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Factors affecting protected species captures in domestic surface longline fisheries

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EXECUTIVE SUMMARY

Meyer, S.[1]; MacKenzie, D.[1] (2022). Factors affecting protected species captures in domestic surface longline fisheries.

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Bycatch of protected species, such as seabirds, is a known issue in various fisheries including surface longlining (SLL). For SLL fisheries in New Zealand, mandatory bycatch mitigation measures include the use of hook-shielding devices (hookpods) and/or tori (streamer) lines, as well as night setting and line weighting. However, there exists a variety of gear configurations and environmental conditions that could further influence bycatch of protected species in SLL fisheries—variables that are often unavailable for analysis unless collected via experimental New Zealand trials. However, variables that could potentially influence non-protected species bycatch were recorded annually as part of New Zealand's fisheries observer services. These additional data provided the opportunity to assess as yet unexplored risk factors that could influence the capture of protected species including seabirds, New Zealand fur seals, sharks and rays, dolphins and whales, and turtles by small SLL vessels and then to inform the development of potential mitigation strategies .

Groomed data on protected species bycatch are stored in the Protected Species Captures Database (PSCDB) and are based on data collected via the fisheries observer services (stored in the Centralised Observer Database (COD)). For this study, the PSCDB was expanded by utilising additional variables that are stored in the COD but were not formerly integrated into the PSCDB. Observed captures of seabirds, New Zealand 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 focused on small SLL vessels operating between the 2006–07 and 2018–19 fishing years.

Negative binomial generalised linear models with varying levels of complexity were fitted to observed captures of seabirds, New Zealand fur seals, and turtles. For seabird species, two alternate models were fitted: (1) a model for all seabird captures combined, and (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 fitted separately to datasets with varying data completeness and (within each dataset) ranked by Akaike information criterion (AIC). However, including many variables at once in the analysis can 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, to include the variables most likely to explain 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 vessel length, moon phase, start month, and an interaction term for area and species. Main effects identified in the New Zealand 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.

[1] Proteus, New Zealand.

Phase 2 model fitting indicated that several other vessel configuration, fishing behaviour, and environmental variables could affect the capture rates of seabirds and New Zealand fur seals. For example, seabird capture rates decreased 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 of light sticks, line setting height, and use of light (short) streamers increased capture rates, while increased night hours and increased distance between bait and tori line had a negative 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. It was recommended 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 during setting and individual snood length.

1. INTRODUCTION

Surface longline (SLL) fishing in New Zealand 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 protected species occur within SLL fisheries, and these captures range from seabirds, marine mammals, marine turtles, to sharks and rays. Incidental seabird captures in New Zealand's SLL fisheries are mitigated through the following mandatory measures:

- Use a hook-shielding device (hookpods), 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 New Zealand 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 New Zealand longline fisheries by 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 by Melvin et al. (2014) and Middleton & Abraham (2007)), and distance to breeding site (discussed for seabird bycatch for New Zealand trawl and longline fisheries by 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 utilising additional variables that are stored in the Centralised Observer Database (COD; Sanders & Fisher 2020) but are not formally integrated into the PSCDB. Observed captures of seabirds, New Zealand fur seals (*Arctocephalus forsteri*), 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 (≤ 45 metres) that operated between the 2006–07 and 2018–19 fishing years (1 October to 30 September) (i.e., hookpods were not integrated into this assessment). Hookpods were not assessed in this analysis because an updated COD including information on hookpods was not available at the time of this analysis.

2. METHODS

2.1 Data preparation

Groomed data from the PSCDB version 5 (Meyer in review) including the 2018–19 fishing year were combined with additional variables (i.e., those not 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, because this time period is considered to reflect the status quo of New Zealand's commercial SLL fishery (e.g., there are no Japanese vessels operating in New Zealand's SLL fisheries at the time of writing), 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, Fisheries New Zealand).

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) to be 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 were 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 2020), which are preserved in both the COD and the *observer_effort_t* table of the PSCDB.

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 could be sufficiently linked to the PSCDB extract.

A total of 2611 records of observed SLL fishing events on small vessels during the 2006–07 to 2018–19 fishing years were available in the PSCDB. There were 238 records without a matching event key resulting in a dataset with 2373 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 Aquatic Environment Working Group (AEWG) (see Table 32 in Appendix A). Data were only fully available for variables that were 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 (see Table 32 in Appendix A).

Many of the variables assessed here were not recorded comprehensively between the 2006–07 and 2018–19 fishing years (e.g., some variables were only recorded very recently, while others were collected already for several years but only sporadically). This scarcity and/or patchiness of records for each variable would cause substantial data pruning if these variables are included in the analysis all at once (see Table 32). To utilise most of the available information from each variable, five datasets were created where variables were included based on different thresholds for data completeness. That is, separate datasets were compiled each with an increasing number of variables that had incomplete records. However, datasets with a higher number of variables, and thus higher data patchiness, resulted in a smaller number of total observations that were available for model fitting. First, an unpruned dataset, containing 2373 fishing events, was compiled and this only included variables that were fully recorded (see Table 1) across all fishing events between the 2006–07 and 2018–19 fishing years. 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 included variables from the unpruned dataset), reducing the size of the dataset to 1069 fishing events. Three additional pruned datasets were created with lower thresholds for data completeness of ≥ 60%, ≥ 20%, and > 0% (each containing variables from previous datasets with higher data completeness). 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 a lower threshold, the dataset was pruned to zero fishing events and was therefore not available for the analysis (but see Section 2.4 Statistical modelling). Note, that not all variables shown in Table 32 were included because 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 dataset size for small-vessel SLL catch and effort was 2611 fishing events from the PSCDB but not all had event keys assigned that could be linked to observer data. Histograms of variables are shown in Appendix G. (Continued on next 2 pages)

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 Figure 3), originally used to summarise estimated captures by 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: New Zealand, Australia
vessel_freezer	Use of vessel freezer: yes, no
moon_phase	Fractional illumination of the moon’s surface between 0 (new moon) and 1 (full moon)
start_month	Start month between 1 (January) 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 for start of set
bathymetry	Bathymetry (m) at start fishing location calculated from New Zealand 250-m gridded bathymetric dataset 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

Table 1: continued.

Variable	Description
≥ 75% data completeness across years (1069 fishing events, or 45% of unpruned dataset)	
wind	Low Beaufort scale 0 to 3 at the start of the set Medium 4 to 6 High Over 6
baskets_number	Number of baskets [i.e., line sections] on the line
line_length	Length of line (km)
distance_to_shore	Distance to shore (m) at start of set
night_hours	Hours of fishing at night (based on the number of hours from dusk until dawn between start (beginning of setting) and end (end of hauling) of fishing event)
min_depth	On current 2018+ set logs this is the minimum hook depth (m). For pre-2018 set logs, this is the expected minimum depth of the line when set (m).
max_depth	On current 2018+ set logs this is the maximum hook depth (m). For pre-2018 set logs, this is the expected maximum depth of the line when set (m).
bait_thrower_used_yn	Use of a bait thrower (Y/N)
wind_beaufortscale	Wind strength in Beaufort scale (continuous variable) at start of the set
number_of_vessels	The number of vessels within a 24 nautical mile radius at start of set
cloud_cover	Percentage of cloud cover at start of the set
snood_signal_time	The snood signal time in second
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	Wind categories at the start of the set: Low Beaufort scale 0 to 3 Medium 4 to 6 High Over 6
vessel_speed	Speed of the vessel during the haul (kn.)
vessel heading	Vessel’s heading at time of observation in degrees (0 to 359) during haul
surface_temperature	Sea surface temperature (decimal degrees C) at start of the set
≥ 20% data completeness across years (336 fishing events or 14% of unpruned dataset)	
tori_length	Length of tori line (m)
tori_height	Height of attachment of tori line above the water (m)
line_entry_yn	Whether the tori line was over bait entry point (Y/N)
bait_stream	Distance between bait landing point and tori line (m)
> 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)
long_streamer_distance	The maximum distance between any long streamers (m). For pre-2018 forms, this is maximum distance between any streamers.
bottom_depth	Depth of bottom at time of haul (m)
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)
line_setting_height	Line setting height (m)
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).

Table 1: continued.

Variable	Description
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)

2.2 Species grouping

Datasets were compiled for seabirds, New Zealand fur seals, turtles, dolphins and whales, and sharks and rays. Seabird species were grouped according to Abraham & Richard (2020), with 8 specific species (note, Buller's albatrosses contained 'Buller's albatross' included the subspecies northern Buller's (Pacific) albatross (*Thalassarche bulleri platei*) and southern Buller's albatross (*T. bulleri bulleri*)) and all remaining bird species were grouped into 'other albatrosses' and 'other birds'. For non-bird species the groups were turtles (leatherback turtle *Dermochelys coriacea*, green turtle *Chelonia mydas*, loggerhead turtle *Caretta caretta*, turtle Chelonioidea; names as per PSCDB), dolphins and whales (long-beaked common dolphin *Delphinus capensis*, Hector's dolphin *Cephalorhynchus hectori*, Dusky dolphin *Lagenorhynchus obscurus*, bottlenose dolphin *Tursiops truncatus*, beaked whales *Mesoplodon spp.*, orca *Orcinus orca*, common dolphin *Delphinus delphis*, long-finned pilot whale *Globicephala melas*, dolphins and toothed whales Odontoceti; names as per PSCDB), and sharks and rays (oceanic whitetip shark *Carcharhinus longimanus*, spine-tailed devil ray *Mobula japanica*, basking shark *Cetorhinus maximus*, porbeagle shark *Lamna nasus*, white pointer shark *Carcharodon carcharias*; names as per PSCDB). More fine-scaled grouping was not considered due to the small number of observed captures. New Zealand 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 2018–19 fishing years in small-vessel SLL fisheries. Shown are the number of observed captures for datasets that include variables with different lower thresholds for data completeness (see column header); when all variables with data completeness > 0% were included then all fishing events were removed from the dataset.

Species	100%	≥ 75%	≥ 60%	≥ 20%	> 0%
Black petrel *Procellaria parkinsoni*	29	21	15	14	–
Buller's albatross *Thalassarche bulleri bulleri*, *T. b. platei*	154	48	24	16	–
Flesh-footed shearwater *Puffinus carneipes*	9	2	2	0	–
Grey petrel *Procellaria cinerea*	16	11	2	1	–
Salvin's albatross *Thalassarche salvini*	5	3	2	2	–
Sooty shearwater *Puffinus griseus*	1	0	0	0	–
White-capped albatross *Thalassarche steadi*	141	44	21	16	–
White-chinned petrel *Procellaria aequinoctialis*	18	8	5	0	–
Other birds	50	14	5	5	–
Other albatrosses	155	62	28	18	–
New Zealand fur seal *Arctocephalus forsteri*	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 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. A list of potentially confounded parameters due to variable correlation is provided in Table 3. Potentially correlated variables were not excluded from the analyses, but the potential correlation was considered when interpreting and refining model fits.

Table 3: List of potentially correlated variable pairs (based on visual data assessment) 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

2.4 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 levels of complexity were fitted to each of the 4 datasets with fishing event records (see Table 1) using the glm.nb-function in R (Venables & Ripley 2002). The base model structure was:

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

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 $\boldsymbol{X}_i$ denotes fixed effects for up to 5 variables recorded on observed fishing event *i*. An offset term for the log-transformed 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 1000, such that the estimated capture rates can be interpreted as captures per 1000 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 dataset 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 defined 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 fitted to the data (separately for all datasets with varying data completeness) and compared using the Akaike information criterion (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 fitted to complete data from Phase 1, and then the expanded model was fitted 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-fitted 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 dataset.

Models were only fitted to observed captures of seabirds, New Zealand 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 were 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 allowed 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, standardised 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 Figure 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 2019), but this was deemed to be impractical for fitting large numbers of models (i.e., > 1000) 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 was fitted in both frameworks and results were compared against each other (Appendix B).

3. RESULTS

3.1 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 New Zealand 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 (Figure 1). The mean annually observed effort for data used in this analysis was 171 123 hooks, with observed effort ranging between 72 963 (2012–13 fishing year) and 341 272 (2016–17 fishing year) hooks (Figure 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) (Figures 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, the northern regions of the North Island, and the east coast of the North Island (Figure 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 were observed captured in the areas Northland and Hauraki, 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 (Figure 3).

Observed captures of New Zealand fur seals mostly occurred off the west coast of South Island, and in the areas Bay of Plenty, and east coast of North Island (Figure 3). Observed captures of turtles, dolphins and whales, and sharks and rays were rare and predominantly occurred in areas off the North Island.

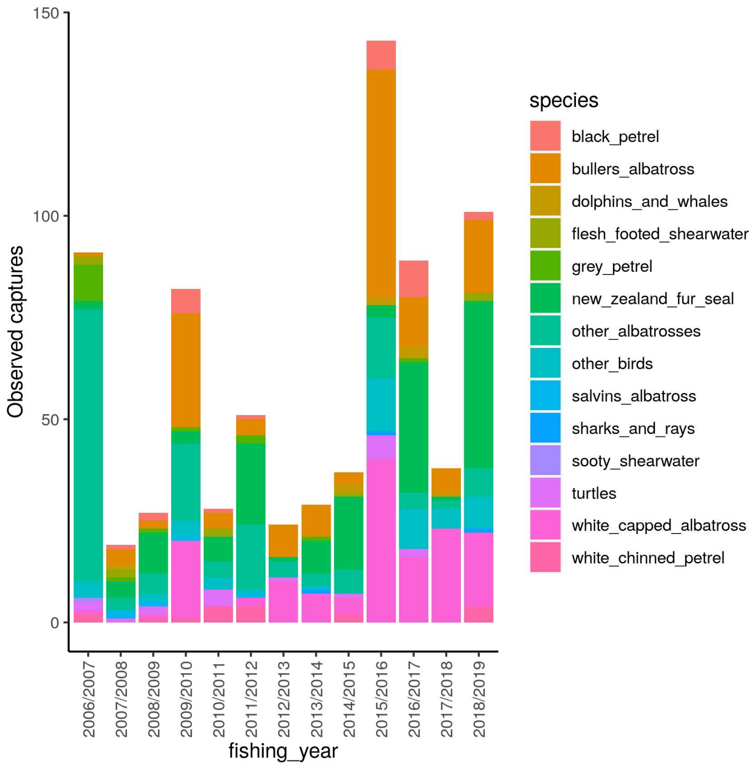

Figure 1: Observed captures of seabirds, New Zealand fur seals, turtles, dolphins and whales, and sharks and rays in small-vessel SLL fisheries between the 2006–07 and 2018–19 fishing years.

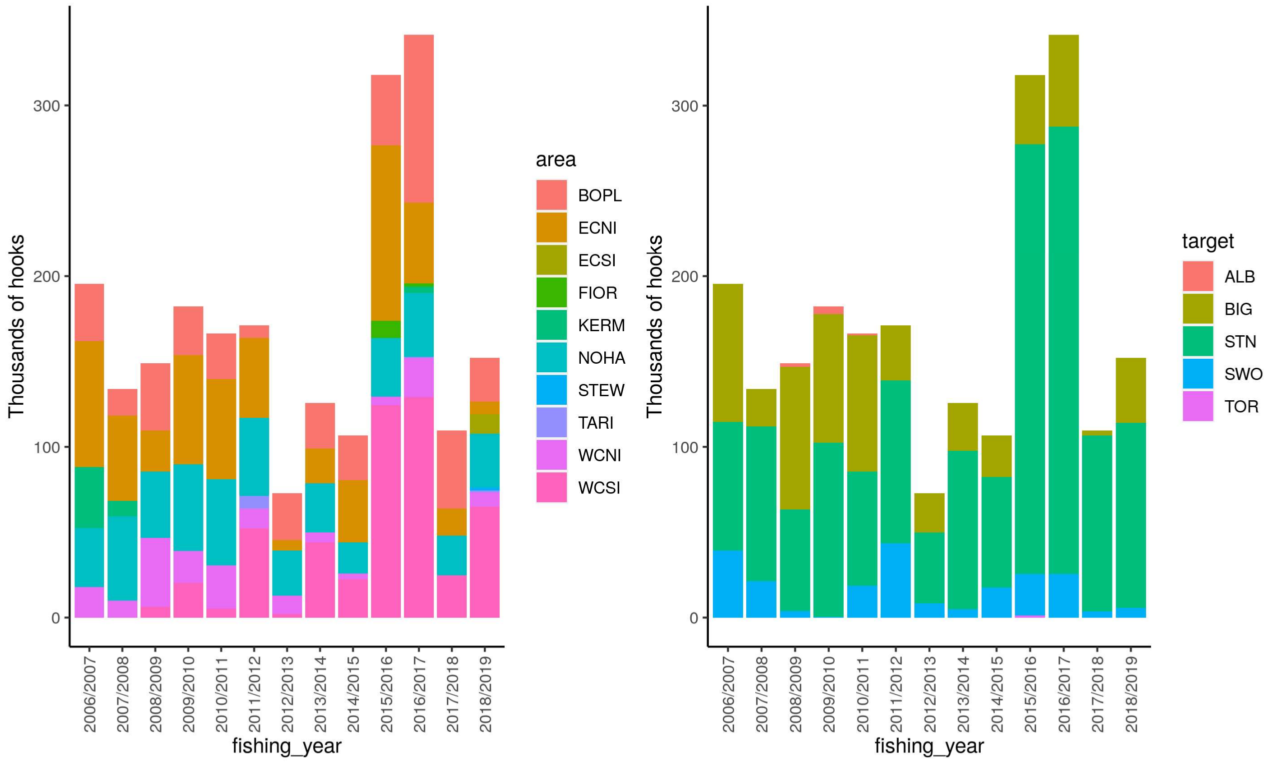

Figure 2: Small-vessel SLL effort (thousands of hooks) between the 2006–07 and 2018–19 fishing years by area (left panel) and target species (right panel); Areas are BOPL: Bay of Plenty; ECNI: east coast North Island; ECSI: east coast South Island; FIOR: Fiordland; KERM: Kermadec Islands; NOHA: Northland 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*).

