 | 10328258.981 | -20243362–20243413 | 0.92 (0.862–0.993) | | | |

## 3.3 NZ fur seal captures model

Tables 18 to 21 show the top-10 models (based on AIC) and the Null model (i.e., intercept model) fitted to observed captures of NZ fur seals combined. For the different datasets between 4 943 and 584 934 models were fitted. Model fitting to all seabird captures suggests a relationship between observed NZ fur seal captures and fishing year for all datasets (i.e., unpruned and pruned datasets). Fitting models to the unpruned dataset suggests including the variables fishing year, area, and start month across all the 10 top models (Table 18). The top model (model 1) also included the variables presence/absence of tori line and bathymetry, and these variables also occurred across the remaining top-10 models. There was also some indication that NZ fur seal captures rates could be influenced by factors such as distance to shore and vessel speed when fitting models to pruned datasets which contained more available parameters (Tables 19 to 21). However, consistently good predictive ability was archived for the models fitted to unpruned data (Fig. 37 in Appendix I), whereas predictive ability was unsatisfactory for most models being fitted to pruned datasets (Figs. 39, 41, and 43 in Appendix I). Plotting standardized residuals from model 1 in Table 18 against predictors does not imply issues with the model fit (i.e., no obvious patterns were observed; Fig. 9).

**Table 18:** Top-10 models fitted to NZ fur seal captures where model fits included variables with 100% data completeness (unpruned dataset with 2 373 fishing events); the total number of explored models was 4 943.

| Model | Description | df | logLik | AIC | Δ AIC |
|---|---|---|---|---|---|
| 1 | fishing_year+area+start_month+mitigation_tori+bathymetry | 36 | -396.202 | 864.4038 | 0 |
| 2 | fishing_year+area+start_month+mitigation_tori | 35 | -398.086 | 866.1722 | 1.7684 |
| 3 | fishing_year+area+start_month+season+mitigation_tori | 35 | -398.086 | 866.1722 | 1.7684 |
| 4 | fishing_year+area+start_month+mitigation_tori+time_of_day | 36 | -397.101 | 866.2024 | 1.7986 |
| 5 | fishing_year+area+vessel_freezer+start_month+mitigation_tori | 36 | -397.279 | 866.5573 | 2.1535 |
| 6 | fishing_year+area+start_month+mitigation_tori+dens | 36 | -397.301 | 866.6013 | 2.1975 |
| 7 | fishing_year+area+start_month+bathymetry | 37 | -398.576 | 867.151 | 2.7472 |
| 8 | fishing_year+area+start_month+season+bathymetry | 35 | -398.576 | 867.151 | 2.7472 |
| 9 | fishing_year+area+moon_phase+start_month+mitigation_tori | 36 | -397.614 | 867.227 | 2.8232 |
| 10 | fishing_year+area+start_month+time_of_day+bathymetry | 36 | -397.701 | 867.4009 | 2.9971 |
| Null model | Intercept | 2 | -510.2799 | 1024.56 | 160.1562 |

**Table 19:** Top-10 models fitted to NZ fur seal captures where model fits included variables with >75% data completeness (1 069 fishing events or 45% of unpruned dataset); the total number of explored models was 174 436.

| Model | Description | df | logLik | AIC | Δ AIC |
|---|---|---|---|---|---|
| 1 | target+fishing_year+vessel_freezer+mitigation_tori+distance_to_shore | 18 | -150.522 | 337.0437 | 0 |
| 2 | target+fishing_year+vessel_freezer+distance_to_shore | 17 | -151.994 | 337.987 | 0.9433 |
| 3 | target+fishing_year+vessel_size+vessel_freezer+distance_to_shore | 19 | -150.002 | 338.0033 | 0.9596 |
| 4 | target+fishing_year+vessel_freezer+season+distance_to_shore | 20 | -149.088 | 338.1768 | 1.1331 |
| 5 | target+fishing_year+vessel_freezer+distance_to_shore+start_wind_direction | 18 | -151.135 | 338.2699 | 1.2262 |
| 6 | target+fishing_year+vessel_freezer+dens+distance_to_shore | 18 | -151.137 | 338.2736 | 1.2299 |
| 7 | target+fishing_year+season+distance_to_shore | 19 | -150.177 | 338.3534 | 1.3097 |
| 8 | target+fishing_year+vessel_freezer+distance_to_shore+night_hours | 18 | -151.185 | 338.3698 | 1.3261 |
| 9 | target+fishing_year+mitigation_tori+dens+distance_to_shore | 18 | -151.237 | 338.4735 | 1.4298 |
| 10 | target+fishing_year+season+mitigation_tori+distance_to_shore | 20 | -149.358 | 338.715 | 1.6713 |
| Null model | Intercept | 2 | -198.434 | 400.869 | 63.825 |

**Table 20:** Top-10 models fitted to NZ fur seal captures where model fits included variables with >60% data completeness (462 fishing events or 19% of unpruned dataset); the total number of explored models was 331 211.

| Model | Description | df | logLik | AIC | Δ AIC |
|---|---|---|---|---|---|
| 1 | fishing_year+dens+distance_to_shore+vessel_speed+surface_temperature | 15 | -69.7975 | 169.5949 | 0 |
| 2 | fishing_year+dens+distance_to_shore+bathymetry:max_depth+surface_temperature | 15 | -70.615 | 171.2299 | 1.635 |
| 3 | fishing_year+vessel_freezer+dens+vessel_speed+surface_temperature | 15 | -70.6826 | 171.3652 | 1.7703 |
| 4 | fishing_year+dens+distance_to_shore+bathymetry:min_depth+surface_temperature | 15 | -70.7151 | 171.4303 | 1.8354 |
| 5 | fishing_year+dens+distance_to_shore+snood_signal_time+surface_temperature | 15 | -70.9971 | 171.9943 | 2.3994 |
| 6 | fishing_year+vessel_freezer+dens+bathymetry:min_depth+surface_temperature | 15 | -71.1433 | 172.2866 | 2.6917 |
| 7 | fishing_year+vessel_size+dens+distance_to_shore+surface_temperature | 15 | -71.3898 | 172.7796 | 3.1847 |
| 8 | fishing_year+dens+distance_to_shore+surface_temperature | 14 | -72.4555 | 172.9109 | 3.316 |
| 9 | fishing_year+dens+distance_to_shore+long_streamer_distance+surface_temperature | 15 | -71.5501 | 173.1002 | 3.5053 |
| 10 | fishing_year+dens+bathymetry+distance_to_shore+surface_temperature | 15 | -71.6047 | 173.2095 | 3.6146 |

| | | | | | |
|---|---|---|---|---|---|
| Null model | | 2 | -113.082 | 230.1643 | 60.5694 |

**Table 21:** Top-10 models fitted to NZ fur seal captures where model fits included variables with >20% data completeness (336 fishing events or 14% of unpruned dataset); the total number of explored models was 584 934.

| **Model** | **Description** | **df** | **logLik** | **AIC** | **Δ AIC** |
|---|---|---|---|---|---|
| 1 | fishing_year+area+max_depth+tori_length+bait_stream | 19 | -27.602 | 93.20391 | 0 |
| 2 | target+fishing_year+area+start_wind_direction+bait_stream | 20 | -26.6867 | 93.37346 | 0.16955 |
| 3 | target+fishing_year+area+night_hours+bait_stream | 20 | -26.697 | 93.39393 | 0.19002 |
| 4 | target+fishing_year+area+wind_beaufortscale+bait_stream | 20 | -26.7433 | 93.48663 | 0.28272 |
| 5 | target+fishing_year+area+distance_to_shore+bait_stream | 20 | -27.0105 | 94.02102 | 0.81711 |
| 6 | target+fishing_year+start_wind_direction+surface_temperature+bait_stream | 16 | -31.037 | 94.07392 | 0.87001 |
| 7 | target+fishing_year+dens+start_wind_direction+bait_stream | 16 | -31.11 | 94.22008 | 1.01617 |
| 8 | target+fishing_year+vessel_size+long_streamer_distance+bait_stream | 16 | -31.1149 | 94.22973 | 1.02582 |
| 9 | target+fishing_year+vessel_freezer+long_streamer_distance+bait_stream | 16 | -31.1211 | 94.24228 | 1.03837 |
| 10 | target+fishing_year+area+bait_stream | 19 | -28.1819 | 94.3638 | 1.15989 |
| Null model | | 2 | -58.3385 | 120.6771 | 27.47319 |

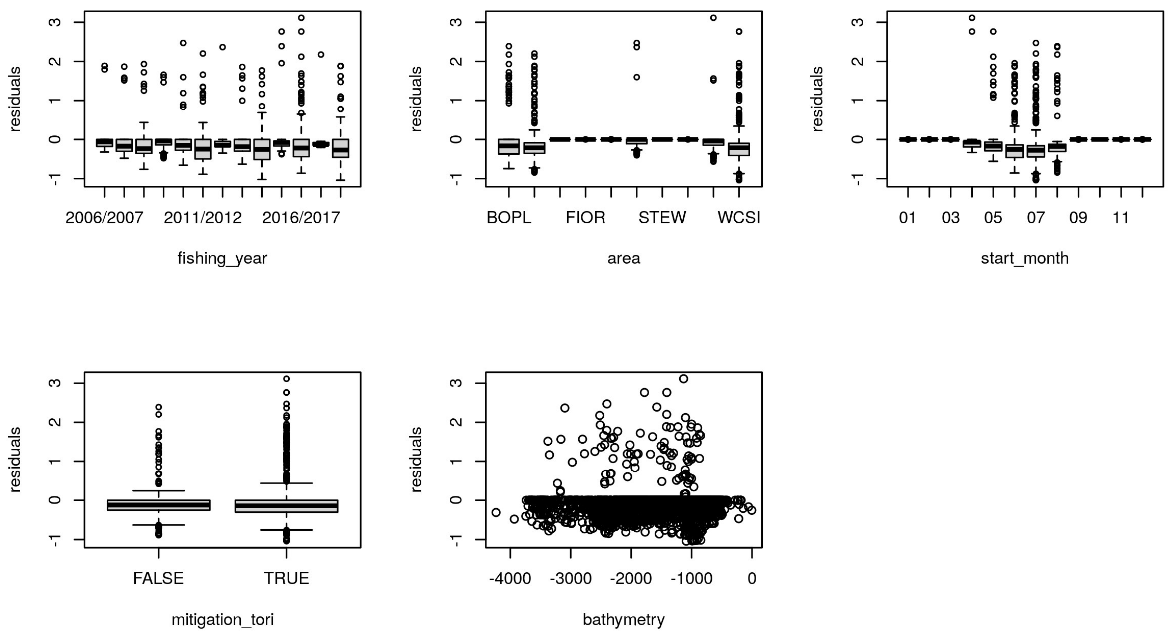



**Figure 9:** Residuals vs predictors from top NZ fur seal captures model (model 1) where model fits included variables with 100% data completeness (Table 18).

Model estimates (model 1 in Table 18) suggest strong interannual variability in NZ fur seal captures rates with proportional changes up to 23.88 (95% CI: 4.417–129.096) or a 22.88% increase in capture rates (in 2011–12 fishing year). Captures of NZ fur seals were area-specific, and no captures were observed for the areas KERM, TARI, FIOR, ECSI, and STEW, hence the large confidence bounds (but note that actual estimates rates would be close to 0). For areas with NZ fur seal captures, the highest capture rate occurred in west coast South Island (WCSI) (proportional change in capture rate: 30.3 (95% CI: 7.653–119.931). NZ fur seal captures only occurred between the month April to August, while capture rates increased over that time period (Table 22). The model further suggests a proportional increase of 2.16 (95% CI: 1.071–4.374) of capture rates for vessels that used a tori line, but tori line might be a proxy for some other vessel-specific components not covered by the model or dataset (personal discussion with William Gibson, FNZ).

**Table 22:** Model estimates from top NZ fur seal captures model (model 1) where model fits included variables with 100% data completeness (Table 18). Base cases for fixed effects: fishing year: 2006–07; area: NOHA (Hauraki Gulf); start_month: 7 (July); mitigation_tori: FALSE.

| | Estimate | SE | 95% CI | Exp(estimate) incl. 95% CI | z-value | p-value |
|---|---|---|---|---|---|---|
| (Intercept) | -8.411 | 1.124 | -10.614–-6.208 | 0 (0–0.002) | -7.484 | <0.001*** |
| fishing_year2007–08 | 1.130 | 0.925 | -0.683–2.943 | 3.1 (0.505–18.973) | 1.221 | 0.222 |
| fishing_year2008–09 | 2.456 | 0.877 | 0.737–4.175 | 11.66 (2.09–65.035) | 2.802 | 0.005** |
| fishing_year2009–10 | 0.490 | 0.982 | -1.435–2.415 | 1.63 (0.238–11.187) | 0.499 | 0.618 |
| fishing_year2010–11 | 2.251 | 0.900 | 0.487–4.015 | 9.5 (1.627–55.423) | 2.502 | 0.012* |
| fishing_year2011–12 | 3.173 | 0.861 | 1.485–4.861 | 23.88 (4.417–129.096) | 3.685 | <0.001*** |
| fishing_year2012–13 | 0.618 | 1.289 | -1.908–3.144 | 1.86 (0.148–23.207) | 0.479 | 0.632 |
| fishing_year2013–14 | 1.946 | 0.906 | 0.17–3.722 | 7 (1.186–41.337) | 2.148 | 0.032* |
| fishing_year2014–15 | 2.977 | 0.843 | 1.325–4.629 | 19.63 (3.761–102.44) | 3.530 | <0.001*** |
| fishing_year2015–16 | -0.088 | 0.975 | -1.999–1.823 | 0.92 (0.135–6.19) | -0.090 | 0.928 |
| fishing_year2016–17 | 2.201 | 0.801 | 0.631–3.771 | 9.03 (1.88–43.422) | 2.747 | 0.006** |
| fishing_year2017–18 | -0.657 | 1.282 | -3.17–1.856 | 0.52 (0.042–6.396) | -0.513 | 0.608 |
| fishing_year2018–19 | 2.975 | 0.820 | 1.368–4.582 | 19.59 (3.927–97.729) | 3.630 | <0.001*** |
| areaBOPL | 1.602 | 0.611 | 0.404–2.8 | 4.96 (1.498–16.437) | 2.622 | 0.009** |
| areaECNI | 2.223 | 0.633 | 0.982–3.464 | 9.23 (2.671–31.934) | 3.514 | <0.001*** |
| areaECSI | -27.630 | 7557000.000 | -14811747.63–14811692.37 | | 0.000 | 1.000 |
| areaFIOR | -28.930 | 15290000.000 | -29968428.93–29968371.07 | | 0.000 | 1.000 |
| areaKERM | -26.720 | 2400000.000 | -4704026.72–4703973.28 | | 0.000 | 1.000 |
| areaSTEW | -30.720 | 47450000.000 | -93002030.72–93001969.28 | | 0.000 | 1.000 |
| areaTARI | -30.050 | 11800000.000 | -23128030.05–23127969.95 | | 0.000 | 1.000 |
| areaWCNI | 0.506 | 0.829 | -1.119–2.13 | 1.66 (0.327–8.422) | 0.610 | 0.542 |
| areaWCSI | 3.411 | 0.702 | 2.035–4.787 | 30.3 (7.653–119.931) | 4.861 | <0.001*** |
| start_month01 | -33.290 | 5634000.000 | -11042673.29–11042606.71 | | 0.000 | 1.000 |
| start_month02 | -34.060 | 5541000.000 | -10860394.06–10860325.94 | | 0.000 | 1.000 |
| start_month03 | -31.690 | 4510000.000 | -8839631.69–8839568.31 | | 0.000 | 1.000 |
| start_month04 | -3.234 | 0.756 | -4.716–-1.752 | 0.04 (0.009–0.173) | -4.278 | <0.001*** |
| start_month05 | -2.341 | 0.413 | -3.15–-1.532 | 0.1 (0.043–0.216) | -5.670 | <0.001*** |
| start_month06 | -0.855 | 0.294 | -1.431–-0.279 | 0.43 (0.239–0.757) | -2.913 | 0.004** |
| start_month08 | 0.257 | 0.407 | -0.541–1.055 | 1.29 (0.582–2.871) | 0.633 | 0.527 |
| start_month09 | -33.240 | 6153000.000 | -12059913.24–12059846.76 | | 0.000 | 1.000 |
| start_month10 | -32.320 | 6417000.000 | -12577352.32–12577287.68 | | 0.000 | 1.000 |
| start_month11 | -30.500 | 2995000.000 | -5870230.5–5870169.5 | | 0.000 | 1.000 |
| start_month12 | -33.390 | 4826000.000 | -9458993.39–9458926.61 | | 0.000 | 1.000 |
| mitigation_toriTRUE | 0.772 | 0.359 | 0.068–1.476 | 2.16 (1.071–4.374) | 2.150 | 0.032* |
| bathymetry | 0.000 | 0.000 | 0–0 | 0.96 (0.914–1) Per 100 m | -1.949 | 0.051 |

Expanding model 1 in Table 18 by additional variables showed that some gear configuration and fishing behaviour-related variables could affect NZ fur seal captures rates (Table 23). For example, using light sticks during fishing could potentially result in an increase of fur seal capture rates with a proportional increase of 42.91 when light sticks were used but note the wide 95% confidence interval of 3.82 to 481.853. The presence of light (or short) streamers seemed to result in higher capture rates. NZ fur seal capture rates decreased with an increase in the number of night hours during fishing (proportional change of 0.57 (95% CI: 0.417–0.768) per additional hour of night fishing).

**Table 23:** Estimated effect size and AIC for models with significant effect for additional parameter $X_i$ (i.e., variable that was not already assessed using the unpruned dataset) being added to top NZ fur seal captures model (model 1; Table 18); *Model 1*: model 1 in Table 18 but re-fitted with fishing events removed that had additional parameter $X_i$ missing; *Model 1 + Xi*: Model 1 from Table 18 plus additional parameter; *Δ AIC*: AIC difference between AICs of *Model 1* and *Model 1 +* $X_i$; *Estimate* and *SE*: Estimated effect size and standard error of additional parameter $X_i$; *Prop. events left* and *N events left*: proportion and total fishing events left compared to unpruned dataset; *Year range*: Range of fishing year (January year shown) with available records for additional parameter $X_i$. Variables are ordered by the number of available fishing events.

| | AIC | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **Model 1** | **Model 1 +** $X_i$ | **Δ AIC** | **Estimate** | **SE** | **95% CI** | **Exp(estimate) incl. 95% CI** | **Prop. events left** | **N events left** | **N captures** | **Year range** |
| night_hours | 835.713 | 827.097 | -8.617 | -0.570 | 0.156 | -0.876–-0.264 | 0.57 (0.417–0.768) | 0.97 | 2 308 | 145 | 2007–2019 |
| max_depth | 840.579 | 832.809 | -7.770 | -0.013 | 0.004 | -0.021–-0.005 | 0.99 (0.979–0.995) | 0.93 | 2 216 | 145 | 2007–2019 |
| cloud_cover | | 666.351 | | 0.011 | 0.004 | 0.003–0.019 | 1.01 (1.003–1.019) | 0.82 | 1 944 | 119 | 2007–2019 |
| snood_signal_time | 748.004 | 737.267 | -10.737 | 0.190 | 0.047 | 0.098–0.282 | 1.21 (1.103–1.326) | 0.81 | 1 942 | 134 | 2007–2019 |
| light_sticks_yn | 161.072 | 149.522 | -11.550 | | | | | 0.13 | 302 | 42 | 2018–2019 |
| *light_sticks_ynY* | | | | 3.759 | 1.234 | 1.34–6.178 | 42.91 (3.82–481.853) | | | | |
| line_setting_height | 161.072 | 124.963 | -36.109 | 3.595 | 0.733 | 2.158–5.032 | 36.42 (8.657–153.19) | 0.13 | 301 | 42 | 2018–2019 |
| dist_bait_to_tori | 161.072 | 140.601 | -20.470 | -2.788 | 0.410 | -3.592–-1.984 | 0.06 (0.028–0.137) | 0.13 | 301 | 42 | 2018–2019 |
| dist_stern_to_bait_min | 161.072 | 145.892 | -15.180 | -0.370 | 0.088 | -0.542–-0.198 | 0.69 (0.581–0.821) | 0.13 | 302 | 42 | 2018–2019 |
| mainline_diameter | 161.072 | 140.844 | -20.228 | -1.160 | 0.269 | -1.687–-0.633 | 0.31 (0.185–0.531) | 0.13 | 302 | 42 | 2018–2019 |
| float_line_length | 161.072 | 152.517 | -8.555 | 0.358 | 0.087 | 0.187–0.529 | 1.43 (1.206–1.696) | 0.13 | 302 | 42 | 2018–2019 |
| number_snoods | 161.072 | 155.026 | -6.046 | 1.002 | 0.264 | 0.485–1.519 | 2.72 (1.623–4.57) | 0.13 | 302 | 42 | 2018–2019 |
| attach1_distance | 161.072 | 147.571 | -13.500 | -0.181 | 0.043 | -0.265–-0.097 | 0.83 (0.767–0.908) | 0.13 | 300 | 42 | 2018–2019 |
| light_streamer_yn | 161.072 | 125.325 | -35.747 | | | | | 0.13 | 300 | 42 | 2018–2019 |
| *light_streamer_yn* | | | | 3.856 | 0.747 | 2.392–5.32 | 47.28 (10.934–204.408) | | | | |
| float_line_diameter | 127.172 | 121.430 | -5.742 | -0.665 | 0.292 | -1.237–-0.093 | 0.51 (0.29–0.911) | 0.12 | 284 | 42 | 2018–2019 |
| snood_length | 127.172 | 120.521 | -6.651 | 0.843 | 0.312 | 0.231–1.455 | 2.32 (1.26–4.282) | 0.12 | 284 | 42 | 2018–2019 |
| aerial_extent | 161.072 | 146.827 | -14.245 | -0.324 | 0.060 | -0.442–-0.206 | 0.72 (0.643–0.814) | 0.12 | 278 | 42 | 2018–2019 |
| weight | 161.072 | 129.443 | -31.629 | 0.053 | 0.010 | 0.033–0.073 | 1.05 (1.034–1.075) | 0.11 | 272 | 42 | 2018–2019 |
| distance_weight_to_hook | 161.072 | 123.391 | -37.681 | 0.022 | 0.004 | 0.014–0.03 | 1.02 (1.014–1.03) | 0.11 | 272 | 42 | 2018–2019 |

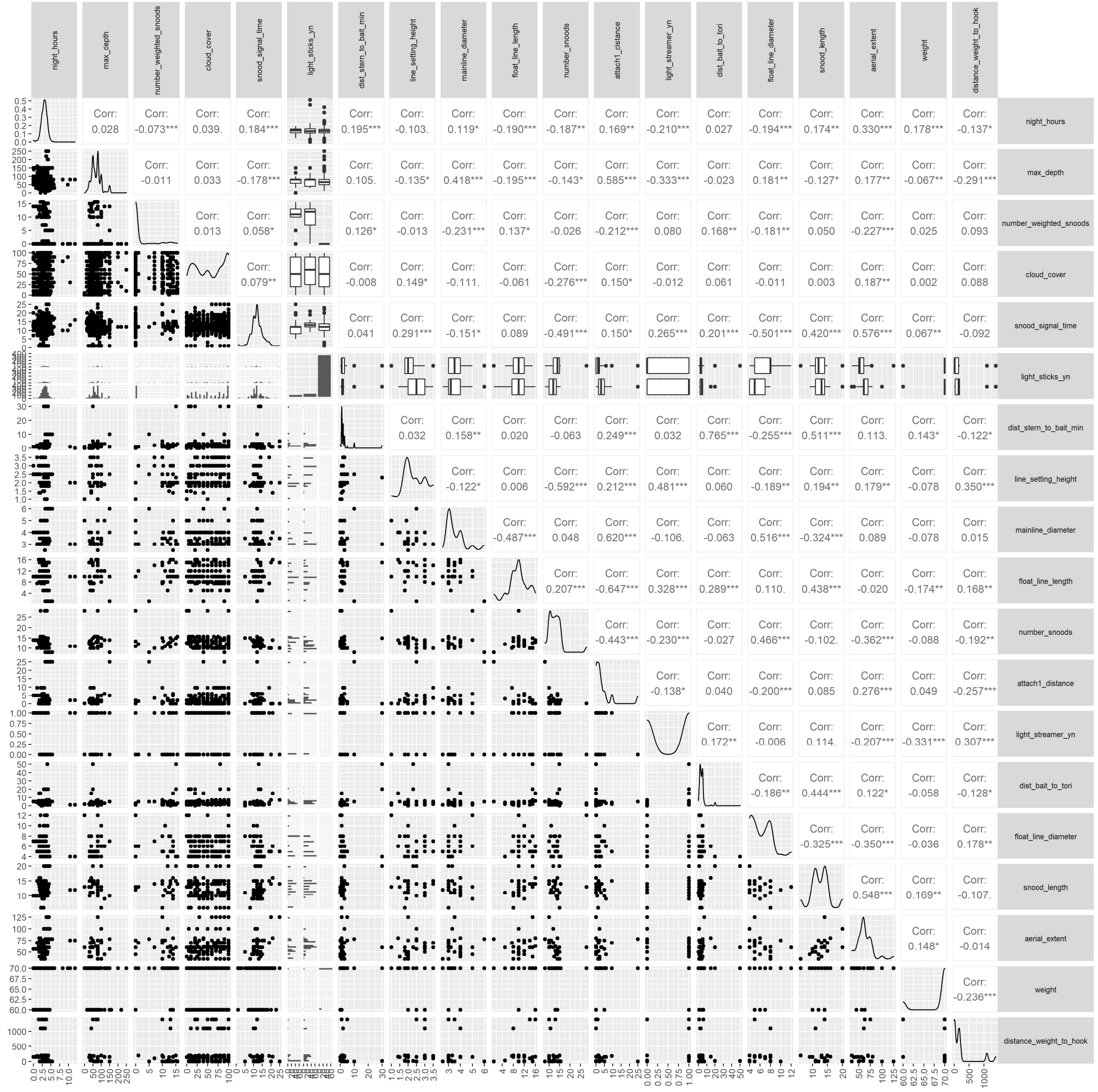


**Figure 10:** Pairwise comparison of significant additional parameters (Table 26) that were added to top all seabirds captures model (model 1; Table 18).

**Table 24:** Estimated effect size and AIC for models with non-significant effect for additional parameter $X_i$ (i.e., variable that was not already assessed using the unpruned dataset) being added to top NZ fur seal captures model (model 1; Table 18); *Model 1*: model 1 in Table 18 but re-fitted with fishing events removed that had additional parameter $X_i$ missing; *Model 1 + Xi*: Model 1 from Table 18 plus additional parameter; *Δ AIC*: AIC difference between AICs of *Model 1* and *Model 1 +* $X_i$; *Estimate* and *SE*: Estimated effect size and standard error of additional parameter $X_i$; *Prop. events left* and *N events left*: proportion and total fishing events left compared to unpruned dataset; *Year range*: Range of fishing year (January year shown) with available records for additional parameter $X_i$. Variables are ordered by the number of available fishing events. Blank field for estimates: model failed.

| | AIC | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **Model 1** | **Model 1 + $X_i$** | **Δ AIC** | **Estimate** | **SE** | **95% CI** | **Exp(estimate) incl. 95% CI** | **Prop. events left** | **N events left** | **N captures** | **Year range** |
| baskets_number | 857.179 | | | | | | | 0.99 | 2 358 | 146 | 2007–2019 |
| line_length | 865.802 | 866.402 | 0.600 | -0.018 | 0.016 | -0.049–0.013 | 0.98 (0.952–1.013) | 0.99 | 2 354 | 149 | 2007–2019 |
| distance_to_shore | 835.713 | 836.277 | 0.564 | 0.000 | 0.000 | 0–0 | 1 (1–1) | 0.97 | 2 309 | 145 | 2007–2019 |
| min_depth | 841.594 | 843.159 | 1.565 | 0.009 | 0.013 | -0.016–0.034 | 1.01 (0.984–1.035) | 0.95 | 2 260 | 145 | 2007–2019 |
| start_wind_direction | 768.637 | 770.347 | 1.710 | -0.001 | 0.001 | -0.003–0.001 | 1 (0.997–1.001) | 0.93 | 2 204 | 130 | 2007–2019 |
| bait_thrower_used_yn | 710.969 | 712.717 | 1.747 | | | | | 0.87 | 2 062 | 107 | 2007–2018 |
| *bait_thrower_used_ynY* | | | | 0.303 | 0.619 | -0.91–1.516 | 1.35 (0.402–4.555) | | | | |
| wind_beaufortscale | 689.089 | 690.968 | 1.878 | 0.027 | 0.076 | -0.122–0.176 | 1.03 (0.885–1.192) | 0.85 | 2 006 | 103 | 2007–2018 |
| number_of_vessels | 685.288 | 687.019 | 1.731 | 0.026 | 0.051 | -0.074–0.126 | 1.03 (0.929–1.134) | 0.84 | 2 003 | 104 | 2007–2018 |
| vessel_speed | 641.730 | 643.481 | 1.751 | -0.069 | 0.137 | -0.338–0.2 | 0.93 (0.714–1.221) | 0.76 | 1 801 | 95 | 2007–2018 |
| vessel_heading | 629.021 | 630.372 | 1.350 | -0.002 | 0.002 | -0.006–0.002 | 1 (0.994–1.002) | 0.74 | 1 763 | 94 | 2007–2018 |
| long_streamer_distance | 697.773 | 699.753 | 1.980 | 0.006 | 0.042 | -0.076–0.088 | 1.01 (0.927–1.092) | 0.73 | 1 725 | 121 | 2008–2019 |
| surface_temperature | 538.382 | 540.381 | 1.999 | -0.003 | 0.133 | -0.264–0.258 | 1 (0.768–1.294) | 0.65 | 1 534 | 80 | 2007–2018 |
| tori_length | 481.499 | 482.824 | 1.325 | -0.002 | 0.003 | -0.008–0.004 | 1 (0.992–1.004) | 0.58 | 1 365 | 68 | 2007–2018 |
| tori_height | 481.452 | 483.064 | 1.612 | 0.038 | 0.059 | -0.078–0.154 | 1.04 (0.925–1.166) | 0.57 | 1 364 | 68 | 2007–2018 |
| line_entry_yn | 481.145 | 481.881 | 0.735 | | | | | 0.57 | 1 362 | 68 | 2007–2018 |
| *line_entry_ynY* | | | | -0.342 | 0.308 | -0.946–0.262 | 0.71 (0.388–1.299) | | | | |
| bait_stream | 456.934 | 458.123 | 1.189 | 0.059 | 0.065 | -0.068–0.186 | 1.06 (0.934–1.205) | 0.55 | 1 294 | 65 | 2007–2018 |
| mitigation_none | 161.997 | 161.997 | 0.000 | | | | | 0.24 | 573 | 25 | 2007–2018 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| bottom_depth | 160.086 | 161.976 | 1.889 | 0.000 | 0.001 | -0.002–0.002 | 1 (0.998–1.002) | 0.15 | 355 | 29 | 2007–2018 |
| discards_during_setting | 161.072 | 165.072 | 4.000 | | | | | 0.13 | 301 | 42 | 2018–2019 |
| *discards_during_settingU* | | | | -11.845 | 26946874.041 | -52815884.965–52815861.275 | | | | | |
| *discards_during_settingY* | | | | 94.591 | 51640162.215 | -101214623.35–101214812.532 | | | | | |
| acoustic_bird_deterrent_yn | | | | | | | | 0.13 | 302 | 42 | 2018–2019 |
| deck_light_yn | 161.072 | 163.072 | 2.000 | | | | | 0.13 | 302 | 42 | 2018–2019 |
| *deck_light_ynY* | | | | -12.860 | 27579472.148 | -54055778.27–54055752.55 | | | | | |
| fishing_gear_discard_yn | 161.072 | 163.072 | 2.000 | | | | | 0.13 | 302 | 42 | 2018–2019 |
| *fishing_gear_discard_ynU* | | | | -11.902 | 22810967.414 | -44709508.033–44709484.229 | | | | | |
| setting_path | 161.072 | 198.967 | 37.895 | | | | | 0.13 | 302 | 42 | 2018–2019 |
| *setting_path1A0* | | | | -25.895 | 61265284.703 | -120079983.913–120079932.123 | | | | | |
| *setting_path1A1* | | | | -62.335 | 90868227.324 | -178101787.89–178101663.22 | | | | | |
| *setting_path1A2* | | | | -27.629 | 61265284.703 | -120079985.647–120079930.389 | | | | | |
| *setting_path1B0* | | | | -29.199 | 91013894.634 | -178387262.682–178387204.284 | | | | | |
| *setting_path1C0* | | | | -24.966 | 61265284.703 | -120079982.984–120079933.052 | | | | | |
| *setting_path1C1* | | | | -24.404 | 61265284.703 | -120079982.422–120079933.614 | | | | | |
| *setting_path2A0* | | | | -32.677 | 90931055.164 | -178224900.798–178224835.444 | | | | | |
| *setting_path3* | | | | -27.523 | 91847696.084 | -180021511.848–180021456.802 | | | | | |
| *setting_path3A0* | | | | -57.327 | 61478506.045 | -120497929.175–120497814.521 | | | | | |
| *setting_path3B2* | | | | 0.529 | 77388559.967 | -151681577.006–151681578.064 | | | | | |
| *setting_path3C0* | | | | 0.026 | 90778791.727 | -177926431.759–177926431.811 | | | | | |
| *setting_path3C1* | | | | -50.939 | 63325105.646 | -124117258.005–124117156.127 | | | | | |
| *setting_path4A0* | | | | -59.010 | 61470999.921 | -120483218.855–120483100.835 | | | | | |
| *setting_path5* | | | | 0.303 | 90778791.727 | -177926431.482–177926432.088 | | | | | |
| *setting_path5A* | | | | -0.814 | 90778791.727 | -177926432.599–177926430.971 | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *setting_path5A0* | | | | -56.701 | 61240831.215 | -120032085.882–120031972.48 | | | | |
| *setting_path5B1* | | | | -89.936 | 90851742.060 | -178069504.374–178069324.502 | | | | |
| *setting_path5B2* | | | | -62.113 | 90828002.116 | -178022946.26–178022822.034 | | | | |
| *setting_path5C1* | | | | -86.110 | 62668811.518 | -122830956.685–122830784.465 | | | | |
| *setting_path5D2* | | | | -60.754 | 90828002.116 | -178022944.901–178022823.393 | | | | |
| *setting_path5U2* | | | | 3.099 | 90778791.727 | -177926428.686–177926434.884 | | | | |
| *setting_path6A* | | | | -3.255 | 90817747.205 | -178002787.777–178002781.267 | | | | |
| *setting_path6A0* | | | | -61.330 | 69804809.724 | -136817488.389–136817365.729 | | | | |
| *setting_path6B* | | | | -3.357 | 90817747.205 | -178002787.879–178002781.165 | | | | |
| *setting_path6C1* | | | | -60.985 | 69804809.170 | -136817486.958–136817364.988 | | | | |
| *setting_path6C2* | | | | -61.363 | 90831774.344 | -178030339.077–178030216.351 | | | | |
| *setting_path6E0* | | | | -61.066 | 67062743.340 | -131443038.012–131442915.88 | | | | |
| attach1_height | 161.072 | 162.577 | 1.505 | 0.433 | 0.305 | -0.165–1.031 | 1.54 (0.848–2.803) | 0.13 | 300 | 42 | 2018–2019 |
| long_streamer_yn | 161.072 | 163.072 | 2.000 | | | | | 0.13 | 300 | 42 | 2018–2019 |
| *long_streamer_yn* | | | | -37.081 | 16740371.622 | -32811165.46–32811091.298 | | | | |
| setting_turns | 161.072 | 163.060 | 1.988 | 0.065 | 0.453 | -0.823–0.953 | 1.07 (0.439–2.593) | 0.13 | 297 | 42 | 2018–2019 |
| setting_strategy | 155.072 | 159.294 | 4.222 | | | | | 0.12 | 286 | 42 | 2018–2019 |
| *setting_strategy2* | | | | -6.511 | 67180393.875 | -131673578.506–131673565.484 | | | | |
| *setting_strategy3* | | | | -30.453 | 2426837.531 | -4756632.014–4756571.108 | | | | |
| *setting_strategy4* | | | | -34.361 | 4328513.218 | -8483920.268–8483851.546 | | | | |
| *setting_strategy5* | | | | -31.818 | 1512629.079 | -2964784.813–2964721.177 | | | | |
| *setting_strategy6* | | | | -32.287 | 6755779.314 | -13241359.742–13241295.168 | | | | |
| surface_float_diameter | 127.172 | 129.172 | 2.000 | 0.041 | 104940.264 | -205682.876–205682.958 | | 0.12 | 284 | 42 | 2018–2019 |
| weighting_type | 161.072 | 136.393 | -24.679 | | | | | 0.11 | 272 | 42 | 2018–2019 |
| *weighting_typeF* | | | | -6.198 | 20669549.404 | -40512323.03–40512310.634 | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *weighting_typeOW* | | | | 30.755 | 8749839.121 | -17149653.922–17149715.432 | | | | |
| *weighting_typeS* | | | | -0.112 | 5843405.944 | -11453075.762–11453075.538 | | | | |
| *weighting_typeSW* | | | | 27.119 | 5407081.244 | -10597852.119–10597906.357 | | | | |
| *weighting_typeW* | | | | 30.736 | 5407081.244 | -10597848.502–10597909.974 | | | | |
| *weighting_typeWC* | | | | -2.632 | 8162412.676 | -15998331.477–15998326.213 | | | | |
| *weighting_typeWS* | | | | 29.442 | 7521786.449 | -14742671.998–14742730.882 | | | | |
| long_streamer_aerial_yn | 161.072 | 160.744 | -0.328 | | | | 0.11 | 258 | 42 | 2018–2019 |
| *long_streamer_aerial_yn* | | | | 44.590 | 11325161.210 | -22197271.382–22197360.562 | | | | |

## 3.4 Turtle captures model

For turtle captures, only unpruned data were used due to the low number of observed captures (see Table 2). The total number of fitted models were 6 884 and the top-10 model included the variables season, time of the day (day vs night), bathymetry, presence/absence of tori line, presence/absence of vessel freezer, moon phase, and target (Table 25). None of the 10 top models showed a good predictive ability (Fig. 44 in Appendix J). The top model with lowest AIC included the variables season and time of day (residuals vs predictor plots shown in Fig. 11) with significantly lower captures during winter and night fishing. Adding additional parameters from pruned datasets to model 1 suggest that the maximum distance between long streamer could increase turtle capture rates (proportional change per meter: 1.13 (95% CI: 1.013; 1.257), and that increased capture rates correspond with increased surface temperature during fishing (proportional change per degree Celsius: 1.52 (95% CI: 1.147; 2.016)).

**Table 25:** Top-10 models fitted to turtle captures where model fits included variables with 100% data completeness (unpruned dataset with 2 373 fishing events); the total number of explored models was 6 884.

| Model | Description | df | logLik | AIC | Δ AIC |
|---|---|---|---|---|---|
| 1 | season+time_of_day | 6 | -101.668 | 215.335 | 0 |
| 2 | season+time_of_day+bathymetry | 7 | -101.208 | 216.417 | 1.082 |
| 3 | target+time_of_day | 7 | -101.330 | 216.659 | 1.324 |
| 4 | season+mitigation_tori+time_of_day | 7 | -101.395 | 216.790 | 1.455 |
| 5 | vessel_freezer+season+time_of_day | 7 | -101.508 | 217.017 | 1.682 |
| 6 | moon_phase+season+time_of_day | 7 | -101.575 | 217.151 | 1.816 |
| 7 | target+bathymetry+bathymetry:time_of_day | 7 | -100.615 | 217.229 | 1.894 |
| 8 | target+bathymetry:time_of_day | 8 | -100.615 | 217.229 | 1.894 |
| 9 | vessel_nation+season+time_of_day | 8 | -101.636 | 217.272 | 1.937 |
| 10 | target+season+time_of_day | 10 | -98.642 | 217.284 | 1.949 |
| Null model | Intercept | 2 | -110.3467 | 224.6934 | 9.3584 |

**Table 26:** Model estimates from top turtle captures model (model 1) where model fits included variables with 100% data completeness (Table 25).

| | Estimate | SE | 95% CI | Exp(Estimate) incl. 95% CI | z-value | Pr(>\|z) |
|---|---|---|---|---|---|---|
| (Intercept) | -3.2639 | 0.664 | -4.565–-1.962 | 0.04 (0.01–0.141) | -4.915 | <0.001*** |
| season2 | -1.102 | 0.604 | -2.286–0.082 | 0.33 (0.102–1.085) | -1.825 | 0.068 |
| season3 | -2.366 | 0.862 | -4.056–-0.676 | 0.09 (0.017–0.508) | -2.744 | 0.006** |
| season4 | -1.378 | 0.890 | -3.122–0.366 | 0.25 (0.044–1.443) | -1.549 | 0.121 |
| time_of_dayNight | -1.661 | 0.531 | -2.702–-0.62 | 0.19 (0.067–0.538) | -3.131 | 0.002** |

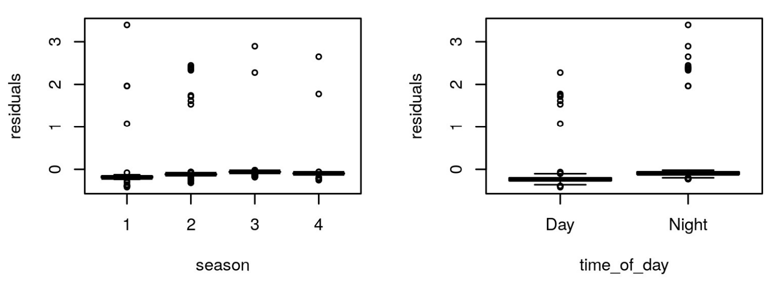



**Figure 11:** Residuals vs predictors from top turtle captures model (model 1) where model fits included variables with 100% data completeness (Table 25).

**Table 27:** Estimated effect size and AIC for models with significant effect for additional parameter $X_i$ (i.e., variable that was not already assessed using the unpruned dataset) being added to top turtle captures model (model 1; Table 25); *Model 1*: model 1 in Table 25 but re-fitted with fishing events removed that had additional parameter $X_i$ missing; *Model 1 + Xi*: Model 1 from Table 25 plus additional parameter; *Δ AIC*: AIC difference between AICs of *Model 1* and *Model 1 + $X_i$*; *Estimate* and *SE*: Estimated effect size and standard error of additional parameter $X_i$; *Prop. events left* and *N events left*: proportion and total fishing events left compared to unpruned dataset; *Year range*: Range of fishing year (January year shown) with available records for additional parameter $X_i$. Variables are ordered by the number of available fishing events.

| | AIC | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **Model 1** | **Model 1 + $X_i$** | **Δ AIC** | **Estimate** | **SE** | **95% CI** | **Exp(estimate) incl. 95% CI** | **Prop. events left** | **N events left** | **N captures** | **Year range** |
| long_streamer_distance | 173.827 | 171.317 | -2.511 | 0.121 | 0.055 | 0.013–0.229 | 1.13 (1.013–1.257) | 0.73 | 1 725 | 15 | 2008–2019 |
| surface_temperature | 166.631 | 160.644 | -5.987 | 0.419 | 0.144 | 0.137–0.701 | 1.52 (1.147–2.016) | 0.65 | 1 534 | 15 | 2007–2019 |

**Table 28:** Estimated effect size and AIC for models with non-significant effect for additional parameter $X_i$ (i.e., variable that was not already assessed using the unpruned dataset) being added to top turtle captures model (model 1; Table 25); Model 1: model 1 in Table 25 but re-fitted with fishing events removed that had additional parameter $X_i$ missing; Model 1 + $X_i$: Model 1 from Table 25 plus additional parameter; Δ AIC: AIC difference between AICs of Model 1 and Model 1 + $X_i$; Estimate and SE: Estimated effect size and standard error of additional parameter $X_i$; Prop. events left and N events left: proportion and total fishing events left compared to unpruned dataset; Year range: Range of fishing year (January year shown) with available records for additional parameter $X_i$. Variables are ordered by the number of available fishing events. Blank field for estimates: model failed.

| | AIC | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **Model 1** | **Model 1 + $X_i$** | **Δ AIC** | **Estimate** | **SE** | **95% CI** | **Exp(estimate) incl. 95% CI** | **Prop. events left** | **N events left** | **N captures** | **Year range** |
| baskets_number | 215.155 | 217.142 | 1.987 | 0.001 | 0.008 | -0.015–0.017 | 1 (0.985–1.017) | 0.99 | 2 358 | 19 | 2007–2019 |
| line_length | 214.871 | 216.374 | 1.503 | 0.012 | 0.013 | -0.013–0.037 | 1.01 (0.987–1.038) | 0.99 | 2 354 | 19 | 2007–2019 |
| distance_to_shore | 193.434 | 194.984 | 1.550 | 0.000 | 0.000 | 0–0 | 1 (1–1) | 0.97 | 2 309 | 17 | 2007–2019 |
| night_hours | 193.428 | 195.408 | 1.980 | 0.042 | 0.298 | -0.542–0.626 | 1.04 (0.582–1.87) | 0.97 | 2 308 | 17 | 2007–2019 |
| min_depth | 194.626 | 196.406 | 1.780 | 0.012 | 0.026 | -0.039–0.063 | 1.01 (0.962–1.065) | 0.95 | 2 260 | 17 | 2007–2019 |
| max_depth | 193.418 | 194.479 | 1.061 | -0.009 | 0.010 | -0.029–0.011 | 0.99 (0.972–1.011) | 0.93 | 2 216 | 17 | 2007–2019 |
| start_wind_direction | 206.202 | 205.907 | -0.295 | 0.004 | 0.003 | -0.002–0.01 | 1 (0.998–1.01) | 0.93 | 2 204 | 18 | 2007–2019 |
| bait_thrower_used_yn | 211.220 | 212.430 | 1.210 | | | | | 0.87 | 2 062 | 19 | 2007–2018 |
| *bait_thrower_used_ynY* | | | | -22.877 | 87809.966 | -172130.41–172084.656 | | | | | |
| wind_beaufortscale | 210.558 | 212.395 | 1.837 | -0.060 | 0.146 | -0.346–0.226 | 0.94 (0.707–1.254) | 0.85 | 2 006 | 19 | 2007–2018 |
| number_of_vessels | 210.608 | 210.271 | -0.337 | -0.287 | 0.214 | -0.706–0.132 | 0.75 (0.493–1.142) | 0.84 | 2 003 | 19 | 2007–2018 |
| cloud_cover | 199.832 | 200.027 | 0.195 | -0.010 | 0.007 | -0.024–0.004 | 0.99 (0.977–1.004) | 0.82 | 1 944 | 18 | 2007–2019 |
| snood_signal_time | 181.046 | 182.370 | 1.324 | -0.071 | 0.085 | -0.238–0.096 | 0.93 (0.789–1.1) | 0.82 | 1 942 | 16 | 2007–2019 |
| vessel_speed | 181.967 | 183.945 | 1.978 | 0.040 | 0.272 | -0.493–0.573 | 1.04 (0.611–1.774) | 0.76 | 1 801 | 16 | 2007–2018 |
| vessel_heading | 181.556 | 182.987 | 1.431 | -0.003 | 0.004 | -0.011–0.005 | 1 (0.989–1.005) | 0.74 | 1 763 | 16 | 2007–2018 |
| tori_length | 121.811 | 123.653 | 1.842 | -0.003 | 0.007 | -0.017–0.011 | 1 (0.983–1.011) | 0.58 | 1 365 | 11 | 2007–2018 |
| tori_height | 121.811 | 123.766 | 1.955 | 0.032 | 0.154 | -0.27–0.334 | 1.03 (0.764–1.396) | 0.57 | 1 364 | 11 | 2007–2018 |
| line_entry_yn | 121.765 | 123.347 | 1.582 | | | | | 0.57 | 1 362 | 11 | 2007–2018 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *line_entry_ynY* | | | | 0.436 | 0.683 | -0.903–1.775 | 1.55 (0.405–5.898) | | | | |
| bait_stream | 121.423 | 123.369 | 1.946 | -0.034 | 0.157 | -0.342–0.274 | 0.97 (0.711–1.315) | 0.55 | 1 294 | 11 | 2007–2018 |
| mitigation_none | 68.981 | 68.981 | 0.000 | | | | | 0.24 | 573 | 6 | 2007–2018 |
| bottom_depth | 30.552 | 32.141 | 1.589 | -0.001 | 0.002 | -0.005–0.003 | 1 (0.995–1.003) | 0.15 | 355 | 3 | 2007–2018 |
| light_sticks_yn | | | | | | | | 0.13 | 302 | 0 | 2018–2019 |
| dist_stern_to_bait_min | | | | | | | | 0.13 | 302 | 0 | 2018–2019 |
| acoustic_bird_deterrent_yn | | | | | | | | 0.13 | 302 | 0 | 2018–2019 |
| deck_light_yn | | | | | | | | 0.13 | 302 | 0 | 2018–2019 |
| fishing_gear_discard_yn | | | | | | | | 0.13 | 302 | 0 | 2018–2019 |
| hook_type | | | | | | | | 0.13 | 302 | 0 | 2018–2019 |
| mainline_material | | | | | | | | 0.13 | 302 | 0 | 2018–2019 |
| mainline_diameter | | | | | | | | 0.13 | 302 | 0 | 2018–2019 |
| float_line_length | | | | | | | | 0.13 | 302 | 0 | 2018–2019 |
| number_snoods | | | | | | | | 0.13 | 302 | 0 | 2018–2019 |
| setting_path | | | | | | | | 0.13 | 301 | 0 | 2018–2019 |
| dist_bait_to_tori | | | | | | | | 0.13 | 301 | 0 | 2018–2019 |
| discards_during_setting | | | | | | | | 0.13 | 301 | 0 | 2018–2019 |
| line_setting_height | | | | | | | | 0.13 | 301 | 0 | 2018–2019 |
| attach1_height | | | | | | | | 0.13 | 300 | 0 | 2018–2019 |
| attach1_distance | | | | | | | | 0.13 | 300 | 0 | 2018–2019 |
| long_streamer_yn | | | | | | | | 0.13 | 300 | 0 | 2018–2019 |
| light_streamer_yn | | | | | | | | 0.13 | 300 | 0 | 2018–2019 |
| setting_turns | | | | | | | | 0.13 | 297 | 0 | 2018–2019 |

| | | | | |
|---|---|---|---|---|
| setting_strategy | 0.12 | 286 | 0 | 2018–2019 |
| float_line_diameter | 0.12 | 284 | 0 | 2018–2019 |
| surface_float_diameter | 0.12 | 284 | 0 | 2018–2019 |
| snood_length | 0.12 | 284 | 0 | 2018–2019 |
| aerial_extent | 0.12 | 278 | 0 | 2018–2019 |
| long_streamer_aerial_yn | 0.11 | 258 | 0 | 2018–2019 |
| weight | 0.11 | 272 | 0 | 2018–2019 |
| weighting_type | 0.11 | 272 | 0 | 2018–2019 |
| distance_weight_to_hook | 0.11 | 272 | 0 | 2018–2019 |

## 4. WORKSHOP OUTCOME

**Date and Time:** Wednesday 09 February
**Location:** Teams
**Chair:** Stefan Meyer (Proteus) William Gibson (FNZ)
**Attendees:** Anton van Helden (DOC); Campbell Murray (FNZ); Chris Dick (FNZ); Clinton Duffy (DOC); Dominic Vallieres (FNZ); Tosin Olateju (FNZ); Jack Fenaughty (FNZ); Heather Benko (FNZ); Dave Goad (Vita Maris): Janice Malloy (Southern Seabirds); Jennifer Devine (NIWA); John Cleal (DWG); Karen Middlemiss (DOC); Shannon Weaver (DOC); Clara Schlieman (FNZ); Igor Debski (DOC); Tiffany Plencner (DOC); Jordi Tablaba (DOC); Rosa Edwards (FINZ); John Wilmer (FINZ); Sue Maturin (F&B);

A workshop has been held on 09/20/2022 to discuss to identify variables that could be used for defining new or re-assessing existing bycatch mitigation methods, and to discuss improvements that could be applied to observer forms to better quantify and analyse variables that could have an influence on protected species captures. Results from the analysis in this report were presented during the meeting and a follow-up discussion was held with focus on:

1. Variables for development of new or improvement of existing mitigation measures.
2. Data gaps and how these can be addressed as part of the observer programme.

The discussion was predominantly based around bycatch mitigation for seabirds.

**Variables for development of new or improvement of existing mitigation measures.**

**Mandatory bycatch mitigation measures.** Initially discussed were whether the effect of already implemented bycatch mitigation measures should have been detected through the modelling. As per Fisheries (Seabird Mitigation Measures—Surface Longlines) Circular 2018 Mandatory bycatch mitigation measures in SLL fisheries include:

- Deploying tori (streamer) lines AND
- Setting at night AND/OR
- Using line weighting (but required at night) OR
- Using hook-shielding device (not included in this analysis)

Figure 12 shows the number of fishing events with and without tori lines between the 2006–07 and 2018–19 fishing years. The results suggested that the configuration of tori lines (e.g., whether the tori line was over the bait entry point, the attachment height, etc.) is influencing seabird captures rather than the pure presence of tori lines.

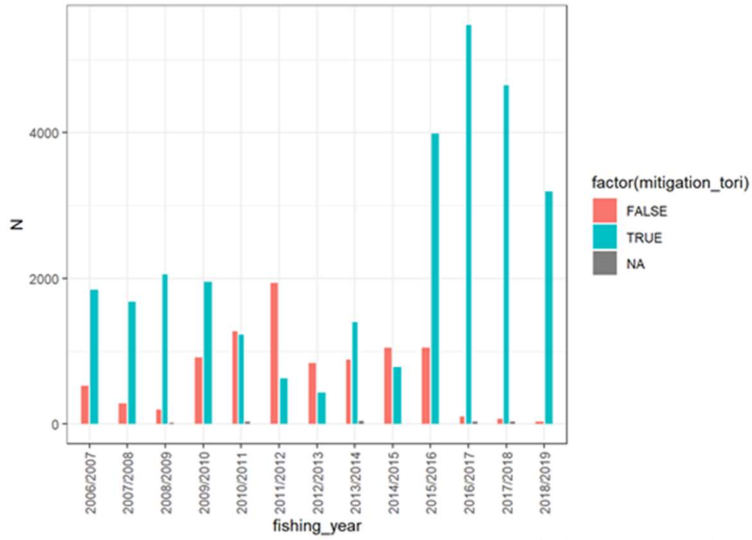



**Figure 12:** Number of fishing events in PSC database for small-vessel (< 45 m) surface longline fisheries with and without tori lines (including missing records) between the 2006–07 and 2018–19 fishing years.

The distribution of fishing start times in each year are provided in Fig. 13. During the workshop questions were raised as to why day vs night fishing was not identified as a variable influencing capture rates. The variable time of the day was defined as: Night (nautical dusk to nautical dawn), day (nautical dawn to nautical dusk); and the calculation was based on the start time of the fishing event. While fishing events could have started during the day most fishing would have occurred during night, or alternatively some fishing might have finished during daylight hours. In this analysis, the number of night hours (i.e., how many hours between start and end of fishing events were at night) were identified as influencing capture rates of seabirds and might therefore be the preferred variable (under the given data structure) to assess the effect of night fishing in seabird captures.

Fig. 13 also shows the number of fishing events using weights since the 2017–18 fishing year. The number of weighted snoods could not be included to the model given that data for this variable have not been fully recorded and it is therefore difficult to distinguish between unweighted snoods and weighted snoods that have not been recorded. However, variables such as the distance between weight and hook seemed to have a, even if weak, effect on seabird capture rates indicating an effect of this mitigation measure on seabird captures.

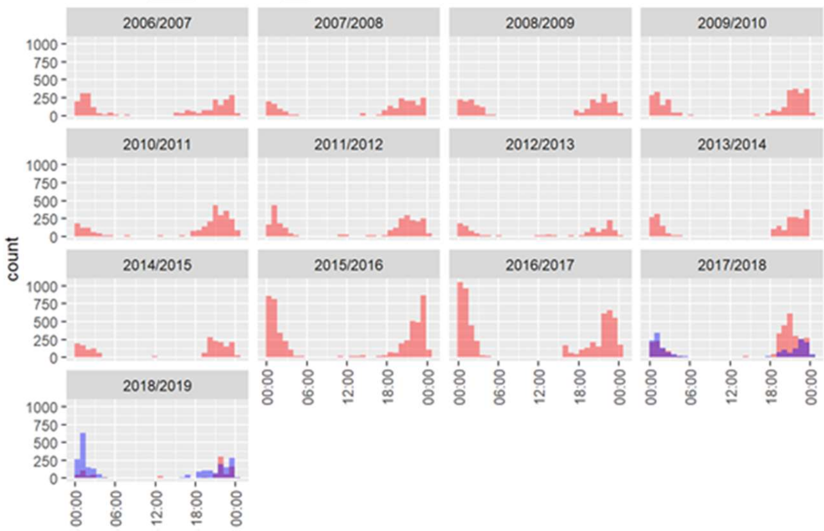



**Figure 13:** Hourly distribution of fishing events in PSC database for small-vessel (< 45 m) surface longline fishing between the 2006–07 and 2018–19 fishing years; red bars: without weighted line; blue bars: with weighted line.

**Tori line setup.** Seabirds are known to favourably forage directly behind the vessel and that the aerial section (or aerial extent) behind the vessels being covered by the tori line is counteracting this behaviour. The results in this analysis suggest that the aerial extent had a positive effect on captures rates (i.e., capture rates would increase with larger aerial extent). The data collection methods/instructions for observers were discussed during the workshop, and it was anticipated that the aerial extent variable might be inaccurate as it is estimated by the observer. The working group agreed that the attachment height of the tori line, which had a strong negative correlation with capture rates, would be a reasonable proxy for aerial extent, or that a wider set of additional variables could be collected to retrospectively calculate the aerial extent of the tori line.

Workshop participants agreed that it is important to determine whether the line is over the line entry point, as birds would otherwise not be deterred from the bait. This is supported by the results of this analysis showing that the capture rate decreased when the tori line was positioned over the bait entry point.

**Gear and fishing behaviour-related variables.** Workshop participants agreed that variables influencing the sink rate of hooks should be a focus of data collected by observers. For example, increasing setting speed would allow setting hooks faster, hence reducing the amount of time that hooks are exposed. On the other hand, it was suggested that setting too fast could lead to shallower hooks setting than intended leading to an increased risk of capturing birds. The latter would imply some type of quadratic relationship between capture rates of seabirds and vessel speed. There was support, based on the results here, that increased vessel speed (during hauling) reduces the capture rate. It was also suggested that models with non-linear relationships could have been explored. Fitting, for example, a quadratic function (done post-hoc on request) for vessel speed, however, does not seem receiving enough support (AIC difference between models with linear and quadratic relationship between captures and vessels is only 1.838 and the quadratic term was non-significant), suggesting the vessel speeds employed by the analysed vessels have not offset the negative relationship between seabird captures and vessel speed.

**Data gaps and how these can be addressed as part of the observer programme.** Overall, there was wide agreement that the sink rate of hooks should be another focus of the observer programme. Anecdotal evidence exists that line shooters increase sink rate by decreasing tension on the backbone (Turner, 2021). The use of line shooters, however, does not seem being recorded in the COD. The analysis showed that increasing snood signal time (the set interval of the snoods in seconds, either measured by line shooters or manually) leads to a reduced capture rate but this would be closely related to the effects of vessel speed.

There was consensus that instructions for data collections on observer forms require clarification or being simplified to reduce ambiguity of recorded observations. For example, the variable *deck_light_yn* (whether there was unnecessary deck lighting while setting) could be useful to see whether seabirds might be attracted to deck lighting and thus are therefore at increased risk to interact with fishing gear. However, there is no instruction as to what unnecessary deck lighting means and thus is subject to the observer's opinion. It was suggested that observers could be equipped with light meters, although that would also require clear instructions as to which area of the boat would be crucial for such measurement (e.g., instructions could be adjusted for observers to see if sea is illumined aft of vessel). In addition, it was suggested to record whether the vessel deck is sheltered, as this would reduce the amount of deck light being reaching the rest of the vessel. A counterargument against reduced deck lighting was raised as this could reduce the visibility of tori lines potentially leading to birds colliding with tori lines as seen in longline fisheries in South Georgia (as per Jack Fenaughty).

Further of interest would be to get comprehensive records of fishing end times as this would allow calculating the fishing duration and number of night hours. However, that would require the observer to observe the entire haul event, which might be impractical. As a solution, the crew could assist with filling in these details. Another suggestion was to measure the length of every snood as each has an independent sink time with potentially snood-specific capture rate. The detected effect of snood length in this analysis would support this hypothesis.

In general, recommendations included to clarify an/or simplify instructions for collection specific variables. Further, it was suggested to identify which variables are collected on the trip level and fishing event level. While fishing event-based variables require a prioritisation approach (i.e., some variables could be mandatory but not all of them as this would be impractical), trip-based variables are more feasible to be collected comprehensively.

**Interpretation of vessel freezer effect.** As per analysis, vessels with freezer on-board had a higher a chance of capturing birds than vessels where freezers were absent. There was some discussion as to whether vessel freezers are used to store processed catch or bait; the meaning of this field is currently under investigation (to be updated in this report). It was suggested that vessel freezers are most likely being used as bait freezer, because the last vessels to use freezers for processed fish were the Japanese charter fleet. In that regard, a request was made during the workshop to summarize bait type and state (whether dyed and/or frozen) for vessels with and without vessel freezer. For most fishing events, bait species and state were unreported (Tables 29 to 31). For those fishing events with reported bait state (54 out of 414 events), all vessels with vessel freezer used undyed bait (Table 30), which could be one reason for increased capture rates on events with vessel freezers (i.e., vessel freezer is simply a proxy for fishing with undyed bait), though more data would be needed to confirm this. Both, vessels with and without vessel freezer all seemed to use thawed or semi-thawed bait (for those events with recorded bait state) (Table 31).



**Table 29:** Bait species and percentage composition grouped by vessels with and without vessel freezer.

| vessel_freezer | bait_1_species | bait_2_species | bait_3_species | avg_bait_1_composition | avg_bait_2_composition | avg_bait_3_composition | n_events |
|---|---|---|---|---|---|---|---|
| FALSE | | | | | | | 1884 |
| FALSE | SQU | | | 100 | | | 206 |
| FALSE | SQU | SAU | | 76 | 24 | | 24 |
| FALSE | SQU | SAN | | 81 | 19 | | 30 |
| FALSE | SQU | PIL | | 87 | 13 | | 19 |
| FALSE | SAN | SQU | | 40 | 60 | | 3 |
| FALSE | SQU | FIS | | 85 | 15 | | 11 |
| FALSE | SQU | FIS | SQU | 75 | 17 | 8 | 3 |
| FALSE | SQX | SAN | | 69 | 31 | | 8 |
| FALSE | FIS | SQX | | 10 | 90 | | 1 |
| FALSE | SQX | FIS | | 90 | 10 | | 5 |
| FALSE | SQX | | | 100 | | | 3 |
| TRUE | | | | | | | 360 |
| TRUE | SQU | SAU | | 73 | 27 | | 38 |
| TRUE | SQU | SAU | JMD | 73 | 18 | 8 | 3 |
| TRUE | SQU | SAN | | 85 | 15 | | 6 |
| TRUE | SQU | | | 100 | | | 7 |

**Table 30:** Bait dyeing per bait species (see Table 32) grouped by vessels with and without vessel freezer.

| vessel_freezer | bait_1_dyed_yn | bait_2_dyed_yn | bait_3_dyed_yn | n_events |
|---|---|---|---|---|
| FALSE | | | | 1886 |
| FALSE | N | | | 296 |
| FALSE | Y | | | 12 |
| FALSE | N | Y | Y | 2 |
| FALSE | N | N | N | 1 |
| TRUE | | | | 360 |
| TRUE | N | | | 51 |
| TRUE | N | N | N | 3 |

**Table 31:** Bait dyeing per bait species (see Table 32) grouped by vessels with and without vessel freezer.

| vessel_freezer | bait_1_state | bait_2_state | bait_3_state | n_events |
|---|---|---|---|---|
| FALSE | NA | NA | NA | 1885 |
| FALSE | T | NA | NA | 205 |
| FALSE | S | NA | NA | 3 |
| FALSE | T | T | NA | 98 |
| FALSE | T | T | T | 3 |
| FALSE | F | F | NA | 1 |
| FALSE | S | S | NA | 2 |
| TRUE | NA | NA | NA | 360 |
| TRUE | S | S | NA | 10 |
| TRUE | T | T | NA | 34 |
| TRUE | S | S | S | 3 |
| TRUE | S | NA | NA | 1 |
| TRUE | T | NA | NA | 6 |

# 5. DISCUSSION

Non-target species captures in small-vessel SLL fisheries between the 2006–07 and 2018–19 fishing years have been analysed to identify risk factors that have not been formally integrated into previous capture estimates. Negative binomial generalised linear models were fitted to observed captures of seabirds, NZ fur seals and turtles. There were not enough observed captures of other taxa (e.g., dolphins and whales) for a meaningful statistical analysis.

The variables included in this analysis predominantly included variables that were related to the configuration of mandatory bycatch mitigation measures (e.g., the attachment height of the tori line) and variables being specific to vessel/fishing behaviour (e.g., vessel speed). However, many of the variables included here were only recorded sporadically or in recent fishing year years (2017–18 to 2018–19) . The sparseness of these variables limited the number of parameters that could be explored in a single modelling approach. Therefore, a two-phase modelling approach was applied. First, a small but complete set of parameters were explored via AIC model selection. Second, the best-supported model from the first model fitting phase was expanded by additional variables that were incomplete, but only a single incomplete variable was added to the top model each time to restrict the degree of data pruning due to missing values.