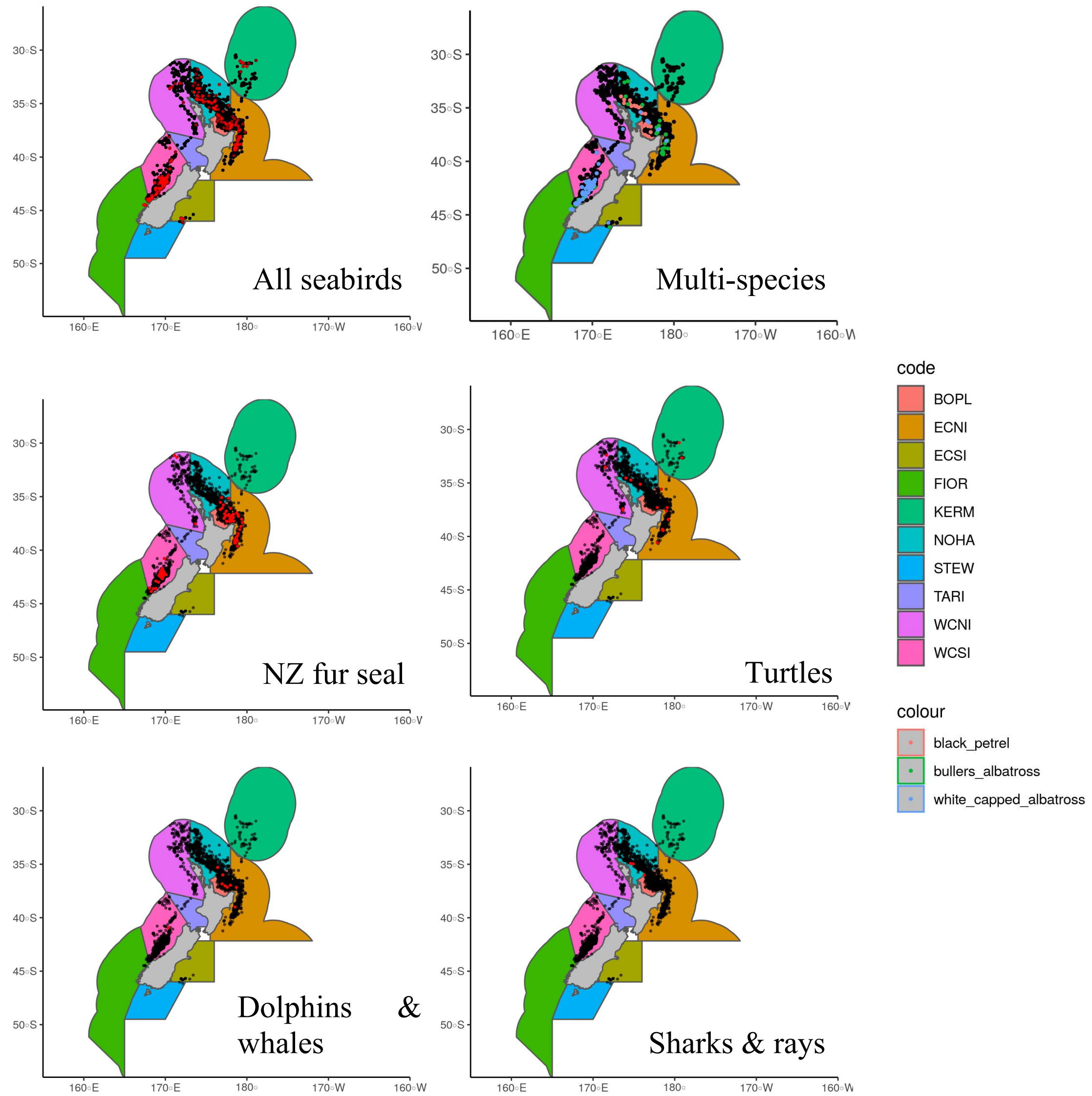

Figure 3: Area variable used in captures modelling. BOPL: Bay of Plenty; ECNI: east coast North Island; ECSI: east coast South Island; FIOR: Fiordland; KERM: Kermadec Islands; NOHA: Northland and Hauraki; STEW: Stewart-Snares shelf; TARI: Taranaki; WCNI: west coast North Island; WCSI: west coast South Island. Also shown are observed fishing events (black dots); observed captures (red dots; and differently coloured dots for the main seabird species datasets used in multi-species model).

3.2 All seabird 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 2379 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 events 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 Figures 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 Figures 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, vessel freezer, moon phase, and start month (Table 4). There existed a decreasing trend in standardised residuals with increasing moon phase (Figure 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) did not result in an improved model fit (results not shown here).

Table 4: Top-10 models fitted to all seabird captures where model fits included variables with 100% data completeness (unpruned dataset with 2373 fishing events); the total number of explored models was 2379.

Model	Description	df	logLik	AIC	Δ AIC
1	fishing_year+area+vessel_freezer+moon_phase+start_month	36	-1023.894	2119.789	0
2	area+vessel_size+vessel_freezer+moon_phase+start_month	26	-1036.033	2124.065	4.276
3	stats_area+fishing_year+vessel_freezer+moon_phase+start_month	68	-995.139	2126.278	6.489
4	area+vessel_freezer+moon_phase+start_month+dens	25	-1038.157	2126.313	6.524
5	area+vessel_nation+vessel_freezer+moon_phase+start_month	25	-1040.109	2130.218	10.429
6	target+area+vessel_freezer+moon_phase+start_month	28	-1037.192	2130.383	10.594
7	area+vessel_freezer+moon_phase+start_month	24	-1041.268	2130.535	10.746
8	area+vessel_freezer+moon_phase+start_month+season	24	-1041.268	2130.535	10.746
9	area+vessel_freezer+moon_phase+start_month+mitigation_tori	25	-1040.368	2130.737	10.948
10	area+vessel_freezer+moon_phase+start_month+time_of_day	25	-1041.034	2132.067	12.278
Null model	Intercept	2	-1212.39	2429	309.211

Table 5: Top-10 models fitted to all seabird captures where model fits included variables with ≥ 75% data completeness (1069 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	-439.205	926.410	0
2	area+vessel_size+moon_phase+start_month+min_depth	24	-439.685	927.369	0.960
3	area+vessel_size+moon_phase+start_month+baskets_number	24	-440.356	928.712	2.302
4	area+vessel_size+vessel_freezer+moon_phase+start_month	24	-440.482	928.963	2.554
5	area+moon_phase+start_month+night_hours+min_depth	23	-441.64	929.279	2.870
6	area+vessel_freezer+moon_phase+start_month+min_depth	23	-441.732	929.464	3.054
7	area+vessel_nation+moon_phase+start_month+min_depth	23	-441.768	929.535	3.126
8	area+moon_phase+start_month+min_depth	22	-442.829	929.659	3.249
9	area+moon_phase+start_month+season+min_depth	22	-442.829	929.659	3.249
10	target+area+moon_phase+start_month+min_depth	25	-439.973	929.945	3.5360
Null model	Intercept	2	-513.293	1030.586	104.177

Table 6: Top-10 models fitted to all seabird 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	-205.88	445.760	0
2	moon_phase+start_month+bait_thrower_used_yn+wind_beaufortscale+surface_temperature	17	-206.593	447.186	1.426
3	target+moon_phase+start_month+bait_thrower_used_yn+surface_temperature	19	-204.617	447.234	1.473
4	moon_phase+start_month+mitigation_tori+bait_thrower_used_yn+surface_temperature	17	-206.794	447.589	1.829
5	vessel_size+moon_phase+start_month+bait_thrower_used_yn+surface_temperature	17	-206.818	447.636	1.876
6	moon_phase+start_month+bait_thrower_used_yn+cloud_cover+surface_temperature	17	-206.862	447.724	1.964
7	moon_phase+start_month+wind+bait_thrower_used_yn+surface_temperature	18	-205.889	447.777	2.016
8	moon_phase+start_month+baskets_number+bait_thrower_used_yn+surface_temperature	17	-206.919	447.838	2.078
9	target+area+moon_phase+start_month+bait_thrower_used_yn	23	-200.927	447.853	2.093
10	moon_phase+start_month+bait_thrower_used_yn+surface_temperature	16	-208.278	448.555	2.795
Null model	Intercept	2	-259.293	522.587	76.827

Table 7: Top-10 models fitted to all seabird 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	306.047	0
2	moon_phase+season+line_length+wind_beaufortscale+surface_temperature	9	-145.933	309.866	3.819
3	moon_phase+season+line_length+surface_temperature+bait_stream	9	-146.146	310.293	4.246
4	moon_phase+season+line_length+surface_temperature+tori_height	9	-146.156	310.312	4.265
5	moon_phase+season+night_hours+cloud_cover+surface_temperature	9	-146.429	310.857	4.810
6	moon_phase+season+line_length+surface_temperature	8	-147.789	311.578	5.531
7	moon_phase+season+mitigation_tori+line_length+surface_temperature	8	-147.789	311.578	5.531
8	moon_phase+season+line_length+surface_temperature+tori_length	9	-146.843	311.686	5.639
9	moon_phase+season+time_of_day+line_length+surface_temperature	9	-146.931	311.863	5.816
10	moon_phase+season+time_of_day+line_length+tori_height	9	-146.997	311.993	5.946
Null model	Intercept	2	-180.111	364.222	58.175

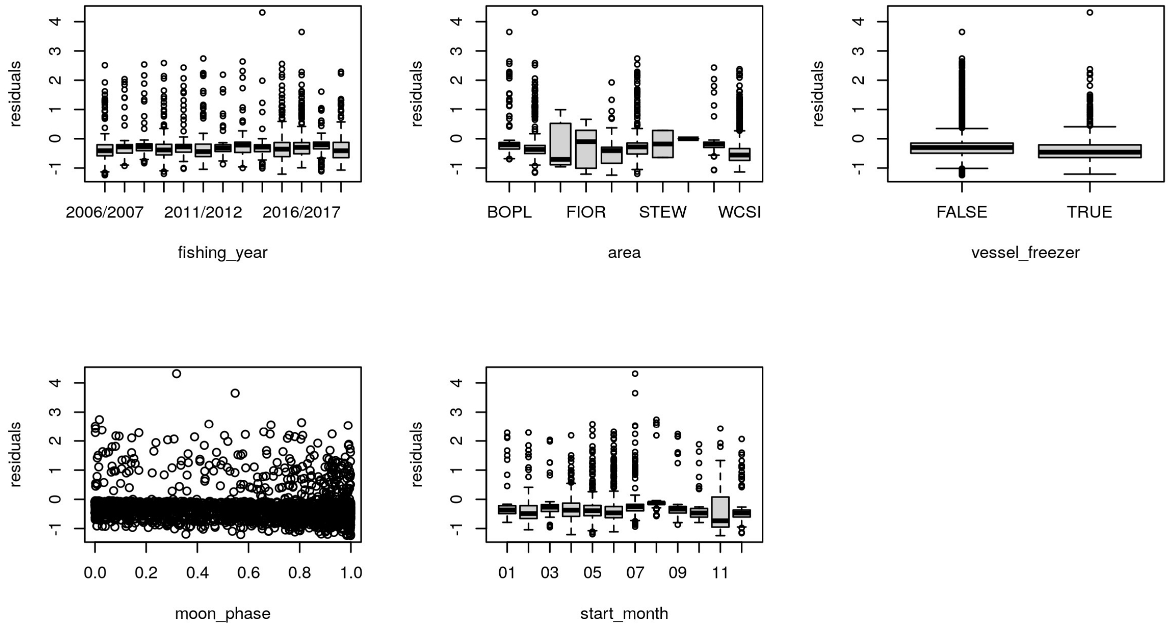

Figure 4: Residuals vs. predictors from top-10 all seabird captures model (model 1) where model fits included variables with 100% data completeness (Table 4).

Model estimates from model 1 (Table 4) are shown in Table 8. The estimated mean capture rate (on log-scale) per 1000 hooks was -2.845 (standard error: 0.535), which converts to approximately 0.058 captures per 1000 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 a 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 1.2 (Table 8). Further, some areas had significantly higher capture rates, such as the east coast South Island (ECSI) where the proportional change in the capture rate was 38.63 (95% CI: 8.085–184.565), but note that only a few seabird captures were observed in this area (see Figure 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 6.025 (95% CI: 2.373–15.302) for capture rates in November) as opposed to lower capture rates over winter (e.g., proportional change of 0.095 (95% CI: 0.027–0.336) or 90.5% reduced capture rate during August). Capture rates also increased proportionally with moon phase by factor 5.749 (95% CI: 3.751–8.811) per unit change in moon phase (Table 8). The results imply that vessels with a vessel freezer on board had capture rates about three times higher (2.869 (95% CI: 1.981–4.154)) compared with vessels without a freezer on board.

Table 8: Model estimates from top all seabird 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. *, **, and * refer to significance levels of 0.05, 0.01, and 0.001, respectively.**

	Estimate	SE	95% CI	exp(estimate) incl. 95% CI	z-value	p-value
(Intercept)	-2.845	0.535	-3.893 – -1.797	0.058 (0.02–0.166)	-5.323	<0.001***
fishing_year2007/2008	-0.869	0.453	-1.757 – 0.019	0.419 (0.173–1.019)	-1.919	0.055
fishing_year2008/2009	-0.881	0.445	-1.753 – -0.009	0.414 (0.173–0.991)	-1.979	0.048*
fishing_year2009/2010	-0.239	0.362	-0.948 – 0.469	0.787 (0.388–1.598)	-0.662	0.508
fishing_year2010/2011	-0.991	0.411	-1.796 – -0.186	0.371 (0.166–0.83)	-2.413	0.016*
fishing_year2011/2012	-1.059	0.380	-1.805 – -0.313	0.347 (0.164–0.731)	-2.783	0.005**
fishing_year2012/2013	0.151	0.506	-0.839 – 1.142	1.163 (0.432–3.133)	0.299	0.765
fishing_year2013/2014	-1.239	0.436	-2.094 – -0.384	0.29 (0.123–0.681)	-2.842	0.004**
fishing_year2014/2015	-1.053	0.454	-1.942 – -0.164	0.349 (0.143–0.849)	-2.32	0.02*
fishing_year2015/2016	-0.815	0.351	-1.503 – -0.127	0.443 (0.222–0.881)	-2.323	0.02*
fishing_year2016/2017	-1.505	0.367	-2.223 – -0.787	0.222 (0.108–0.455)	-4.107	<0.001***
fishing_year2017/2018	-0.484	0.458	-1.382 – 0.414	0.616 (0.251–1.513)	-1.056	0.291
fishing_year2018/2019	-0.718	0.390	-1.483 – 0.047	0.488 (0.227–1.048)	-1.841	0.066
areaECNI	0.932	0.324	0.297 – 1.566	2.539 (1.346–4.787)	2.879	0.004**
areaECSI	3.654	0.798	2.09 – 5.218	38.629 (8.085–184.565)	4.578	<0.001***
areaFIOR	3.712	0.661	2.417 – 5.007	40.936 (11.212–149.456)	5.62	<0.001***
areaKERM	0.344	0.529	-0.692 – 1.38	1.41 (0.501– 3.975)	0.65	0.516
areaNOHA	0.334	0.319	-0.29 – 0.958	1.397 (0.748–2.606)	1.049	0.294
areaSTEW	3.613	1.727	0.228 – 6.998	37.077 (1.256–1094.442)	2.092	0.036*
areaTARI	-33.740	21220000.000	-41591233.74 – 41591166.26	-	0	1
areaWCNI	-0.324	0.488	-1.281 – 0.633	0.723 (0.278–1.883)	-0.663	0.507
areaWCSI	2.657	0.337	1.996 – 3.318	14.253 (7.36–27.605)	7.876	<0.001***
vessel_freezerTRUE	1.054	0.189	0.684 – 1.424	2.869 (1.982–4.154)	5.583	<0.001***
moon_phase	1.749	0.218	1.322 – 2.176	5.749 (3.751–8.811)	8.035	<0.001***
start_month02	-0.276	0.536	-1.326 – 0.774	0.759 (0.266–2.168)	-0.515	0.606
start_month03	-0.844	0.642	-2.101 – 0.414	0.43 (0.122–1.513)	-1.315	0.188
start_month04	-1.221	0.513	-2.227 – -0.215	0.295 (0.108–0.807)	-2.378	0.017*
start_month05	-0.903	0.489	-1.862 – 0.057	0.406 (0.155–1.059)	-1.844	0.065
start_month06	-0.254	0.478	-1.191 – 0.683	0.776 (0.304–1.98)	-0.531	0.595
start_month07	-1.262	0.474	-2.191 – -0.333	0.283 (0.112–0.717)	-2.665	0.008**
start_month08	-2.354	0.645	-3.617 – -1.091	0.095 (0.027–0.336)	-3.652	<0.001***
start_month09	0.014	0.549	-1.061 – 1.089	1.014 (0.346–2.971)	0.026	0.979
start_month10	0.750	0.582	-0.39 – 1.89	2.117 (0.677–6.619)	1.289	0.197
start_month11	1.796	0.475	0.864 – 2.728	6.025 (2.373–15.302)	3.779	<0.001***
start_month12	0.945	0.473	0.018 – 1.873	2.574 (1.018–6.508)	1.997	0.046*

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 that 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), several 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 recorded on between 272 and 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, the low sample size for some variables should be considered) (Figure 5).

For most variables, the estimated effects had expected directions (i.e., positive, negative, or no relationship between the variable and catch rate) (Table 9). Mandatory bycatch mitigation measures seemed to reduce 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 0.609 (95% CI: 0.385–0.964) or 51% reduction compared with tori lines not being set over the bait entry point. Against expectations, increasing 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 increases the aerial extent, resulted in a proportional change of the capture rate of 0.374 (95% CI: 0.191–0.731) or 63% decrease per unit change in attachment height (range from 3 to 17 m). There existed also a small decrease in capture rates (1% or proportional change of 0.991 (95% CI: 0.983–0.999)) per unit (cm) increase in the distance between the weight and the hook. Increasing the number of night hours also resulted in a proportional change of the capture rate by 0.818 (95% CI: 0.671–0.998) 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 0.946 (95% CI: 0.915–0.979)). Further, an increasing number of turns (range from 0 to 2 turns) during setting increased capture rates by 94% (or proportional change of 1.945 (95% CI: 1.145–3.304)). Increasing float line length resulted in reduced seabird capture rates (proportional change per metre 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 1.267 (95% CI: 1.077–1.49) in capture rates per additional degree Celsius).

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 seabird 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; for binary variables (outcomes are 'Yes' or 'No' with the latter being the base case), the estimated effect for 'Yes' (e.g., for line_entry_yn) is provided.

	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	2028.419	2017.765	-10.654	-0.0000055	0.0000017	-0.0000089 – -0.0000022	0.946 (0.915–0.979) per 10 km	0.973	2309	518	2007–2019
night_hours	2028.286	2024.858	-3.428	-0.201	0.101	-0.399 – -0.002	0.818 (0.671–0.998)	0.973	2308	518	2007–2019
min_depth	2045.131	2041.005	-4.126	-0.023	0.009	-0.04 – -0.006	0.977 (0.96–0.994)	0.952	2260	570	2007–2019
vessel_heading	1596.265	1589.090	-7.175	-0.004	0.001	-0.007 – -0.001	0.996 (0.993–0.999)	0.743	1763	446	2007–2018
surface_temperature	1376.257	1369.878	-6.379	0.236	0.083	0.074 – 0.398	1.267 (1.077–1.49)	0.646	1534	351	2007–2018
tori_length	1152.689	1141.913	-10.776	-0.007	0.002	-0.011 – -0.003	0.993 (0.989–0.997)	0.575	1365	300	2007–2018
line_entry_yn	1148.949	1145.400	-3.549					0.574	1362	299	2007–2018
Yes				-0.495	0.234	-0.953 – -0.037	0.609 (0.385–0.964)				
dist_stern_to_bait_min	293.323	291.590	-1.733	0.042	0.019	0.005 – 0.078	1.043 (1.005–1.082)	0.127	302	95	2018–2019
mainline_diameter	293.323	287.707	-5.616	0.598	0.213	0.18 – 1.016	1.818 (1.197–2.761)	0.127	302	95	2018–2019
float_line_length	293.323	287.875	-5.448	-0.279	0.109	-0.494 – -0.065	0.756 (0.61–0.937)	0.127	302	95	2018–2019
dist_bait_to_tori	293.323	291.380	-1.944	0.047	0.022	0.003 – 0.09	1.048 (1.003–1.095)	0.127	301	95	2018–2019
attach1_height	293.323	286.692	-6.631	-0.984	0.342	-1.654 – -0.313	0.374 (0.191–0.731)	0.126	300	95	2018–2019
attach1_distance	293.323	289.332	-3.991	0.080	0.030	0.021 – 0.139	1.083 (1.021–1.149)	0.126	300	95	2018–2019
setting_turns	292.515	290.271	-2.244	0.665	0.270	0.135 – 1.195	1.945 (1.145–3.304)	0.125	297	95	2018–2019
float_line_diameter	233.962	231.967	-1.995	-0.309	0.141	-0.586 – -0.032	0.734 (0.556–0.968)	0.120	284	70	2018–2019
aerial_extent	293.323	292.367	-0.956	0.079	0.039	0.002 – 0.155	1.082 (1.002–1.168)	0.117	278	95	2018–2019
distance_weight_to_hook	293.323	290.771	-2.552	-0.009	0.004	-0.017 – -0.001	0.991 (0.983–0.999)	0.115	272	95	2018–2019

Table 10: 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 all seabird 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 + X_i*: *t* 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 with 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; for binary variables (outcomes are 'Yes' or 'No' with the latter being the base case), the estimated effect for 'Yes' (e.g., for line_entry_yn) is provided. Blank field for estimates: model failed. (Continued on next page)

	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	2118.082	2118.679	0.597	-0.001	0.003	-0.006 – 0.004	0.999 (0.994 – 1.004)	0.994	2358	579	2007 – 2019
line_length	2104.625	2104.897	0.272	-0.006	0.009	-0.024 – 0.012	0.994 (0.977 – 1.012)	0.992	2354	578	2007 – 2019
max_depth	2011.501	2013.868	2.366	0.000	0.002	-0.005 – 0.004	1 (0.995 – 1.004)	0.934	2216	566	2007 – 2019
start_wind_direction	1971.098	1971.260	0.162	-0.001	0.001	-0.002 – 0	0.999 (0.998 – 1)	0.928	2204	534	2007 – 2019
bait_thrower_used_yn	1812.901	1811.518	-1.384					0.869	2062	484	2007 – 2018
Yes				0.647	0.403	-0.142 – 1.437	1.91 (0.867 – 4.207)				
wind_beaufortscale	1769.444	1770.416	0.972	-0.007	0.048	-0.101 – 0.086	0.993 (0.904 – 1.09)	0.845	2006	475	2007 – 2018
number_of_vessels	1768.213	1768.740	0.527	0.008	0.043	-0.077 – 0.092	1.008 (0.926 – 1.096)	0.844	2003	477	2007 – 2018
cloud_cover	1616.437	1617.879	1.442	0.000	0.002	-0.005 – 0.005	1 (0.996 – 1.005)	0.819	1944	418	2007 – 2019
snood_signal_time	1817.559	1819.195	1.635	-0.026	0.033	-0.09 – 0.038	0.974 (0.914 – 1.039)	0.818	1942	515	2007 – 2019
vessel_speed	1605.025	1604.440	-0.584	-0.141	0.093	-0.323 – 0.04	0.868 (0.724 – 1.041)	0.759	1801	444	2007 – 2018
long_streamer_distance	1650.234	1649.265	-0.969	-0.020	0.025	-0.069 – 0.03	0.981 (0.933 – 1.03)	0.727	1725	453	2008 – 2019
tori_height	1152.685	1153.374	0.689	-0.029	0.048	-0.123 – 0.065	0.972 (0.884 – 1.068)	0.575	1364	300	2007 – 2018
bait_stream	1109.054	1109.887	0.832	-0.019	0.049	-0.116 – 0.078	0.981 (0.891 – 1.081)	0.545	1294	288	2007 – 2018
bottom_depth								0.150	355	112	2007 – 2018
light_sticks_yn	293.323	296.181	2.858					0.127	302	95	2018 – 2019
Yes				-0.126	0.378	-0.866 – 0.613	0.881 (0.421 – 1.847)				
acoustic_bird_deterrent_yn	293.323							0.127	302	95	2018 – 2019
deck_light_yn	293.323	296.293	2.970					0.127	302	95	2018 – 2019
Yes				5.782	9575210.253	-18767406.313 – 18767417.877	324.31 (0 – Inf)				

Table 10: continued.

Variable	AIC Model 1	AIC 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
fishing_gear_discard_yn	293.323	296.293	2.970					0.127	302	95	2018 – 2019
Yes				-1.514	4640629.833	-9095635.985 – 9095632.958	0.22 (0 – Inf)				
hook_type	293.323							0.127	302	95	2018 – 2019
number_snoods	293.323	296.170	2.847	-0.038	0.099	-0.231 – 0.155	0.963 (0.794 – 1.168)	0.127	302	95	2018 – 2019
line_setting_height	293.323	295.363	2.040	-0.401	0.370	-1.126 – 0.324	0.67 (0.324 – 1.383)	0.127	301	95	2018 – 2019
discards_during_setting	283.339	288.308	4.970					0.127	301	94	2018 – 2019
Yes				27.370	16499039.615	-32338090.276 – 32338145.016	770187631975.682 (0 – Inf)				
Unknown				-0.031	1.406	-2.787 – 2.726	0.970 (0.062 – 15.266)				
long_streamer_yn	293.323	296.293	2.970					0.126	300	95	2018 – 2019
Yes				-4.465	10569122.468	-20715484.503 – 20715475.573	0.012 (0 – Inf)				
light_streamer_yn	293.323	293.251	-0.072					0.126	300	95	2018 – 2019
Yes				-1.357	0.850	-3.022 – 0.308	0.257 (0.049 – 1.361)				
surface_float_diameter	233.962	236.251	2.289	-0.572	304917.132	-597638.15 – 597637.006	0.564 (0 – Inf)	0.120	284	70	2018 – 2019
snood_length	233.962	234.617	0.655	0.107	0.077	-0.044 – 0.257	1.112 (0.957 – 1.293)	0.120	284	70	2018 – 2019
weight	293.323	291.920	-1.403	-0.024	0.014	-0.051 – 0.002	0.976 (0.95 – 1.002)	0.115	272	95	2018 – 2019
long_streamer_aerial_yn	293.323	294.430	1.107					0.109	258	95	2018 – 2019
Yes				-0.802	0.549	-1.877 – 0.274	0.449 (0.153 – 1.315)				

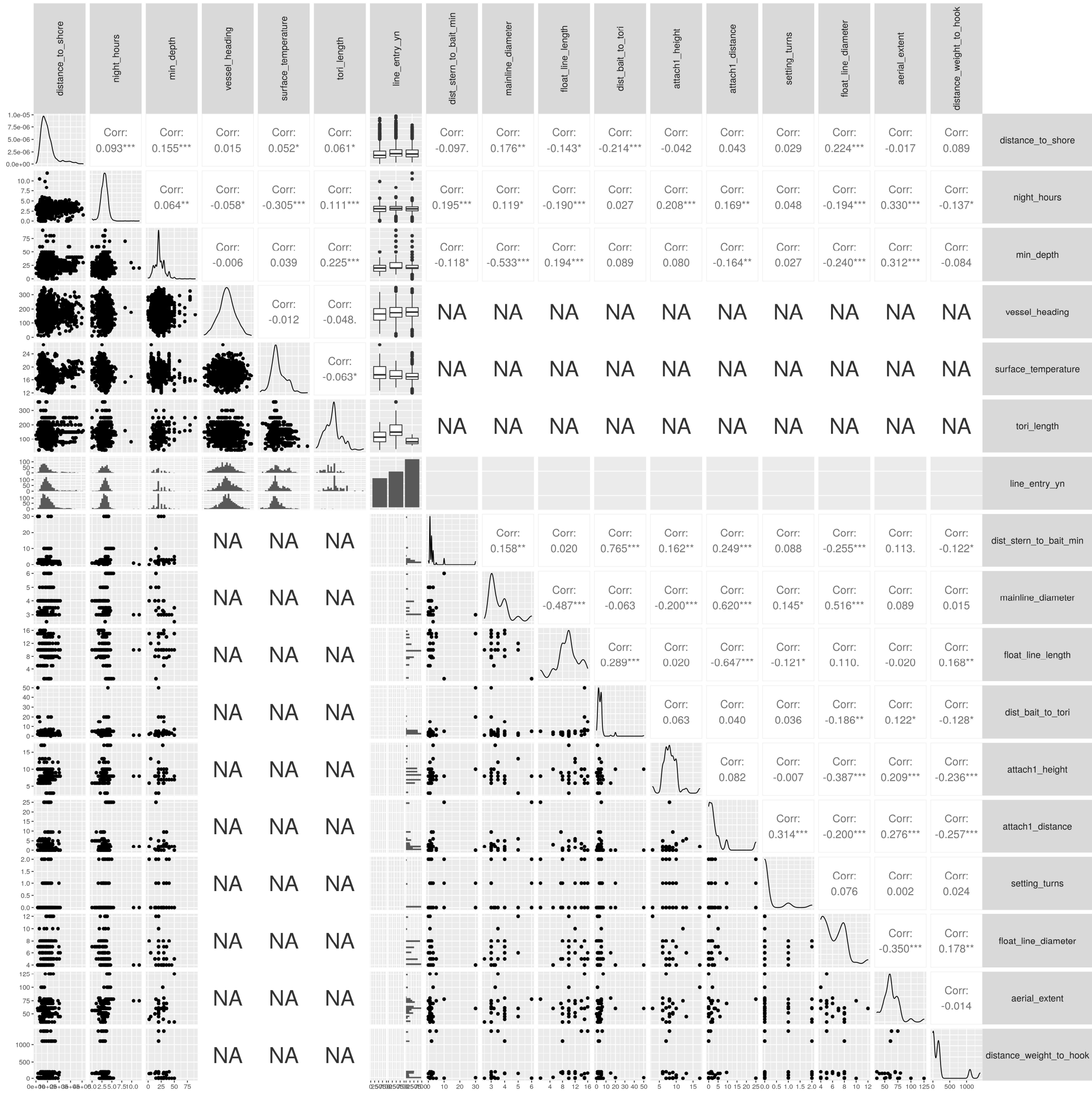

Figure 5: Pairwise comparison of significant additional parameters (Table 9) that were added to top all seabird captures model (model 1; Table 4).

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

Tables 11 to 14 show the top-10 (or top-13 in Table 11) and intercept models when fitting a multi-species captures model to observed captures of black petrel, white-capped albatross, and Buller's albatross. For the different datasets between 6884 and 510 415 models were fitted. Models 1 to 10 in each table show that very similar results were obtained compared with 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 dataset did not include fishing year (as opposed to the top model in the all seabird captures model), but note that fewer captures were available for this model fit (i.e., only three species were included). In contrast to the all seabirds model, the multi-species model fit supported the inclusion of vessel size as opposed to the presence/absence of a vessel freezer. Standardised residuals vs. predictor plots (Figures 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 (Figure 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 where captures might have occurred. The coarse *area* variable therefore seemed to be 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 had very localised distributions (e.g., black petrel in Hauraki Gulf region). Another post-hoc adjustment was to remove the initial moon phase-species interaction as the difference in AICs between the two top models (model 11 without, and model 12 with, moon phase-species interaction) was only 0.289. The post-hoc adjusted model (model 11) received the strongest support. Model 11 was further supported by the good alignment between mean predicted captures per area and the actual mean observed captures per area (see Figures 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 2373 fishing events); the total number of explored models was 6884 plus 3 post-hoc adjusted models (11 to 13).

Model	Description	df	logLik	AIC	Δ AIC
11	area:species + vessel_size + start_month + moon_phase	44	-799.082	1688.164	0
12	area:species + vessel_size + start_month + moon_phase:species	46	-797.227	1688.453	0.289
13	area:species + vessel_size + start_month + dens + moon_phase:species	47	-796.983	1689.965	1.801
1	area+vessel_size+start_month+dens+moon_phase:species	28	-853.445	1762.89	74.726
2	area+vessel_freezer+start_month+dens+moon_phase:species	27	-854.745	1763.49	75.326
3	fishing_year+area+vessel_freezer+start_month+moon_phase:species	38	-844.919	1765.838	77.674
4	stats_area+vessel_size+start_month+dens+moon_phase:species	60	-822.996	1765.992	77.828
5	stats_area+vessel_freezer+start_month+dens+moon_phase:species	59	-824.471	1766.942	78.778
6	area+vessel_size+vessel_freezer+start_month+moon_phase:species	28	-856.646	1769.291	81.127
7	area+vessel_size+season+dens+moon_phase:species	20	-865.31	1770.622	82.458
8	stats_area+fishing_year+vessel_freezer+start_month+moon_phase:species	70	-816.932	1773.865	85.701
9	fishing_year+area+start_month+dens+moon_phase:species	38	-848.963	1773.927	85.763
10	fishing_year+area+vessel_size+start_month+moon_phase:species	39	-848.327	1774.654	86.49
Null model	intercept	2	-1071.161	2146.322	458.158

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 (1069 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	-345.785	721.569	0
2	fishing_year+area+moon_phase+season+baskets_number	24	-336.833	721.666	0.097
3	fishing_year+area+start_month+dens+moon_phase:species	34	-326.896	721.793	0.224
4	area+moon_phase+season+baskets_number+distance_to_shore	15	-346.308	722.617	1.048
5	area+season+dens+moon_phase:species+baskets_number	17	-344.955	723.911	2.342
6	fishing_year+area+season+moon_phase:species+baskets_number	26	-335.962	723.924	2.355
7	fishing_year+area+moon_phase+start_month+time_of_day	32	-330.132	724.263	2.694
8	area+start_month+dens+moon_phase:species+distance_to_shore	25	-337.199	724.397	2.828
9	area+season+time_of_day+moon_phase:species+baskets_number	17	-345.212	724.424	2.855
10	area+season+moon_phase:species+baskets_number+distance_to_shore	17	-345.585	725.171	3.602
Null model	Intercept	2	-419.734	843.468	121.899

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	-178.869	391.738	0
2	fishing_year+moon_phase+season+mitigation_tori+time_of_day	17	-179.026	392.051	0.313
3	fishing_year+area+season+dens+long_streamer_distance	21	-175.075	392.151	0.412
4	fishing_year+moon_phase+season+dens+time_of_day	17	-179.121	392.242	0.504
5	fishing_year+moon_phase+season+time_of_day+wind_beaufortscale	17	-179.33	392.659	0.921
6	fishing_year+area+moon_phase+season+dens	21	-175.357	392.714	0.976
7	fishing_year+area+moon_phase+season+long_streamer_distance	21	-175.367	392.735	0.997
8	fishing_year+season+mitigation_tori+dens+time_of_day	17	-179.451	392.901	1.163
9	fishing_year+moon_phase+season+time_of_day+distance_to_shore	17	-179.685	393.369	1.631
10	fishing_year+area+moon_phase+season+baskets_number	21	-175.733	393.466	1.728
Null model	Intercept		-231.619	467.238	75.500

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	moon_phase+season+dens+time_of_day+tori_length	9	-145.271	308.542	0
2	moon_phase+season+cloud_cover+surface_temperature+tori_length	9	-145.3	308.601	0.059
3	moon_phase+season+time_of_day+cloud_cover+tori_length	9	-145.339	308.678	0.136
4	season+dens+time_of_day+cloud_cover+tori_length	9	-145.425	308.850	0.308
5	moon_phase+season+dens+surface_temperature+tori_length	9	-145.503	309.006	0.465
6	moon_phase+season+time_of_day+surface_temperature+tori_length	9	-145.555	309.110	0.569
7	season+time_of_day+cloud_cover+tori_length+bait_stream	9	-145.622	309.243	0.701
8	fishing_year+season+dens+time_of_day+tori_length	17	-137.673	309.345	0.803
9	season+dens+time_of_day+surface_temperature+tori_length	9	-145.768	309.535	0.993
10	season+time_of_day+cloud_cover+surface_temperature+tori_length	9	-145.799	309.598	1.0560
Null model	Intercept	2	-172.324	348.6474	40.106

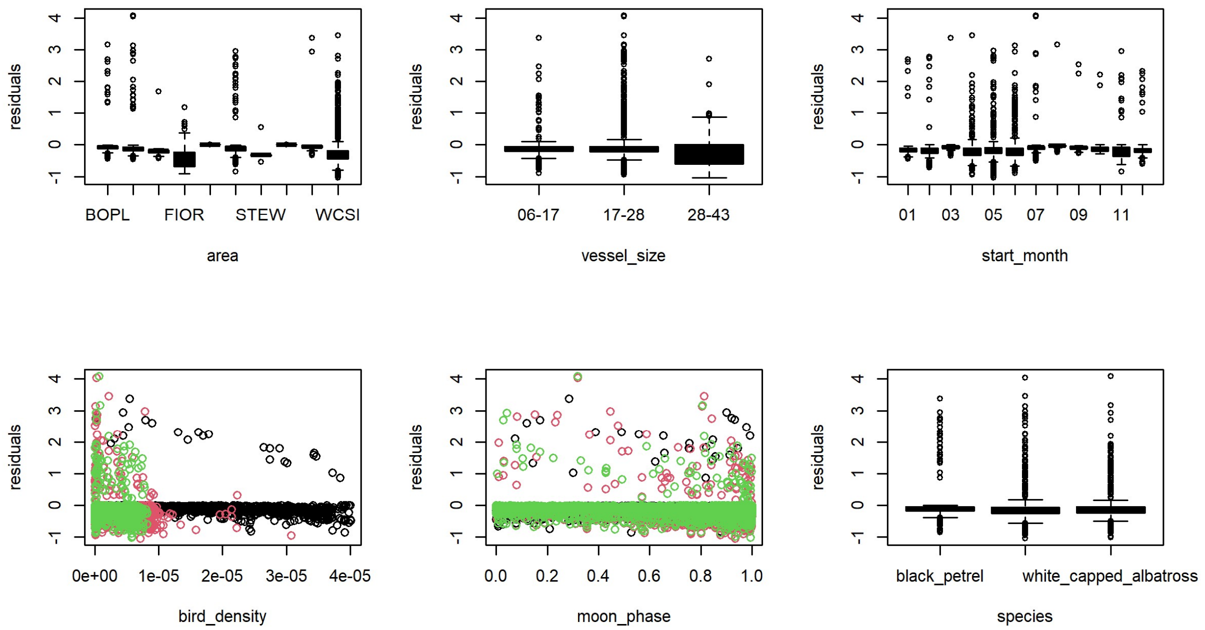

Figure 6: Residuals vs. predictors from second top multi-species seabird captures model (model 1) where model fits included variables with 100% data completeness (Table 11).