For seabirds, models suggested that captures are influenced by moon phase and timing of fishing during the year (i.e., during which month or season). Bycatch mitigation measures seemed effective but strongly depended how these were employed. For example, tori line efficacy was substantially reduced if not properly aligned with the bait or mainline entry point, and bycatch mitigation was improved if the tori lines were attached high enough at the stern of the vessel (one variable that determines the aerial extent of the tori line). Further factors influencing seabird captures were gear configuration and vessel behaviour variables such as the number of turns during setting, vessel speed, and snood length – all factors affecting the sink rate of the mainline and/or hooks and therefore the amount of time during which hooks are exposed to seabirds.

The results, specifically regarding seabird captures, were discussed during a workshop. A main outcome was that there exists the need for specific observer instructions for the collection of gear- and bycatch mitigation measure-specific variables. For example, aerial extent, expected to reduce the risk of seabird captures, is a variable where accuracy strongly depends on the observer's ability to estimate the length of the tori line from the attachment point at the vessel to the point where the line submerges. Consequently, the effect of aerial extent on seabird captures could not be successfully determined in this analysis. The attachment height of tori lines provided a reasonable proxy for aerial extent, and was negatively correlated with seabird capture rates, but more variables would be required to estimate the actual effect of aerial extent on seabird captures (e.g., aerial extent would be a function of attachment height, tori line length, vessel speed, and buoy attachment).

Similarly, deck lighting could attract birds, hence leading to a higher risk of seabird captures. However, there was no effect of deck lighting detected in this analysis and this was most likely due to the subjective instruction of "whether there was unnecessary deck lighting while setting". Suggestions from the workshop included to equip observers with light meters, to adjust the wording of instructions to as to see whether the sea is illumined aft of vessel, and to record whether the deck was sheltered, which would reduce the amount of light emitted from the deck to the rest of the vessel.

Another recommendation was that variables influencing the sink rate of hooks should be a focus of observer data collection. For example, increasing setting speed would allow setting hooks faster, hence reducing the amount of time that hooks are exposed, but there could be reverse effects if vessel speed is too fast which could result in shallower hooks setting than intended.

One main effect increasing the capture of seabirds was the presence of a vessel freezer and a suggestion from the workshop was that most vessels with freezer used these to freeze bait and that this might imply an effect of bait quality on seabird capture rates. COD data imply that vessels with freezer on-board used undyed bait, which would explain the estimated higher capture rates, but the data re bait state were too sparse for final conclusions. Consequently, bait composition and bait state (dyed vs. undyed, frozen vs. thawed or semi-thawed) was suggest by the workshop participants as another data collection focus for observers.

NZ fur seal captures were influence by factors such as the month of fishing, bathymetry, and whether tori line was deployed. In addition, gear-configuration, and vessel-behaviour variables (including bycatch mitigation measures aimed to reduce bird bycatch) affected fur seal captures. For example, an increasing number of night hours resulted in a substantial decrease of fur seal captures. However, there results suggest that this effect was offset by the presence of light sticks resulting in higher fur seal capture rate, probably because fur seals are attracted to light sticks. Both, fishing events with and without light sticks were characterised by the same average night hours (approximately 3 hours on average), similar number of fishing events (179 and 123 fishing events with and without light sticks, respectively), and raw captures rates being clearly elevated when light sticks were utilized (on average 0.42 captures per 1 000 hooks vs. 0.01 captures per 1 000 hooks for events with and without light sticks, respectively). Consequently, there exists potential to impose regulations re light sticks use to reduce NZ fur seal captures in SLL fisheries. Note, that estimates for light stick use were characterised by wide uncertainty because this variable has only been collected very recently (since the 2017–18 fishing year) and more data is needed to get accurate estimates of the effect of light sticks on NZ fur seal captures.

Vessels with tori lines deployed appeared to have higher captures rates of NZ fur seals. Tori line streamer might act as a visual attractor to fur seals, or as an acoustic cue especially during strong winds (raw capture rates for vessels with tori lines suggest that captures rates increased from 0.05, 0.06 to 0.07 captures per 1 000 hooks when wind strength increases from low (~2 kts), to medium (~4kts), and high (~7 kts), respectively). Alternatively, the variable for presence/absence of tori lines could be a proxy for another gear configuration not being included in this analysis.

While this work has not revealed any novel mitigation strategies for bycatch mitigation it highlights important areas of improvement to understand and improve employed measures applied in small-vessel SLL fisheries. Information re gear and bycatch mitigation measure configuration requires a mandatory set of variables, and for these clear instructions are required to reduce the level of subjectivity that could result otherwise during data collection. The low observation of some species and variables might have biased some of the estimates from this analysis, but detected effects emphasise areas for potential focus for future data collection (e.g., whether tori line was positioned over the bait entry point). More data (i.e., observed captures) are required to assess risk factors for turtles, sharks & rays, and dolphins & whales. Non-linear relationships have not been explored during this assessment, primarily given the limited sample size for most of the variables explored in this project but should be considered once more data are available.

## 6. REFERENCES


Abraham ER, Berkenbusch K (2019). Preparation of data for protected species capture estimation, updated to 2016–17. New Zealand Aquatic Environment and Biodiversity Report No. 233. 49 p.

Abraham ER, Richard Y (2019). Estimated capture of seabirds in New Zealand trawl and longline fisheries, to 2016–17. New Zealand Aquatic Environment and Biodiversity Report 226. 85 p.

Abraham ER, Thompson FN (2015). Captures of all birds in southern bluefin longline fisheries, in the New Zealand Exclusive Economic Zone, during the 2017–18 fishing year. Retrieved from https://psc.dragonfly.co.nz/2019v1/released/birds/southern-bluefin/all-vessels/eez/2017-18/, Jan 7, 2021."

Abraham ER, Tremblay-Boyer L, Berkenbusch K. (2019). Estimated captures of New Zealand fur seal, common dolphin, and turtles in New Zealand commercial fisheries, to 2017–18. New Zealand Aquatic Environment and Biodiversity Report No. XXX. 89 p. – DRAFT

Abraham, ER, Richard Y (2020). Estimated captures of seabirds in New Zealand trawl and longline fisheries, to 2017–18. New Zealand Aquatic Environment and Biodiversity Report No. 249. 86 p.

Baird SJ, Doonan, I (Manuscript held by the Ministry, 2017) Characterisation of seabird captures in trawl nets in New Zealand fisheries 2008-15. Draft report held by Ministry for Primary Industries. Available on request.

Bull L (2007). A review of methodologies for mitigating incidental catch of seabirds in New Zealand fisheries (p. 57). Science & Technical Pub., Department of Conservation.

Hamilton S, Baker GB (2019). Technical mitigation to reduce marine mammal bycatch and entanglement in commercial fishing gear: lessons learnt and future directions. Reviews in Fish Biology and Fisheries, 29(2), 223-247.

Howard S (2015). Mitigation options for shark bycatch in longline fisheries. New Zealand Aquatic Environment and Biodiversity Report No. 148. 47 p.

Melvin EF, Guy TJ, Read LB (2014). Best practice seabird bycatch mitigation for pelagic longline fisheries targeting tuna and related species. Fisheries Research, 149, 5-18.

Middleton DAJ, Abraham ER (2007). The efficacy of warp strike mitigation devices: trials in the 2006 squid fishery. Final Research Report for Ministry of Fisheries contract IPA2006-02

R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Richard Y, Abraham ER & Berkenbusch K (2020). Counts of seabirds around commercial fishing vessels within New Zealand waters. 43 pages. (Unpublished report prepared for the Department of Conservation, retrieved from https://files.dragonfly.co.nz/publications/pdf/Richardetal_2020_seabird-counts.pdf, Dec 3, 2020.)

Sanders BM, Fisher DO (2018). Database documentation for the Ministry for Primary Industries Centralised Observer Database cod NIWA Fisheries Data Management Database Documentation Series Revised Oct 2018

Stan Development Team (2020). RStan: the R interface to Stan. R package version 2.21.2. http://mc-stan.org/.

Swimmer Y, Gutierrez A, Bigelow K, Barceló C, Schroeder B, Keene K, Shattenkirk K, Foster DG (2017). Sea Turtle Bycatch Mitigation in U.S. Longline Fisheries. Front. Mar. Sci. 4:260. doi: 10.3389/fmars.2017.00260

Turner, P (2021). Towards Improving Seabird Bycatch Mitigation in New Zealand's Surface Longline Fleet: Fishers' Behaviours, Barriers and Drivers. Social research report - prepared for: Southern Seabirds Trust.

Vehtari A, Gelman A, Gabry J (2017). Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. Statistics and Computing. 27(5), 1413--1432. doi:10.1007/s11222-016-9696-4 (journal version, preprint arXiv:1507.04544).

Venables WN, Ripley BD (2002) Modern Applied Statistics with S. Fourth Edition. Springer, New York. ISBN 0-387-95457-0

Waugh SM, MacKenzie DI, Fletcher D (2008). Seabird bycatch in New Zealand trawl and longline fisheries, 1998-2004. In Papers and Proceedings of the Royal Society of Tasmania (Vol. 142, No. 1, pp. 45-66).

## APPENDIX A: INITIAL DATA SUMMARY PRESENTED TO AEWG IN NOVEMBER 2021

**Table 32:** Proportion of small-vessel surface longline fishing events with each variable recorded in each year between 2006–07 and 2018–19, and average proportion across years. Additional columns from the COD were pre-fixed with the associated COD table (e.g., x_surface_lining_effort).

| **Variable** | **2006–07** | **2007–08** | **2008–09** | **2009–10** | **2010–11** | **2011–12** | **2012–13** | **2013–14** | **2014–15** | **2015–16** | **2016–17** | **2017–18** | **2018–19** | **Average** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| fishing_year | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| total_hook_num | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| season | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| area | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| area_name | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| area_seabirds | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| fishery | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| fishery_seabirds | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| fma_area | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| x_surface_lining_effort__hooks_set | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| mitigation_tori | 1 | 1 | 0.99 | 1 | 0.99 | 1 | 1 | 0.98 | 1 | 1 | 0.99 | 0.99 | 1 | 1 |
| moon_phase | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| region_seabird | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| start_lat | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| start_long | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| start_month | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| start_solar_altitude | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| start_time | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| stats_area | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| target | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| x_surface_lining_effort__tori_used_yn | 1 | 1 | 0.99 | 1 | 0.99 | 1 | 1 | 0.98 | 1 | 1 | 0.99 | 0.99 | 1 | 1 |
| vessel_class | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| vessel_key | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| vessel_length | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| vessel_nation | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| vessel_size | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **x_surface_lining_effort__baskets_number** | **1** | **1** | **0.99** | **1** | **0.92** | **1** | **1** | **1** | **0.99** | **1** | **1** | **1** | **1** | **0.99** |
| x_surface_lining_effort__line_length | 1 | 1 | 1 | 1 | 1 | 0.92 | 1 | 1 | 1 | 1 | 1 | 0.99 | 0.99 | 0.99 |
| catch | 1 | 0.99 | 1 | 0.96 | 1 | 1 | 0.87 | 0.92 | 1 | 1 | 0.95 | 1 | 1 | 0.98 |
| distance_to_shore | 1 | 1 | 1 | 0.96 | 1 | 1 | 0.87 | 0.92 | 1 | 1 | 0.95 | 1 | 1 | 0.98 |
| night_hours | 1 | 1 | 0.99 | 0.96 | 1 | 1 | 0.87 | 0.92 | 1 | 1 | 0.95 | 1 | 1 | 0.98 |
| x_surface_lining_effort__min_depth | 1 | 0.99 | 0.85 | 1 | 0.88 | 1 | 0.98 | 0.79 | 0.98 | 0.96 | 0.94 | 1 | 0.99 | 0.95 |
| x_surface_lining_effort__max_depth | 1 | 0.99 | 0.85 | 0.99 | 0.88 | 1 | 0.98 | 0.79 | 0.98 | 0.83 | 0.94 | 1 | 1 | 0.94 |
| x_surface_lining_effort__start_wind_direction | 0.99 | 0.92 | 0.93 | 0.93 | 0.95 | 0.92 | 0.92 | 0.88 | 0.89 | 0.93 | 0.89 | 0.99 | 0.94 | 0.93 |
| x_haul_effort__haul_time | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.52 | 0 | 0.86 |
| x_surface_lining_effort__bait_thrower_used_yn | 1 | 1 | 0.97 | 1 | 1 | 1 | 1 | 0.97 | 1 | 1 | 0.99 | 0.52 | 0 | 0.85 |
| x_haul_effort__haul_latitude | 1 | 1 | 1 | 0.99 | 0.99 | 1 | 1 | 1 | 0.97 | 1 | 0.99 | 0.52 | 0 | 0.85 |
| x_haul_effort__haul_longitude | 1 | 1 | 1 | 0.99 | 0.99 | 1 | 1 | 1 | 0.97 | 1 | 0.99 | 0.52 | 0 | 0.85 |
| mitigation_other | 1 | 1 | 0.97 | 1 | 1 | 1 | 1 | 0.97 | 1 | 1 | 0.99 | 0.52 | 0 | 0.85 |
| x_surface_lining_effort__cloud_cover | 0.89 | 0.75 | 0.88 | 0.93 | 0.98 | 0.81 | 0.99 | 0.81 | 0.75 | 0.71 | 0.71 | 0.99 | 0.71 | 0.83 |
| x_surface_lining_effort__number_of_longliners | 0.94 | 0.93 | 0.98 | 0.89 | 1 | 0.99 | 1 | 0.94 | 0.99 | 0.99 | 0.99 | 0.52 | 0 | 0.83 |
| x_surface_lining_effort__number_of_vessels | 0.94 | 0.93 | 0.99 | 0.89 | 1 | 0.99 | 1 | 0.93 | 0.99 | 0.99 | 0.97 | 0.52 | 0 | 0.83 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| x_haul_effort__wind_beaufortscale | 0.99 | 1 | 0.94 | 0.95 | 0.98 | 1 | 1 | 0.98 | 0.89 | 0.96 | 0.97 | 0.51 | 0 | 0.83 |
| x_surface_lining_effort__snood_signal_time | 0.8 | 0.65 | 0.83 | 0.58 | 0.76 | 0.97 | 0.99 | 0.54 | 0.78 | 0.9 | 0.86 | 0.94 | 0.9 | 0.82 |
| **x_haul_effort__wind_direction** | **0.99** | **0.95** | **0.85** | **0.85** | **0.93** | **0.75** | **0.85** | **0.89** | **0.79** | **0.88** | **0.86** | **0.49** | **0** | **0.75** |
| x_haul_effort__vessel_speed | 0.95 | 0.94 | 0.88 | 0.91 | 0.83 | 0.88 | 0.98 | 0.81 | 0.79 | 0.81 | 0.87 | 0.28 | 0 | 0.72 |
| x_haul_effort__vessel_heading | 0.95 | 0.92 | 0.86 | 0.9 | 0.83 | 0.88 | 0.95 | 0.79 | 0.77 | 0.74 | 0.87 | 0.25 | 0 | 0.7 |
| x_haul_effort__surface_temperature | 0.85 | 0.87 | 0.6 | 0.8 | 0.69 | 0.78 | 0.67 | 0.39 | 0.71 | 0.75 | 0.81 | 0.4 | 0 | 0.63 |
| **x_surface_lining_effort__line_entry_yn** | **0.76** | **0.82** | **0.92** | **0.55** | **0.39** | **0.23** | **0.21** | **0.48** | **0.42** | **0.79** | **0.93** | **0.51** | **0** | **0.58** |
| x_surface_lining_effort__tori_height | 0.76 | 0.82 | 0.92 | 0.55 | 0.39 | 0.23 | 0.21 | 0.49 | 0.42 | 0.79 | 0.93 | 0.51 | 0 | 0.58 |
| x_surface_lining_effort__tori_length | 0.76 | 0.82 | 0.92 | 0.55 | 0.39 | 0.23 | 0.21 | 0.49 | 0.42 | 0.8 | 0.93 | 0.51 | 0 | 0.58 |
| x_surface_lining_effort__bait_stream | 0.75 | 0.82 | 0.82 | 0.51 | 0.38 | 0.23 | 0.21 | 0.48 | 0.39 | 0.74 | 0.87 | 0.44 | 0 | 0.55 |
| **mitigation_none** | **0.22** | **0.15** | **0.09** | **0.32** | **0.5** | **0.6** | **0.66** | **0.37** | **0.52** | **0.21** | **0.01** | **0** | **0** | **0.22** |
| x_surface_lining_effort__bird_area | 1 | 1 | 1 | 0.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2 |
| x_surface_lining_effort__acoustic_bird_deterrent_yn | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.48 | 1 | 0.14 |
| x_haul_effort__bottom_depth | 0.16 | 0.02 | 0.11 | 0.03 | 0.07 | 0.11 | 0.12 | 0.06 | 0.05 | 0.36 | 0.34 | 0.05 | 0 | 0.14 |
| x_surface_lining_effort__deck_light_yn | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.48 | 1 | 0.14 |
| x_surface_lining_effort__discards_during_setting | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.48 | 1 | 0.14 |
| x_surface_lining_effort__dist_bait_to_tori | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.47 | 0.93 | 0.14 |
| x_surface_lining_effort__dist_stern_to_bait_min | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.48 | 1 | 0.14 |
| x_sll_baskets__hook_type | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.46 | 1 | 0.14 |
| x_surface_lining_effort__light_sticks_yn | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.48 | 1 | 0.14 |
| x_surface_lining_effort__line_setting_height | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.48 | 0.99 | 0.14 |
| x_surface_lining_effort__setting_path | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.48 | 1 | 0.14 |
| x_surface_lining_effort__setting_strategy | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.48 | 0.93 | 0.14 |
| x_surface_lining_effort__setting_turns | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.46 | 0.98 | 0.14 |
| x_sll_baskets__number_weighted_snoods | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.37 | 0.87 | 0.12 |
| x_sll_baskets__distance_weight_to_hook | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.37 | 0.73 | 0.11 |
| x_sll_baskets__weight | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.37 | 0.73 | 0.11 |
| x_sll_baskets__weighting_type | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.37 | 0.73 | 0.11 |
| x_surface_lining_effort__avg_sticks_per_basket | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.31 | 0.68 | 0.09 |
| x_surface_lining_effort__line_feed_rate | 0.25 | 0.14 | 0.09 | 0 | 0.08 | 0.04 | 0 | 0.05 | 0.07 | 0 | 0.09 | 0 | 0 | 0.05 |
| fishing_duration | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.38 | 0.03 |
| x_surface_lining_effort__bait_sink_distance | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| x_surface_lining_effort__bait_surface_distance | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| x_fishing_event__haul_offal_discharge | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| mitigation_baffler | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| x_fishing_event__shot_offal_discharge | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| total_net_length | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| x_fishing_event__tow_offal_discharge | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| x_surface_lining_effort__weather_code | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## APPENDIX B: INITIAL BAYESIAN MODEL EXPLORATION (IN PROGRESS)

An initial model exploration was carried out to compare result from Bayesian generailsed linear models as described in Abaraham & Richard (2019) against negative binomial genarelised linear models using the glm.nb function using the MASS-package in R (Venables & Ripley, 2002).

Adopting the modelling approach by Abaraham & Richard (2019), the mean catch rate ($\mu_i$) for a single fishing event *i* of events was assumed to be the product of the effects:

$$\mu_i = \alpha \boldsymbol{X}_i, \qquad (2)$$

where α is the intercept, with a log-normal prior, defined with a mean of -3 and a standard deviation of 5 on the log scale, and $\boldsymbol{X}$ being a matrix of fixed effects for fishing event *i*. Fixed effects that were fitted in this pre-liminary assessment were:

1. Area (see Fig. 3)
2. Bathymetry
3. Fishing year
4. Fishery management area
5. Number of hooks set
6. Presence/absence of tori lines
7. Moon phase
8. Season
9. Start month
10. Start solar altitude
11. Target species
12. Number of counted birds around fishing vessels (only applied to seabird models) based on paper forms (Richard et al. 2020), as a proxy for seabird density (seabird density layers were not available for this initial assessment) (Fig. 14).

In progress:

- Models were fitted separately to each bird species, NZ fur seals and to groups of turtles, dolphins & whales, and sharks & rays.

- Model selection: AIC for glm.nb; LOO for Bayesian GLM

- Model were fitted separately to each variable and the model with lowest AIC or LOO was carried forward by adding next variable; if there was support for including another variable then the procedure was repeated until there was no further support.

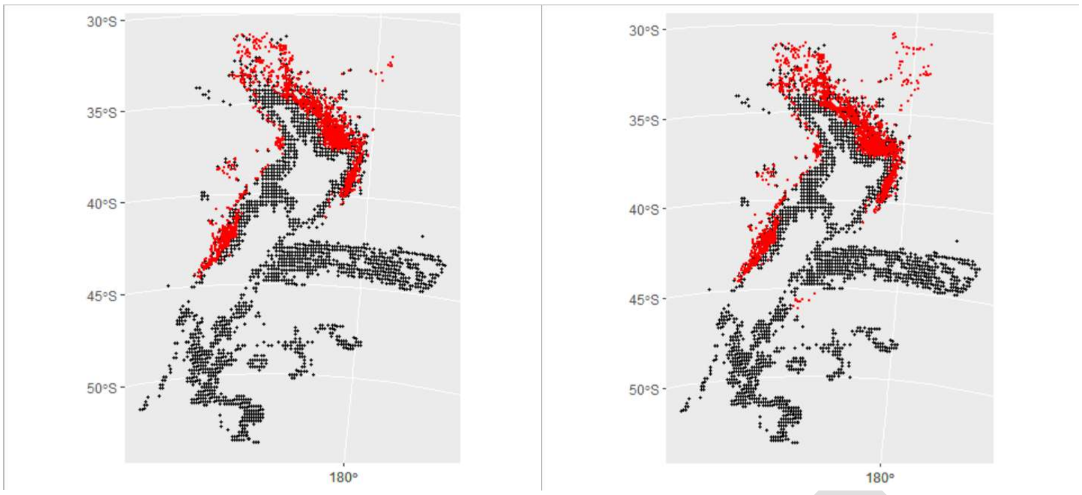



**Figure 14 Comparison of observed fishing event locations for small vessel surface-longline fisheries (black; domestic and Australian) vs. locations of 'Seabirds arounds vessels' data (red) for all fishing methods (fishing years for both datasets ranging from 2007–08 to 2017–18; left panel). RHS panel: Same data but fishing years 2006–07 and 2018–19 included in observed fishing event locations.**

**Table 33 Initial model exploration based on (1) generalized linear model fitting with negative binomial distribution (model selection based on AIC) and (2) standardized captures model by Abraham & Richard (2019) (model selection based on LOO).**

| **Species** | **AIC** | **LOO** |
|---|---|---|
| Black petrel | Season + black petrel mean counts | Season |
| Buller's albatross | FMA + moon phase + target | FMA + moon phase + target |
| Flesh-footed shearwater | Season | NULL MODEL |
| Grey petrel | - | NULL MODEL |
| Other albatrosses | Start month + moon phase + area + solar altitude | Start month + moon phase |
| Other birds | FMA | FMA |
| Salvin's albatross | - | NULL MODEL |
| Sooty shearwater | - | NULL MODEL |
| White-capped albatross | FMA + moon phase | FMA + moon phase |
| White-chinned petrel | Start month + FMA | Start month |
| Dolphins and whales | - | NULL MODEL |
| Turtles | Start solar altitude | NULL MODEL |
| New Zealand fur seals | Start month + fishing year + area | Season |
| Sharks and rays | - | NULL MODEL |

Failed models (full data set): Sooty shearwater, mean_counts and bathymetry: 5 203 and 689 divergent transitions, respectively.

*Table 34 Expected log pointwise predictive density: Black petrel*

| | elpd_diff | se_diff | elpd_loo |
|---|---|---|---|
| season | 0 | 0 | -115.244 |
| start_month | -2.94993 | 3.431776 | -118.194 |
| target | -14.1361 | 3.16111 | -129.38 |
| mean_counts | -19.438 | 6.966615 | -134.682 |
| start_sloar_altitude | -24.7188 | 5.822268 | -139.963 |
| fma_area | -27.1977 | 6.822544 | -142.442 |
| area | -27.5027 | 7.036571 | -142.747 |
| hooks_set | -36.8716 | 7.863391 | -152.116 |
| bathymetry | -38.4916 | 7.859956 | -153.736 |
| fishing_year | -38.6167 | 8.779816 | -153.861 |
| moon_phase | -39.1562 | 7.835877 | -154.401 |
| Null-model | -39.7601 | 7.83784 | -155.004 |
| mitigation_tori | -39.9649 | 8.037415 | -155.209 |
| line_weight_yn | -40.7032 | 8.129682 | -155.948 |

*Table 35 Expected log pointwise predictive density: Buller's albatross*

| | elpd_diff | se_diff | elpd_loo |
|---|---|---|---|
| fma_area | 0 | 0 | -408.275 |
| area | -2.5248 | 3.404307 | -410.8 |
| mean_counts | -26.0215 | 9.250507 | -434.296 |
| start_month | -26.45 | 10.65899 | -434.725 |
| season | -27.3355 | 10.56735 | -435.61 |
| target | -42.5967 | 9.749899 | -450.871 |
| moon_phase | -50.2234 | 11.85572 | -458.498 |
| fishing_year | -55.0008 | 10.9132 | -463.276 |
| bathymetry | -56.9942 | 11.60728 | -465.269 |
| start_sloar_altitude | -59.1748 | 11.86313 | -467.45 |
| line_weight_yn | -60.9664 | 11.93088 | -469.241 |
| hooks_set | -62.0859 | 12.14864 | -470.361 |
| Null-model | -62.0939 | 11.94831 | -470.369 |
| mitigation_tori | -63.0038 | 12.01664 | -471.279 |

*Table 36 Expected log pointwise predictive density: Flesh-footed shearwater*

| | elpd_diff | se_diff | elpd_loo |
|---|---|---|---|
| season | 0 | 0 | -49.5795 |
| start_month | -0.14833 | 2.698791 | -49.7278 |
| bathymetry | -3.49372 | 4.455379 | -53.0732 |
| start_sloar_altitude | -3.56685 | 3.992644 | -53.1463 |
| moon_phase | -4.96108 | 4.686585 | -54.5405 |
| target | -5.06332 | 4.196269 | -54.6428 |

| | | | |
|---|---|---|---|
| Null-model | -5.2504 | 4.667226 | -54.8299 |
| line_weight_yn | -5.88682 | 5.070139 | -55.4663 |
| fishing_year | -6.11006 | 5.536715 | -55.6895 |
| hooks_set | -6.47016 | 4.603463 | -56.0496 |
| mitigation_tori | -6.5223 | 4.826447 | -56.1018 |
| area | -8.32546 | 4.092285 | -57.9049 |
| fma_area | -9.11058 | 4.617771 | -58.69 |
| mean_counts | -11.675 | 7.120126 | -61.2545 |

*Table 37 Expected log pointwise predictive density: Grey petrel*

| | elpd_diff | se_diff | elpd_loo |
|---|---|---|---|
| fishing_year | 0 | 0 | -90.6262 |
| start_month | -0.0681 | 5.907351 | -90.6943 |
| fma_area | -0.69238 | 5.886952 | -91.3186 |
| area | -1.9073 | 5.850439 | -92.5335 |
| target | -3.45379 | 6.008065 | -94.08 |
| moon_phase | -3.46444 | 7.253245 | -94.0907 |
| line_weight_yn | -5.10836 | 5.738221 | -95.7346 |
| bathymetry | -5.18287 | 6.372814 | -95.8091 |
| hooks_set | -5.34013 | 5.780881 | -95.9664 |
| start_sloar_altitude | -6.19832 | 6.571463 | -96.8245 |
| Null-model | -6.77879 | 5.840452 | -97.405 |
| season | -7.36622 | 5.976161 | -97.9924 |
| mitigation_tori | -7.41508 | 6.074552 | -98.0413 |
| mean_counts | -8.7271 | 7.597976 | -99.3533 |

*Table 38 Expected log pointwise predictive density: Other albatrosses*

| | elpd_diff | se_diff | elpd_loo |
|---|---|---|---|
| start_month | 0 | 0 | -428.375 |
| season | -3.87091 | 5.073709 | -432.245 |
| area | -6.48912 | 9.574874 | -434.864 |
| fma_area | -19.2207 | 9.735106 | -447.595 |
| target | -21.7703 | 7.996192 | -450.145 |
| start_sloar_altitude | -21.961 | 9.072268 | -450.336 |
| fishing_year | -24.8318 | 9.890337 | -453.206 |
| moon_phase | -28.5546 | 13.43949 | -456.929 |
| mean_counts | -40.818 | 11.73462 | -469.193 |
| mitigation_tori | -41.9786 | 13.49702 | -470.353 |
| line_weight_yn | -44.0676 | 13.09992 | -472.442 |
| Null-model | -44.1023 | 13.01416 | -472.477 |
| bathymetry | -45.0456 | 13.08931 | -473.42 |
| hooks_set | -45.1275 | 13.10475 | -473.502 |

*Table 39 Expected log pointwise predictive density: Other birds*

| | elpd_diff | se_diff | elpd_loo |
|---|---|---|---|
| fma_area | 0 | 0 | -213.07 |
| area | -1.52191 | 1.492196 | -214.592 |
| mean_counts | -12.0833 | 7.917149 | -225.153 |
| season | -20.2641 | 6.29939 | -233.334 |
| bathymetry | -23.6036 | 6.549159 | -236.673 |
| start_month | -25.6304 | 6.274355 | -238.7 |
| target | -28.0293 | 7.671179 | -241.099 |
| mitigation_tori | -28.1336 | 8.704545 | -241.203 |
| line_weight_yn | -29.7899 | 8.568345 | -242.86 |
| hooks_set | -29.8977 | 8.783841 | -242.967 |
| fishing_year | -30.8901 | 9.115666 | -243.96 |
| start_sloar_altitude | -32.2009 | 9.015548 | -245.271 |
| Null-model | -32.3402 | 9.060947 | -245.41 |
| moon_phase | -32.6561 | 9.056405 | -245.726 |

*Table 40 Expected log pointwise predictive density: Salvin's albatross*

| | elpd_diff | se_diff | elpd_loo |
|---|---|---|---|
| moon_phase | 0 | 0 | -34.7052 |
| line_weight_yn | -2.0762 | 1.298769 | -36.7814 |
| Null-model | -2.46631 | 1.426362 | -37.1716 |
| fma_area | -2.84064 | 1.619003 | -37.5459 |
| target | -2.84636 | 2.177296 | -37.5516 |
| hooks_set | -2.96686 | 1.857192 | -37.6721 |
| start_sloar_altitude | -3.39705 | 1.902839 | -38.1023 |
| bathymetry | -3.78633 | 1.914319 | -38.4916 |
| fishing_year | -4.03304 | 2.016492 | -38.7383 |
| area | -4.45101 | 2.950758 | -39.1563 |
| mitigation_tori | -4.51445 | 2.949913 | -39.2197 |
| season | -5.24132 | 3.760174 | -39.9466 |
| start_month | -6.70035 | 3.492558 | -41.4056 |
| mean_counts | -10.3798 | 5.663363 | -45.0851 |

*Table 41 Expected log pointwise predictive density: Sooty shearwater*

| | elpd_diff | se_diff | elpd_loo |
|---|---|---|---|
| season | 0 | 0 | -9.48811 |
| target | -0.14592 | 0.140431 | -9.63402 |
| start_sloar_altitude | -0.51581 | 0.331134 | -10.0039 |
| bathymetry | -0.78739 | 0.850075 | -10.2755 |
| fma_area | -0.99807 | 0.976165 | -10.4862 |
| mitigation_tori | -1.10568 | 1.059614 | -10.5938 |
| area | -1.23672 | 1.182543 | -10.7248 |

| | | | |
|---|---|---|---|
| Null-model | -1.33246 | 1.275175 | -10.8206 |
| moon_phase | -1.58349 | 1.457664 | -11.0716 |
| line_weight_yn | -1.72097 | 1.686029 | -11.2091 |
| hooks_set | -2.13764 | 2.051457 | -11.6257 |
| start_month | -2.31239 | 2.244431 | -11.8005 |
| mean_counts | -2.44041 | 2.009178 | -11.9285 |
| fishing_year | -2.91837 | 2.838297 | -12.4065 |

*Table 42 Expected log pointwise predictive density: White-capped albatross*

| | **elpd_diff** | **se_diff** | **elpd_loo** |
|---|---|---|---|
| fma_area | 0 | 0 | -341.006 |
| area | -4.46362 | 2.301838 | -345.47 |
| mean_counts | -33.2948 | 9.683907 | -374.301 |
| season | -43.3167 | 10.63335 | -384.323 |
| start_month | -45.3265 | 10.21564 | -386.332 |
| bathymetry | -60.7757 | 13.23606 | -401.782 |
| target | -65.4913 | 11.45532 | -406.497 |
| fishing_year | -66.239 | 12.66293 | -407.245 |
| moon_phase | -73.3852 | 13.59922 | -414.391 |
| line_weight_yn | -75.9605 | 13.64207 | -416.966 |
| start_sloar_altitude | -82.351 | 13.65613 | -423.357 |
| mitigation_tori | -82.6221 | 14.16904 | -423.628 |
| Null-model | -82.9454 | 13.79517 | -423.951 |
| hooks_set | -83.5914 | 13.87051 | -424.597 |

*Table 43 Expected log pointwise predictive density: White-chinned petrel*

| | **elpd_diff** | **se_diff** | **elpd_loo** |
|---|---|---|---|
| start_month | 0 | 0 | -92.3256 |
| area | -1.26471 | 5.668174 | -93.5903 |
| fma_area | -3.36351 | 5.93883 | -95.6891 |
| start_sloar_altitude | -7.2098 | 5.717744 | -99.5354 |
| mean_counts | -7.60376 | 9.687835 | -99.9293 |
| mitigation_tori | -8.39756 | 5.373788 | -100.723 |
| fishing_year | -9.65552 | 3.652231 | -101.981 |
| target | -10.786 | 5.86774 | -103.112 |
| season | -11.4711 | 4.929223 | -103.797 |
| hooks_set | -12.4819 | 5.416738 | -104.807 |
| Null-model | -12.7681 | 5.22085 | -105.094 |
| line_weight_yn | -12.8962 | 5.086436 | -105.222 |
| moon_phase | -13.6242 | 5.407156 | -105.95 |
| bathymetry | -13.8248 | 5.298387 | -106.15 |

*Table 44 Expected log pointwise predictive density: Dolphins and whales*

| | elpd_diff | se_diff | elpd_loo |
|---|---|---|---|
| Null-model | 0 | 0 | -60.5353 |
| fishing_year | -0.38857 | 2.573942 | -60.9239 |
| mean_counts | -0.50827 | 1.062222 | -61.0436 |
| mitigation_tori | -0.64495 | 0.761526 | -61.1802 |
| start_month | -0.84662 | 0.395651 | -61.3819 |
| hooks_set | -0.89271 | 0.475127 | -61.428 |
| bathymetry | -0.91433 | 0.474535 | -61.4496 |
| line_weight_yn | -1.76867 | 1.662834 | -62.304 |
| fma_area | -1.883 | 2.091856 | -62.4183 |
| area | -2.20875 | 3.392648 | -62.744 |
| start_sloar_altitude | -3.012 | 1.726895 | -63.5473 |
| moon_phase | -3.76768 | 2.64931 | -64.303 |
| season | -4.77395 | 3.011971 | -65.3092 |

*Table 45 Expected log pointwise predictive density: New Zealand fur seal*

| | elpd_diff | se_diff | elpd_loo |
|---|---|---|---|
| season | 0 | 0 | -464.405 |
| start_sloar_altitude | -8.82268 | 6.732675 | -473.228 |
| moon_phase | -17.2274 | 5.470554 | -481.632 |
| area | -18.137 | 7.921673 | -482.542 |
| start_month | -18.4109 | 6.189621 | -482.816 |
| fishing_year | -21.1832 | 9.021905 | -485.588 |
| fma_area | -24.7602 | 7.540417 | -489.165 |
| line_weight_yn | -39.277 | 6.89402 | -503.682 |
| mitigation_tori | -41.6028 | 7.281775 | -506.008 |
| Null-model | -42.3876 | 6.891484 | -506.793 |
| mean_counts | -43.006 | 7.198008 | -507.411 |
| bathymetry | -43.2784 | 6.978879 | -507.684 |
| hooks_set | -43.3158 | 6.895282 | -507.721 |

*Table 46 Expected log pointwise predictive density: Sharks and rays*

| | elpd_diff | se_diff | elpd_loo |
|---|---|---|---|
| bathymetry | 0 | 0 | -19.8646 |
| area | -2.17853 | 1.396544 | -22.0432 |
| fma_area | -3.30866 | 2.047007 | -23.1733 |
| start_sloar_altitude | -3.7721 | 2.330322 | -23.6367 |
| mean_counts | -3.96017 | 2.431246 | -23.8248 |
| start_month | -4.4121 | 2.809829 | -24.2767 |
| moon_phase | -4.6222 | 2.808933 | -24.4868 |

| | | | |
|---|---|---|---|
| Null-model | -4.66502 | 2.808723 | -24.5297 |
| hooks_set | -5.15011 | 3.137889 | -25.0148 |
| mitigation_tori | -5.68366 | 3.616869 | -25.5483 |
| line_weight_yn | -5.72672 | 3.413603 | -25.5914 |
| season | -6.87303 | 4.320309 | -26.7377 |
| fishing_year | -7.20604 | 4.541794 | -27.0707 |

*Table 47 Expected log pointwise predictive density: Turtles*

| | **elpd_diff** | **se_diff** | **elpd_loo** |
|---|---|---|---|
| start_month | 0 | 0 | -103.954 |
| fma_area | -2.42491 | 4.696251 | -106.379 |
| start_sloar_altitude | -3.15273 | 3.200175 | -107.107 |
| area | -3.62058 | 4.543349 | -107.575 |
| line_weight_yn | -5.55163 | 4.198867 | -109.506 |
| moon_phase | -7.0613 | 5.564933 | -111.015 |
| Null-model | -7.63201 | 4.384262 | -111.586 |
| mitigation_tori | -8.36363 | 4.601375 | -112.318 |
| mean_counts | -8.52776 | 4.648874 | -112.482 |
| bathymetry | -8.63346 | 4.581196 | -112.588 |
| hooks_set | -8.72125 | 4.786638 | -112.675 |
| fishing_year | -8.97243 | 6.231516 | -112.926 |
| season | -9.57166 | 6.431044 | -113.526 |

Removed from initial glm.nb fitting due to issues (not enough captures): grey petrel and Salvin's albatross

*Table 48 Model selection for black petrel captures*

| **variable** | **AIC** | **delta_AIC** |
|---|---|---|
| season | 233.6863 | 0 |
| start_month | 242.7354 | -9.0491 |
| target | 263.4031 | -29.7168 |
| black_petrel_mean_counts | 269.3939 | -35.7076 |
| fma_area | 291.4026 | -57.7163 |
| start_solar_altitude | 291.9494 | -58.2631 |
| area | 292.7238 | -59.0375 |
| bullers_albatross_mean_counts | 299.7606 | -66.0743 |
| grey_petrel_mean_counts | 300.058 | -66.3717 |
| white_capped_albatross_mean_counts | 300.9872 | -67.3009 |
| other_albatrosses_mean_counts | 302.9398 | -69.2535 |
| hooks_set | 307.0183 | -73.332 |
| moon_phase | 307.7927 | -74.1064 |
| bathymetry | 308.1179 | -74.4316 |
| mitigation_tori | 309.7739 | -76.0876 |

| | | |
|---|---|---|
| fishing_year | 309.9078 | -76.2215 |
| NULL_model | 309.9156 | -76.2293 |
| sooty_shearwater_mean_counts | 310.2387 | -76.5524 |
| white_chinned_petrel_mean_counts | 310.3398 | -76.6535 |
| flesh_footed_shearwater_mean_counts | 310.7304 | -77.0441 |
| line_weight_yn | 311.3435 | -77.6572 |
| other_birds_mean_counts | 311.8168 | -78.1305 |
| salvins_albatross_mean_counts | 311.9016 | -78.2153 |

*Table 49 Model selection: Buller's albatross captures*

| **variable** | **AIC** | **delta_AIC** |
|---|---|---|
| fma_area | 828.124 | 0 |
| area | 829.0482 | -0.92419 |
| start_month | 869.7481 | -41.6241 |
| season | 872.3034 | -44.1794 |
| grey_petrel_mean_counts | 892.6924 | -64.5684 |
| white_capped_albatross_mean_counts | 903.8283 | -75.7043 |
| target | 904.2915 | -76.1674 |
| moon_phase | 912.8787 | -84.7546 |
| bullers_albatross_mean_counts | 913.1737 | -85.0497 |
| fishing_year | 919.6125 | -91.4885 |
| start_solar_altitude | 930.3447 | -102.221 |
| white_chinned_petrel_mean_counts | 936.0275 | -107.903 |
| bathymetry | 936.0871 | -107.963 |
| black_petrel_mean_counts | 939.1295 | -111.005 |
| other_birds_mean_counts | 939.3297 | -111.206 |
| sooty_shearwater_mean_counts | 940.1948 | -112.071 |
| NULL_model | 940.292 | -112.168 |
| line_weight_yn | 941.5243 | -113.4 |
| mitigation_tori | 941.5856 | -113.462 |
| other_albatrosses_mean_counts | 942.0126 | -113.889 |
| salvins_albatross_mean_counts | 942.1179 | -113.994 |
| hooks_set | 942.1942 | -114.07 |
| flesh_footed_shearwater_mean_counts | 942.29 | -114.166 |

*Table 50 Model selection: Flesh-footed shearwater captures*

| variable | AIC | delta_AIC |
|---|---|---|
| season | 99.11723 | 0 |
| start_month | 105.7519 | -6.63467 |
| bathymetry | 108.0286 | -8.91141 |
| start_solar_altitude | 108.2977 | -9.18046 |
| other_albatrosses_mean_counts | 108.453 | -9.33576 |
| sooty_shearwater_mean_counts | 108.9649 | -9.84764 |
| moon_phase | 109.0793 | -9.9621 |
| target | 109.2099 | -10.0927 |
| NULL_model | 109.3955 | -10.2782 |
| bullers_albatross_mean_counts | 109.7786 | -10.6614 |
| flesh_footed_shearwater_mean_counts | 110.768 | -11.6508 |
| black_petrel_mean_counts | 110.8525 | -11.7353 |
| line_weight_yn | 110.9111 | -11.7938 |
| grey_petrel_mean_counts | 110.9397 | -11.8224 |
| hooks_set | 111.0056 | -11.8883 |
| white_capped_albatross_mean_counts | 111.2196 | -12.1024 |
| mitigation_tori | 111.2485 | -12.1313 |
| white_chinned_petrel_mean_counts | 111.3814 | -12.2641 |
| other_birds_mean_counts | 111.3901 | -12.2729 |
| salvins_albatross_mean_counts | 111.3944 | -12.2772 |
| fishing_year | 117.9337 | -18.8165 |
| fma_area | 120.1886 | -21.0714 |
| area | 121.8288 | -22.7115 |

*Table 51 Model selection: Other albatrosses captures*

| variable | AIC | delta_AIC |
|---|---|---|
| start_month | 851.8726 | 0 |
| season | 860.2856 | -8.41304 |
| start_solar_altitude | 865.6868 | -13.8142 |
| area | 868.1865 | -16.314 |
| fma_area | 892.3891 | -40.5165 |
| target | 898.6936 | -46.8211 |
| fishing_year | 899.8103 | -47.9377 |
| moon_phase | 905.6474 | -53.7748 |
| flesh_footed_shearwater_mean_counts | 914.188 | -62.3154 |
| salvins_albatross_mean_counts | 928.544 | -76.6714 |
| other_albatrosses_mean_counts | 933.8653 | -81.9928 |
| mitigation_tori | 935.4242 | -83.5516 |
| bathymetry | 939.2358 | -87.3632 |
| bullers_albatross_mean_counts | 940.372 | -88.4994 |
| other_birds_mean_counts | 941.2167 | -89.3441 |
| line_weight_yn | 941.5677 | -89.6951 |
| NULL_model | 941.9127 | -90.0401 |
| grey_petrel_mean_counts | 942.2398 | -90.3673 |
| white_chinned_petrel_mean_counts | 942.6123 | -90.7397 |
| hooks_set | 942.6325 | -90.7599 |
| white_capped_albatross_mean_counts | 943.1777 | -91.3051 |
| black_petrel_mean_counts | 943.8913 | -92.0188 |
| sooty_shearwater_mean_counts | 943.8986 | -92.026 |

*Table 52 Model selection: Other birds captures*

| variable | AIC | delta_AIC |
|---|---|---|
| fma_area | 435.8771 | 0 |
| area | 436.6884 | -0.81126 |
| season | 466.8341 | -30.957 |
| bullers_albatross_mean_counts | 469.6628 | -33.7857 |
| grey_petrel_mean_counts | 471.7833 | -35.9062 |
| bathymetry | 475.7644 | -39.8873 |
| white_capped_albatross_mean_counts | 477.0286 | -41.1515 |
| start_month | 478.0223 | -42.1452 |
| mitigation_tori | 483.2608 | -47.3837 |
| flesh_footed_shearwater_mean_counts | 484.5909 | -48.7137 |
| other_birds_mean_counts | 484.7118 | -48.8347 |
| target | 486.3995 | -50.5224 |
| line_weight_yn | 486.6635 | -50.7864 |
| white_chinned_petrel_mean_counts | 487.6236 | -51.7465 |
| black_petrel_mean_counts | 488.6003 | -52.7232 |
| fishing_year | 488.7744 | -52.8972 |
| hooks_set | 489.6729 | -53.7957 |
| NULL_model | 490.8737 | -54.9966 |
| start_solar_altitude | 491.3173 | -55.4401 |
| salvins_albatross_mean_counts | 491.3309 | -55.4538 |
| moon_phase | 491.5927 | -55.7155 |
| other_albatrosses_mean_counts | 492.2134 | -56.3363 |
| sooty_shearwater_mean_counts | 492.6734 | -56.7962 |

*Table 53 Model selection: White-capped albatross captures*

| variable | AIC | delta_AIC |
|---|---|---|
| fma_area | 691.1313 | 0 |
| area | 695.4536 | -4.32229 |
| season | 766.1979 | -75.0665 |
| start_month | 775.1775 | -84.0461 |
| white_capped_albatross_mean_counts | 787.8982 | -96.7669 |
| grey_petrel_mean_counts | 788.0169 | -96.8855 |
| bullers_albatross_mean_counts | 806.9761 | -115.845 |
| target | 811.9204 | -120.789 |
| fishing_year | 816.1486 | -125.017 |
| bathymetry | 821.6382 | -130.507 |
| moon_phase | 829.5971 | -138.466 |
| white_chinned_petrel_mean_counts | 834.7506 | -143.619 |
| other_birds_mean_counts | 837.3591 | -146.228 |
| start_solar_altitude | 838.9796 | -147.848 |
| line_weight_yn | 841.3242 | -150.193 |
| black_petrel_mean_counts | 844.3338 | -153.202 |
| flesh_footed_shearwater_mean_counts | 846.5993 | -155.468 |
| NULL_model | 847.9274 | -156.796 |
| mitigation_tori | 848.1448 | -157.013 |
| salvins_albatross_mean_counts | 849.8096 | -158.678 |
| sooty_shearwater_mean_counts | 849.9116 | -158.78 |
| hooks_set | 849.9156 | -158.784 |
| other_albatrosses_mean_counts | 849.9209 | -158.79 |

*Table 54 Model selection: White-chinned petrel captures*

| variable | AIC | delta_AIC |
|---|---|---|
| start_month | 187.9789 | 0 |
| flesh_footed_shearwater_mean_counts | 194.4478 | -6.46888 |
| area | 195.2599 | -7.28103 |
| fma_area | 196.1382 | -8.15929 |
| mitigation_tori | 199.2966 | -11.3177 |
| start_solar_altitude | 200.0849 | -12.106 |
| other_birds_mean_counts | 201.7121 | -13.7332 |
| salvins_albatross_mean_counts | 203.9418 | -15.9629 |
| season | 205.4726 | -17.4937 |
| fishing_year | 205.6692 | -17.6904 |
| sooty_shearwater_mean_counts | 205.9361 | -17.9573 |
| grey_petrel_mean_counts | 206.7974 | -18.8186 |
| target | 206.8411 | -18.8622 |
| black_petrel_mean_counts | 206.9773 | -18.9984 |
| white_capped_albatross_mean_counts | 207.5615 | -19.5826 |
| NULL_model | 208.0273 | -20.0484 |
| hooks_set | 208.153 | -20.1741 |
| white_chinned_petrel_mean_counts | 208.5324 | -20.5536 |
| line_weight_yn | 208.74 | -20.7611 |
| other_albatrosses_mean_counts | 209.2633 | -21.2844 |
| moon_phase | 209.9189 | -21.94 |
| bathymetry | 209.9313 | -21.9524 |
| bullers_albatross_mean_counts | 209.99 | -22.0112 |

*Table 55 Model selection: Turtle captures*

| **variable** | **AIC** | **delta_AIC** |
|---|---|---|
| start_solar_altitude | 211.0655 | 0 |
| target | 217.5358 | -6.47026 |
| fma_area | 219.8003 | -8.73483 |
| season | 221.0291 | -9.96354 |
| line_weight_yn | 221.0634 | -9.99785 |
| other_birds_mean_counts | 222.0916 | -11.0261 |
| bullers_albatross_mean_counts | 222.0925 | -11.0269 |
| area | 222.1002 | -11.0347 |
| white_capped_albatross_mean_counts | 222.8664 | -11.8009 |
| grey_petrel_mean_counts | 222.8769 | -11.8113 |
| flesh_footed_shearwater_mean_counts | 223.27 | -12.2044 |
| NULL_model | 223.4645 | -12.399 |
| other_albatrosses_mean_counts | 224.4054 | -13.3399 |
| salvins_albatross_mean_counts | 224.5535 | -13.488 |
| start_month | 224.8848 | -13.8193 |
| moon_phase | 224.9025 | -13.837 |
| sooty_shearwater_mean_counts | 225.0204 | -13.9549 |
| mitigation_tori | 225.1944 | -14.1289 |
| white_chinned_petrel_mean_counts | 225.3161 | -14.2506 |
| black_petrel_mean_counts | 225.3955 | -14.33 |
| hooks_set | 225.398 | -14.3325 |
| bathymetry | 225.4319 | -14.3664 |
| fishing_year | 228.038 | -16.9725 |

*Table 56 Model selection: New Zealand fur seal captures*

| variable | AIC | delta_AIC |
|---|---|---|
| start_month | 936.2606 | 0 |
| target | 946.7912 | -10.5306 |
| season | 963.2848 | -27.0242 |
| start_solar_altitude | 963.7214 | -27.4608 |
| fishing_year | 964.5304 | -28.2698 |
| area | 972.1175 | -35.8569 |
| fma_area | 986.4944 | -50.2338 |
| black_petrel_mean_counts | 995.9208 | -59.6602 |
| line_weight_yn | 1001.98 | -65.7196 |
| white_chinned_petrel_mean_counts | 1003.161 | -66.9001 |
| bullers_albatross_mean_counts | 1003.32 | -67.0593 |
| grey_petrel_mean_counts | 1009.382 | -73.1217 |
| sooty_shearwater_mean_counts | 1011.038 | -74.7777 |
| salvins_albatross_mean_counts | 1011.78 | -75.5193 |
| other_birds_mean_counts | 1012.448 | -76.1869 |
| white_capped_albatross_mean_counts | 1012.648 | -76.3875 |
| hooks_set | 1012.863 | -76.6024 |
| NULL_model | 1013.365 | -77.1043 |
| other_albatrosses_mean_counts | 1014.464 | -78.2038 |
| bathymetry | 1014.673 | -78.4123 |
| mitigation_tori | 1014.794 | -78.5335 |
| moon_phase | 1014.871 | -78.6103 |
| flesh_footed_shearwater_mean_counts | 1015.207 | -78.9467 |

## APPENDIX C: PREDICTIVE CHECKING FOR ALL SEABIRDS CAPTURES MODEL

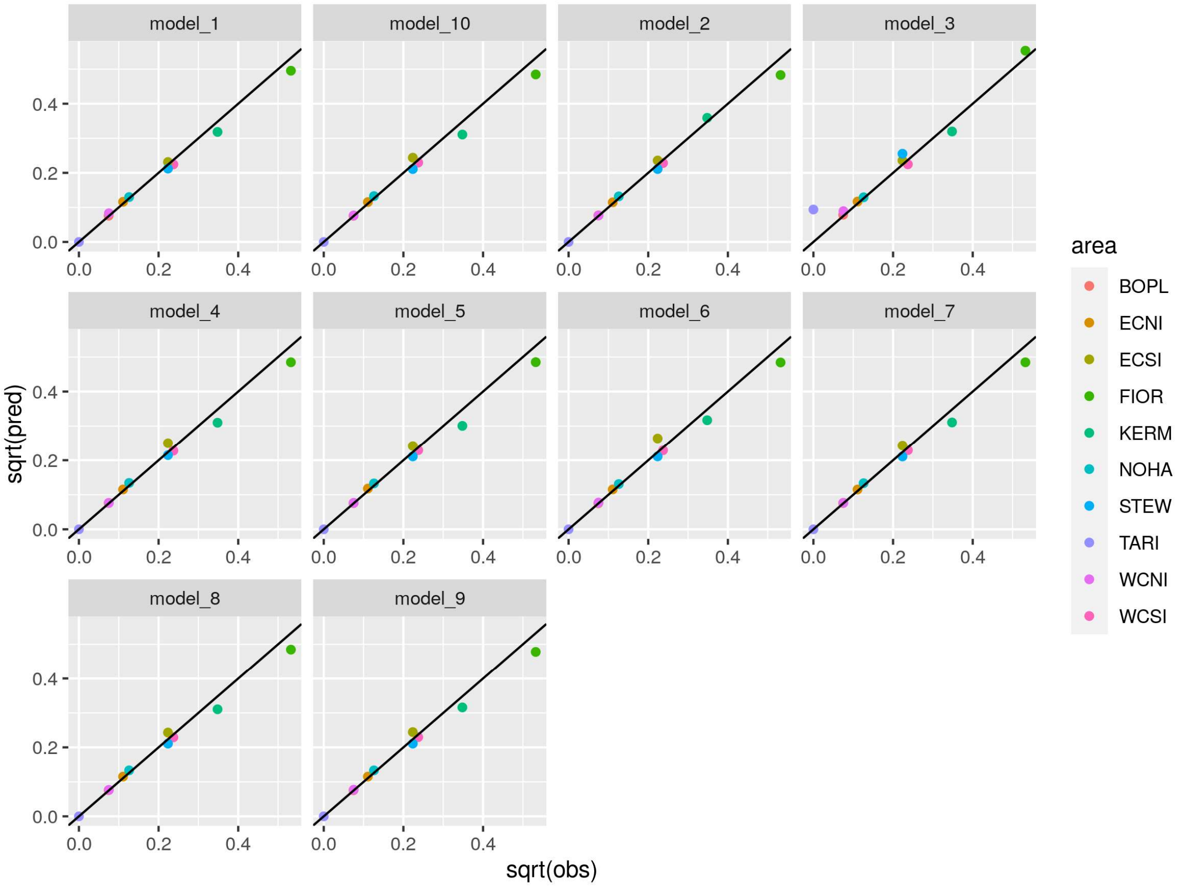



**Figure 15:** Mean predicted vs. mean observed all birds captures in each area for top-10 models fitted to all seabirds captures where model fits included variables with 100% data completeness (Table 4).

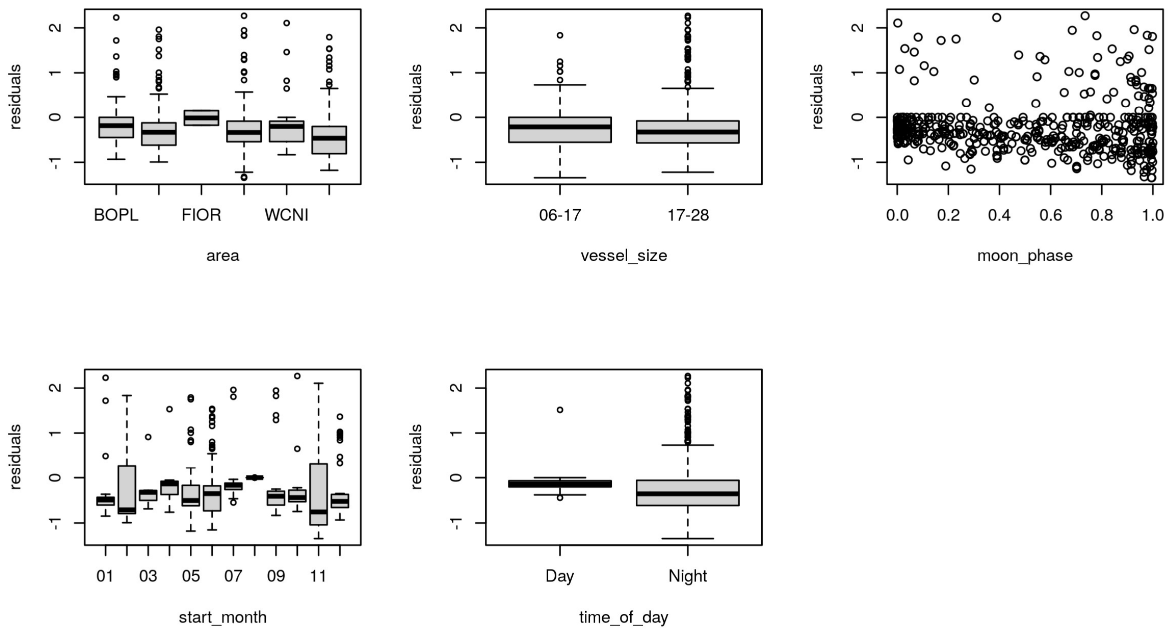



**Figure 16:** Residuals vs predictors from top all seabirds captures model (model 1) where model fits included variables with >75% data completeness (Table 5).

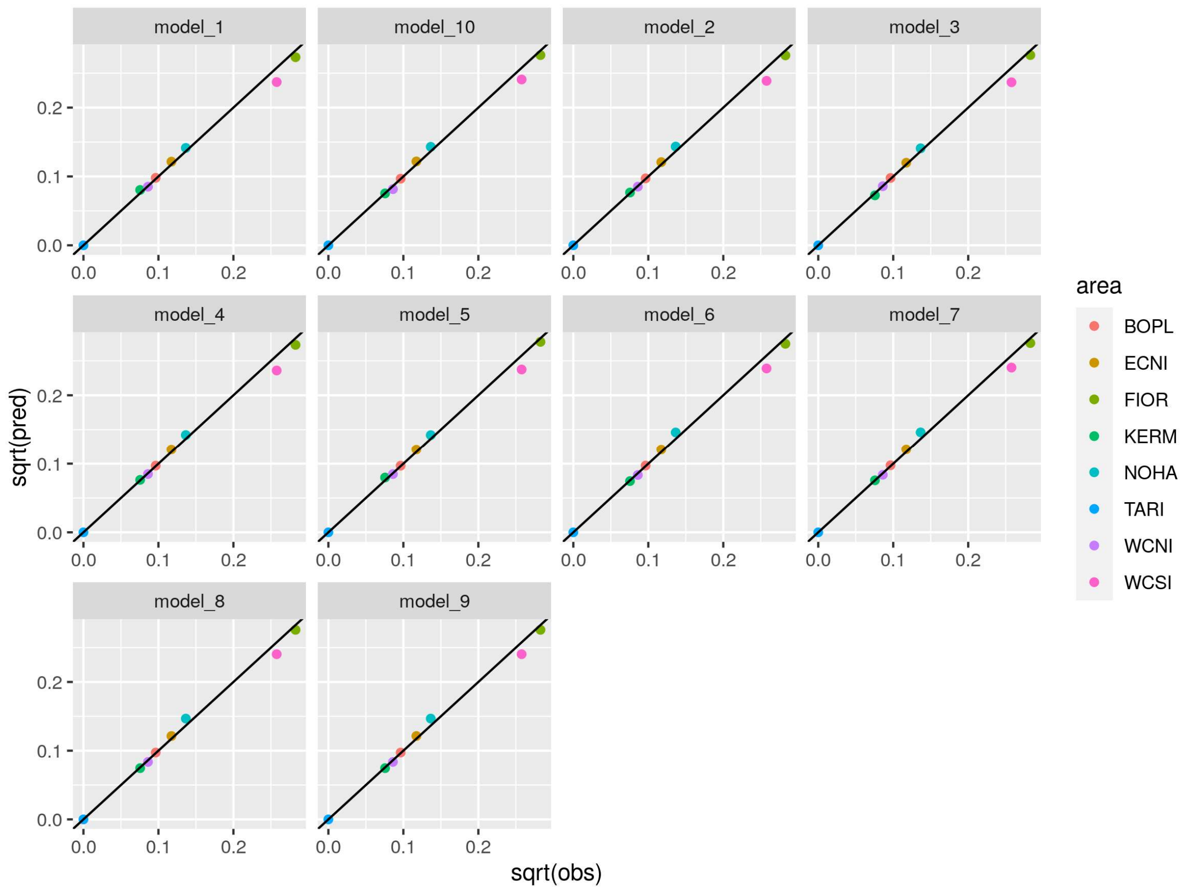



**Figure 17:** predicted vs. mean observed all birds captures in each area for top-10 models fitted to all seabirds fitted to all birds captures where model fits included variables with >75% data completeness (Table 5).

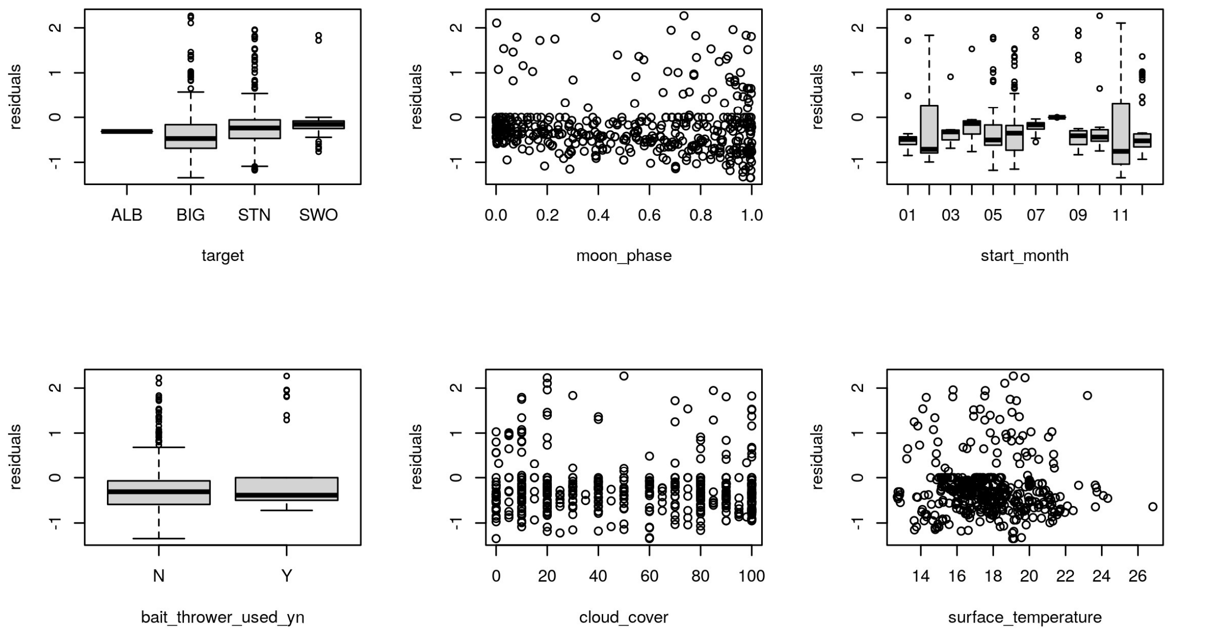



**Figure 18:** Residuals vs. predictor variables from top all bird captures model fitted to data set pruned to 60% of original data set.

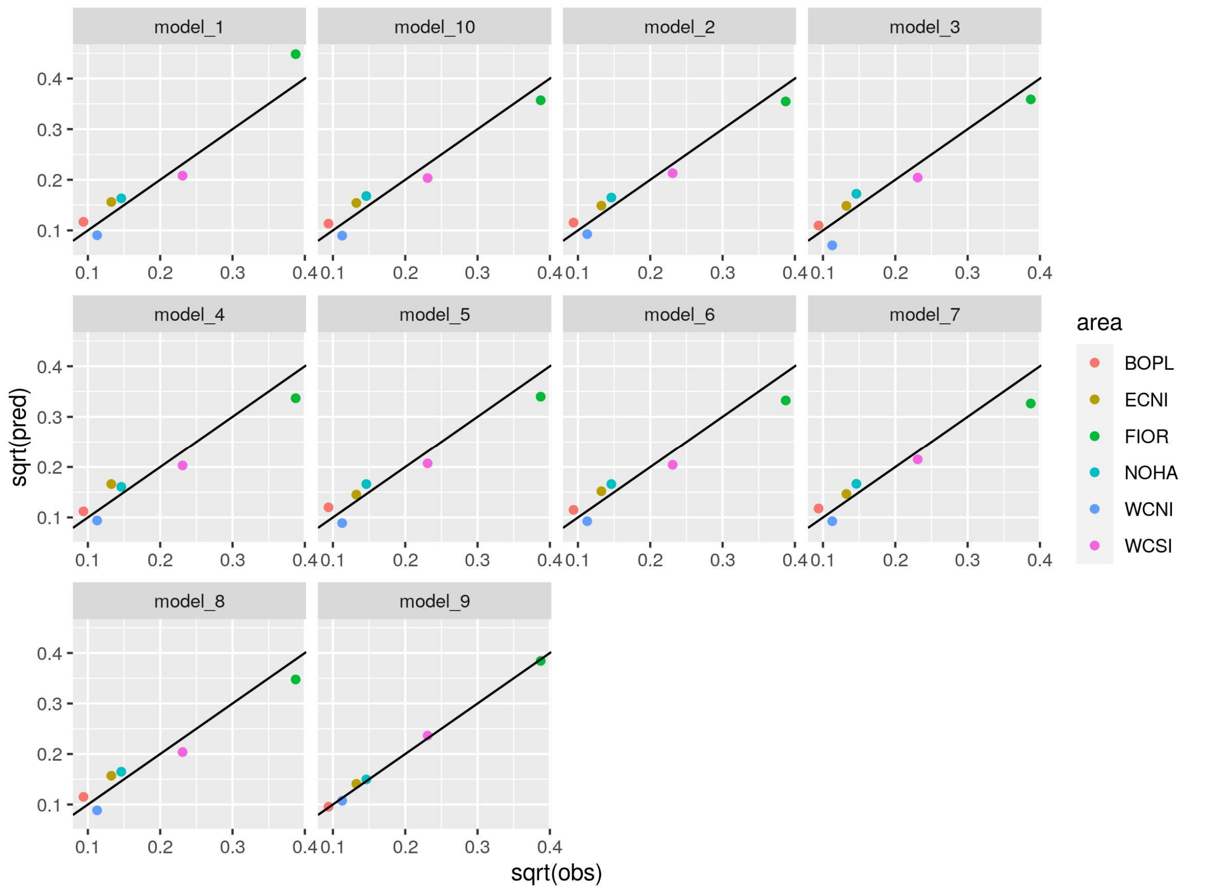



**Figure 19:** Mean predicted vs. mean observed all birds captures in each area for top-10 models fitted to all seabirds fitted to all birds captures where model fits included variables with >60% data completeness (Table 6).