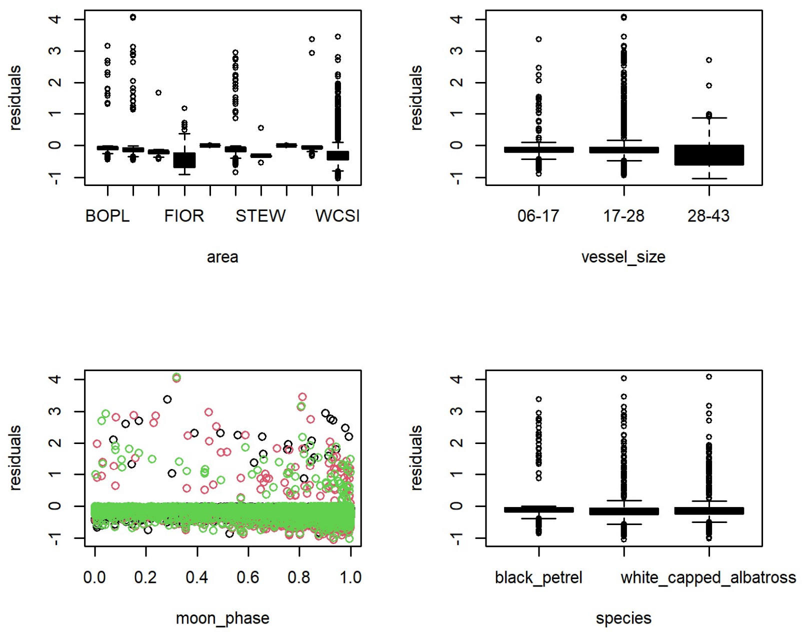

Figure 7: Residuals vs. predictors from top multi-species seabird captures model (model 11) where model fits included variables with 100% data completeness (Table 11).

Model estimates from model 11 (Table 11) are shown in Table 15. The estimated mean capture (on log-scale) per thousand hooks was -3.186 (standard error: 0.641), which converts to approximately 0.041 captures per 1000 hooks on actual scale. Similar to the all seabirds model, there was a significant start month effect with lower capture rates over the winter months. Increasing moon phase also resulted in significantly higher capture rates with a proportional increase of 12.256 (95% CI: 7.172–20.944) per unit change in moon phase. Vessel length affected capture rates in this model fit, with a proportional change of capture rates of 0.516 (95% CI: 0.312–0.853) and 3.995 (95% CI: 1.727–9.24) for vessel lengths in the range of 17 to 28 m and 28 to 43 m, respectively.

Table 15: Model estimates from top multi-species seabird captures model (model 11) where model fits included variables with 100% data completeness (Table 11). *, **, and * refer to significance levels of 0.05, 0.01, and 0.001, respectively. (Continued on next page)**

	Estimate	SE	95% CI	exp(estimate) incl. 95% CI	z-value	p-value
(Intercept)	-3.186	0.641	-4.442– -1.93	0.041 (0.012–0.145)	-4.974	<0.001***
vessel_size17–28	-0.662	0.257	-1.165– -0.159	0.516 (0.312–0.853)	-2.581	0.01**
vessel_size28–43	1.385	0.428	0.547–2.223	3.995 (1.727–9.24)	3.237	0.001**
start_month02	-0.501	0.680	-1.832–0.831	0.606 (0.16–2.296)	-0.737	0.461
start_month03	-1.464	1.144	-3.706–0.778	0.231 (0.025–2.178)	-1.28	0.2
start_month04	-0.641	0.648	-1.912–0.63	0.527 (0.148–1.877)	-0.989	0.323
start_month05	-0.537	0.633	-1.777–0.702	0.584 (0.169–2.019)	-0.85	0.396
start_month06	0.172	0.612	-1.027–1.37	1.187 (0.358–3.937)	0.281	0.779
start_month07	-1.505	0.632	-2.743– -0.267	0.222 (0.064–0.766)	-2.383	0.017*
start_month08	-3.019	1.117	-5.208– -0.83	0.049 (0.005–0.436)	-2.703	0.007**
start_month09	-0.676	0.876	-2.393–1.042	0.509 (0.091–2.834)	-0.771	0.441
start_month10	-0.209	0.912	-1.996–1.579	0.812 (0.136–4.849)	-0.229	0.819
start_month11	0.959	0.618	-0.253–2.171	2.61 (0.777–8.77)	1.551	0.121
start_month12	0.605	0.619	-0.609–1.818	1.831 (0.544–6.162)	0.976	0.329
moon_phase	2.506	0.273	1.97–3.042	12.256 (7.172–20.944)	9.168	<0.001
areaBOPL:speciesblack_petrel	-2.358	0.488	-3.314– -1.402	0.095 (0.036–0.246)	-4.834	<0.001***
areaECNI:speciesblack_petrel	-4.787	1.019	-6.784– -2.79	0.008 (0.001–0.061)	-4.696	<0.001***
areaECSI:speciesblack_petrel	-33.930	19350000.000	-37926033.93–37925966.07	0	0	1
areaFIOR:speciesblack_petrel	-35.450	19370000.000	-37965235.45–37965164.55	0	0	1
areaKERM:speciesblack_petrel	-36.880	7544000.000	-14786276.88–14786203.12	0	0	1
areaNOHA:speciesblack_petrel	-2.055	0.481	-2.997– -1.113	0.128 (0.05–0.328)	-4.276	<0.001***
areaSTEW:speciesblack_petrel	-33.970	47450000.000	-93002033.97–93001966.03	0	0	1
areaTARI:speciesblack_petrel	-35.650	20890000.000	-40944435.65–40944364.35	0	0	1
areaWCNI:speciesblack_petrel	-3.652	1.069	-5.747– -1.557	0.026 (0.003–0.211)	-3.416	<0.001***
areaWCSI:speciesblack_petrel	-35.050	2779000.000	-5446875.05– 5446804.95	0	0	1
areaBOPL:speciesbullers_albatross	-3.827	0.793	-5.382– -2.272	0.022 (0.005–0.103)	-4.825	<0.001***

Table 15: continued.

	Estimate	SE	95% CI	exp(estimate) incl. 95% CI	z-value	p-value
areaECNI:speciesbullers_albatross	-1.558	0.288	-2.122– -0.994	0.211 (0.12–0.37)	-5.413	<0.001***
areaECSI:speciesbullers_albatross	-33.930	19350000.000	-37926033.93– 37925966.07	0	0	1
areaFIOR:speciesbullers_albatross	1.768	0.678	0.44– 3.096	5.859 (1.552–22.116)	2.609	0.009**
areaKERM:speciesbullers_albatross	-36.880	7544000.000	-14786276.88– 14786203.12	0	0	1
areaNOHA:speciesbullers_albatross	-2.971	0.565	-4.079– -1.863	0.051 (0.017–0.155)	-5.254	<0.001***
areaSTEW:speciesbullers_albatross	2.073	1.882	-1.616–5.762	7.949 (0.199–317.895)	1.101	0.271
areaTARI:speciesbullers_albatross	-35.650	20890000.000	-40944435.65– 40944364.35	0	0	1
areaWCNI:speciesbullers_albatross	-34.730	4217000.000	-8265354.73– 8265285.27	0	0	1
areaWCSI:speciesbullers_albatross	-0.147	0.214	-0.566–0.273	0.864 (0.568–1.313)	-0.685	0.493
areaBOPL:specieswhite_capped_albatross	-3.845	0.799	-5.411– -2.279	0.021 (0.004–0.102)	-4.812	<0.001***
areaECNI:specieswhite_capped_albatross	-3.393	0.541	-4.453– -2.333	0.034 (0.012–0.097)	-6.276	<0.001***
areaECSI:specieswhite_capped_albatross	0.590	1.194	-1.75– 2.931	1.805 (0.174–18.738)	0.494	0.621
areaFIOR:specieswhite_capped_albatross	1.292	0.709	-0.098–2.682	3.64 (0.906–14.62)	1.822	0.069.
areaKERM:specieswhite_capped_albatross	-36.880	7544000.000	-14786276.88– 14786203.12	0	0	1
areaNOHA:specieswhite_capped_albatross	-4.989	1.086	-7.118– -2.86	0.007 (0.001–0.057)	-4.593	<0.001***
areaSTEW:specieswhite_capped_albatross	-33.970	47450000.000	-93002033.97– 93001966.03	0	0	1
areaTARI:specieswhite_capped_albatross	-35.650	20890000.000	-40944435.65– 40944364.35	0	0	1
areaWCNI:specieswhite_capped_albatross	-3.660	1.073	-5.763– -1.557	0.026 (0.003–0.211)	-3.412	<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; 0.334 (95% CI: 0.161–0.695) on actual scale; or 67% decrease in capture rate per unit (m) increase in attachment height) suggests that the aerial extent of the tori line is a strong factor influencing the effectiveness of tori lines.

Gear configuration and vessel behaviour variables that had a strong effect on capture rates were mainline diameter, floatline length, and number of turns during line setting (Table 16). Increasing mainline diameter resulted in increased capture rates (1.829 (95% CI: 1.155–2.897) proportional change per unit change on mainline diameter), whereas increases in floatline length led to decreasing capture rates (0.79 (95% CI: 0.627–0.997) proportional change per unit change in floatline length). Further, for every increase in the number of turns (range from 0 to 2 turns), the capture rate proportionally increased by 2.045 (95% CI: 1.132–3.694). Capture rates decreased by about 9% for every additional 10 km off the shore (i.e., proportional change per 10 km is 0.910 (95% CI: 0.864–0.958)). 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, the low sample size for some variables should be considered) (Figure 8). Non-significant parameters are provided in Table 17.

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 11 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 with 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.

Variable	AIC Model 11	AIC 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
distance_to_shore	1792.920	1780.458	-12.462	-0.000009	0.000003	- 0.000015– -0.000004	0.910 (0.864–0.958) per 10 km	0.888	2309	323	2007–2019
night_hours	1792.907	1790.003	-2.903	-0.281	0.124	-0.524– -0.039	0.755 (0.592–0.962)	0.887	2308	323	2007–2019
min_depth	1740.235	1733.226	-7.009	-0.034	0.012	-0.057– -0.012	0.966 (0.945–0.989)	0.869	2260	319	2007–2019
wind_beaufortscale	1453.099	1451.064	-2.035	-0.121	0.060	-0.239– -0.002	0.886 (0.787–0.998)	0.771	2006	254	2007–2018
vessel_heading	1290.321	1282.234	-8.087	-0.006	0.002	-0.009– -0.002	0.995 (0.991–0.998)	0.678	1763	239	2007–2018
tori_length	1044.079	1040.686	-3.393	-0.006	0.003	-0.011– -0.001	0.994 (0.989–0.999)	0.525	1365	178	2007–2018
dist_stern_to_bait_min	339.824	326.036	-13.788	0.193	0.059	0.078–0.308	1.213 (1.081–1.361)	0.116	302	67	2018–2019
mainline_diameter	339.824	334.201	-5.623	0.604	0.235	0.144–1.064	1.829 (1.155–2.897)	0.116	302	67	2018–2019
float_line_length	339.824	336.792	-3.032	-0.235	0.119	-0.467– -0.003	0.79 (0.627–0.997)	0.116	302	67	2018–2019
dist_bait_to_tori	339.824	333.278	-6.546	0.109	0.034	0.043–0.176	1.116 (1.044–1.192)	0.116	301	67	2018–2019
attach1_height	339.824	331.703	-8.121	-1.097	0.374	-1.829– -0.365	0.334 (0.161–0.695)	0.115	300	67	2018–2019
attach1_distance	339.824	336.306	-3.518	0.077	0.033	0.011–0.142	1.08 (1.011–1.153)	0.115	300	67	2018–2019
setting_turns	339.277	336.253	-3.024	0.716	0.302	0.124–1.307	2.045 (1.132–3.694)	0.114	297	67	2018–2019
weight	339.824	333.816	-6.008	-0.035	0.016	-0.066– -0.005	0.965 (0.936–0.995)	0.105	272	67	2018–2019

Table 17: 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 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 X_i missing; *Model 11 + X_i*: *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 Xi; *Prop. events left* and *N events left*: proportion and total fishing events left compared with 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; for binary variables (outcomes are 'Yes' or 'No' with the latter being the base case), the estimated effect for 'Yes' (e.g., for line_entry_yn) is provided. Blank field for estimates: model failed. (Continued on next page)

	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	1801.185	1802.788	1.603	0.002	0.003	-0.004–0.008	1.002 (0.996–1.008)	0.907	2358	324	2007–2019
line_length	1800.095	1798.533	-1.562	-0.022	0.011	-0.044–0	0.979 (0.957–1)	0.905	2354	324	2007–2019
max_depth	1699.426	1699.691	0.264	-0.003	0.002	-0.008–0.001	0.997 (0.992–1.001)	0.852	2216	315	2007–2019
start_wind_direction	1648.363	1650.252	1.890	0.0003	0.0009	-0.001–0.002	1 (0.999–1.002)	0.847	2204	290	2007–2019
bait_thrower_used_yn	1474.181	1475.967	1.786	-0.389	0.828	-2.012–1.235	0.678 (0.134–3.437)	0.793	2062	257	2007–2018
number_of_vessels	1434.764	1436.543	1.779	-0.027	0.058	-0.14–0.087	0.974 (0.869–1.091)	0.770	2003	253	2007–2018
cloud_cover								0.747	1944	203	2007–2019
snood_signal_time								0.747	1942	296	2007–2019
vessel_speed	1314.579	1313.073	-1.506	-0.226	0.119	-0.459–0.008	0.798 (0.632–1.008)	0.692	1801	240	2007–2018
long_streamer_distance	1606.499	1604.985	-1.514	0.063	0.032	-0.001–0.127	1.065 (0.999–1.136)	0.663	1725	308	2008–2019
surface_temperature	1005.068	1004.609	-0.459	0.196	0.118	-0.035–0.427	1.217 (0.965–1.533)	0.590	1534	158	2007–2018
tori_height	1044.079	1045.950	1.871	-0.019	0.055	-0.127–0.088	0.981 (0.881–1.092)	0.524	1364	178	2007–2018
line_entry_yn	1037.468							0.524	1362	177	2007–2018
bait_stream	995.625	997.564	1.940	0.015	0.060	-0.102–0.132	1.015 (0.903–1.141)	0.498	1294	171	2007–2018
bottom_depth	417.398	418.093	0.694	0.0005	0.0004	0–0.001	1.001 (1–1.001)	0.136	355	85	2007–2018
light_sticks_yn	339.824	341.143	1.320	0.464	0.541	-0.596–1.524	1.591 (0.551–4.593)	0.116	302	67	2018–2019
acoustic_bird_deterrent_yn	339.824							0.116	302	67	2018–2019

Table 17: continued.