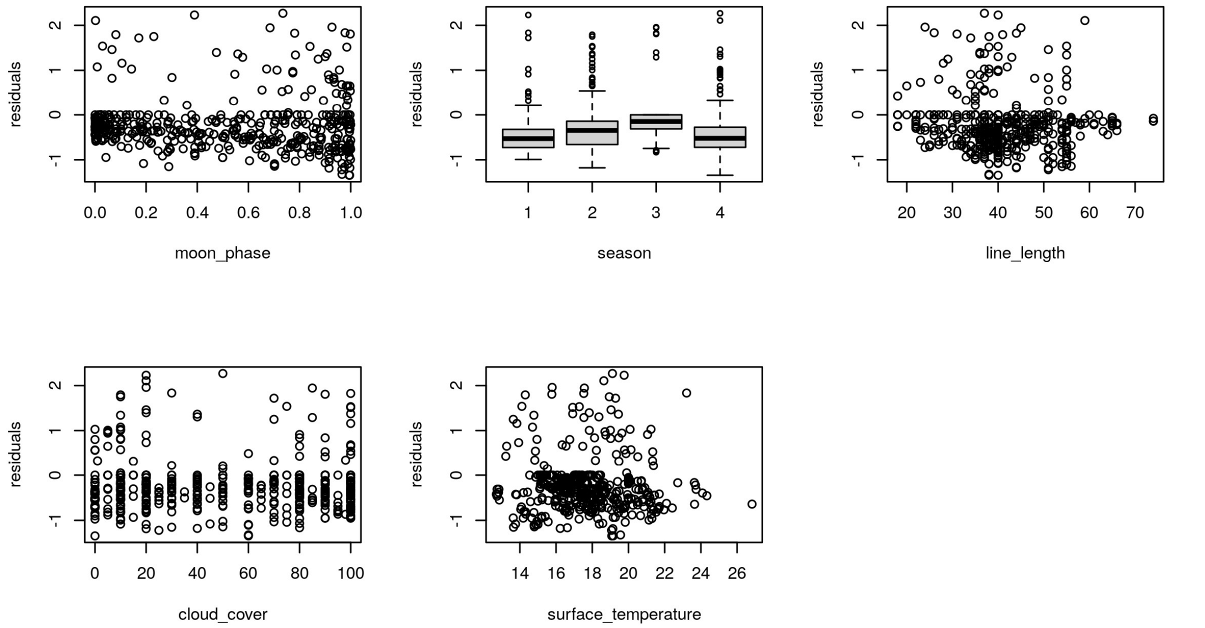



**Figure 20:** Residuals vs. predictor variables from top all bird captures model fitted to data set pruned to 50% of original data set.

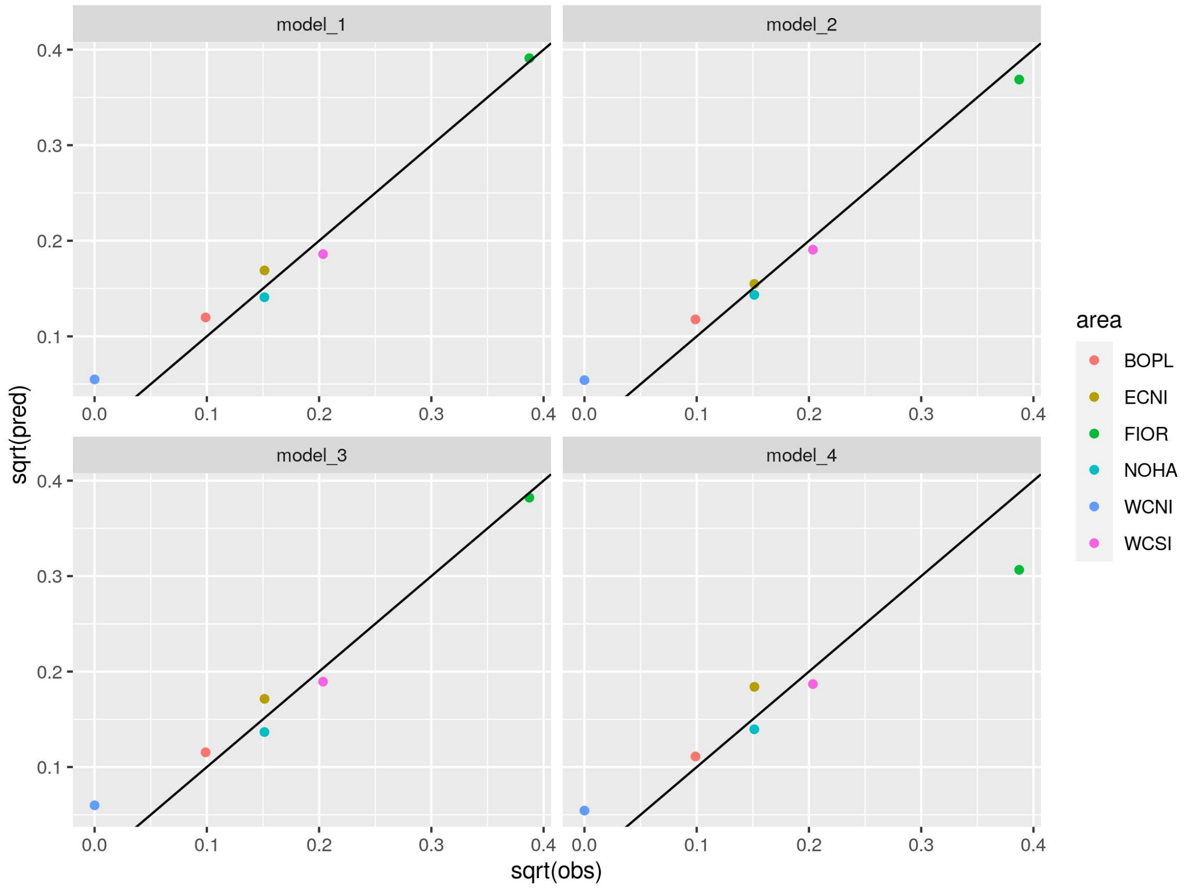



**Figure 21:** Mean predicted vs. mean observed all birds captures in each area for top-10 multi-species models fitted to all birds captures where model fits included variables with >20% data completeness (Table 7).

# APPENDIX D: PREDICTIVE CHECKING FOR MULTI-SPECIES CAPTURES MODEL: BLACK PETREL, WHITE-CAPPED ALBATROSS, BULLER'S ALBATROSS

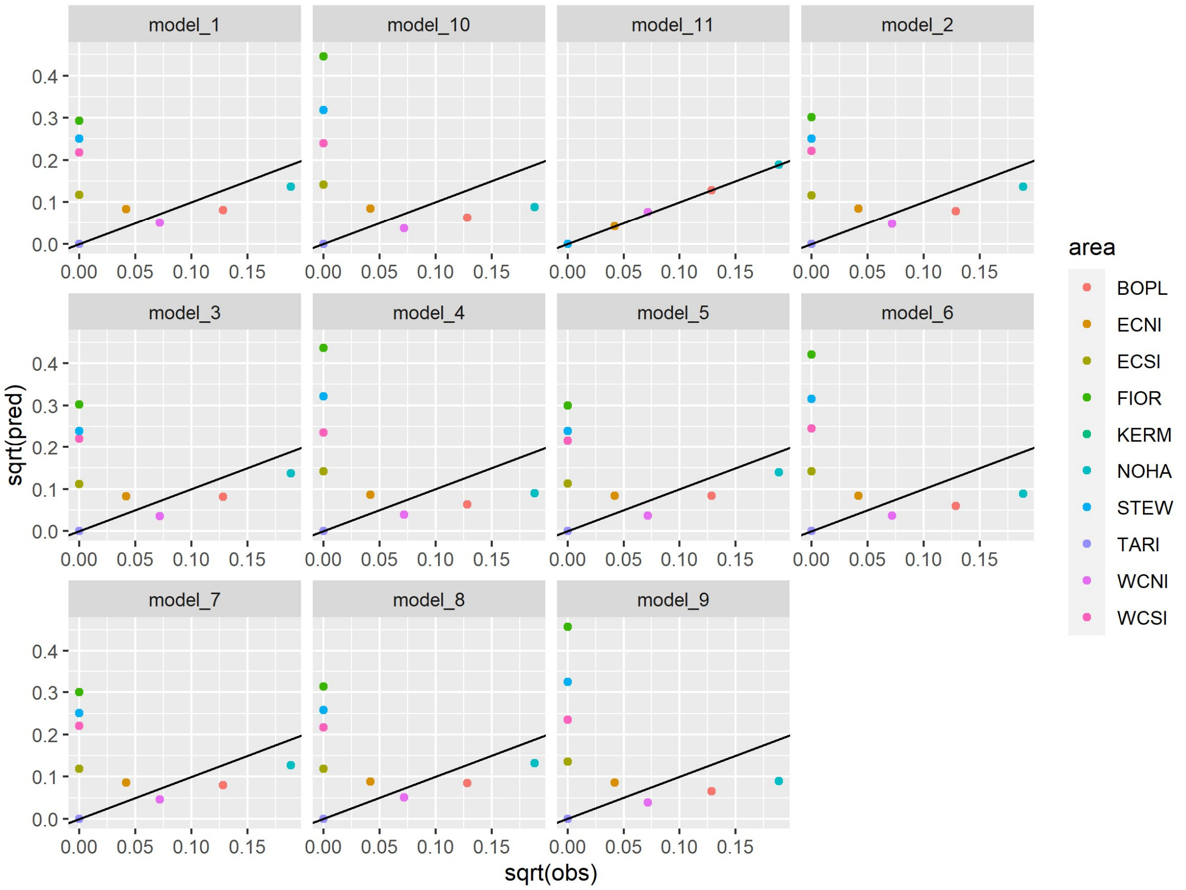



**Figure 22:** Mean predicted vs. mean observed black petrel captures in each area for top-11 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with 100% data completeness (Table 13).

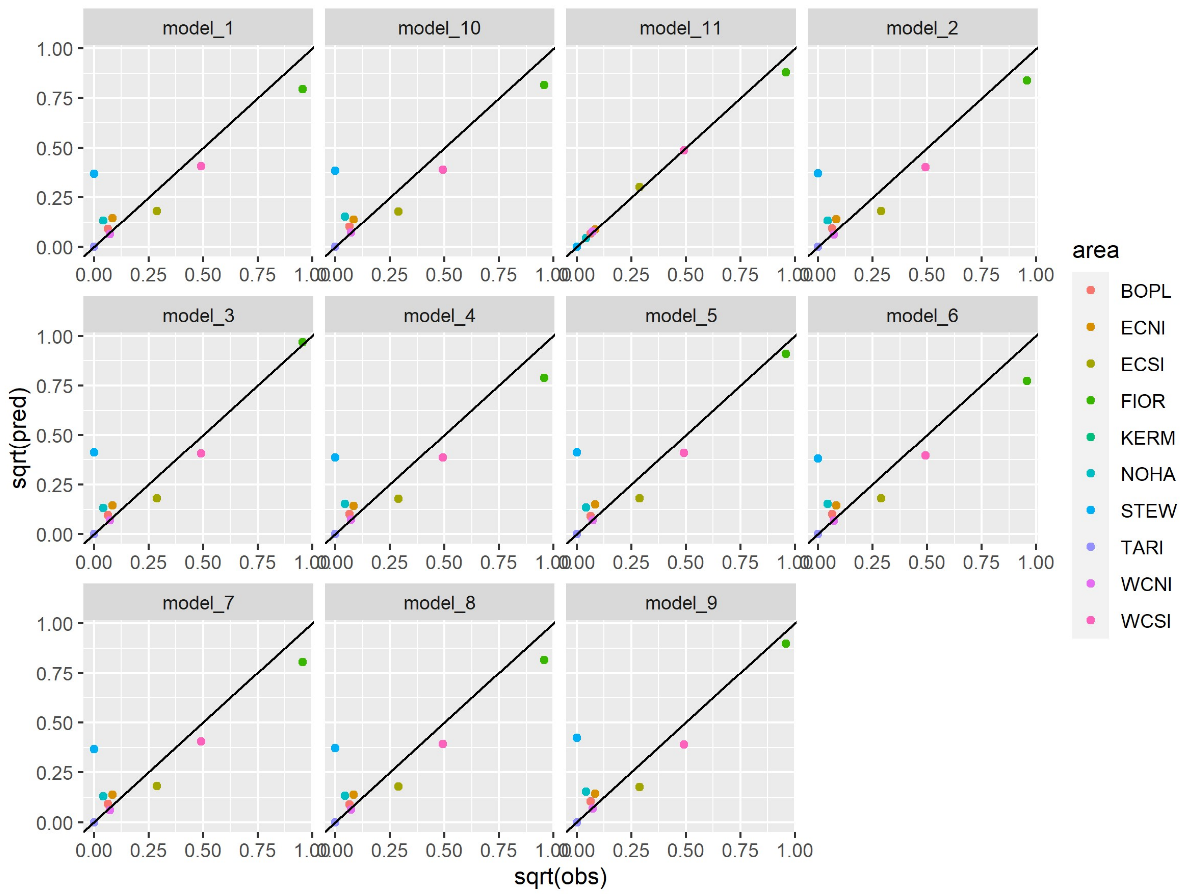



**Figure 23:** Mean predicted vs. mean observed white-capped albatross captures in each area for top-11 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with 100% data completeness (Table 13).

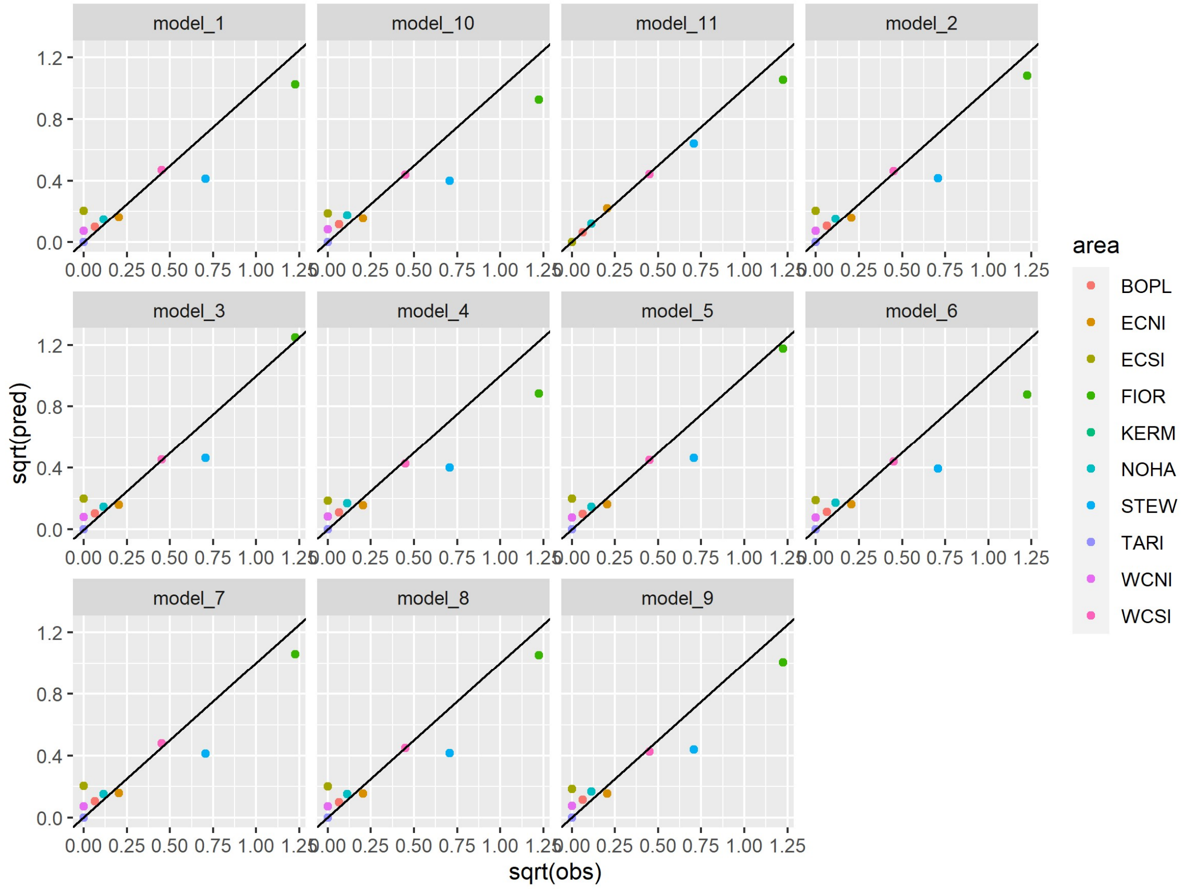



**Figure 24:** Mean predicted vs. mean observed Buller's albatross captures in each area for top-11 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with 100% data completeness (Table 13).

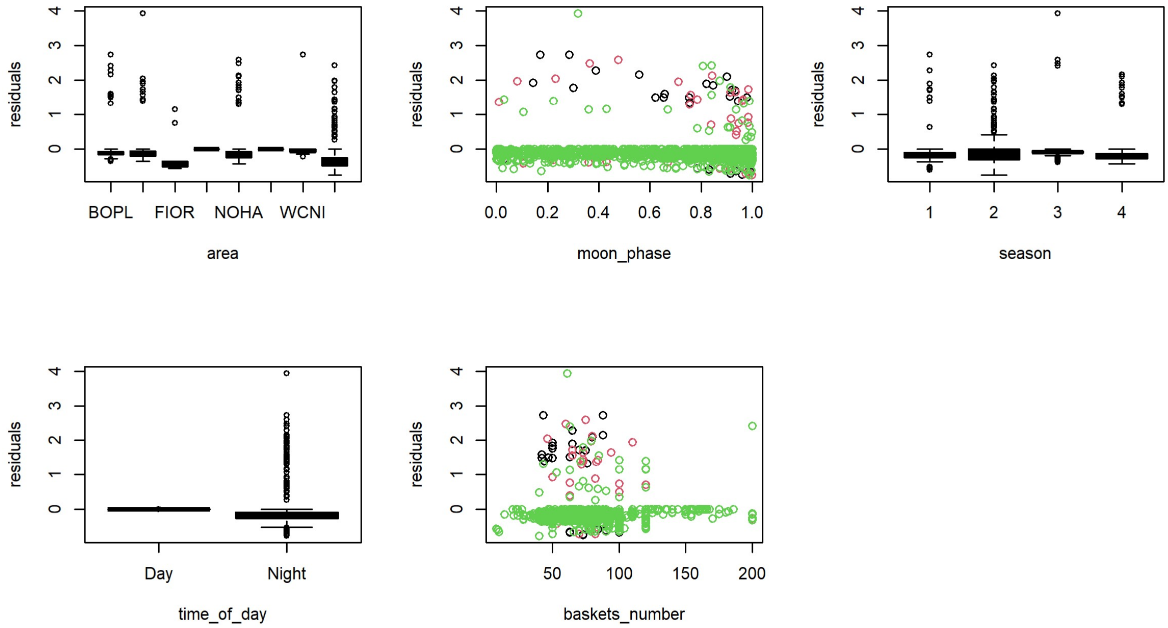



**Figure 25:** Residuals vs predictors from top multi-species seabird captures model (model 1) where model fits included variables with >75% data completeness (Table 14).

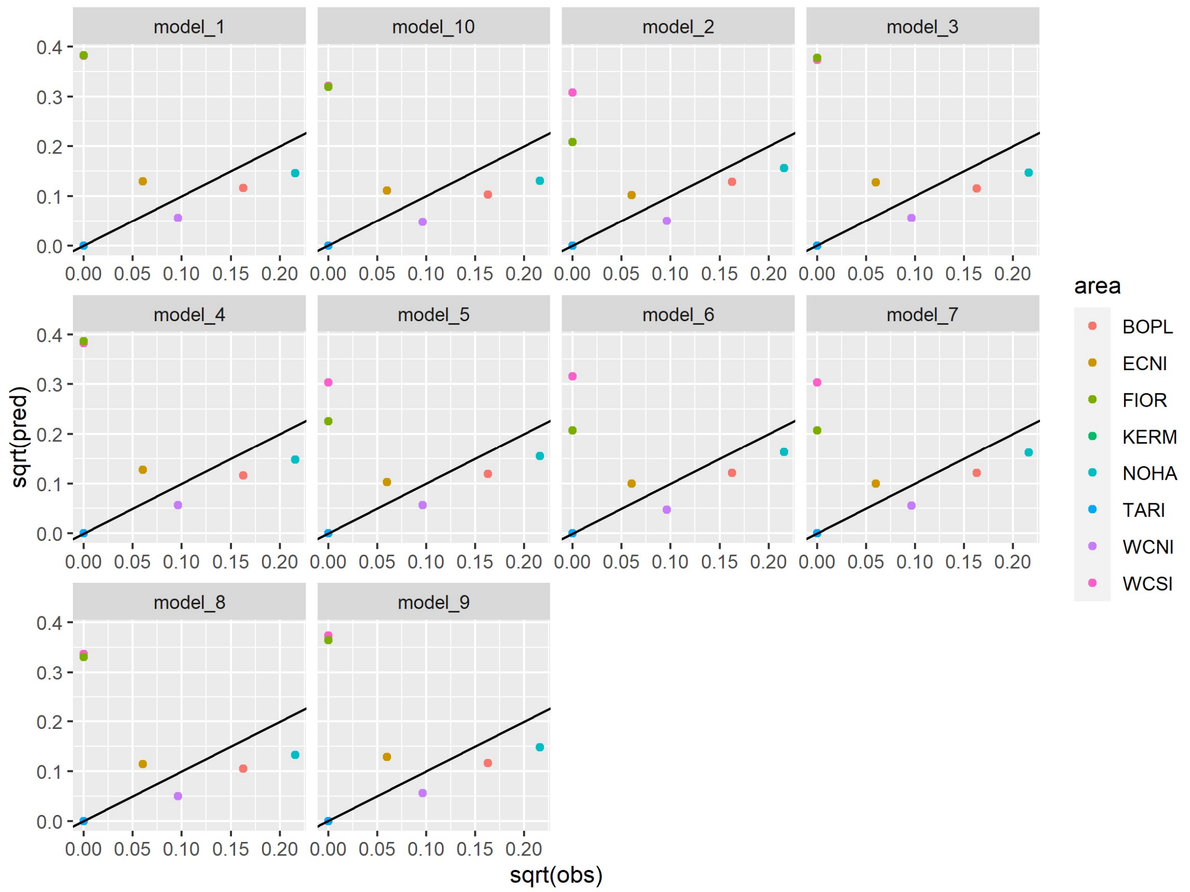



**Figure 26:** Mean predicted vs. mean observed black petrel captures in each area for top-10 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with >75% data completeness (Table 14).

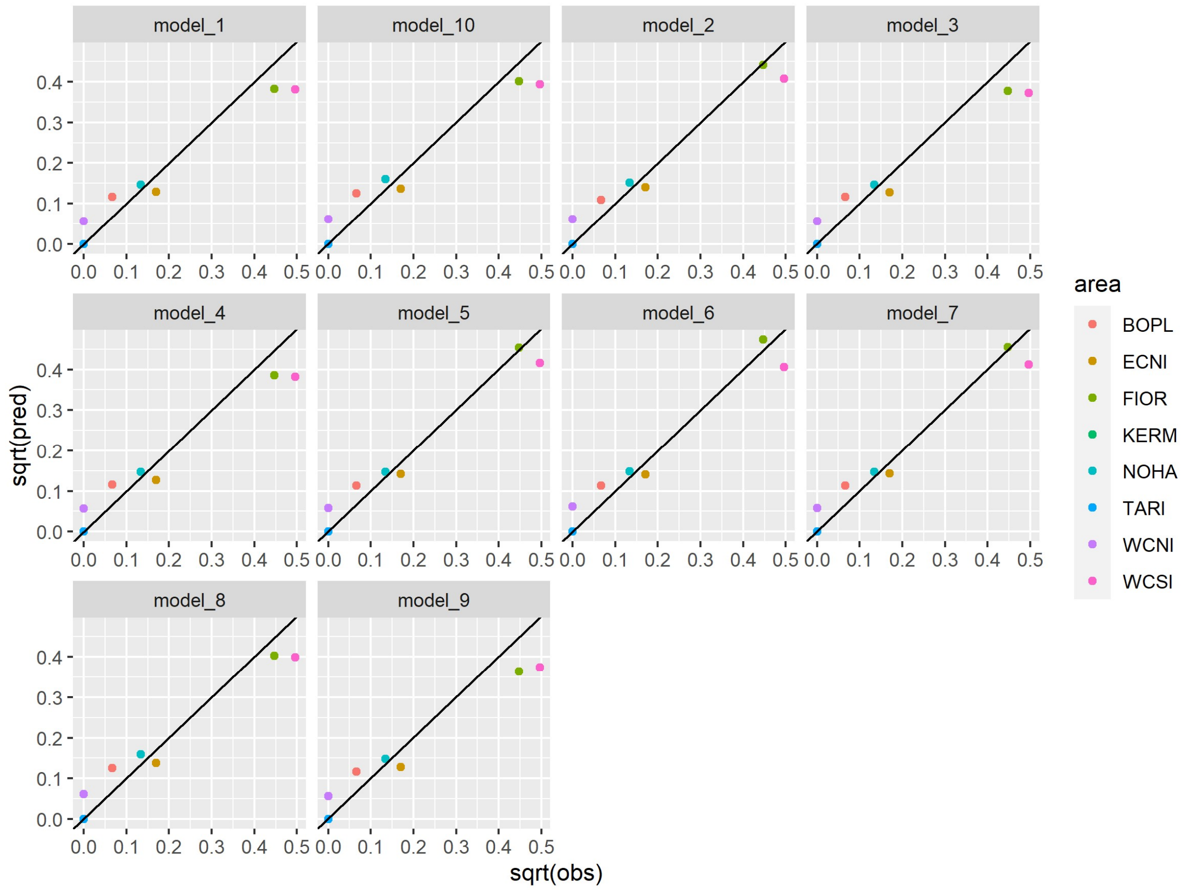



**Figure 27:** Mean predicted vs. mean observed Buller's albatross captures in each area for top-10 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with >75% data completeness (Table 14).

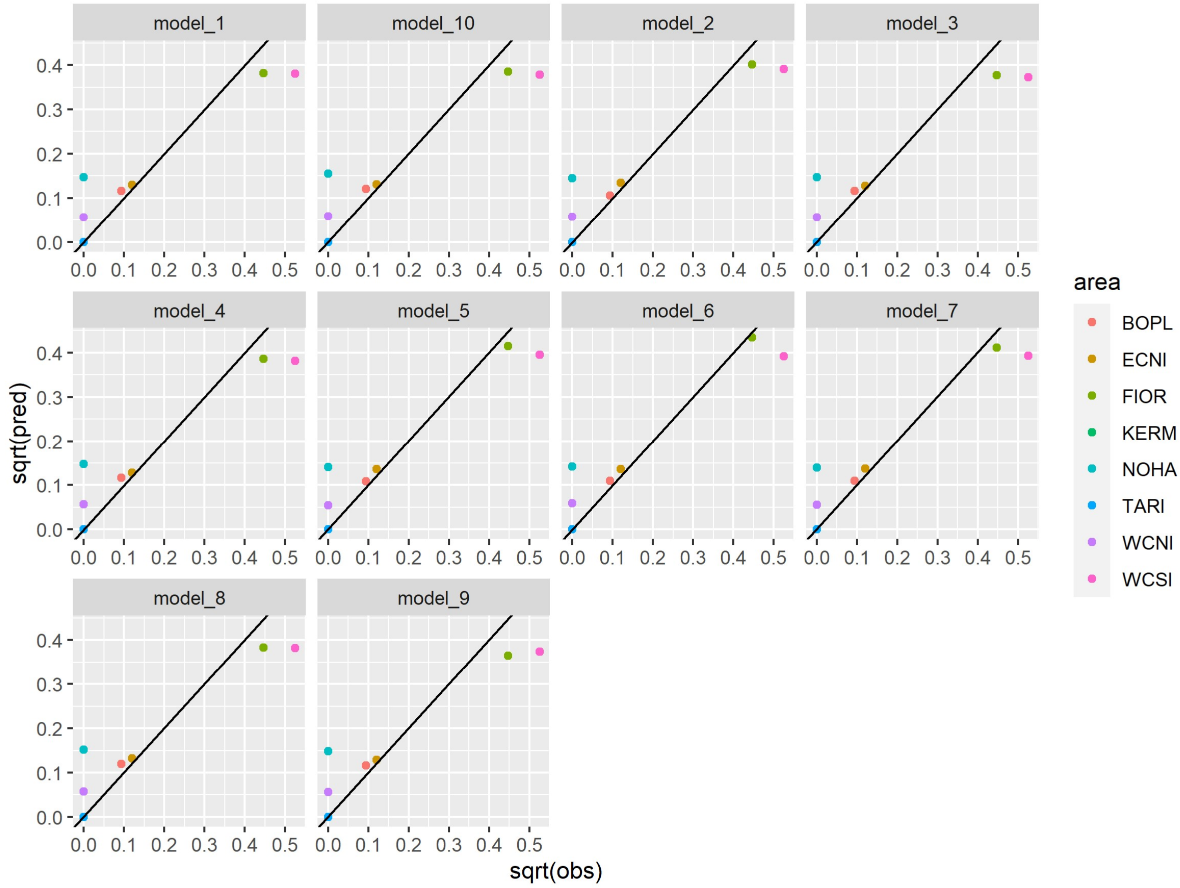



**Figure 28:** Mean predicted vs. mean observed white-capped albatross captures in each area for top-10 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with >75% data completeness (Table 14).

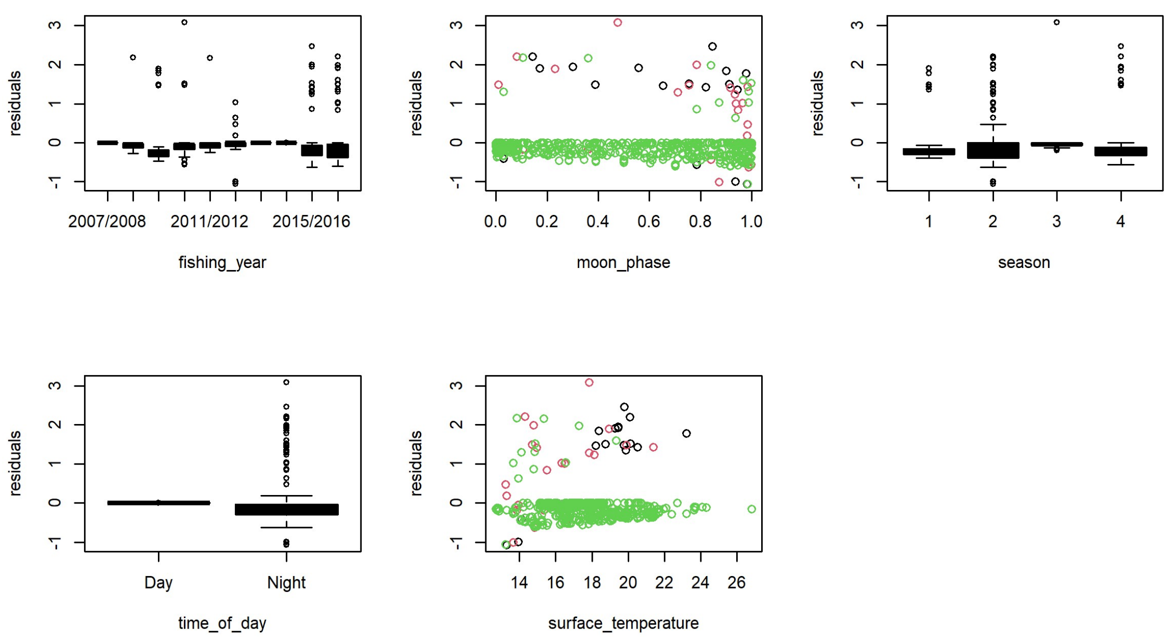


**Figure 29:** Residuals vs predictors from top multi-species seabird captures model (model 1) where model fits included variables with >60% data completeness (Table 15).