Variable	AIC Model 11	AIC 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
deck_light_yn	339.824	341.824	2	-3.016	15005072.391	-29409944.902–29409938.87	0.049 (0–Inf)	0.116	302	67	2018–2019
fishing_gear_discard_yn	339.824	339.022	-0.802	-30.530	2400586.965	-4705180.981–4705119.921	0 (0–Inf)	0.116	302	67	2018–2019
number_snoods	339.824	341.093	1.270	-0.161	0.190	-0.533–0.211	0.851 (0.587–1.235)	0.116	302	67	2018–2019
line_setting_height	339.824	341.734	1.911	-0.182	0.591	-1.34–0.977	0.834 (0.262–2.656)	0.116	301	67	2018–2019
long_streamer_yn	339.824	341.824	2					0.115	300	67	2018–2019
Yes				-1.709	3679580.430	-7211979.352–7211975.933	0.181 (0–Inf)				
light_streamer_yn	339.824	341.712	1.888					0.115	300	67	2018–2019
Yes				0.223	0.621	-0.995–1.44	1.249 (0.37–4.221)				–
float_line_diameter	263.634	264.475	0.843	-0.501	0.735	-1.941–0.939	0.606 (0.144–2.556)	0.109	284	47	2018–2019
surface_float_diameter	263.634	254.472	-9.161	-0.830	60858.234	-119282.976–119281.317	0.436 (0–Inf)	0.109	284	47	2018–2019
snood_length	263.634	264.511	0.878	0.281	0.253	-0.215–0.777	1.324 (0.806–2.175)	0.109	284	47	2018–2019

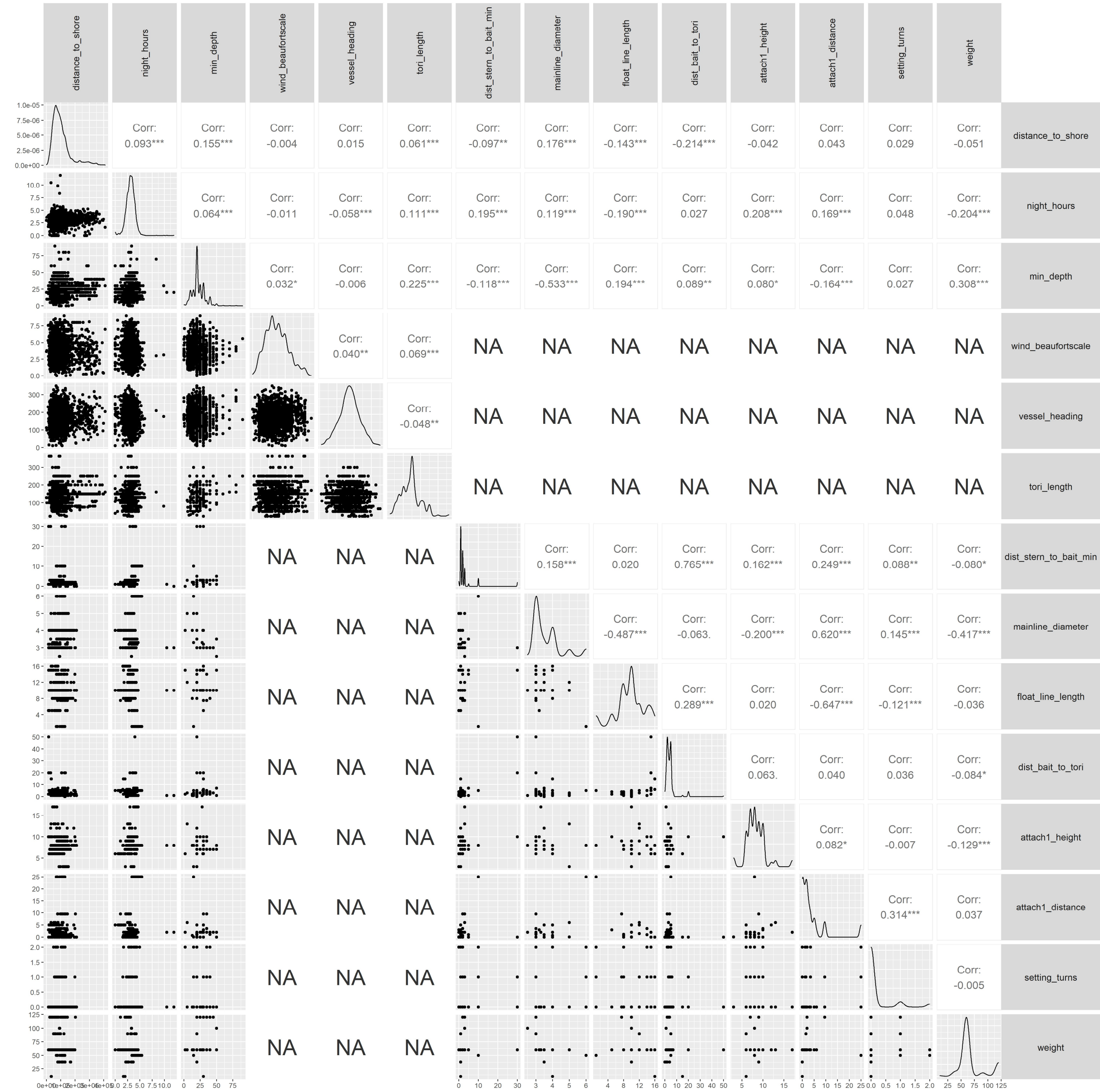

Figure 8: Pairwise comparison of significant additional parameters (Table 16) that were added to top multi-species captures model (model 11; Table 11).

3.4 New Zealand 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 New Zealand fur seals combined. For the different datasets between 4943 and 584 934 models were fitted. Model fitting to New Zealand fur seal captures suggests a relationship between observed New Zealand fur seal captures and fishing year for all datasets (i.e., unpruned and pruned datasets). When fitting models to the unpruned dataset, all top-10 models suggest a relationship of New Zealand fur seal catch rates with the variables fishing year, area, and start month (Table 18). The top model (model 1) also included the variables presence/absence of tori line and bathymetry, and these variables also occurred across most of the remaining top-10 models. Consistently good predictive ability was achieved for the models fitted to unpruned data (Figure 37 in Appendix E), whereas predictive ability was unsatisfactory for most models being fitted to pruned datasets (Figures 39, 41, and 43 in Appendix E). Plotting standardised residuals from model 1 in Table 18 against predictors showed no issues with the model fit (i.e., no obvious patterns were observed; Figure 9).

Table 18: **Top-10 models fitted to New Zealand fur seal captures where model fits included variables with 100% data completeness (unpruned dataset with 2373 fishing events); the total number of explored models was 4943.**

Model	Description	df	logLik	AIC	Δ AIC
1	fishing_year+area+start_month+mitigation_tori+bathymetry	36	-397.383	866.766	0
2	fishing_year+area+start_month+mitigation_tori	35	-399.273	868.546	1.780
3	fishing_year+area+start_month+season+mitigation_tori	35	-399.273	868.546	1.780
4	fishing_year+area+start_month+mitigation_tori+time_of_day	36	-398.336	868.671	1.906
5	fishing_year+area+vessel_freezer+start_month+mitigation_tori	36	-398.502	869.003	2.238
6	fishing_year+area+start_month+bathymetry	35	-399.754	869.508	2.742
7	fishing_year+area+start_month+season+bathymetry	35	-399.754	869.508	2.742
8	fishing_year+area+moon_phase+start_month+mitigation_tori	36	-398.776	869.552	2.786
9	fishing_year+area+start_month+time_of_day+bathymetry	36	-398.919	869.838	3.073
10	fishing_year+area+vessel_nation+start_month+mitigation_tori	36	-399.264	870.528	3.762
Null model	Intercept	2	-512.642	1029.285	162.519

Table 19: **Top-10 models fitted to New Zealand 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	-150.363	336.726	0
2	target+fishing_year+vessel_size+vessel_freezer+distance_to_shore	19	-149.777	337.553	0.827
3	target+fishing_year+vessel_freezer+distance_to_shore	17	-151.794	337.587	0.861
4	target+fishing_year+vessel_freezer+season+distance_to_shore	20	-148.878	337.756	1.030
5	target+fishing_year+vessel_freezer+distance_to_shore+night_hours	18	-150.914	337.828	1.102
6	target+fishing_year+vessel_freezer+distance_to_shore+start_wind_direction	18	-150.918	337.835	1.109
7	target+fishing_year+vessel_freezer+dens+distance_to_shore	18	-150.934	337.868	1.142
8	target+fishing_year+season+distance_to_shore	19	-149.978	337.955	1.229
9	target+fishing_year+mitigation_tori+dens+distance_to_shore	18	-151.083	338.165	1.439
10	target+fishing_year+dens+distance_to_shore+night_hours	18	-151.106	338.212	1.486
Null model	Intercept	2	-198.263	400.526	63.800

Table 20: Top-10 models fitted to New Zealand 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	target+fishing_year+vessel_size+vessel_freezer+vessel_speed	17	-70.747	175.494	0
2	fishing_year+vessel_size+vessel_freezer+vessel_speed+surface_temperature	15	-72.775	175.550	0.056
3	fishing_year+vessel_freezer+distance_to_shore+vessel_speed+surface_temperature	15	-73.158	176.317	0.823
4	target+fishing_year+vessel_freezer+vessel_speed+surface_temperature	17	-71.582	177.165	1.671
5	target+fishing_year+vessel_size+vessel_freezer+baskets_number	17	-71.877	177.755	2.261
6	target+fishing_year+vessel_size+vessel_freezer+mitigation_tori	17	-71.881	177.762	2.2680
7	target+fishing_year+vessel_size+vessel_freezer+surface_temperature	17	-72.002	178.004	2.510
8	fishing_year+vessel_size+vessel_freezer+distance_to_shore+surface_temperature	15	-74.017	178.034	2.540
9	target+fishing_year+vessel_size+vessel_freezer	16	-73.119	178.238	2.744
10	fishing_year+vessel_freezer+vessel_speed+surface_temperature	14	-75.253	178.506	3.011
Null model		2	-113.079	230.158	54.66

Table 21: Top-10 models fitted to New Zealand 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	93.204	0.000
2	target+fishing_year+area+start_wind_direction+bait_stream	20	-26.687	93.373	0.170
3	target+fishing_year+area+night_hours+bait_stream	20	-26.697	93.394	0.190
4	target+fishing_year+area+wind_beaufortscale+bait_stream	20	-26.743	93.487	0.283
5	target+fishing_year+area+distance_to_shore+bait_stream	20	-27.011	94.021	0.817
6	target+fishing_year+start_wind_direction+surface_temperature+bait_stream	16	-31.037	94.074	0.870
7	target+fishing_year+vessel_size+long_streamer_distance+bait_stream	16	-31.115	94.230	1.026
8	target+fishing_year+vessel_freezer+long_streamer_distance+bait_stream	16	-31.121	94.242	1.038
9	target+fishing_year+area+bait_stream	16	-28.182	94.364	1.160
10	target+fishing_year+area+mitigation_tori+bait_stream	19	-28.182	94.364	1.160
Null model		2	-58.457	120.913	27.709

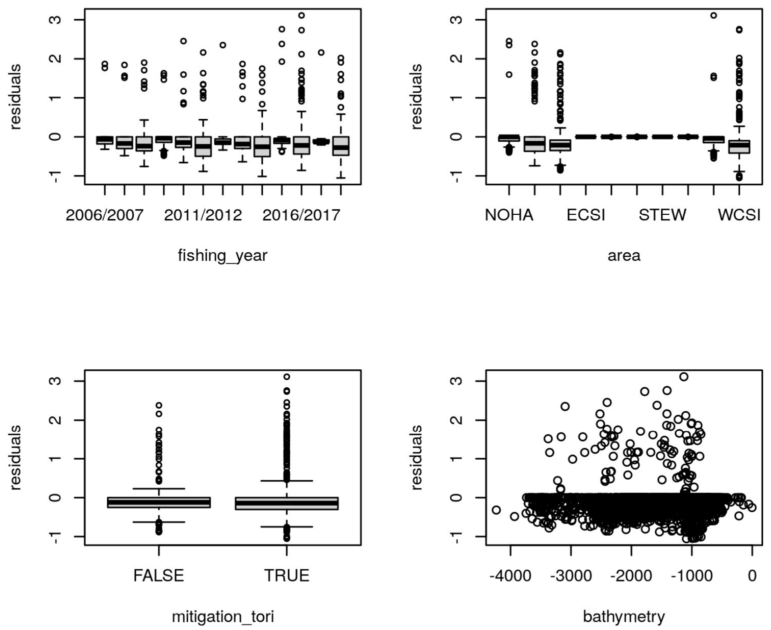

Figure 9: Residuals vs. predictors from top New Zealand fur seal captures model (model 1) where model fits included variables with 100% data completeness (Table 18).

Model estimates (model 1 in Table 18) suggest strong interannual variability in New Zealand fur seal capture rates with proportional changes up to 23.547 (95% CI: 4.319–128.379) in the 2011–12 fishing year (Table 22). Captures of New Zealand 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 capture rate estimates would be close to 0). For areas with New Zealand fur seal captures, the highest capture rate occurred in west coast South Island (WCSI) (proportional change in capture rate: 30.661 (95% CI: 7.701–122.071). New Zealand fur seal captures only occurred between the month April to August, and capture rates increased over that time period (Table 22). The model further shows a proportional increase in capture rates of 2.176 (95% CI: 1.071–4.421) 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 communication with William Gibson, Fisheries New Zealand).

Expanding model 1 in Table 18 by additional variables showed that some gear configuration and fishing behaviour-related variables could affect New Zealand fur seal capture 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, though confidence intervals were also large for this variable. New Zealand fur seal capture rates decreased with an increase in the number of night hours during fishing (proportional change of 0.565 (95% CI: 0.416–0.768) per additional hour of night fishing). Overall, the potential predictor variables shown in Table 23 were not strongly correlated with each other (Figure 10). Some exceptions were gear configuration variables that seem to reflect redundant information, such as the lateral distance from bait entry point to tori line (dist_bait_to_tori) and the minimum distance from stern to bait entry point (dist_stern_to_bait_min) (Pearson correlation coefficient was 0.765; Figure 10). Non-significant parameters are shown in Table 24.

Table 22: Model estimates from top New Zealand 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. *, **, and * refer to significance levels of 0.05, 0.01, and 0.001, respectively. (continued on next page)**

	Estimate	SE	95% CI	exp(estimate) incl. 95% CI	z-value	p-value
(Intercept)	-7.383	1.131	-9.6 – -5.166	0.001 (0 – 0.006)	-6.528	0.000***
fishing_year2007/2008	1.125	0.929	-0.695 – 2.945	3.08 (0.499 – 19.008)	1.212	0.226
fishing_year2008/2009	2.438	0.881	0.711 – 4.165	11.45 (2.036 – 64.402)	2.767	0.006**
fishing_year2009/2010	0.486	0.986	-1.447 – 2.418	1.625 (0.235 – 11.221)	0.493	0.622
fishing_year2010/2011	2.239	0.903	0.469 – 4.009	9.384 (1.598 – 55.118)	2.479	0.013*
fishing_year2011/2012	3.159	0.865	1.463 – 4.855	23.547 (4.319 – 128.379)	3.651	0.000***
fishing_year2012/2013	0.634	1.292	-1.899 – 3.166	1.885 (0.15 – 23.715)	0.491	0.624
fishing_year2013/2014	1.947	0.909	0.165 – 3.729	7.008 (1.179 – 41.655)	2.141	0.032*
fishing_year2014/2015	2.963	0.848	1.302 – 4.624	19.356 (3.675 – 101.951)	3.495	0.000***
fishing_year2015/2016	-0.102	0.978	-2.019 – 1.814	0.903 (0.133 – 6.137)	-0.104	0.917
fishing_year2016/2017	2.185	0.805	0.607 – 3.763	8.891 (1.836 – 43.06)	2.714	0.007**
fishing_year2017/2018	-0.685	1.285	-3.203 – 1.834	0.504 (0.041 – 6.259)	-0.533	0.594
fishing_year2018/2019	3.052	0.823	1.439 – 4.665	21.158 (4.214 – 106.216)	3.707	0.000***
areaBOPL	1.594	0.613	0.393 – 2.795	4.923 (1.481 – 16.367)	2.602	0.009**
areaECNI	2.218	0.635	0.974 – 3.462	9.189 (2.647 – 31.894)	3.494	0.000***
areaECSI	-27.720	7562000.000	-14821547.72 – 14821492.28		0	1.000
areaFIOR	-28.920	15270000.000	-29929228.92 – 29929171.08		0	1.000
areaKERM	-26.720	2398000.000	-4700106.72 – 4700053.28		0	1.000
areaSTEW	-30.800	47450000.000	-93002030.8 – 93001969.2		0	1.000
areaTARI	-30.030	11800000.000	-23128030.03 – 23127969.97		0	1.000
areaWCNI	0.506	0.831	-1.123 – 2.134	1.658 (0.325 – 8.452)	0.609	0.543
areaWCSI	3.423	0.705	2.041 – 4.805	30.661 (7.701 – 122.071)	4.856	0.000***
start_month01	-33.290	5549000.000	-10876073.29 – 10876006.71		0	1.000
start_month02	-34.070	5508000.000	-10795714.07 – 10795645.93		0	1.000
start_month03	-31.680	4453000.000	-8727911.68 – 8727848.32		0	1.000
start_month04	-3.269	0.757	-4.752 – -1.786	0.038 (0.009 – 0.168)	-4.32	0.000***

Table 22: continued.

	Estimate	SE	95% CI	exp(estimate) incl. 95% CI	z-value	p-value
start_month05	-2.376	0.415	-3.189 – -1.563	0.093 (0.041 – 0.21)	-5.725	0.000***
start_month06	-0.857	0.296	-1.437 – -0.277	0.424 (0.238 – 0.758)	-2.898	0.004**
start_month08	0.259	0.410	-0.543 – 1.062	1.296 (0.581 – 2.892)	0.633	0.527
start_month09	-33.250	6146000.000	-12046193.25 – 12046126.75		0	1.000
start_month10	-32.320	6396000.000	-12536192.32 – 12536127.68		0	1.000
start_month11	-30.520	2996000.000	-5872190.52 – 5872129.48		0	1.000
start_month12	-33.430	4818000.000	-9443313.43 – 9443246.57		0	1.000
mitigation_toriTRUE	0.778	0.362	0.069 – 1.486	2.176 (1.071 – 4.421)	2.151	0.031*
bathymetry	0.0005	0.0002	-0.009 – 0.000001	0.956 (0.913 – 1) per 100 m	-1.954	0.051.

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 New Zealand 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 + X_i*: 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 with 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. For binary variables (outcomes are 'Yes' or 'No' with the latter being the base case), the estimated effect for 'Yes' (e.g., for line_entry_yn) is provided.

	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	0.565 (0.416–0.768)	0.887	2308	145	2007–2019
max_depth	840.579	832.809	-7.770	-0.013	0.004	-0.02– -0.005	0.987 (0.98–0.995)	0.852	2216	145	2007–2019
cloud_cover		666.351		0.011	0.004	0.003–0.019	1.011 (1.003–1.019)	0.747	1944	119	2007–2019
snood_signal_time	748.004	737.267	-10.737	0.190	0.047	0.098–0.281	1.209 (1.103–1.325)	0.747	1942	134	2007–2019
light_sticks_yn	161.072	149.522	-11.550					0.116	302	42	2018–2019
Yes				3.759	1.234	1.341–6.177	42.91 (3.824–481.524)				
dist_stern_to_bait_min	161.072	145.892	-15.180	-0.370	0.088	-0.543– -0.197	0.691 (0.581–0.821)	0.116	302	42	2018–2019
mainline_diameter	161.072	140.844	-20.228	-1.160	0.269	-1.688– -0.633	0.313 (0.185–0.531)	0.116	302	42	2018–2019
float_line_length	161.072	152.517	-8.555	0.358	0.087	0.187–0.529	1.43 (1.205–1.697)	0.116	302	42	2018–2019
number_snoods	161.072	155.026	-6.046	1.002	0.264	0.485–1.518	2.723 (1.624–4.565)	0.116	302	42	2018–2019
line_setting_height	161.072	124.963	-36.109	3.595	0.733	2.159–5.031	36.416 (8.66–153.13)	0.116	301	42	2018–2019
dist_bait_to_tori	161.072	140.601	-20.470	-2.788	0.410	-3.592– -1.985	0.062 (0.028–0.137)	0.116	301	42	2018–2019
attach1_distance	161.072	147.571	-13.500	-0.181	0.043	-0.266– -0.097	0.834 (0.767–0.908)	0.115	300	42	2018–2019
light_streamer_yn	161.072	125.325	-35.747					0.115	300	42	2018–2019
Yes				3.856	0.747	2.393–5.32	47.295 (10.947–204.33)				
float_line_diameter	127.172	121.430	-5.742	-0.665	0.292	-1.236– -0.093	0.514 (0.291–0.911)	0.109	284	40	2018–2019
snood_length	127.172	120.521	-6.651	0.843	0.312	0.231–1.454	2.322 (1.26–4.282)	0.109	284	40	2018–2019
aerial_extent	161.072	146.827	-14.245	-0.324	0.060	-0.441– -0.207	0.723 (0.644–0.813)	0.107	278	42	2018–2019
weight	161.072	129.443	-31.629	0.053	0.010	0.033–0.073	1.054 (1.034–1.076)	0.105	272	42	2018–2019
distance_weight_to_hook	161.072	123.391	-37.681	0.022	0.004	0.013–0.03	1.022 (1.014–1.031)	0.105	272	42	2018–2019

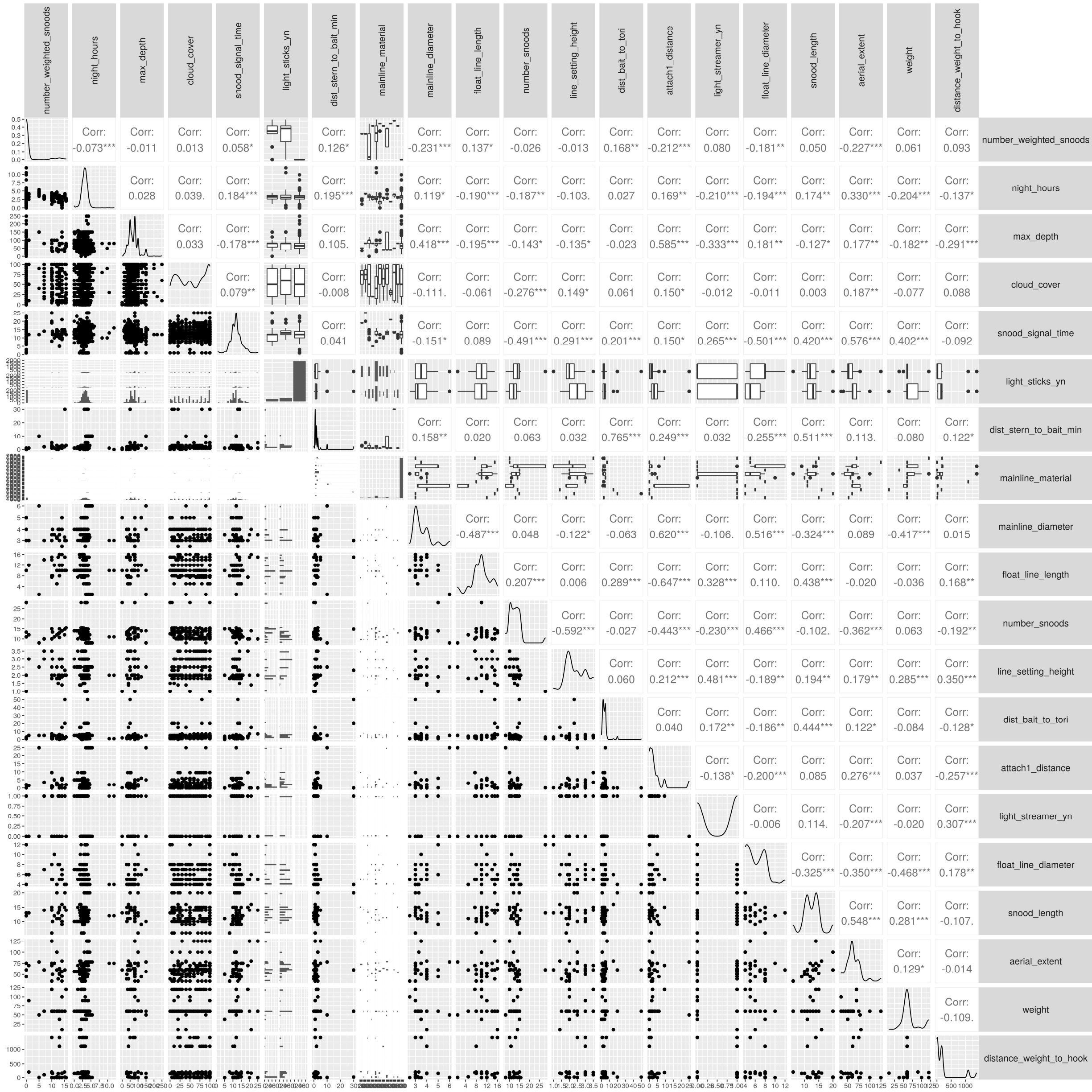

Figure 10: Pairwise comparison of significant additional parameters (Table 23) that were added to top a New Zealand fur seal captures model (model 1; Table 18).

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 New Zealand 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 + X_i*: 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 with 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. For binary variables (outcomes are 'Yes' or 'No' with the latter being the base case), the estimated effect for 'Yes' (e.g., for line_entry_yn) is provided. Blank field for estimates: model failed. (Continued on next page)

	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							0.907	2358	146	2007–2019
line_length	865.802	866.402	0.600	-0.018	0.016	-0.048–0.012	0.982 (0.953–1.012)	0.905	2354	149	2007–2019
distance_to_shore	835.713	836.277	0.564	0.000	0.000	0–0	1 (1–1)	0.888	2309	145	2007–2019
min_depth	841.594	843.159	1.565	0.009	0.013	-0.016–0.035	1.009 (0.984–1.035)	0.869	2260	145	2007–2019
start_wind_direction	768.637	770.347	1.710	-0.001	0.001	-0.003–0.002	0.999 (0.997–1.002)	0.847	2204	130	2007–2019
bait_thrower_used_yn	710.969	712.717	1.747					0.793	2062	107	2007–2018
Yes				0.303	0.619	-0.91–1.517	1.354 (0.402–4.556)				
baskets_number	857.179							0.907	2358	146	2007–2019
wind_beaufortscale	689.089	690.968	1.878	0.027	0.076	-0.121–0.176	1.028 (0.886–1.192)	0.771	2006	103	2007–2018
number_of_vessels	685.288	687.019	1.731	0.026	0.051	-0.075–0.126	1.026 (0.928–1.134)	0.770	2003	104	2007–2018
vessel_speed	641.730	643.481	1.751	-0.069	0.137	-0.337–0.199	0.933 (0.714–1.221)	0.692	1801	95	2007–2018
vessel_heading	629.021	630.372	1.350	-0.002	0.002	-0.006–0.003	0.998 (0.994–1.003)	0.678	1763	94	2007–2018
long_streamer_distance	697.773	699.753	1.980	0.006	0.042	-0.075–0.088	1.006 (0.927–1.092)	0.663	1725	121	2008–2019
surface_temperature	538.382	540.381	1.999	-0.003	0.133	-0.263–0.257	0.997 (0.769–1.293)	0.590	1534	80	2007–2018
tori_length	481.499	482.824	1.325	-0.002	0.003	-0.008–0.003	0.998 (0.992–1.003)	0.525	1365	68	2007–2018
tori_height	481.452	483.064	1.612	0.038	0.059	-0.078–0.154	1.039 (0.925–1.167)	0.524	1364	68	2007–2018
line_entry_yn	481.145	481.881	0.735					0.524	1362	68	2007–2018
Yes				-0.342	0.308	-0.946–0.261	0.71 (0.388–1.298)				
bait_stream	456.934	458.123	1.189	0.059	0.065	-0.067–0.186	1.061 (0.935–1.204)	0.498	1294	65	2007–2018
bottom_depth	160.086	161.976	1.889	0.000	0.001	-0.001–0.002	1 (0.999–1.002)	0.136	355	29	2007–2018

Table 24: continued.

Variable	AIC Model 1	AIC 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
acoustic_bird_deterrent_yn	161.072							0.116	302	42	2018–2019
deck_light_yn	161.072	163.072	2.000					0.116	302	42	2018–2019
Yes				-12.860	27579472.148	-54055778.27–54055752.549	0 (0–Inf)				
fishing_gear_discard_yn	161.072	163.072	2.000					0.116	302	42	2018–2019
Yes				-11.902	22810967.414	-44709508.033–44709484.229	0 (0–Inf)				
attach1_height	161.072	162.577	1.505	0.433	0.305	-0.164–1.03	1.542 (0.849–2.802)	0.115	300	42	2018–2019
long_streamer_yn	161.072	163.072	2.000	-37.081	16740371.622	-32811165.461–32811091.299	0 (0–Inf)	0.115	300	42	2018–2019
Yes											
setting_turns	161.072	163.060	1.988	0.065	0.453	-0.822–0.952	1.067 (0.44–2.591)	0.114	297	42	2018–2019
surface_float_diameter	127.172	129.172	2.000	0.041	104940.264	-205682.877–205682.959	1.042 (0–Inf)	0.109	284	40	2018–2019
long_streamer_aerial_yn	161.072	160.744	-0.328					0.099	258	42	2018–2019
Yes				44.590	11325161.210	-22197271.383–22197360.562	23177183527494164480 (0–Inf)				Yes

3.5 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 6884 and the top-10 models included the variables season, time of the day (day vs. night), presence/absence of vessel freezer, bathymetry, presence/absence of tori line, moon phase, and target (Table 25). None of the 10 top models showed a good predictive ability (see Figure 44 in Appendix F). The top model with lowest AIC included the variables season and time of day (residuals vs. predictor plots shown in Figure 11) with significantly lower captures during winter and night fishing (Table 26). Adding additional parameters from pruned datasets to model 1 shows that the maximum distance between long streamers could increase turtle capture rates (proportional change per metre: 1.129 (95% CI: 1.013–1.258), and that increased capture rates correspond with increased sea surface temperature during fishing (proportional change per degree Celsius: 1.521 (95% CI: 1.147–2.017)) (Table 27). The non-significant parameters from the Phase 2 model fitting are shown in Table 28.

Table 25: Top-10 models fitted to turtle captures where model fits included variables with 100% data completeness (unpruned dataset with 2373 fishing events); the total number of explored models was 6884.

Model	Description	df	logLik	AIC	Δ AIC
1	season+time_of_day	6	-101.896	215.792	0.000
2	season+time_of_day+bathymetry	7	-101.455	216.909	1.117
3	target+time_of_day	7	-101.589	217.177	1.386
4	season+mitigation_tori+time_of_day	7	-101.630	217.261	1.469
5	vessel_freezer+season+time_of_day	7	-101.736	217.473	1.681
6	moon_phase+season+time_of_day	7	-101.804	217.607	1.815
7	vessel_nation+season+time_of_day	7	-101.862	217.723	1.931
8	target+bathymetry:time_of_day	8	-100.878	217.756	1.965
9	target+bathymetry+bathymetry:time_of_day	8	-100.878	217.756	1.965
10	target+season+time_of_day	10	-98.897	217.794	2.003
Null model	Intercept	2	-110.612	225.224	9.432

Table 26: Model estimates from top turtle captures model (model 1) where model fits included variables with 100% data completeness (Table 25). *, **, and * refer to significance levels of 0.05, 0.01, and 0.001, respectively.**

	Estimate	SE	95% CI	Exp(Estimate) incl. 95% CI	z-value	Pr(>|z)
(Intercept)	-2.206	0.666	-3.512– -0.901	0.11 (0.03–0.41)	-3.312	<0.001***
season2	-1.137	0.604	-2.322–0.047	0.321 (0.098–1.05)	-1.882	0.06.
season3	-2.383	0.862	-4.073– -0.693	0.092 (0.017–0.5)	-2.763	0.006**
season4	-1.419	0.891	-3.165–0.327	0.242 (0.042–1.39)	-1.592	0.111
time_of_dayNight	-1.664	0.532	-2.706– -0.622	0.189 (0.067–0.54)	-3.129	0.002**

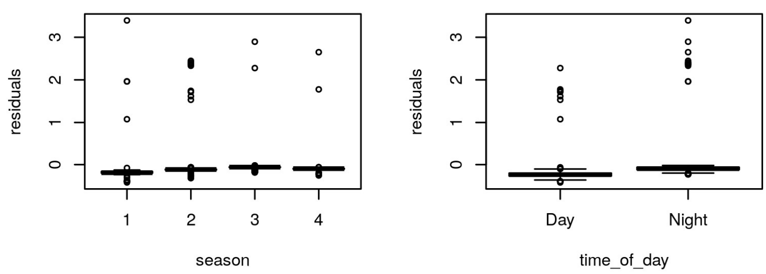

Figure 11: Residuals vs. predictors from top turtle captures model (model 1) where model fits included variables with 100% data completeness (Table 25).

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 with 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.

Variable	AIC		Δ AIC	Estimate	SE	95% CI	Exp(estimate) incl. 95% CI	Prop. events left	N events left	N captures	Year range
	Model 1	Model 1 + X_i									
long_streamer_distance	173.827	171.317	-2.511	0.121	0.0552	0.013–0.229	1.129 (1.013–1.258)	0.663	1725	15	2008–2019
surface_temperature	166.631	160.644	-5.987	0.419	0.1441	0.137–0.702	1.521 (1.147–2.017)	0.590	1534	15	2007–2018

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 with 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. For binary variables (outcomes are 'Yes' or 'No' with the latter being the base case), the estimated effect for 'Yes' (e.g., for line_entry_yn) is provided. Blank field for estimates: model failed. (Continued on next page)

Variable	AIC Model 1	AIC 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	0.0009	0.008	-0.014–0.016	1.001 (0.986–1.016)	0.907	2358	19	2007–2019
line_length	214.871	216.374	1.503	0.012	0.013	-0.013–0.036	1.012 (0.987–1.037)	0.905	2354	19	2007–2019
distance_to_shore	193.434	194.984	1.550	0	0	0–0	1 (1–1)	0.888	2309	17	2007–2019
night_hours	193.428	195.408	1.980	0.042	0.298	-0.542–0.626	1.043 (0.582–1.87)	0.887	2308	17	2007–2019
min_depth	194.626	196.406	1.780	0.012	0.026	-0.039–0.063	1.012 (0.962–1.065)	0.869	2260	17	2007–2019
max_depth	193.418	194.479	1.061	-0.009	0.010	-0.028–0.01	0.991 (0.973–1.01)	0.852	2216	17	2007–2019
start_wind_direction	206.202	205.907	-	0.004	0.003	-0.001–0.009	1.004 (0.999–1.009)	0.847	2204	18	2007–2019
bait_thrower_used_yn	211.220	212.430	1.210					0.793	2062	19	2007–2018
Yes				-22.877	87809.97	-172130.411–172084.657	0 (0–Inf)				
wind_beaufortscale	210.558	212.395	1.837	-0.060	0.146	-0.345–0.226	0.942 (0.708–1.253)	0.771	2006	19	2007–2018
number_of_vessels	210.608	210.271	-	-0.287	0.214	-0.706–0.132	0.75 (0.494–1.141)	0.770	2003	19	2007–2018
cloud_cover	199.832	200.027	0.195	-0.010	0.007	-0.024–0.005	0.99 (0.976–1.005)	0.747	1944	18	2007–2019
snood_signal_time	181.046	182.370	1.324	-0.071	0.085	-0.237–0.096	0.932 (0.789–1.1)	0.747	1942	16	2007–2019
vessel_speed	181.967	183.945	1.978	0.04	0.272	-0.494–0.574	1.041 (0.61–1.775)	0.692	1801	16	2007–2018
vessel_heading	181.556	182.987	1.431	-0.003	0.004	-0.011–0.005	0.997 (0.989–1.005)	0.678	1763	16	2007–2018
tori_length	121.811	123.653	1.842	-0.003	0.007	-0.016–0.011	0.997 (0.984–1.011)	0.525	1365	11	2007–2018
tori_height	121.811	123.766	1.955	0.032	0.154	-0.269–0.333	1.033 (0.764–1.395)	0.524	1364	11	2007–2018
line_entry_yn	121.765	123.347						0.524	1362	11	2007–2018
Yes			1.582	0.4358	0.683	-0.902–1.774	1.546 (0.406–5.895)				
bait_stream	121.423	123.369	1.946	-0.0344	0.157	-0.342–0.273	0.966 (0.71–1.314)	0.498	1294	11	2007–2018
bottom_depth	30.552	32.141	1.589	-0.0012	0.002	-0.006–0.003	0.999 (0.995–1.003)	0.136	355	3	2007–2018
light_sticks_yn								0.116	302	0	2018–2019
dist_stern_to_bait_min								0.116	302	0	2018–2019

Table 28: continued.