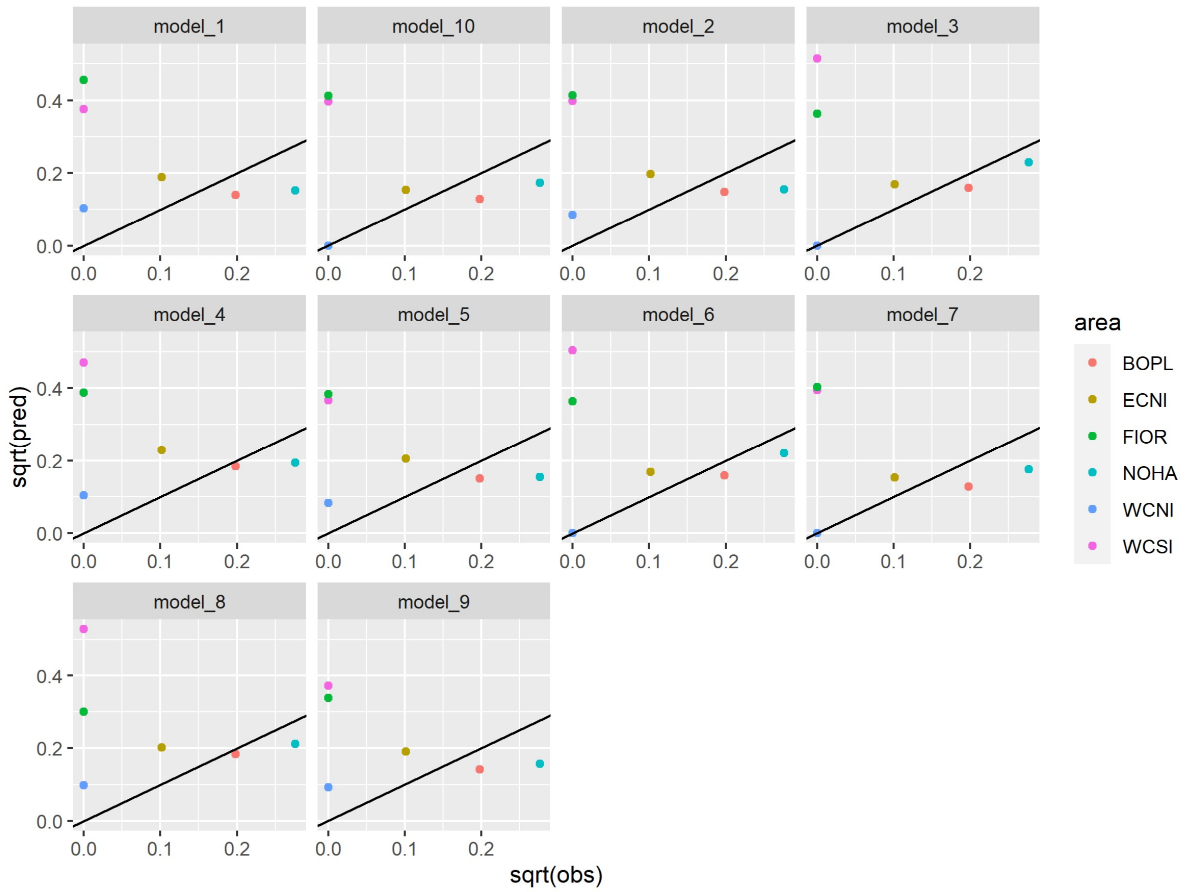



**Figure 30:** Mean predicted vs. mean observed black petrel captures in each area for top-10 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with >60% data completeness (Table 15).

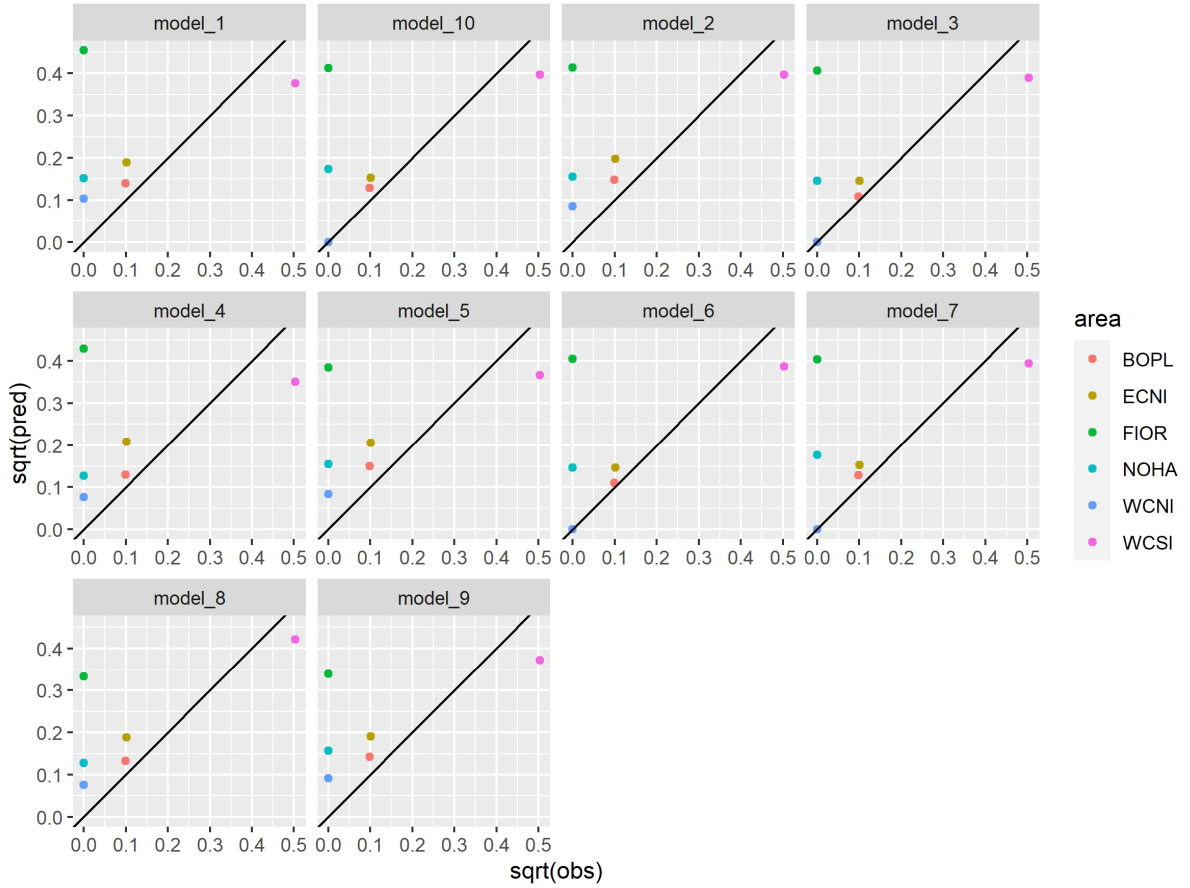



**Figure 31:** Mean predicted vs. mean observed Buller's albatross captures in each area for top-10 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with >60% data completeness (Table 15).

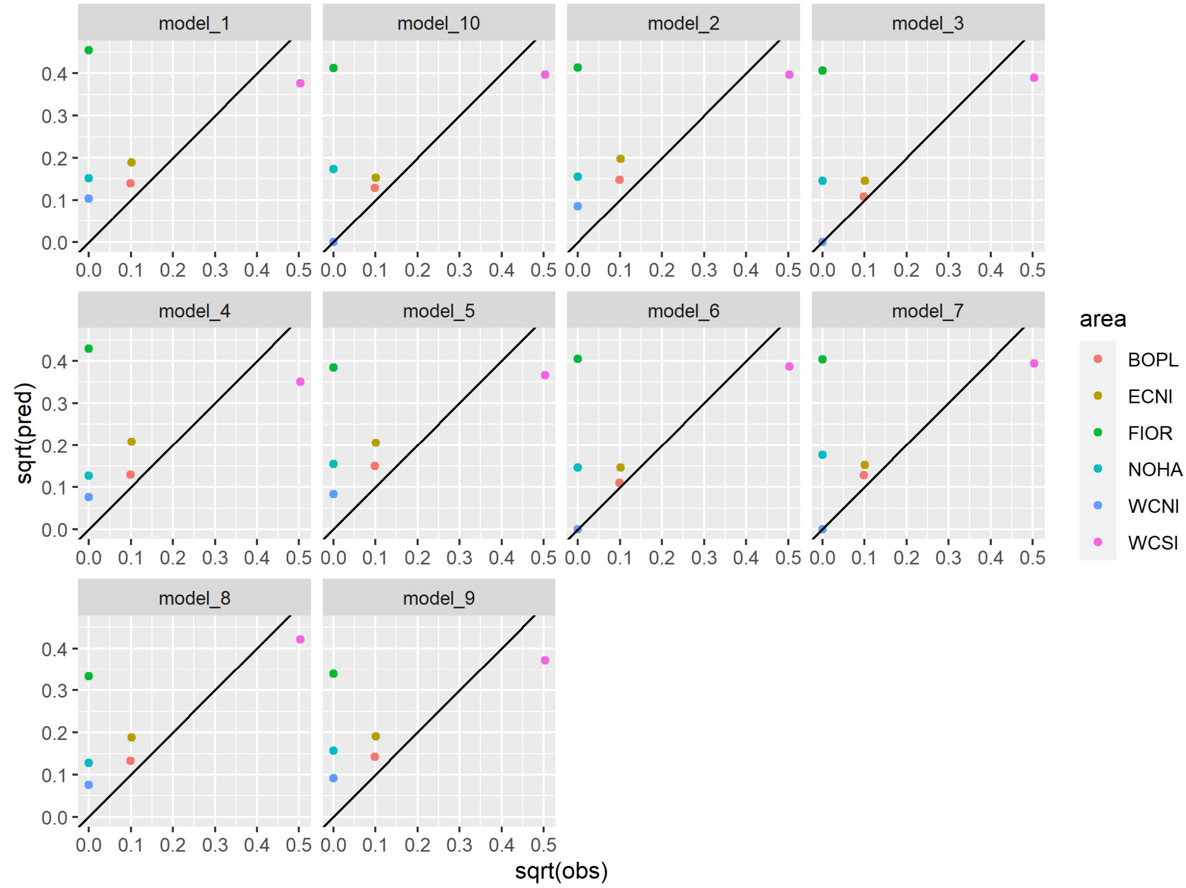



**Figure 32:** Mean predicted vs. mean observed white-capped albatross captures in each area for top-10 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with >60% data completeness (Table 15).

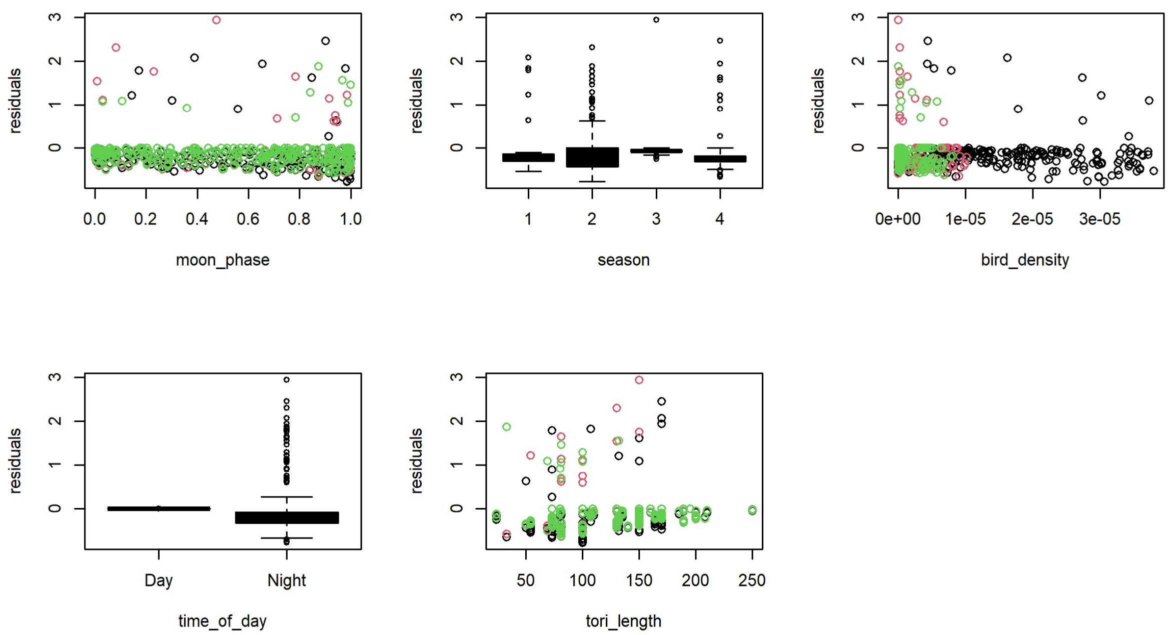



**Figure 33:** Residuals vs predictors from top multi-species seabird captures model (model 1) where model fits included variables with >20% data completeness (Table 15).

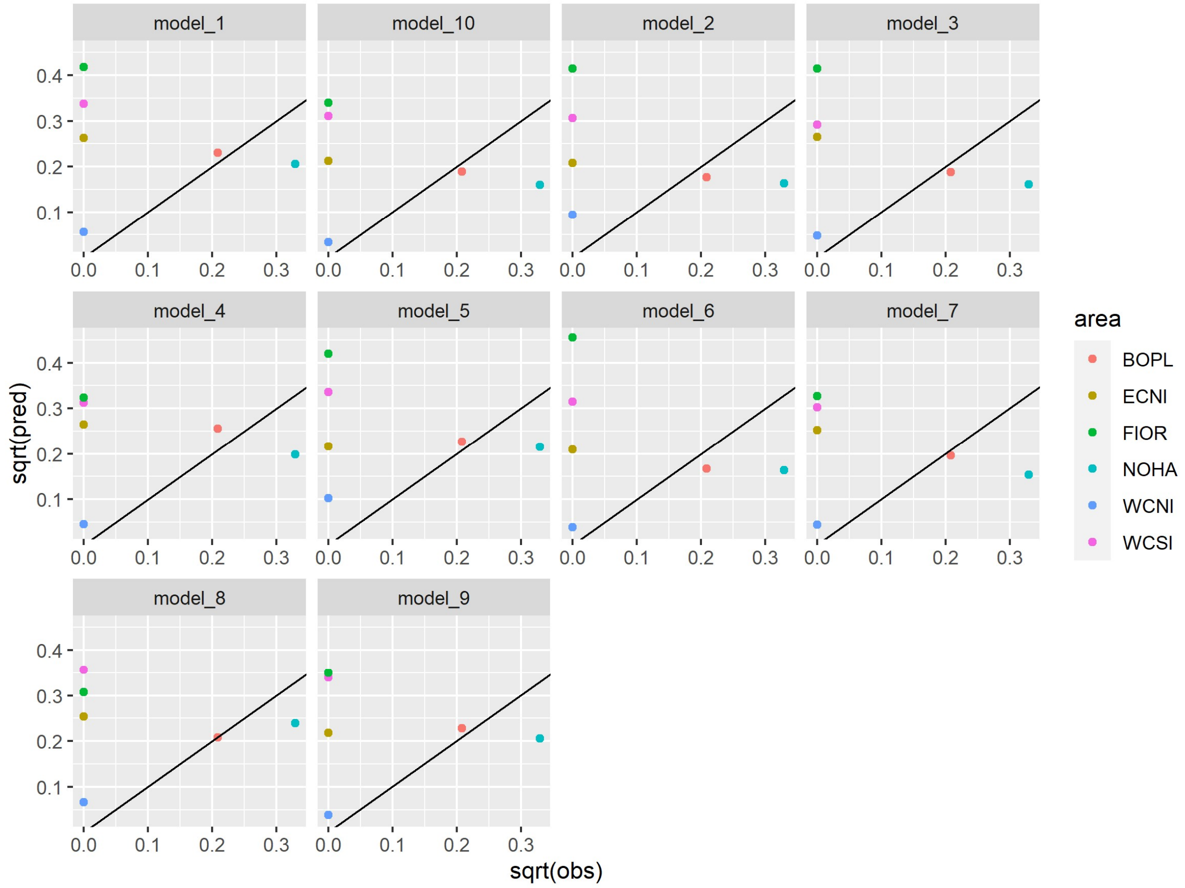



**Figure 34:** Mean predicted vs. mean observed black petrel captures in each area for top-10 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with >20% data completeness (Table 16).

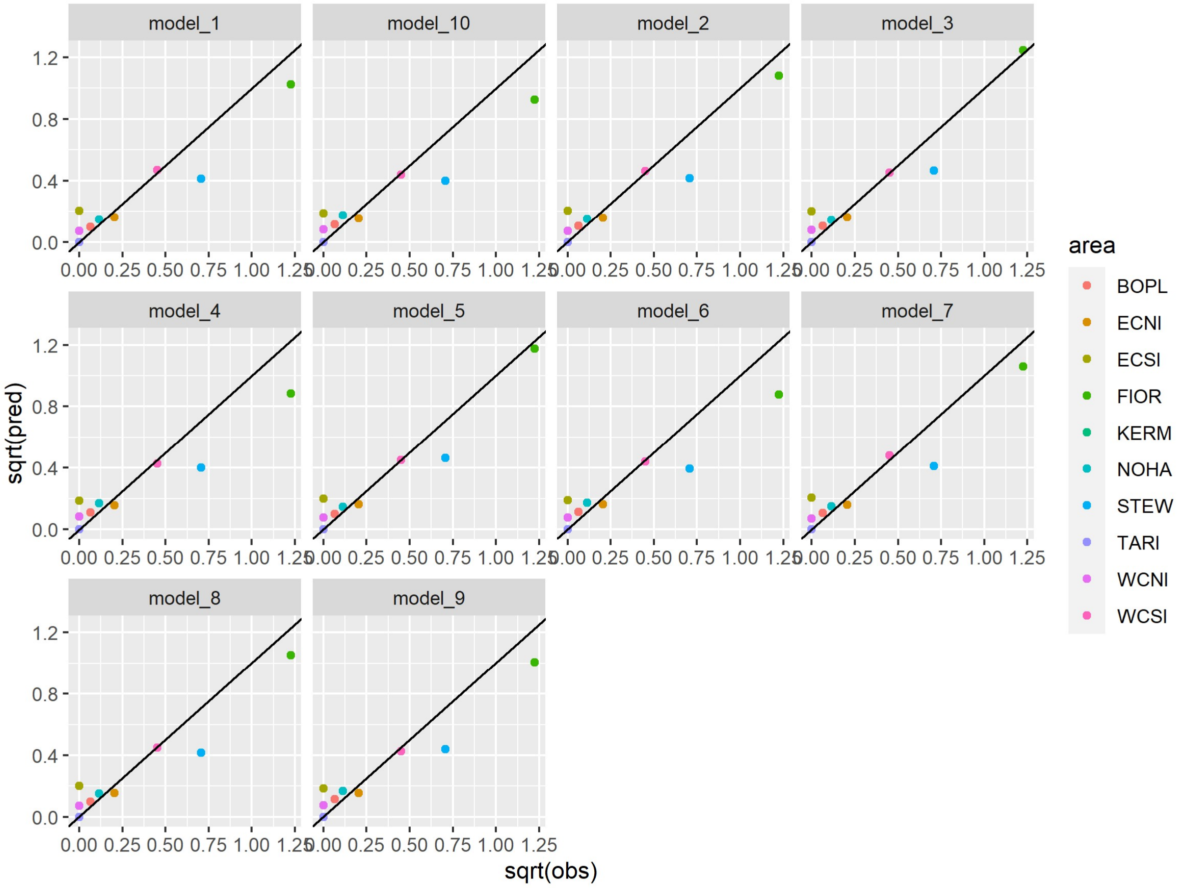



**Figure 35:** Mean predicted vs. mean observed Buller's albatross captures in each area for top-10 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with >20% data completeness (Table 16).

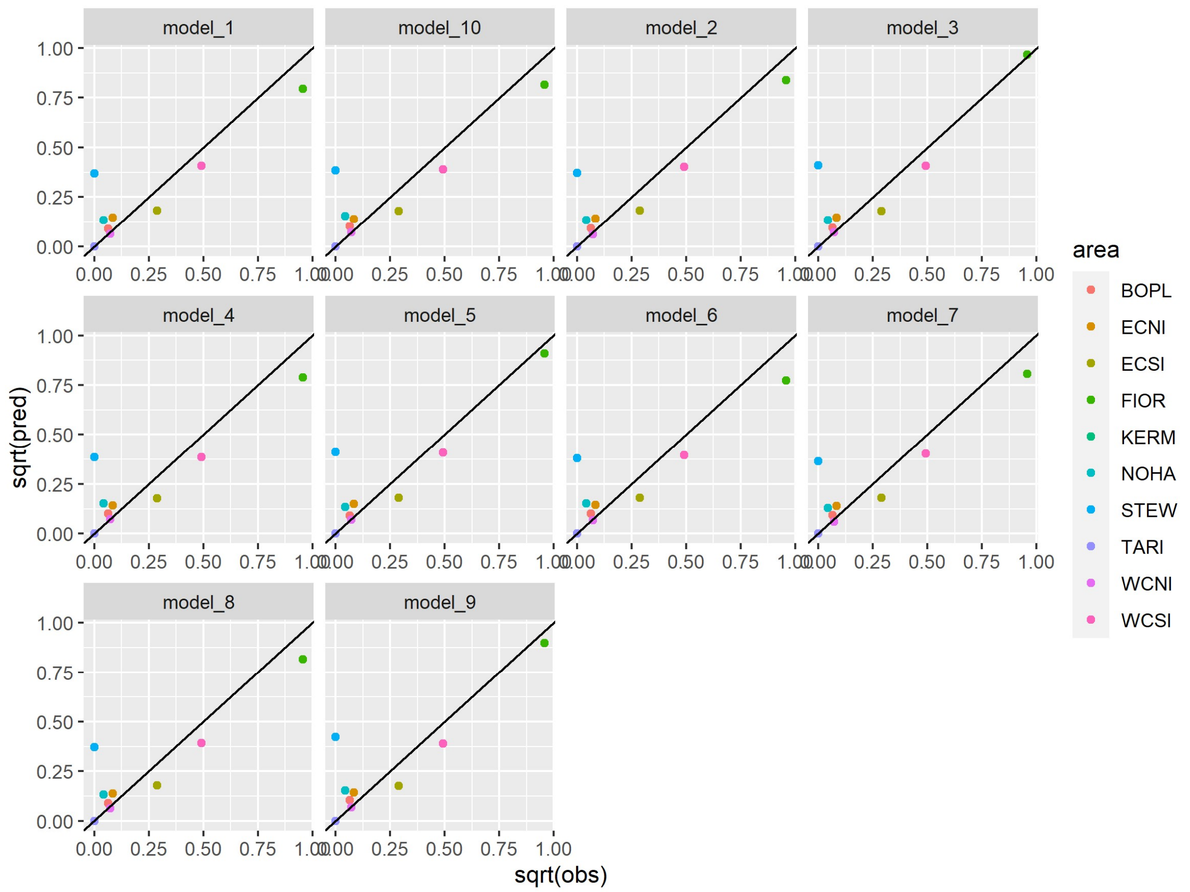



**Figure 36:** Mean predicted vs. mean observed white-capped albatross captures in each area for top-10 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with >20% data completeness (Table 16).

# APPENDIX D: PREDICTIVE CHECKING FOR NZ FUR SEAL CAPTURES MODEL

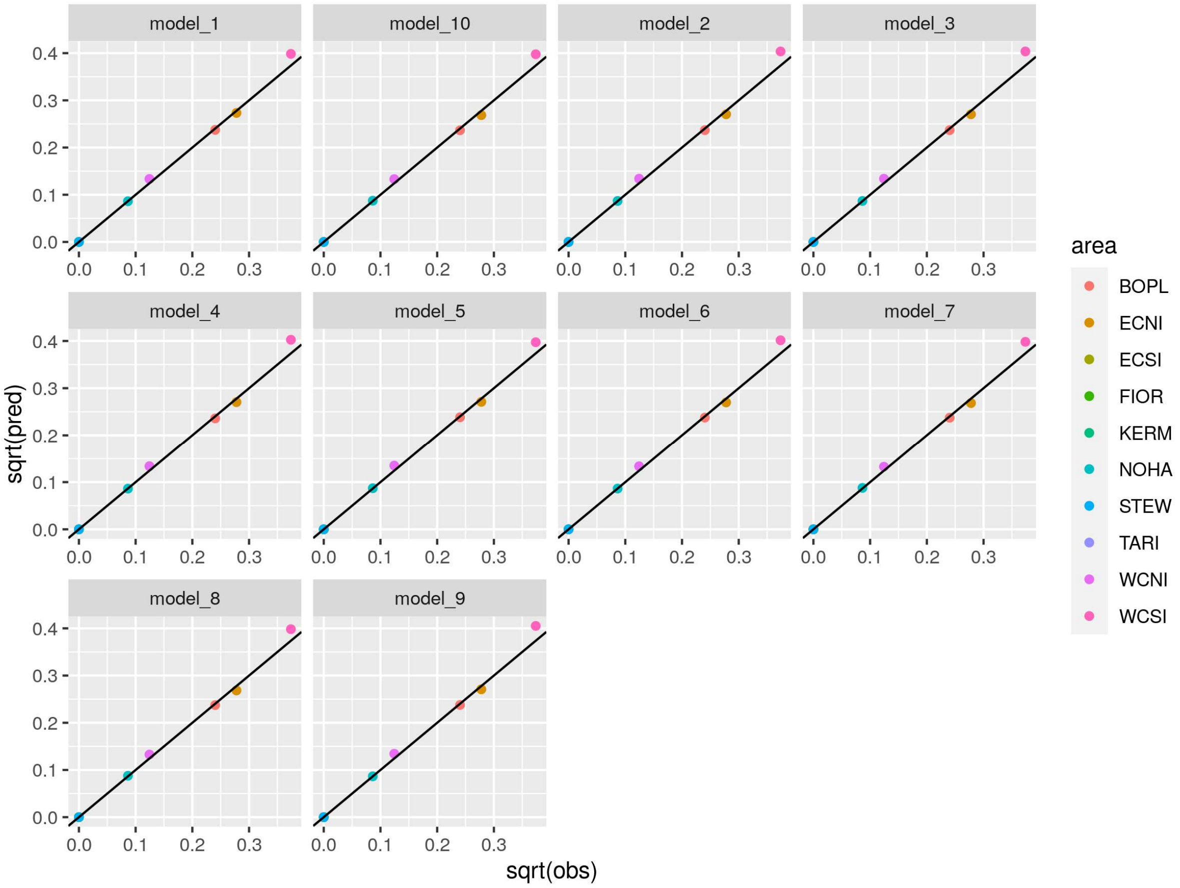



**Figure 37:** Mean predicted vs. mean observed NZ fur seal captures in each area. Mean predicted vs. mean observed NZ fur seal captures in each area for top-10 multi-species models fitted to all birds captures where model fits included variables with 100% data completeness (Table 18).

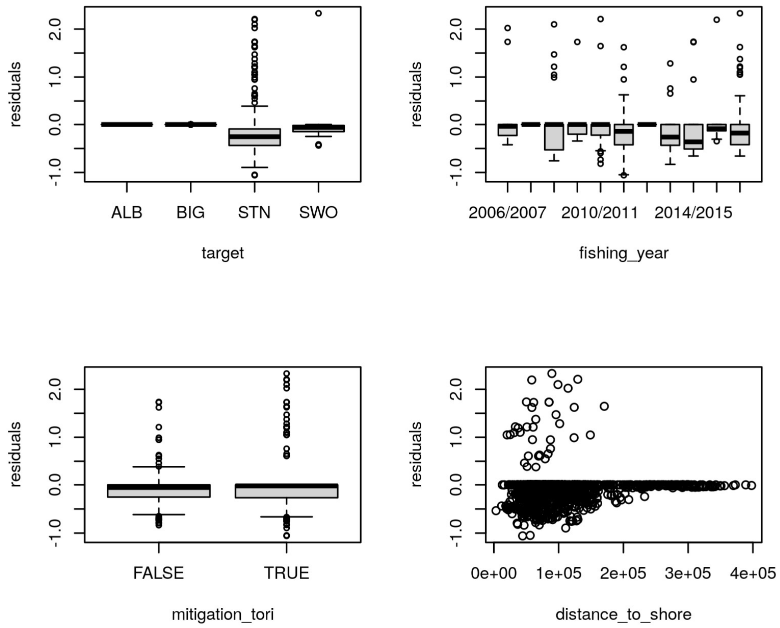



**Figure 38:** Residuals vs predictors from top NZ fur seal captures model (model 1) where model fits included variables with >75% data completeness (Table 19).

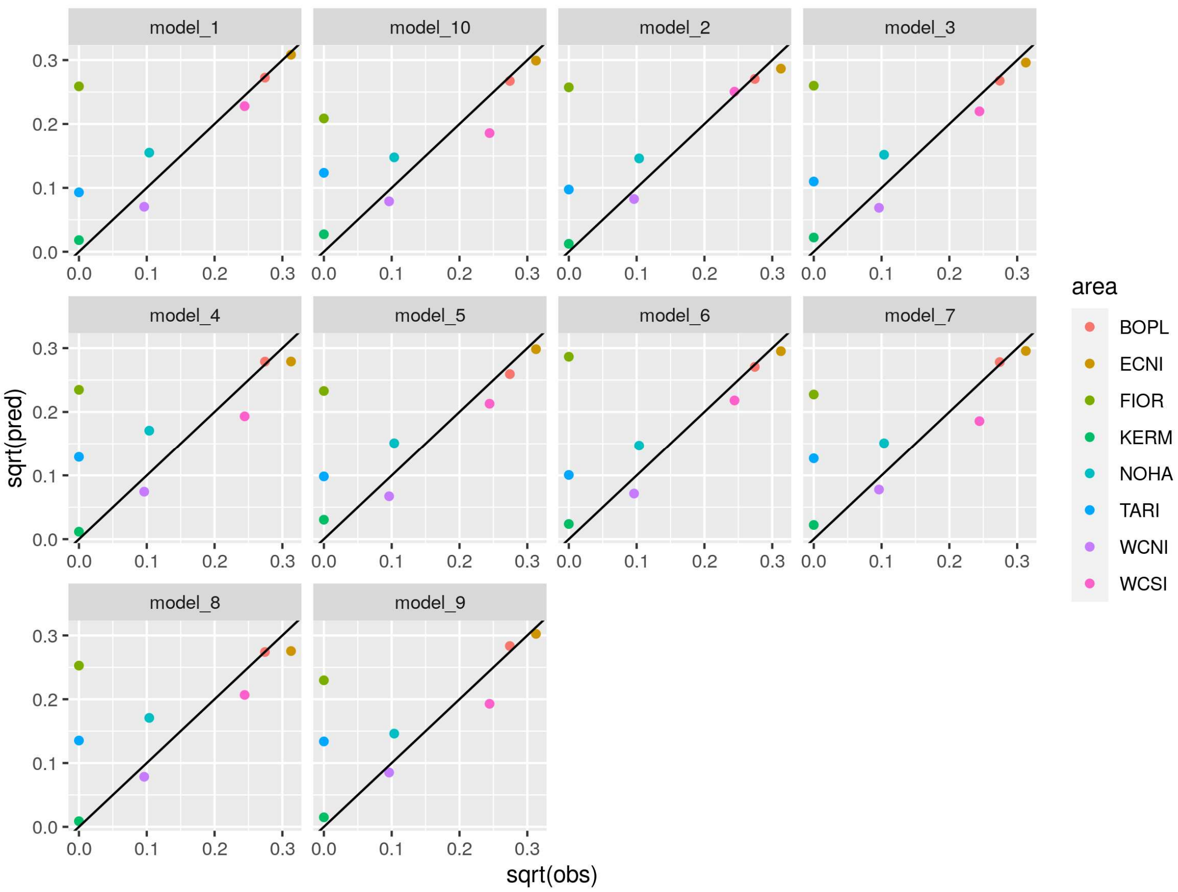



**Figure 39:** Mean predicted vs. mean observed NZ fur seal captures in each area. Mean predicted vs. mean observed NZ fur seal captures in each area for top-10 multi-species models fitted to all birds captures where model fits included variables with >70% data completeness (Table 19).