Variable	AIC Model 1	AIC 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
acoustic_bird_deterrent_yn								0.116	302	0	2018–2019
deck_light_yn								0.116	302	0	2018–2019
fishing_gear_discard_yn								0.116	302	0	2018–2019
hook_type								0.116	302	0	2018–2019
mainline_material								0.116	302	0	2018–2019
mainline_diameter								0.116	302	0	2018–2019
float_line_length								0.116	302	0	2018–2019
number_snoods								0.116	302	0	2018–2019
line_setting_height								0.116	301	0	2018–2019
setting_path								0.116	301	0	2018–2019
discards_during_setting								0.116	301	0	2018–2019
dist_bait_to_tori								0.116	301	0	2018–2019
attach1_height								0.115	300	0	2018–2019
attach1_distance								0.115	300	0	2018–2019
long_streamer_yn								0.115	300	0	2018–2019
light_streamer_yn								0.115	300	0	2018–2019
setting_turns								0.114	297	0	2018–2019
setting_strategy								0.110	286	0	2018–2019
float_line_diameter								0.109	284	0	2018–2019
surface_float_diameter								0.109	284	0	2018–2019
snood_length								0.109	284	0	2018–2019
aerial_extent								0.107	278	0	2018–2019
weight								0.105	272	0	2018–2019
weighting_type								0.105	272	0	2018–2019
distance_weight_to_hook								0.105	272	0	2018–2019
long_streamer_aerial_yn								0.099	258	0	2018–2019
baskets_number								0.116	302	0	2018–2019
line_length								0.116	302	0	2018–2019

4. WORKSHOP OUTCOME

Date and Time: Wednesday 09 February 2022
Location: Microsoft Teams
Chair: Stefan Meyer (Proteus) William Gibson (Fisheries New Zealand)

Attendees: Anton van Helden, Clinton Duffy, Igor Debski, Jordi Tablaba, Karen Middlemiss, Shannon Weaver, Tiffany Plencner (Department of Conservation); Campbell Murray, Chris Dick, Clara Schlieman, Dominic Vallieres, Heather Benko, Tosin Olateju (Fisheries New Zealand); Dave Goad (Vita Maris); Jack Fenaughty (Sanford); Janice Molloy (Southern Seabirds Trust); Jennifer Devine (National Institute of Water and Atmospheric Research); John Cleal (Deepwater Group); John Wilmer, Rosa Edwards (Fisheries Inshore New Zealand); Sue Maturin (Forest & Bird).

A workshop was held on 09/02/2022, including members from the central government organisations Ministry for Primary Industries (Fisheries New Zealand) and Department of Conservation, industry representatives (e.g., Deepwater Group) and representatives of non-governmental organisations (e.g., Forest & Bird), to discuss 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 which influence protected species captures. Results from the analysis in this report were presented during the meeting and a follow-up discussion was held with a focus on:

1. variables for development of new or improvement of existing mitigation measures, and
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/ORusing line weighting OR
- alternatively, to tori lines, night setting and/or line weighting using hook-shielding devices (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.

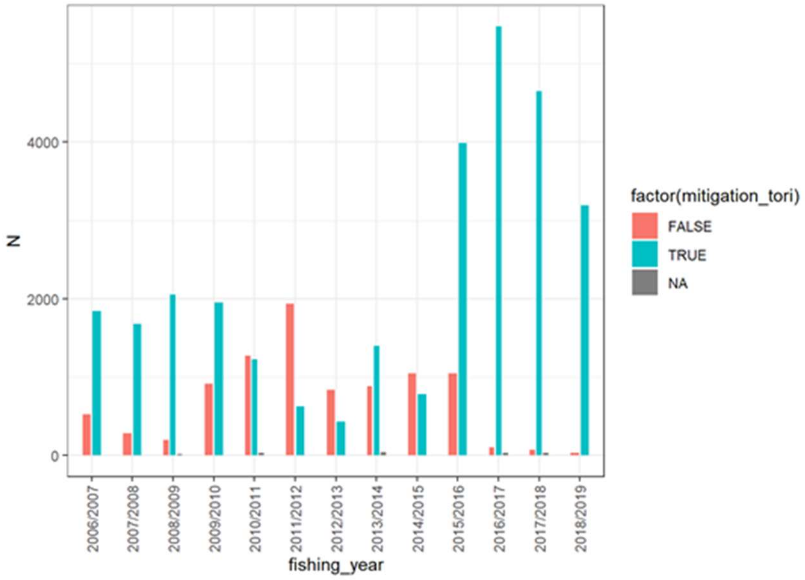

Figure 12: Number of fishing events in PSC database for small-vessel (< 45 m) surface longline fisheries with and without tori lines (including missing records) between the 2006–07 and 2018–19 fishing years.

The distribution of fishing start times in each year are provided in Figure 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. The start time of the fishing event refers to the beginning of the setting process which can take up to several hours (e.g., 3 to 6 hours) (Trygg Mat Tracking and IMCS Network 2021) and is the time with highest seabird interaction and bycatch in longline fisheries (Brothers et al. 2010). Hauling preferably begins during sunrise (Trygg Mat Tracking and IMCS Network 2021). In other words, the variable *time of the day* covers setting during daylight and night and therefore masks the effect of line exposure to seabirds on bycatch, which is highest during daytime. The concept for this variable was that the presence of longlines results in interactions with seabirds but that this risk is reduced during night. 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 line setting on seabird captures.

Figure 13 also shows the number of fishing events using weighted lines since the 2017–18 fishing year. The number of weighted snoods could not be included in the model because 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 an, even if weak, effect on seabird capture rates indicating an effect of this mitigation measure on seabird captures.

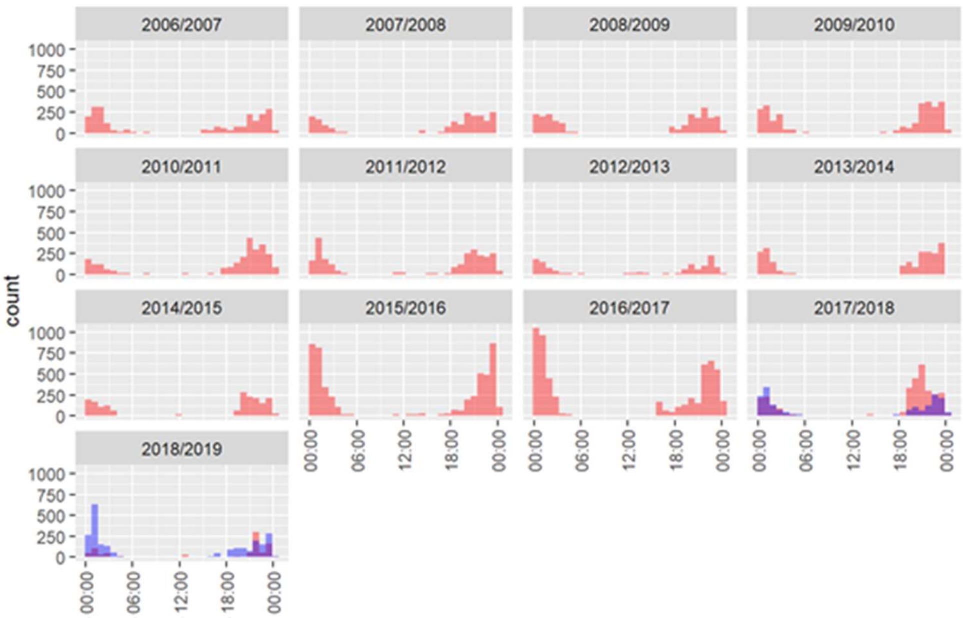

Figure 13: Hourly distribution of fishing events in PSC database for small-vessel (< 45 m) surface longline fishing between the 2006–07 and 2018–19 fishing years; red bars: without weighted line; blue bars: with weighted line.

Tori line setup. Seabirds are known to favourably forage directly behind the vessel and the aerial section (or aerial extent) behind the vessels being covered by the tori line has an influence on counteracting this behaviour. The results in this analysis suggest that the aerial extent had a positive effect on capture rates (i.e., capture rates increased 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 because it is only 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, because 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 of the vessel would allow hooks to be set 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 hook setting than intended, leading to an increased risk of capturing birds. Directly assessing vessel speed during setting was not possible because this variable was recorded during hauling. However, other significant effects exist that support that the sink rate of hooks is an influential factor of seabird captures, such as the distance between weight and hook, and the number of turns during setting.

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 to be 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.

There was consensus that instructions for data collection on observer forms require clarification or simplification 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 therefore be at increased risk of interaction with fishing gear. However, there is no instruction as to what unnecessary deck lighting means and thus recording of this variable 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 the sea is illuminated aft of a vessel). In addition, it was suggested to record whether the vessel deck is sheltered, because this would reduce the amount of deck light reaching the rest of the vessel. A counter-argument against reduced deck lighting was raised; reduced deck lighting could lessen the visibility of tori lines and potentially lead to birds colliding with tori lines, as seen in longline fisheries in South Georgia (Jack Fenaughty pers. comm.).

Further data collection could include comprehensive records of fishing end times, to allow calculation of the fishing duration and number of night hours, which was calculated as the number of night hours between start (beginning of hauling) and end (end of hauling) fishing time. 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 because 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 the need to clarify and/or simplify instructions for collection of specific variables. Further, it was suggested to identify which variables are collected at 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 (for all seabirds model), vessels with a freezer on-board had a higher chance of capturing birds than vessels where freezers were absent. It was suggested that vessel freezers are most likely being used as bait freezers, because the last vessels to use freezers for processed fish were the Japanese charter fleet (which stopped fishing within the New Zealand Exclusive Economic Zone in 2015). In that regard, a request was made during the workshop to summarise bait type and state (whether dyed and/or frozen) for vessels with and without freezers. 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 freezers used undyed bait (Table 30), which could be one reason for increased capture rates (because blue-dyed bait is expected to reduce seabird bycatch due to lowered contrast between bait and surrounding water) 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. Vessels with and without a 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 a freezer; vessel freezer: presence (TRUE) or absence (FALSE) of vessel freezer; bait_1_species, bait_2_species, bait_3_species: bait species one to three (if applicable); bait_1_composition, bait_2_composition, bait_3_composition: percentage of total baited hooks comprising bait 1 species, bait 2 species, and bait 3 species; n_events: number of fishing events in each group; bait species are: arrow squid *Nototodarus sloanii* (SQU), saury *Scomberesox saurus* (SAU), pilchard *Sardinops sagax* (PIL), fish (FIS), undefined squid (SQX) and jack mackerel *Trachurus declivis* JMD .

vessel_freezer	bait_1_species	bait_2_species	bait_3_species	bait_1_composition	bait_2_composition	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 grouped by vessels with and without a freezer; vessel freezer: presence (TRUE) or absence (FALSE) of vessel freezer; bait_1_dyed_yn, bait_2_dyed_yn, bait_3_dyed_yn: whether first, second, and third bait species was dyed (Y: yes, N: No); n_events: number of fishing events in each group.

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 state per bait species grouped by vessels with and without a freezer; vessel freezer: presence (TRUE) or absence (FALSE) of vessel freezer; bait_1_state, bait_2_state, bait_3_state: bait state of first, second and third bait species (T = thawed, S = semi-thawed, and F = frozen). n_events: number of fishing events in each group.**

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

Protected 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 formerly integrated into previous capture estimates. Negative binomial generalised linear models were fitted to observed captures of seabirds, New Zealand 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 assessed in this analysis were predominantly 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., number of night hours). However, many of the variables included here were only recorded sporadically or in recent fishing 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, five datasets with different data completeness (i.e., the more variables were included the fewer observations were available) were created. Each dataset was explored via AIC model selection and results across datasets with different completeness were assessed for consistency. Second, the best-supported model from the first model fitting to complete data from Phase 1 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.

This rather pragmatic two-phase approach only allowed the estimation of the effect of the additional variables given the structure of the top-ranked model fitted to complete data, and other base model structures were not considered. However, results in Phase 1 showed that similar conclusions are obtained when fitting models to data with different completeness (i.e., with varying observations available for model fitting), which indicates that the top AIC-ranked model fitted to complete data includes the main variables for explaining variation in the observed captures of all species assessed in this project.

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 on 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 (there is 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 increasing number of turns during setting leading to higher capture rates and increasing distance between weight and hook lowering capture rates – 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 during setting of the gear.

The results, specifically regarding seabird captures, were discussed during a workshop. A main outcome was the need for specific observer instructions for the collection of gear-specific and bycatch mitigation measure-specific variables. For example, aerial extent, expected to reduce the risk of seabird captures when the extent is increased, is a variable where accuracy strongly depends on the observer's ability to estimate the length of the tori line from the attachment point on 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 during setting, and float 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 as to assessing whether the sea is illuminated 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 hook setting than intended.

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

New Zealand fur seal captures were influenced by factors such as the month of fishing, bathymetry, and whether a 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, the results suggest that this effect was offset by the presence of light sticks resulting in higher fur seal capture rates, 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) and a similar number of fishing events (179 and 123 fishing events with and without light sticks, respectively), but raw capture rates were clearly elevated when light sticks were utilised (on average 0.42 captures per 1000 hooks vs. 0.01 captures per 1000 hooks for events with and without light sticks, respectively). Consequently, there exists potential to impose regulations regarding light stick use to reduce New Zealand fur seal captures in SLL fisheries. Note, that estimates for light stick use were characterised by wide uncertainty because this variable had only been collected very recently (since the 2017–18 fishing year) and more data are needed to get accurate estimates of the effect of light sticks on New Zealand fur seal captures.

Vessels with tori lines deployed appeared to have higher capture rates of New Zealand fur seals. Tori line streamers might act as a visual attractant to fur seals, or as an acoustic cue especially during strong winds (raw capture rates for vessels with tori lines show that capture rates increased from 0.05 to 0.06 to 0.07 captures per 1000 hooks when wind strength increased from low (~ 2 kn.), to medium (~ 4 kn.), to high (~ 7 kn.), respectively). Alternatively, the variable for presence/absence of tori lines could be a proxy for another gear configuration not included in this analysis.

Estimated effect sizes from this work should be interpreted carefully, because some of the variables might not have been collected with a consistent approach. For example, some variables (e.g., whether there existed unnecessary deck lighting) were likely interpreted subjectively by the observer. Furthermore, data collection instructions have sometimes changed throughout years. Also, the low sample size or potential bias of some of the collected variables towards some fraction of the fleet might have impacted estimated effects. Therefore, results here should be interpreted as being indicative and controlled test studies should be implemented for variables of further interest.

While this work has not revealed any novel strategies for bycatch mitigation, it highlights important areas to understand and improve currently employed measures applied in small-vessel SLL fisheries. Data collection regarding the configuration of gear and bycatch mitigation measures requires a mandatory set of variables and clear instructions to reduce the level of subjectivity during data collection. The low level of observation for some species and variables might have biased some of the estimates from this analysis, but detected effects emphasise areas of 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 and rays, and dolphins and 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. ACKNOWLEDGEMENTS

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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

An initial model exploration was carried out to compare results from Bayesian generalised linear models as described by Abraham & Richard (2019) against results based on negative binomial generalised linear models using the glm.nb function using the MASS-package in R (Venables & Ripley 2002).

Adopting the modelling approach of Abraham & Richard (2019), the mean catch rate (μ_i) for a single fishing event *i* 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 ***X*** being a matrix of fixed effects for fishing event *i*. Fixed effects that were fitted in this preliminary assessment were:

1. Area (see Figure 3)
2. Bathymetry
3. Fishing year
4. Fishery management area (FMA)
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) (Figure 14).

Models were fitted separately to each bird species, New Zealand fur seals and to groups of turtles, dolphins & whales, and sharks & rays. First, for each species (group) 13 models were fit separately for each variable and an intercept model. Then, models were ranked using AIC (for negative binomial genarelised linear models using the glm.nb function) and the theoretical expected log pointwise predictive density (ELPD) based on leave-one-out (LOO) cross-validation (for negative Bayesian generalised linear model fitting). For negative binomial generalised linear models, the top model was compared against the intercept model and carried into another iteration of model fitting if the AIC difference between both models was 10 (very strong support to include variable). Similarly, for Bayesian generalised linear models each model with fixed effect included was compared against the intercept model and the model with lowest elpd_loo was carried forward if the difference in elpd_diff between models was larger than twice the standard error of the elpd_diff between both models. The top models from the negative binomial generalised linear model fitting and negative Bayesian generalised linear model fitting were then carried forward into a second model fit where a second variable was included from the set of unselected variables and again assessed via AIC and ELPD. This procedure was repeated until there was no further support to include more variables.

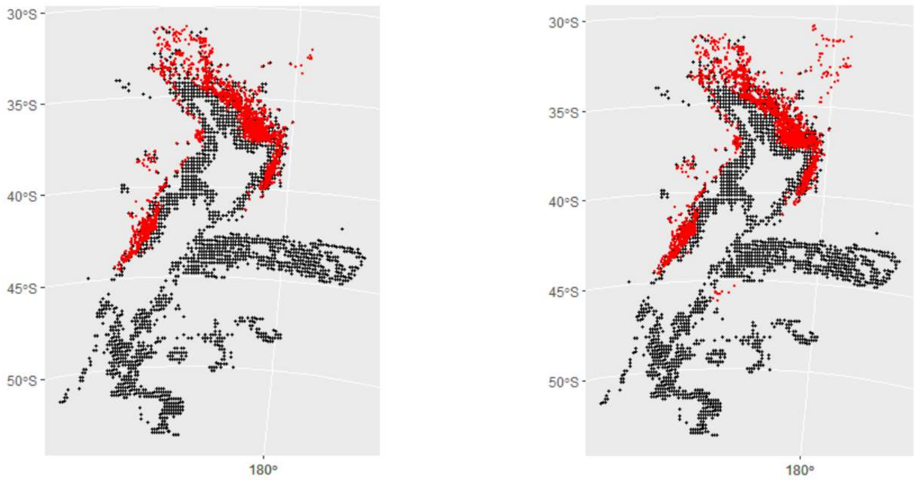

Figure 14: Comparison of observed fishing event locations for small vessel surface longline fisheries (black; domestic and Australian) vs. locations of 'Seabirds around vessels' data (red) for all fishing methods (fishing years for both datasets ranging from 2007–08 to 2017–18; left panel). RHS panel: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

Overall, similar results were obtained when either fitting negative binomial generalised linear models or Bayesian generalised linear models to observed captures, although model fits failed in some cases (only for species with low numbers of observed captures) (Table 33). For example for black petrels the inclusion of a season term was supported in both model fits, although negative binomial GLM fitting also included the variable black petrel mean counts. Both models fitted to Buller's albatross captures included the variables FMA, moon phase, and target. Similarly, the same variables (FMA and moon phase) were included for both models fitted to captures of white-capped albatrosses.