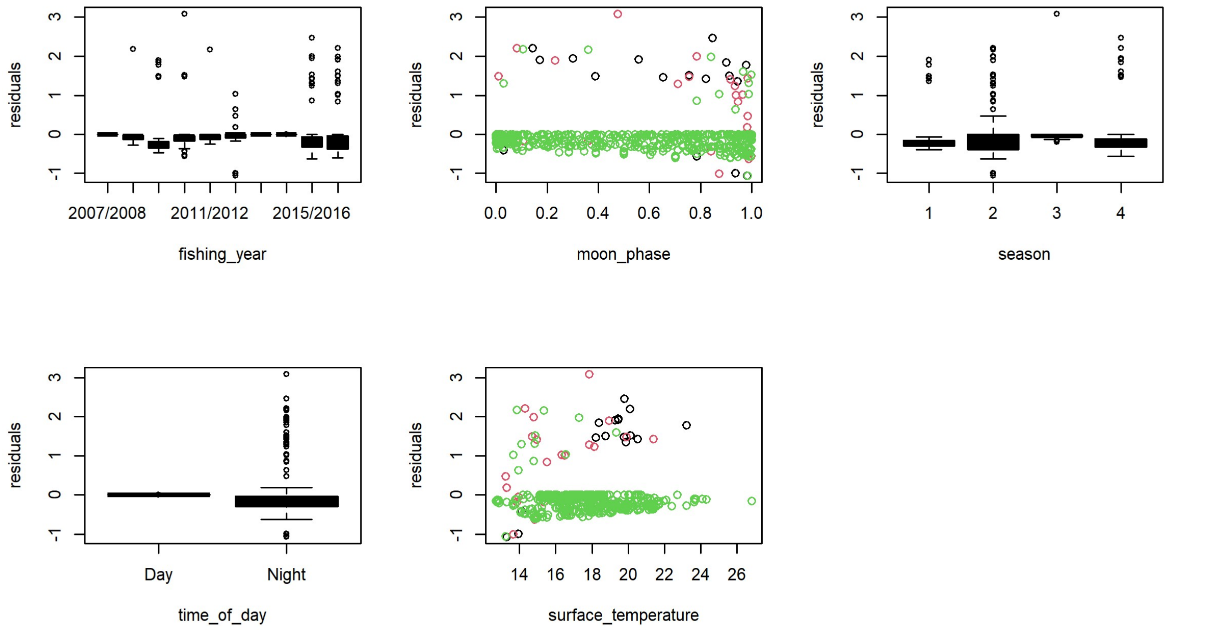



**Figure 40:** Residuals vs predictors from top NZ fur seal captures model (model 1) where model fits included variables with >60% data completeness (Table 20).

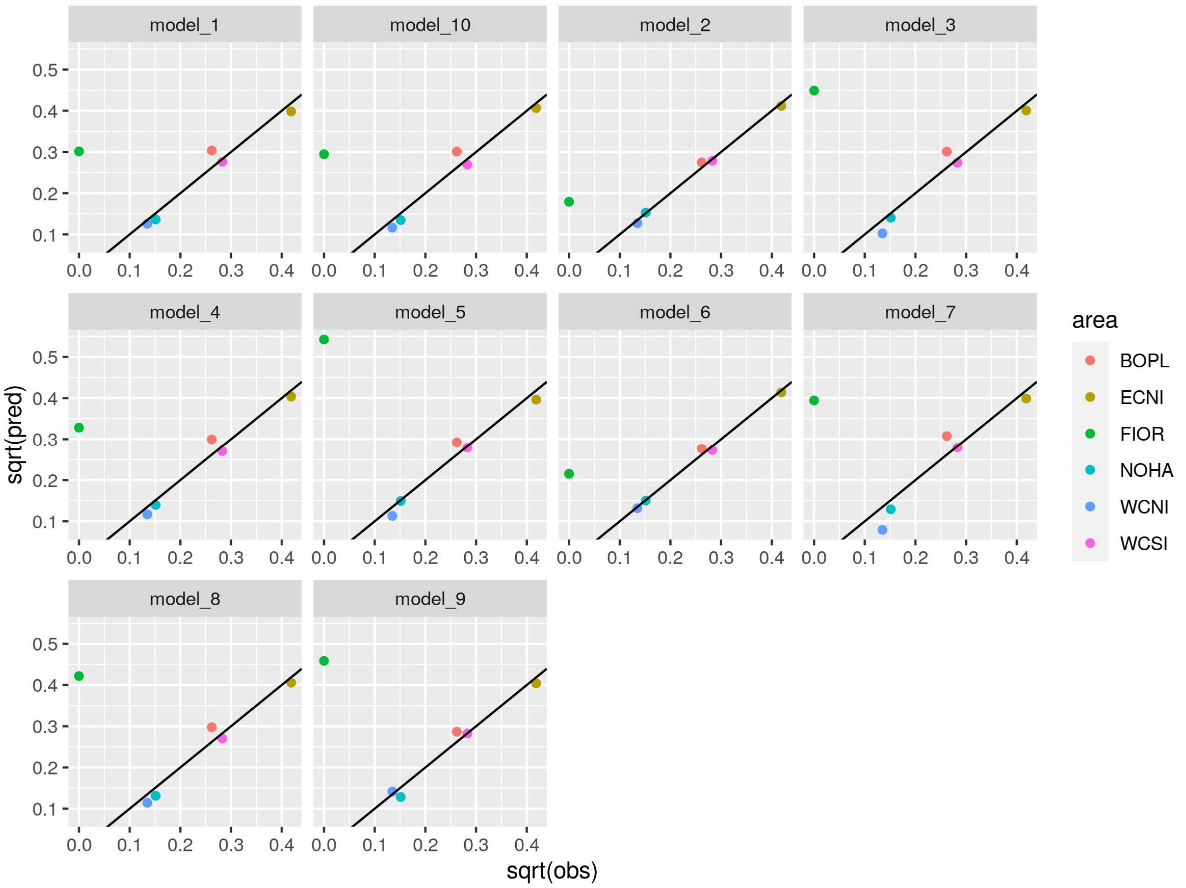


**Figure 41:** Mean predicted vs. mean observed NZ fur seal captures in each area. Mean predicted vs. mean observed NZ fur seal captures in each area for top-10 multi-species models fitted to all birds captures where model fits included variables with >60% data completeness (Table 20).

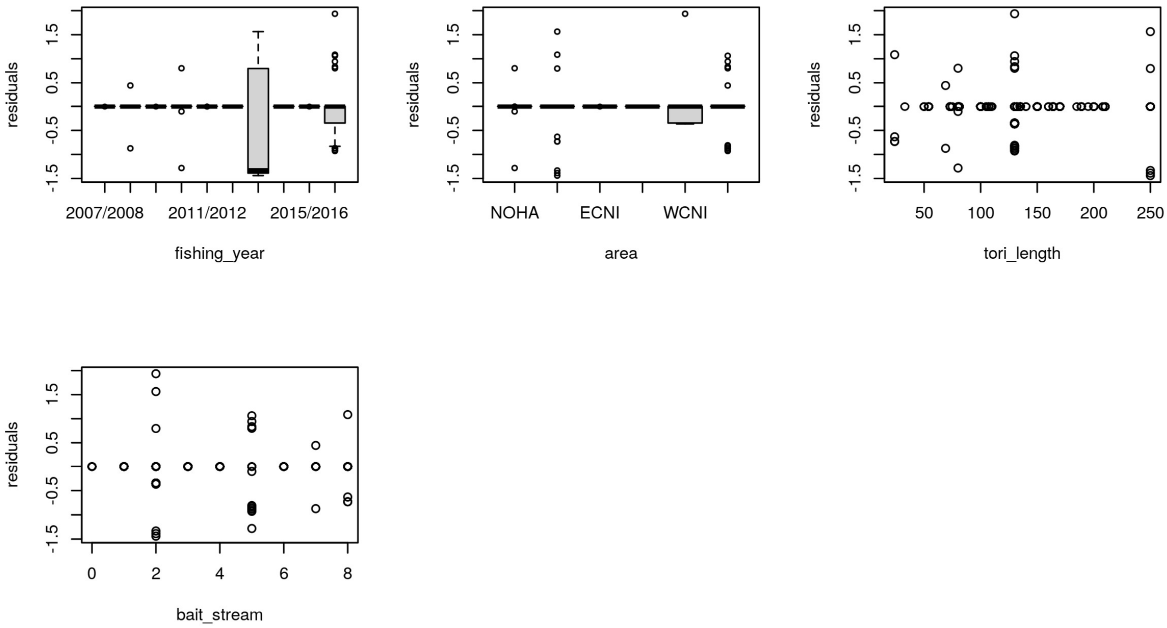



**Figure 42:** Residuals vs predictors from top NZ fur seal captures model (model 1) where model fits included variables with >20% data completeness (Table 21).

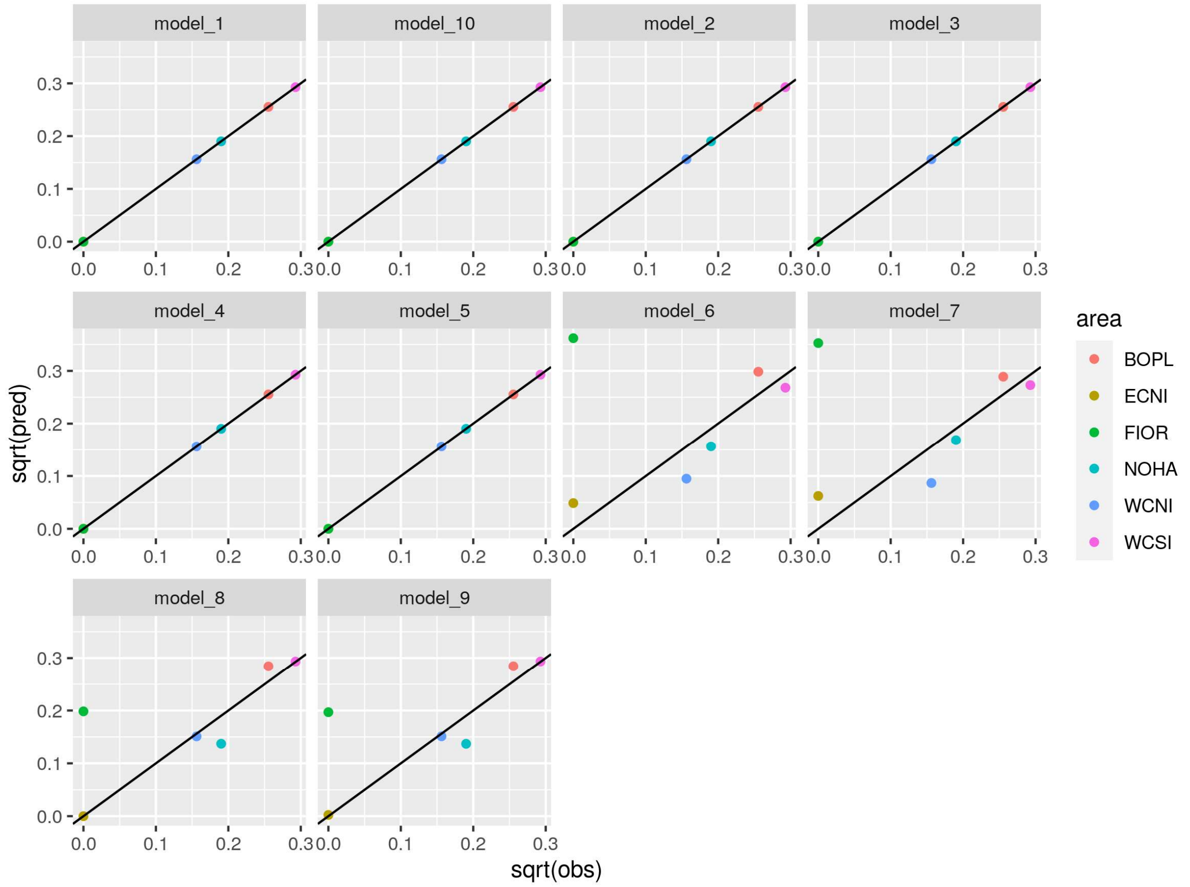



**Figure 43:** Mean predicted vs. mean observed NZ fur seal captures in each area. Mean predicted vs. mean observed NZ fur seal captures in each area for top-10 multi-species models fitted to all birds captures where model fits included variables with >20% data completeness (Table 21).

## APPENDIX E: PREDICTIVE CHECKING FOR TURTLE CAPTURES MODEL

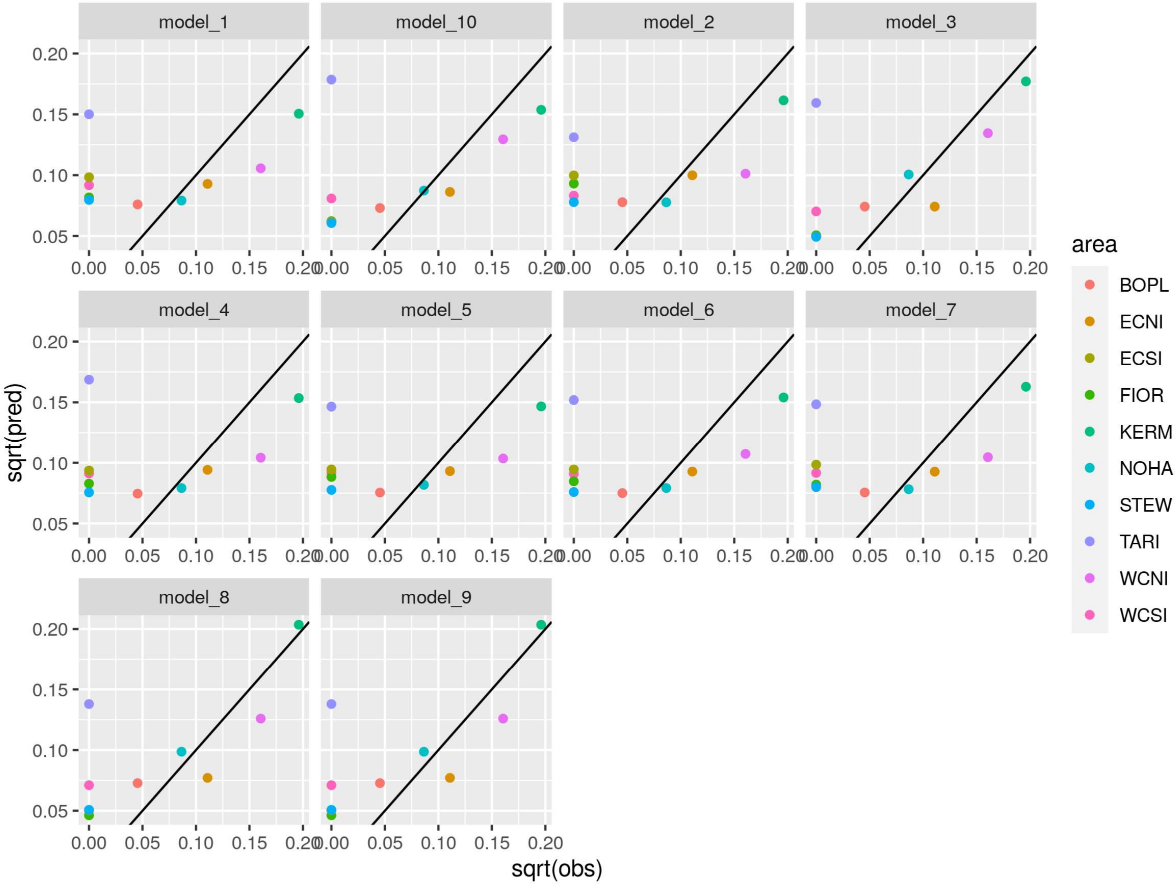
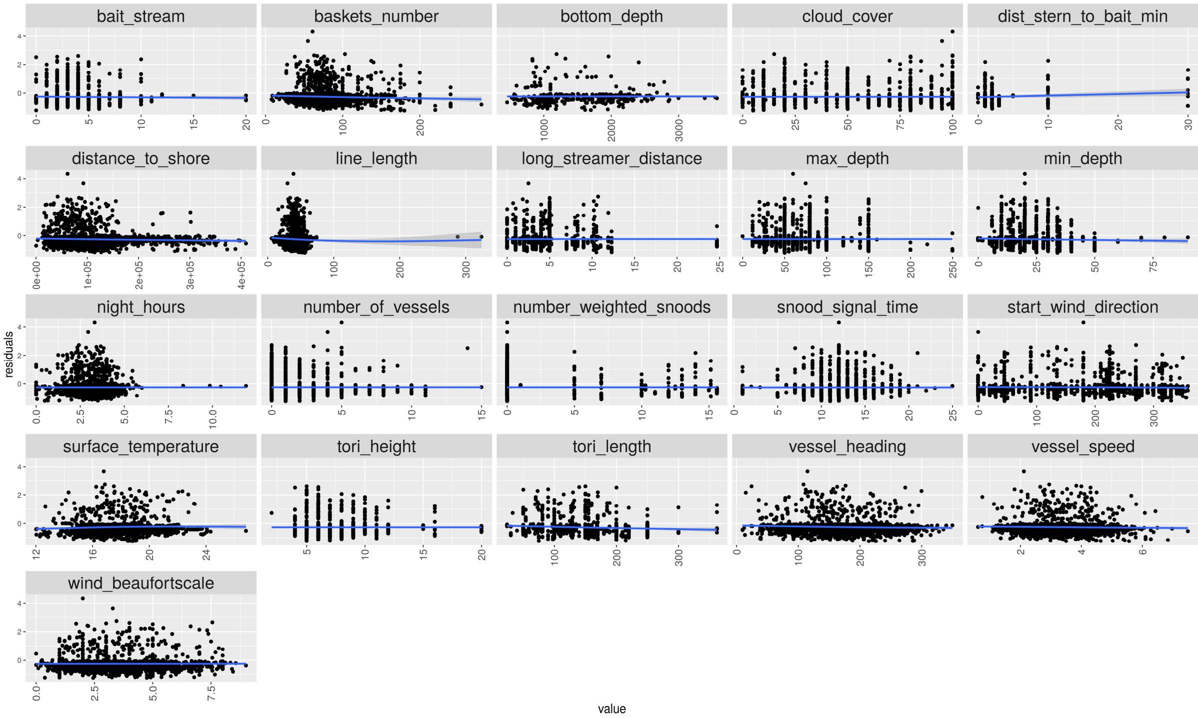
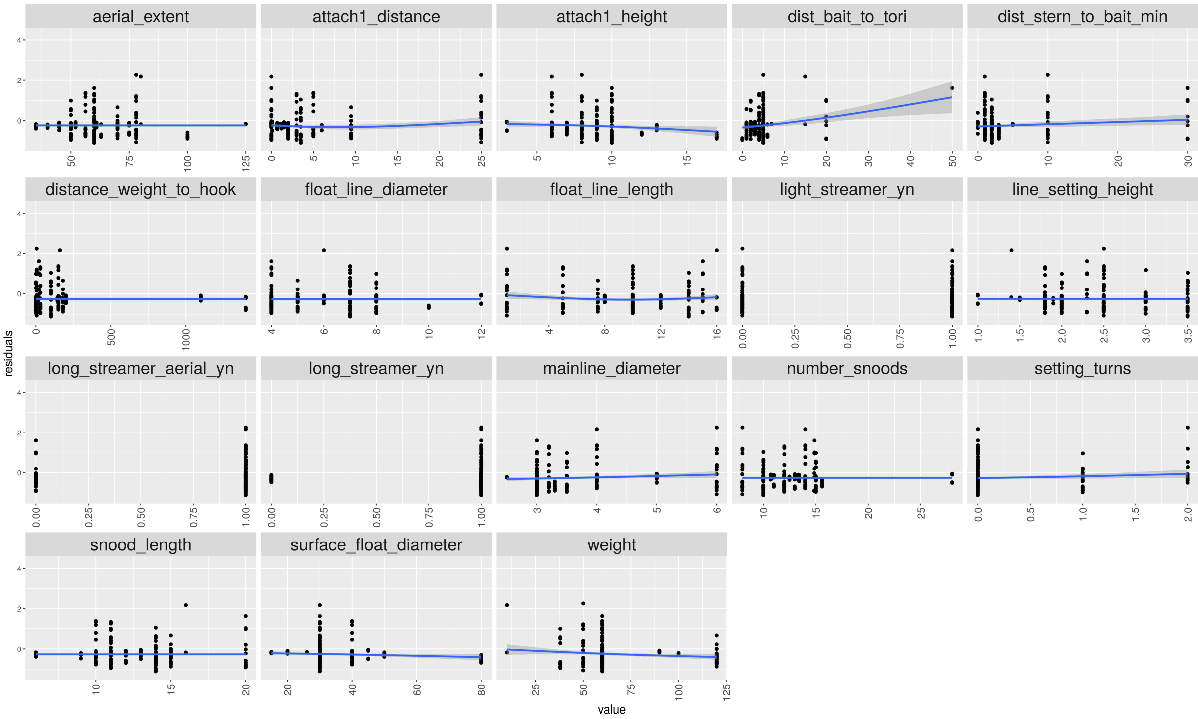
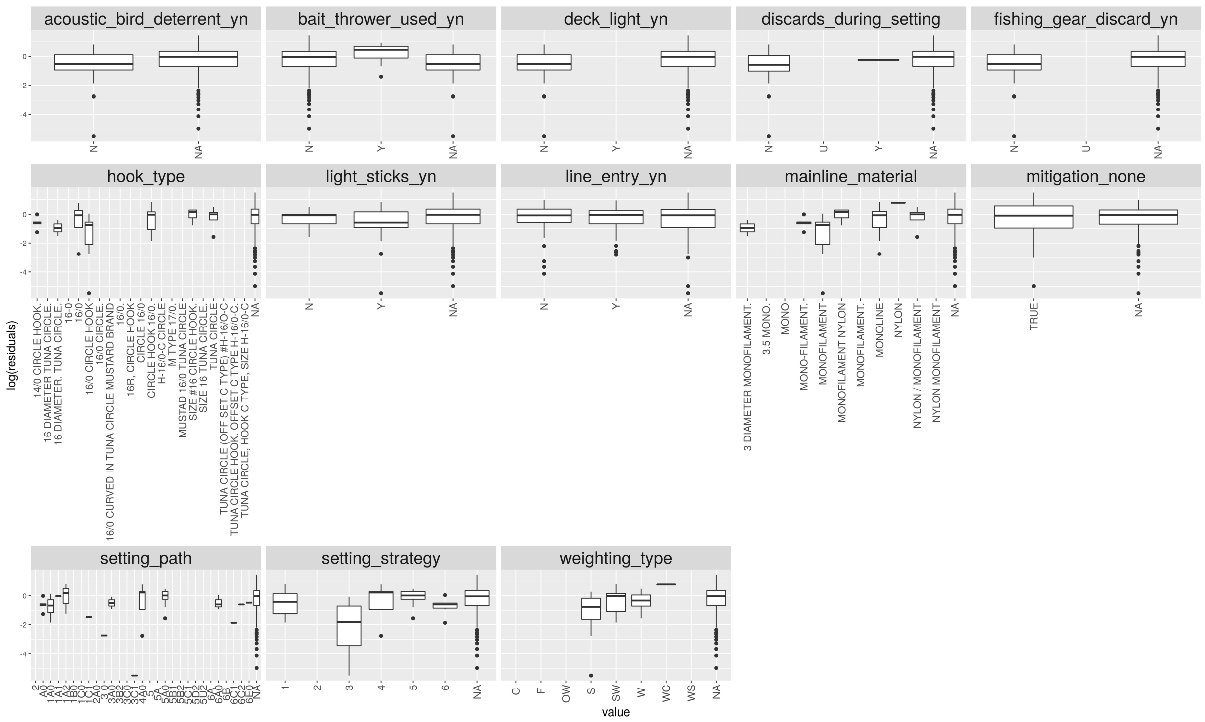



**Figure 44:** Mean predicted vs. mean observed turtle captures in each area for top-10 models fitted to turtle captures where model fits included variables with 100% data completeness (Table 25).

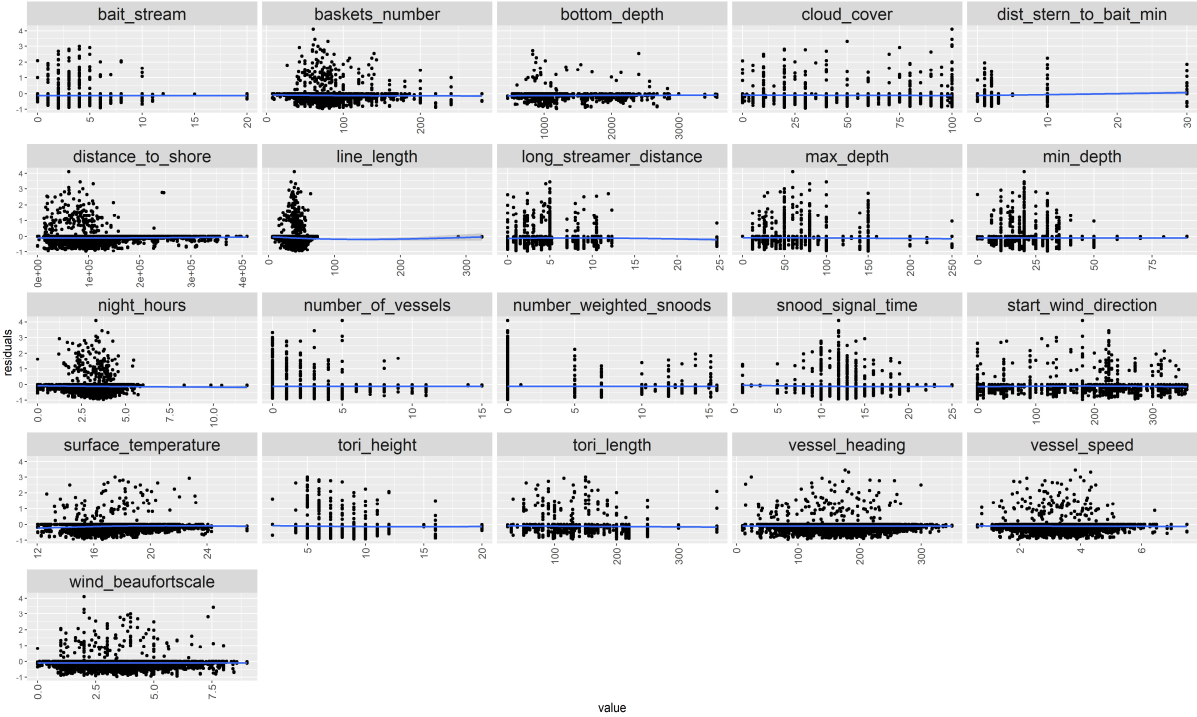
## APPENDIX F: RESIDUALS VS ADDITIONAL PREDICTORS FOR ALL BIRDS CAPTURES MODEL

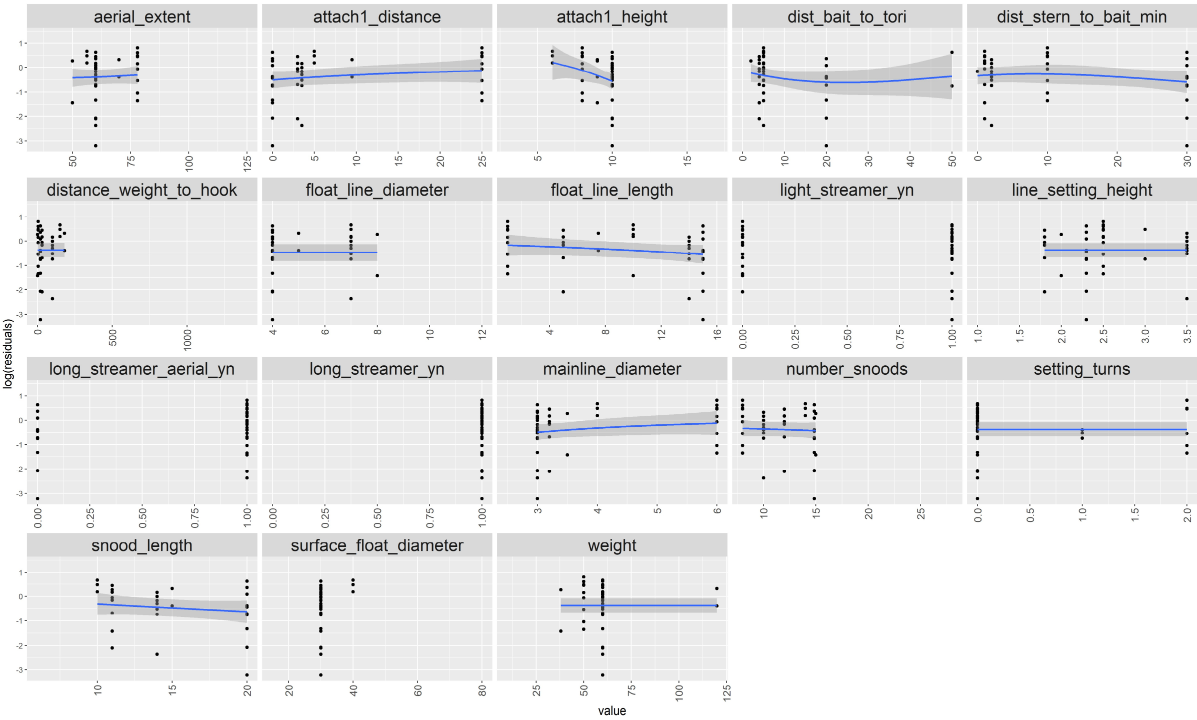

bait_stream
baskets_number
bottom_depth
cloud_cover
dist_stern_to_bait_min
distance_to_shore
line_length
long_streamer_distance
max_depth
min_depth
night_hours
number_of_vessels
number_weighted_snoods
snood_signal_time
start_wind_direction
surface_temperature
tori_height
tori_length
vessel_heading
vessel_speed
wind_beaufortscale
residuals
value

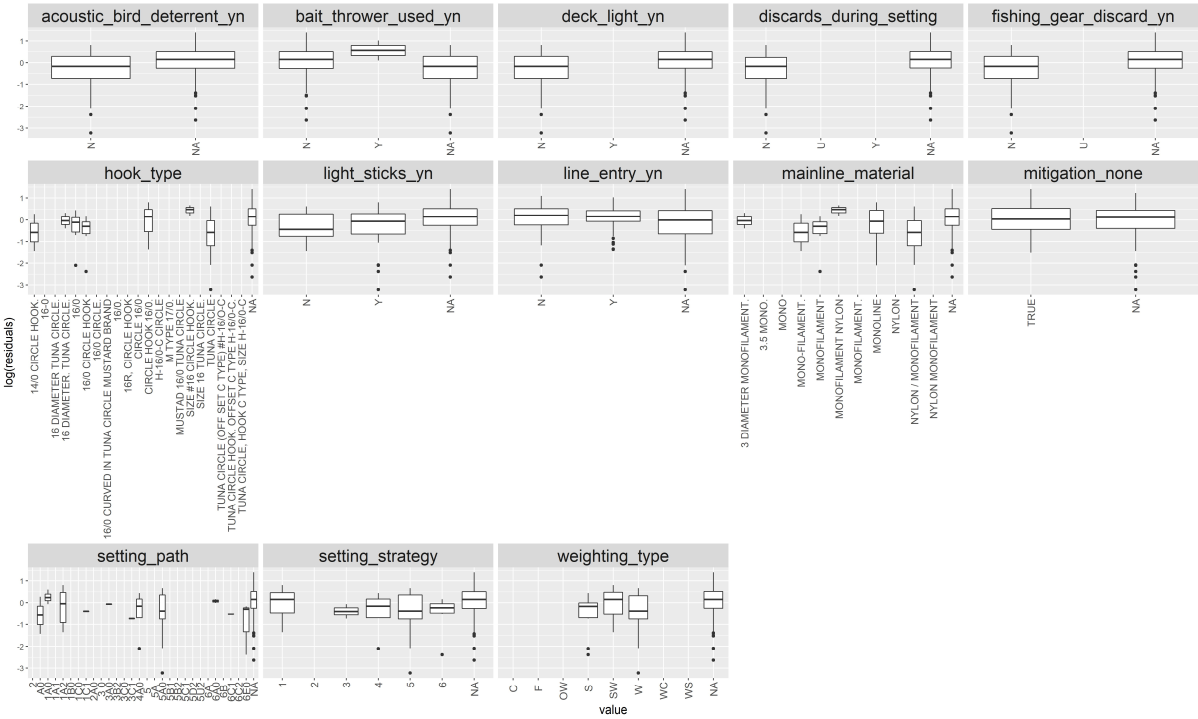

aerial_extent
attach1_distance
attach1_height
dist_bait_to_tori
dist_stern_to_bait_min
distance_weight_to_hook
float_line_diameter
float_line_length
light_streamer_yn
line_setting_height
long_streamer_aerial_yn
long_streamer_yn
mainline_diameter
number_snoods
setting_turns
snood_length
surface_float_diameter
weight
residuals
value



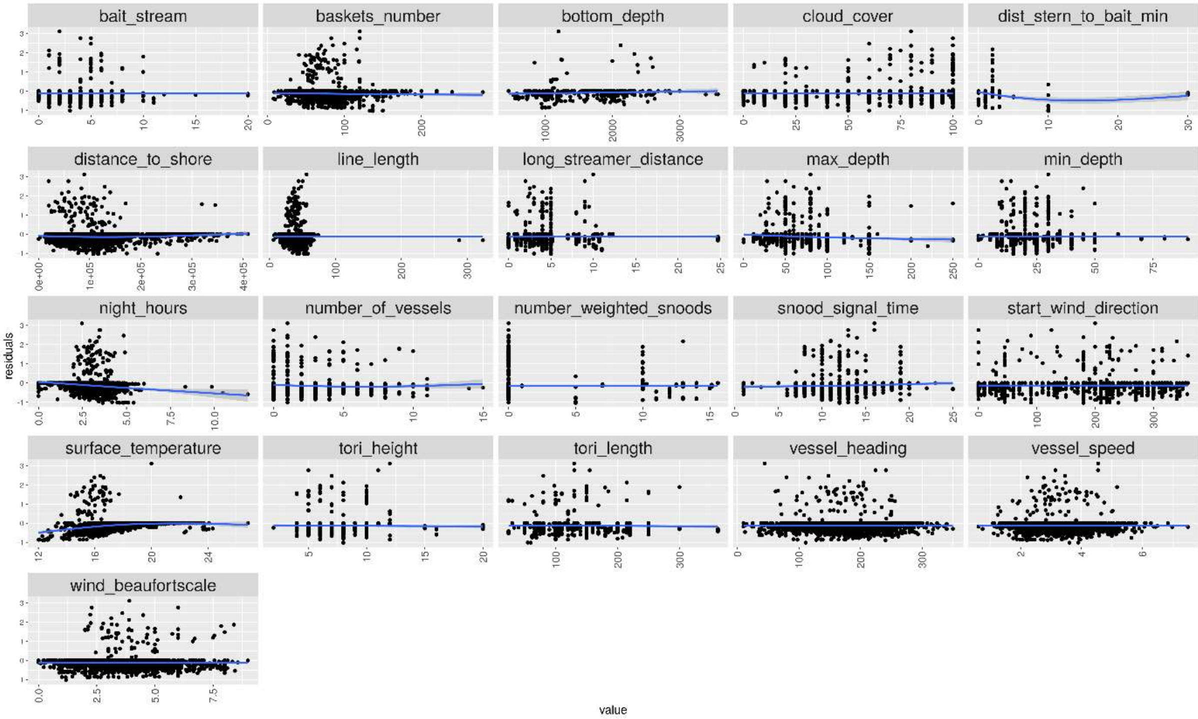

# APPENDIX G: RESIDUALS VS ADDITIONAL PREDICTORS FOR MULTI-SPECIES CAPTURES MODEL: BLACK PETRELS, WHITE-CHINED PETREL, BULLER'S ALBATROSS

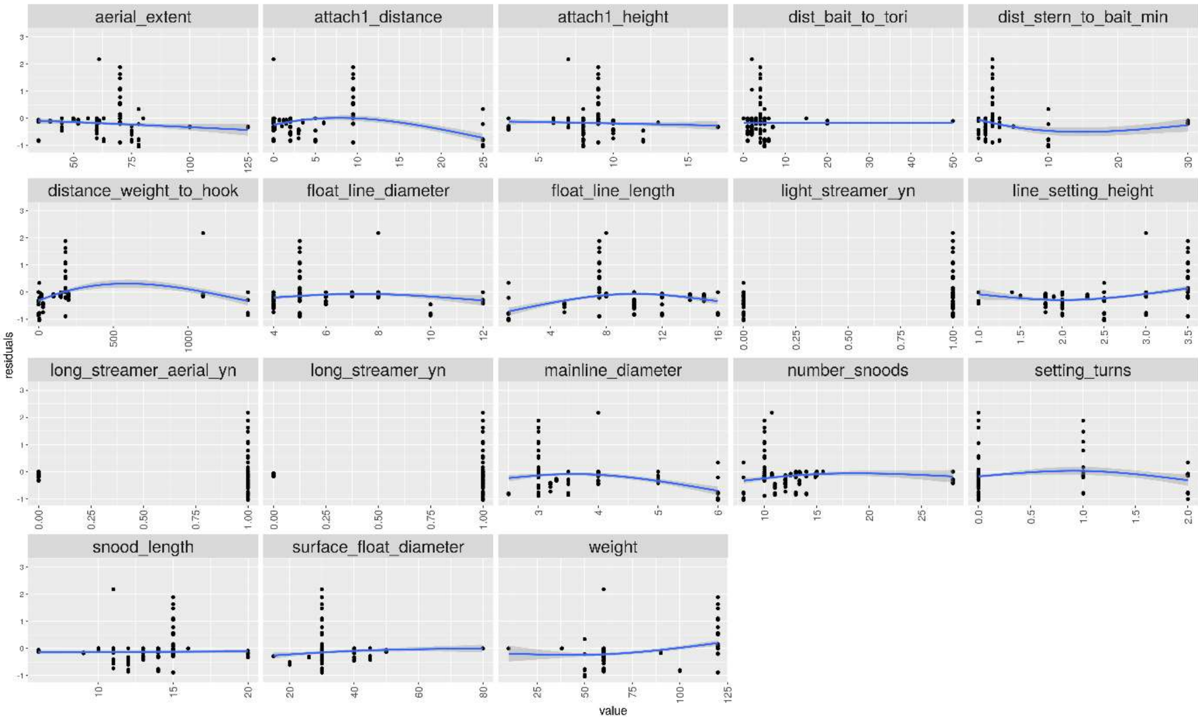

bait_stream
baskets_number
bottom_depth
cloud_cover
dist_stern_to_bait_min
distance_to_shore
line_length
long_streamer_distance
max_depth
min_depth
night_hours
number_of_vessels
number_weighted_snoods
snood_signal_time
start_wind_direction
surface_temperature
tori_height
tori_length
vessel_heading
vessel_speed
wind_beaufortscale
residuals
value

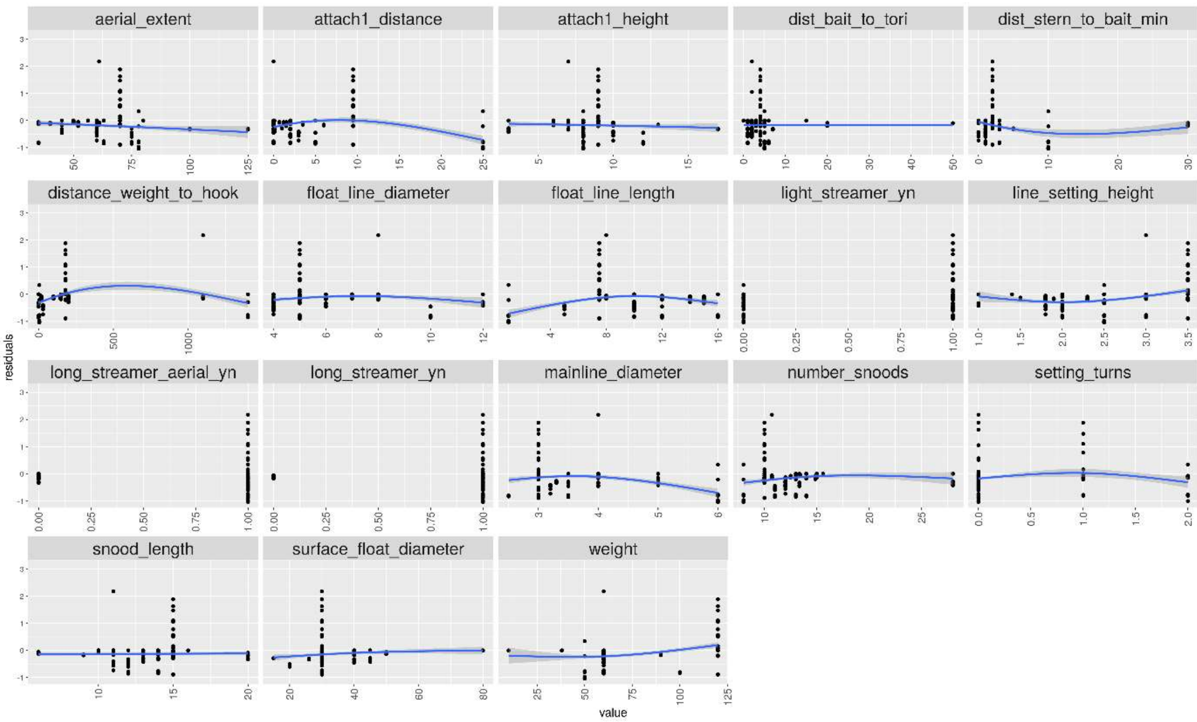

aerial_extent
attach1_distance
attach1_height
dist_bait_to_tori
dist_stern_to_bait_min
distance_weight_to_hook
float_line_diameter
float_line_length
light_streamer_yn
line_setting_height
long_streamer_aerial_yn
long_streamer_yn
mainline_diameter
number_snoods
setting_turns
snood_length
surface_float_diameter
weight
log(residuals)
value


acoustic_bird_deterrent_yn
bait_thrower_used_yn
deck_light_yn
discards_during_setting
fishing_gear_discard_yn
hook_type
light_sticks_yn
line_entry_yn
mainline_material
mitigation_none
setting_path
setting_strategy
weighting_type
log(residuals)
value

## APPENDIX H: RESIDUALS VS ADDITIONAL PREDICTORS FOR FUR SEAL CAPTURES MODEL


bait_stream
baskets_number
bottom_depth
cloud_cover
dist_stern_to_bait_min
distance_to_shore
line_length
long_streamer_distance
max_depth
min_depth
night_hours
number_of_vessels
number_weighted_snoods
snood_signal_time
start_wind_direction
surface_temperature
tori_height
tori_length
vessel_heading
vessel_speed
wind_beaufortscale
residuals
value


aerial_extent
attach1_distance
attach1_height
dist_bait_to_tori
dist_stern_to_bait_min
distance_weight_to_hook
float_line_diameter
float_line_length
light_streamer_yn
line_setting_height
long_streamer_aerial_yn
long_streamer_yn
mainline_diameter
number_snoods
setting_turns
snood_length
surface_float_diameter
weight
residuals
value


aerial_extent
attach1_distance
attach1_height
dist_bait_to_tori
dist_stern_to_bait_min
distance_weight_to_hook
float_line_diameter
float_line_length
light_streamer_yn
line_setting_height
long_streamer_aerial_yn
long_streamer_yn
mainline_diameter
number_snoods
setting_turns
snood_length
surface_float_diameter
weight
residuals
value

## APPENDIX I: RESIDUALS VS ADDITIONAL PREDICTORS FOR TURTLE CAPTURES MODEL

## APPENDIX J: HISTOGRAMMS FOR DATA OF SIGNIFICANT ADDITIONAL PREDICTORS FOR ALL SEABIRDS MODEL

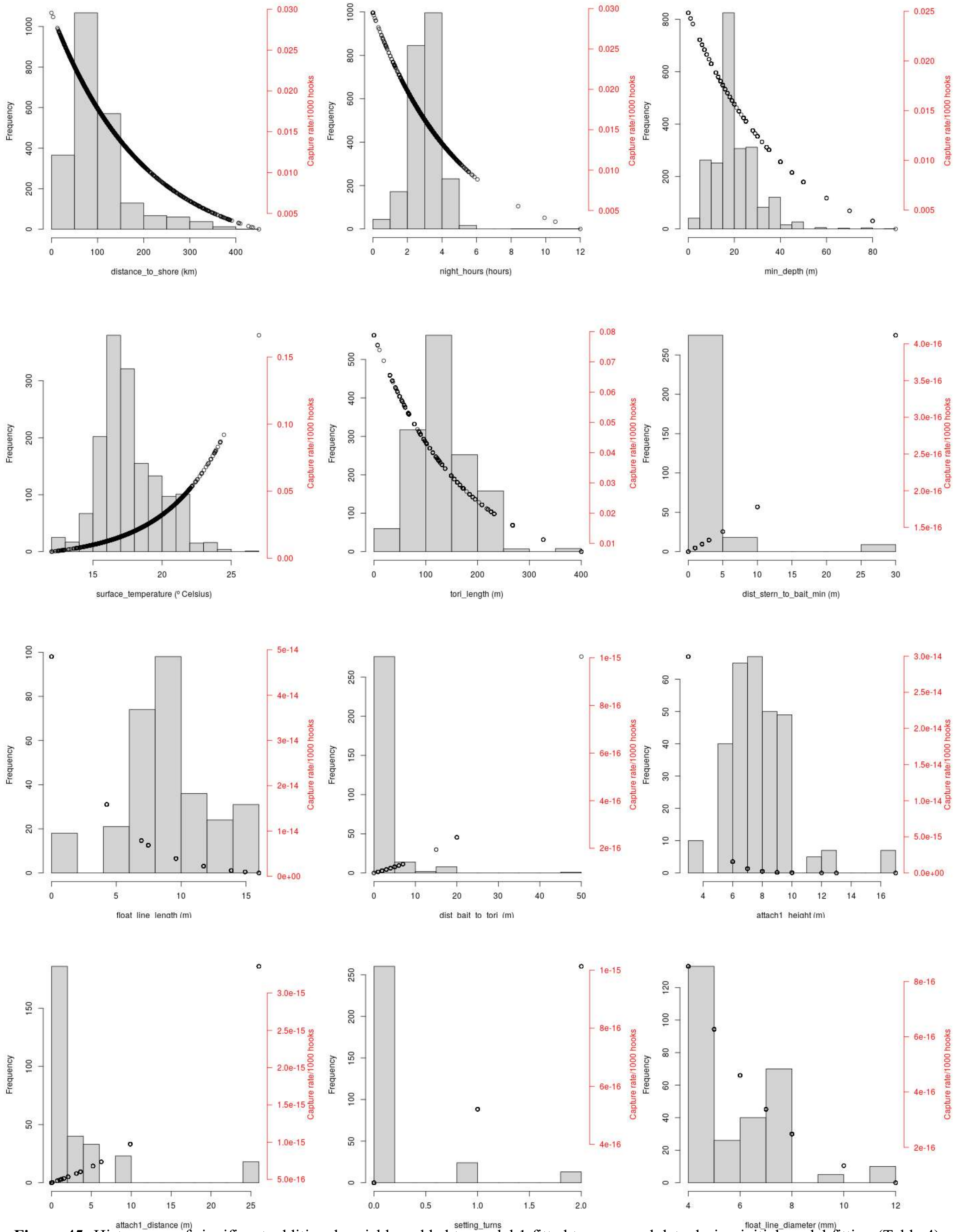
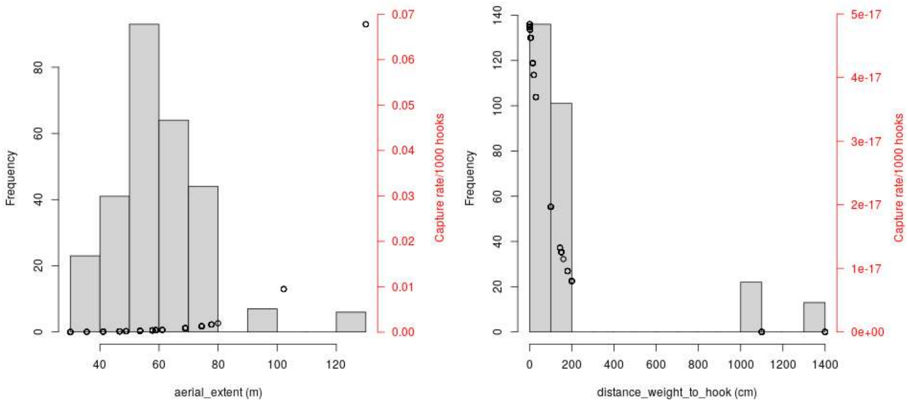
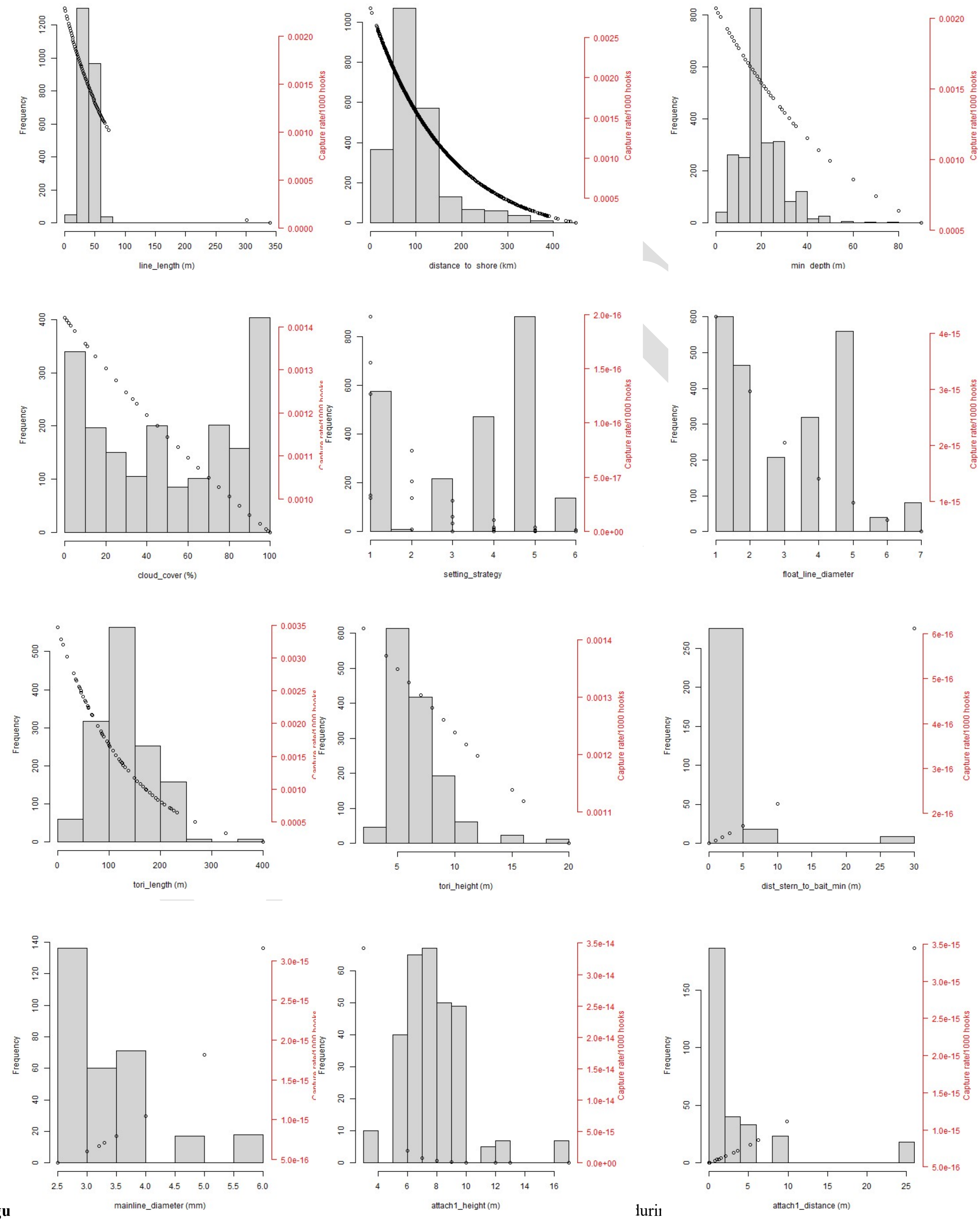



**Figure 45:** Histograms of significant additional variables added to model 1 fitted to unpruned data during initial model fitting (Table 4), and capture rate on actual scale for each variable (all else being equal; see Table 8 for fixed effect base cases).


Frequency
Capture rate/1000 hooks
aerial_extent (m)
distance_weight_to_hook (cm)

DRAFT

## APPENDIX K: HISTOGRAMMS FOR DATA OF SIGNIFICANT ADDITIONAL PREDICTORS FOR MULTI-SPECIES SEABIRDS MODEL: BLACK PETREL, WHITE-CAPPED ALBATROSS, BULLER'S ALBATROSS




**Figu** ... luriı
rate on actual scale for each variable (all else being equal; see Table 8 for fixed effect base cases).

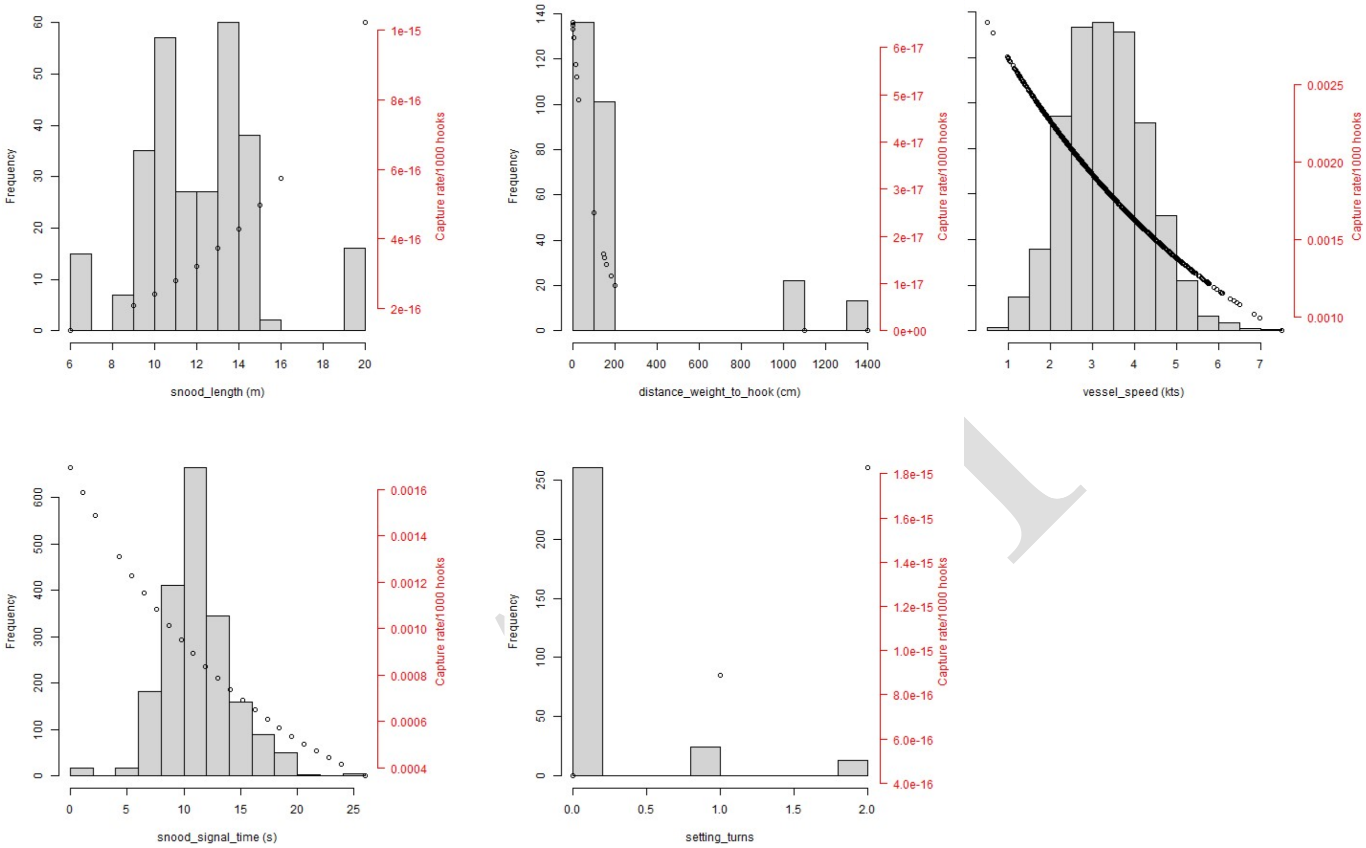



*Figure 48: Fig. XX continued*

## APPENDIX L: HISTOGRAMMS FOR DATA OF SIGNIFICANT ADDITIONAL PREDICTORS FOR NZ FUR SEAL CAPTURES MODEL

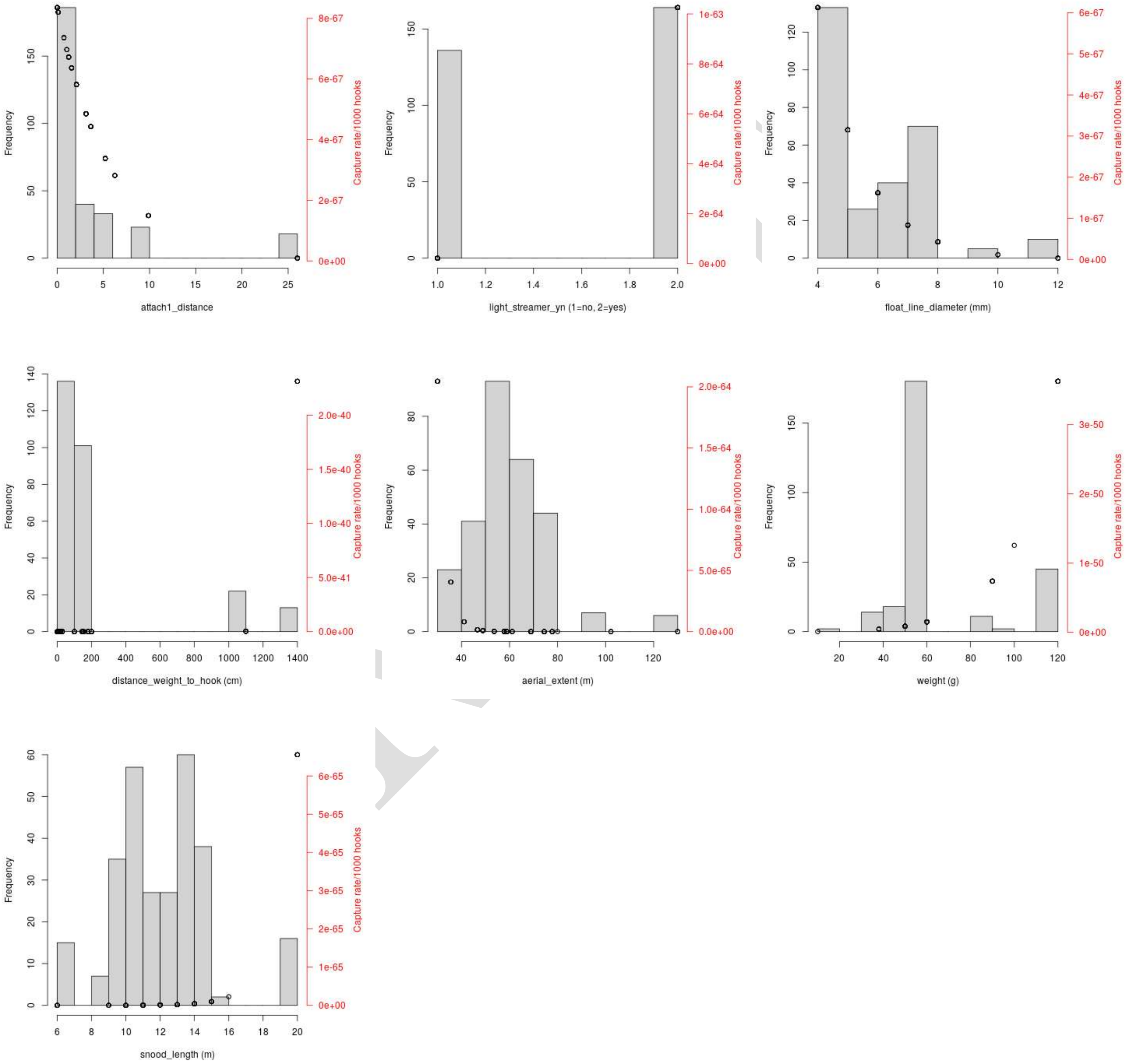

Frequency
Capture rate/1000 hooks
attach1_distance
light_streamer_yn (1=no, 2=yes)
float_line_diameter (mm)
distance_weight_to_hook (cm)
aerial_extent (m)
weight (g)
snood_length (m)

*Figure 49*

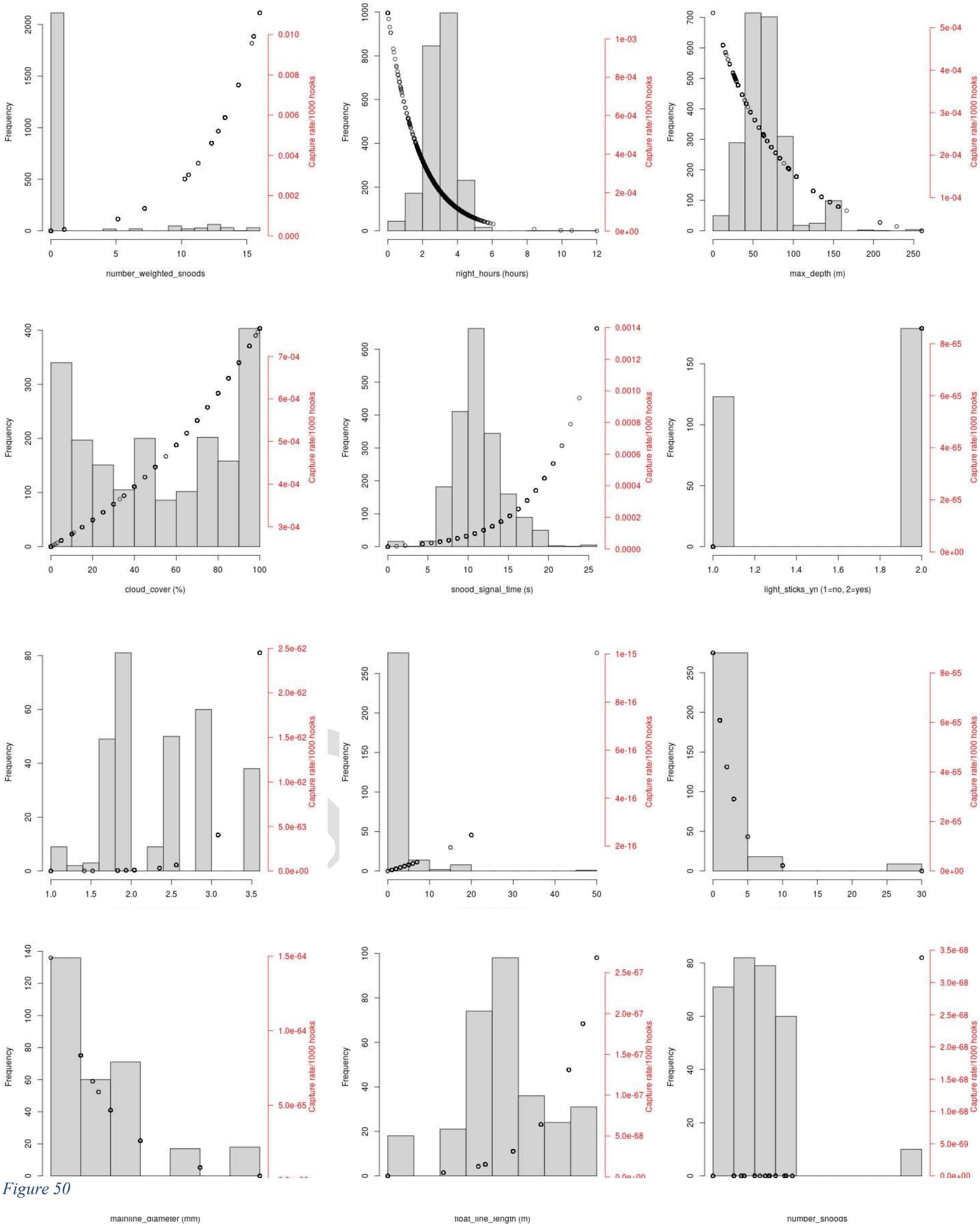

Frequency
Capture rate/1000 hooks
number_weighted_snoods
night_hours (hours)
max_depth (m)
cloud_cover (%)
snood_signal_time (s)
light_sticks_yn (1=no, 2=yes)
mainline_diameter (mm)
float_line_length (m)
number_snoods

*Figure 50*

## APPENDIX M: HISTOGRAMMS FOR DATA OF SIGNIFICANT ADDITIONAL PREDICTORS FOR TURTLE CAPTURES MODEL

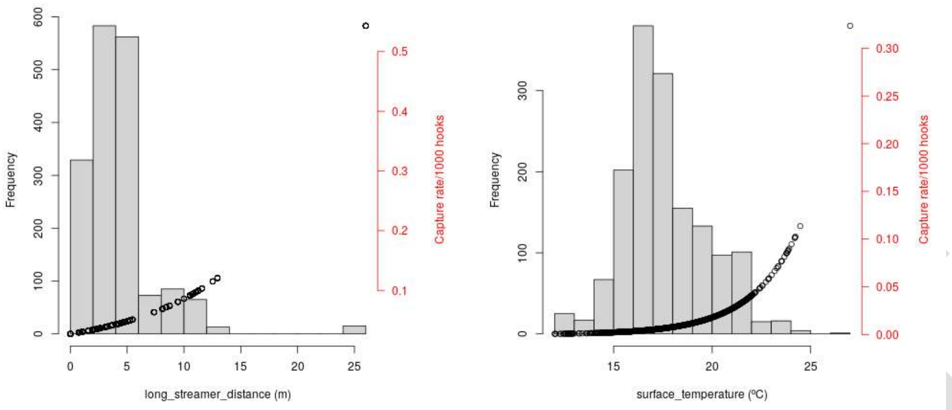



*Figure 51*