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

Species	Based on negative binomial generalised linear models	Based on Bayesian generalised linear models
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	Failed model fit	NULL MODEL
Other albatrosses	Start month + moon phase + area + solar altitude	Start month + moon phase
Other birds	FMA	FMA
Salvin's albatross	Failed model fit	NULL MODEL
Sooty shearwater	Failed model fit	Failed model fit
White-capped albatross	FMA + moon phase	FMA + moon phase
White-chinned petrel	Start month + FMA	Start month
Dolphins and whales	Failed model fit	NULL MODEL
Turtles	Start solar altitude	NULL MODEL
New Zealand fur seals	Start month + fishing year + area	Season
Sharks and rays	Failed model fit	NULL MODEL

APPENDIX C: PREDICTIVE CHECKING FOR ALL SEABIRD CAPTURES MODEL

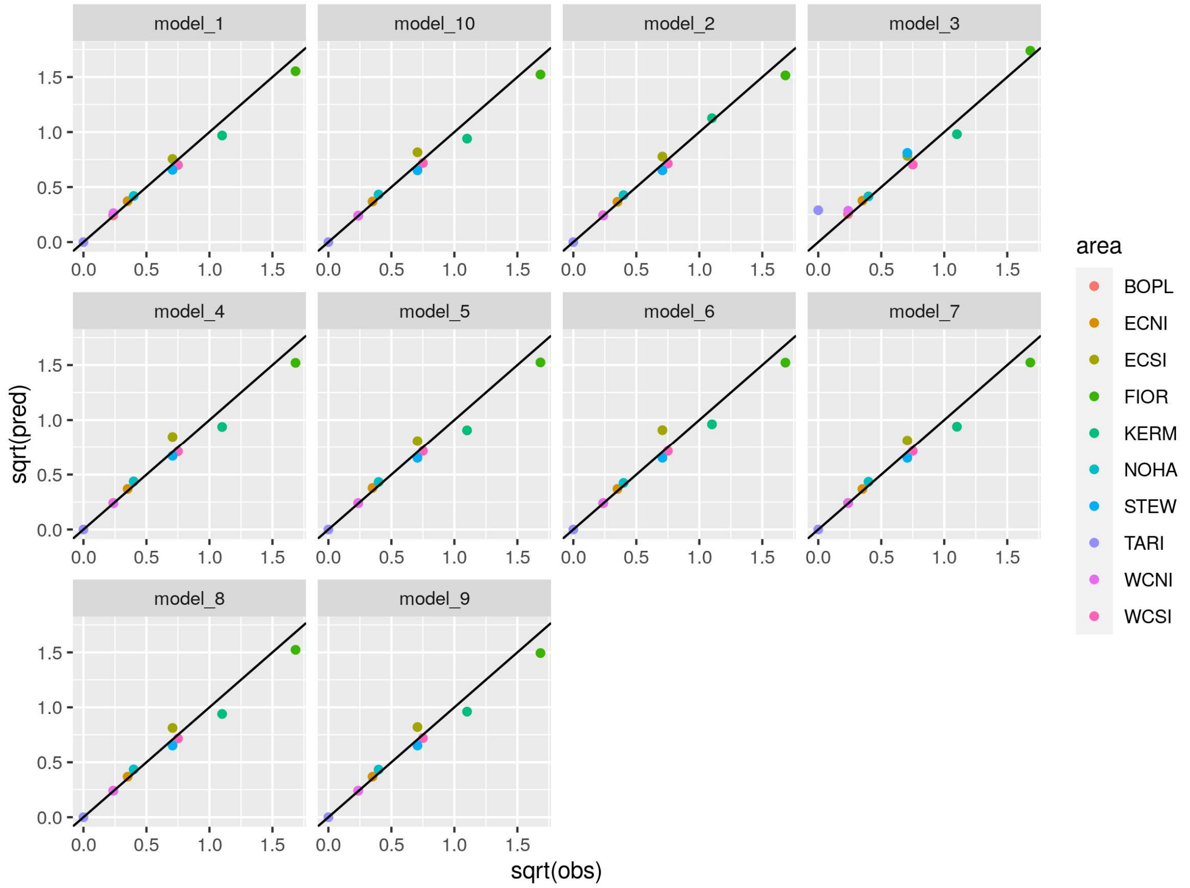

Figure 15: Mean square-root predicted (sqrt(pred)) vs. mean square-root observed (sqrt(obs)) captures in each area for top-10 models fitted to all seabird captures where model fits included variables with 100% data completeness (Table 4).

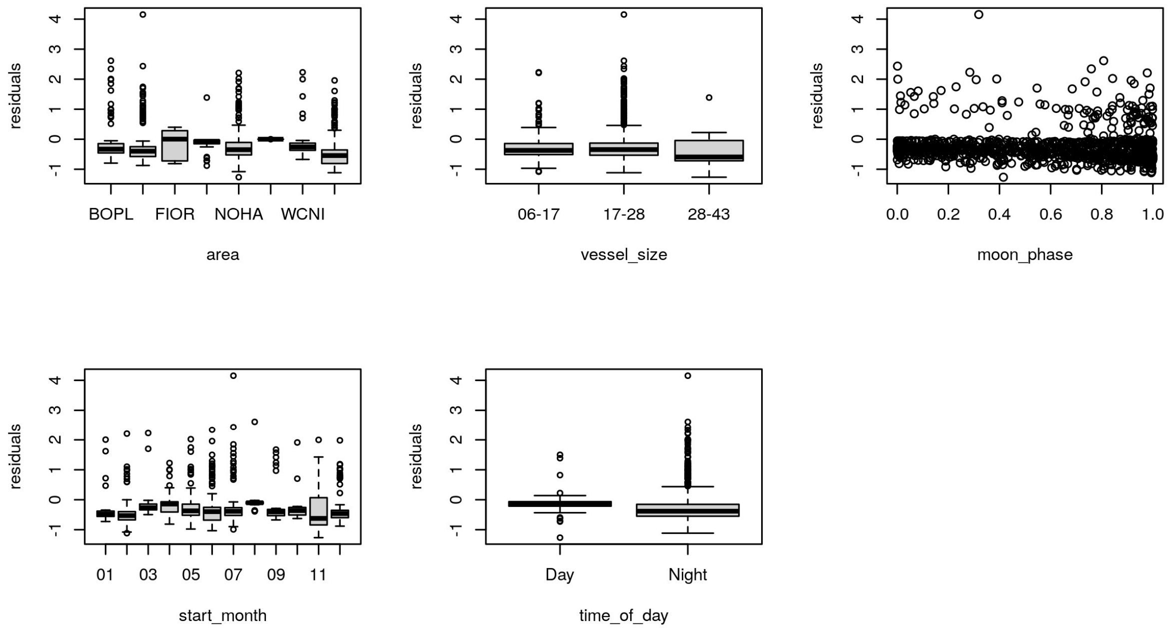

Figure 16: Residuals vs. predictors from top all seabird captures model (model 1) where model fits included variables with ≥ 75% data completeness (Table 5).

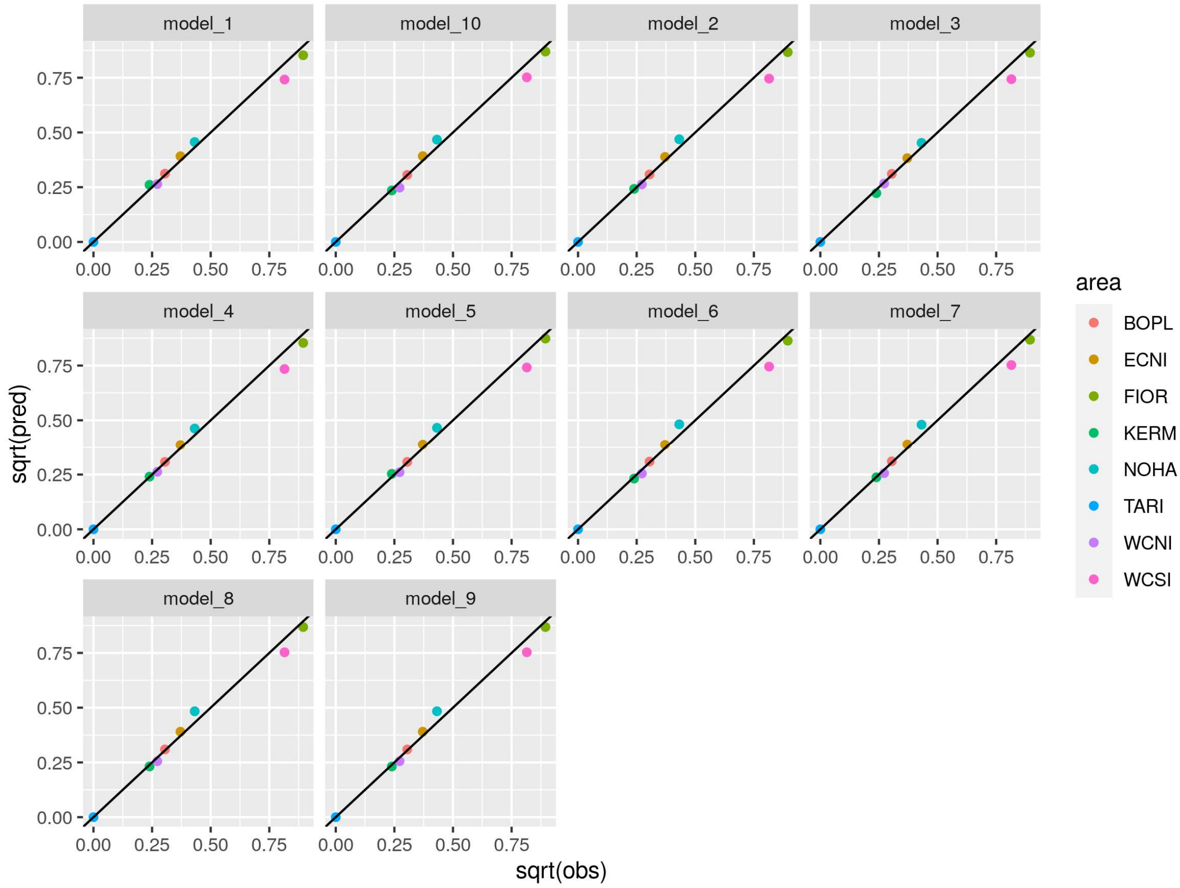

Figure 17: Mean square-root predicted (sqrt(pred)) vs. mean square-root observed (sqrt(obs)) captures in each area for top-10 models fitted to all seabird captures where model fits included variables with ≥ 75% data completeness (Table 5).

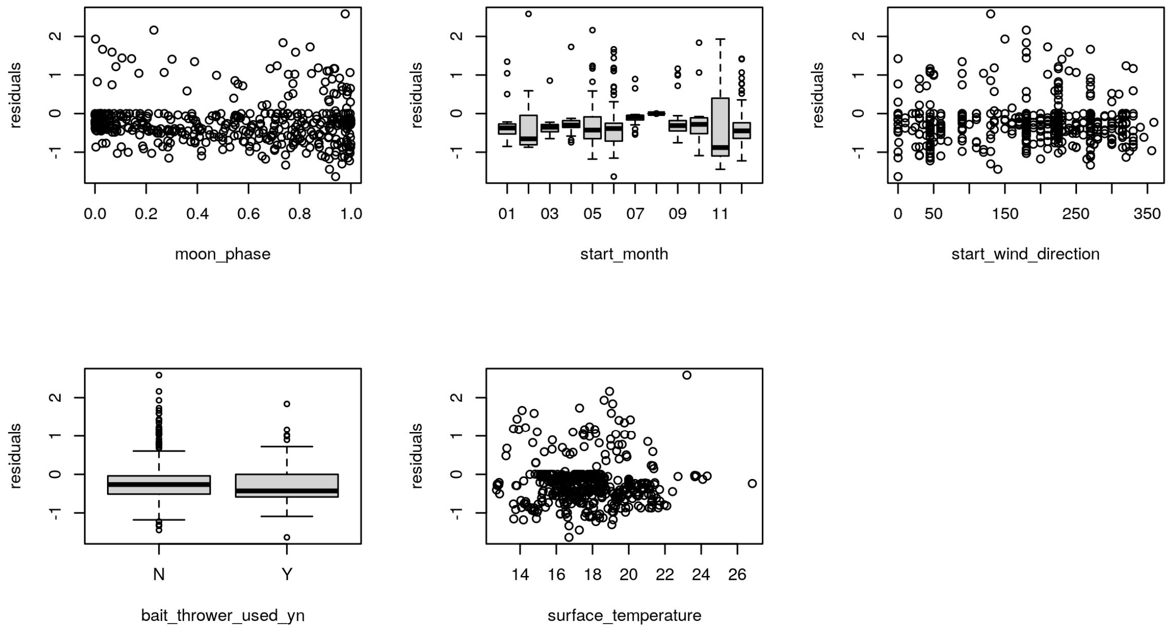

Figure 18: Residuals vs. predictor variables from top all bird captures model (model 1) where model fits included variables with ≥ 60% data completeness.

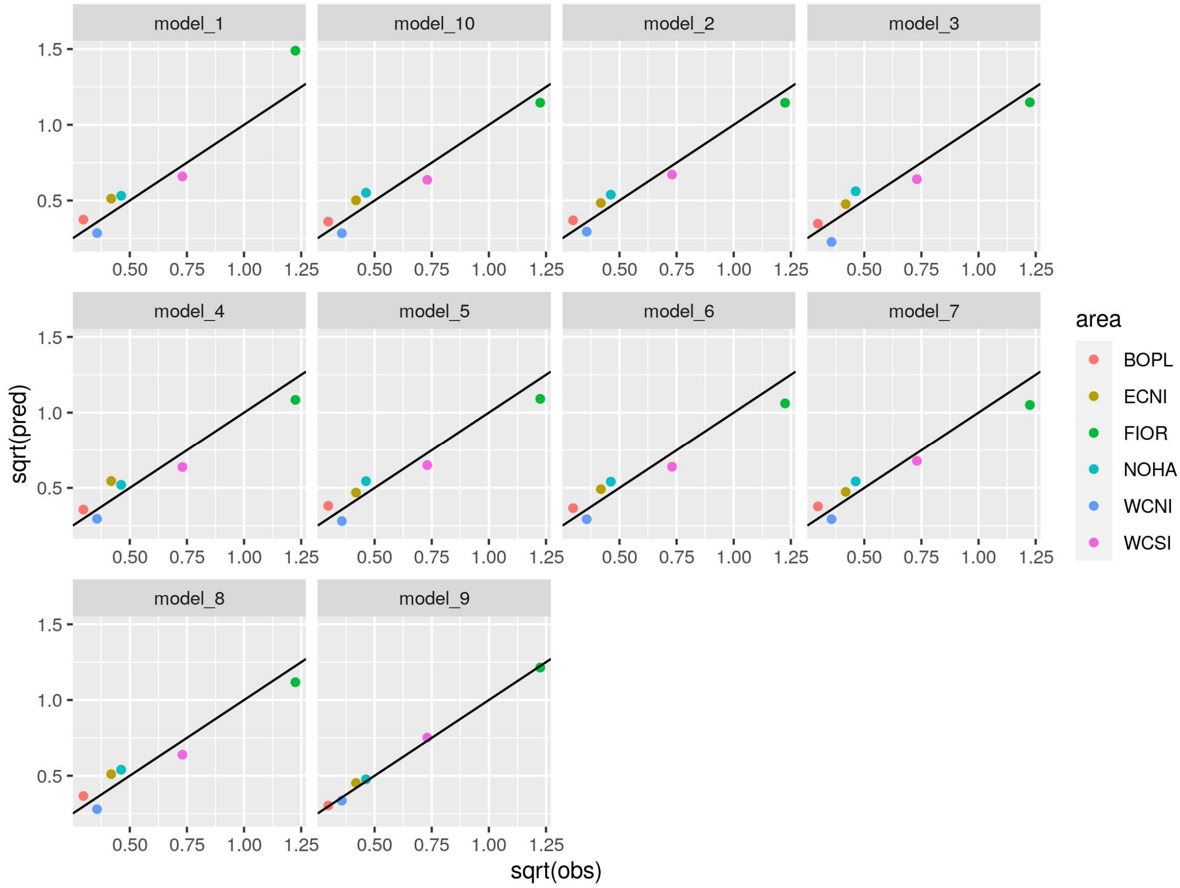

Figure 19: Mean square-root predicted (sqrt(pred)) vs. mean square-root observed (sqrt(obs)) captures in each area for top-10 models fitted to all seabird captures where model fits included variables with ≥ 60% data completeness (Table 6).

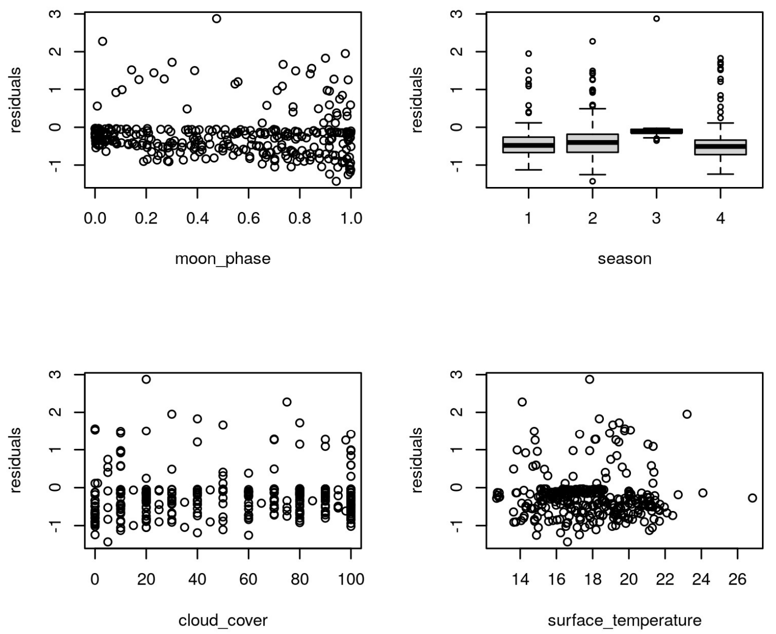

Figure 20: Residuals vs. predictor variables from top all bird captures model (model 1) where model fits included variables with ≥ 20% data completeness.

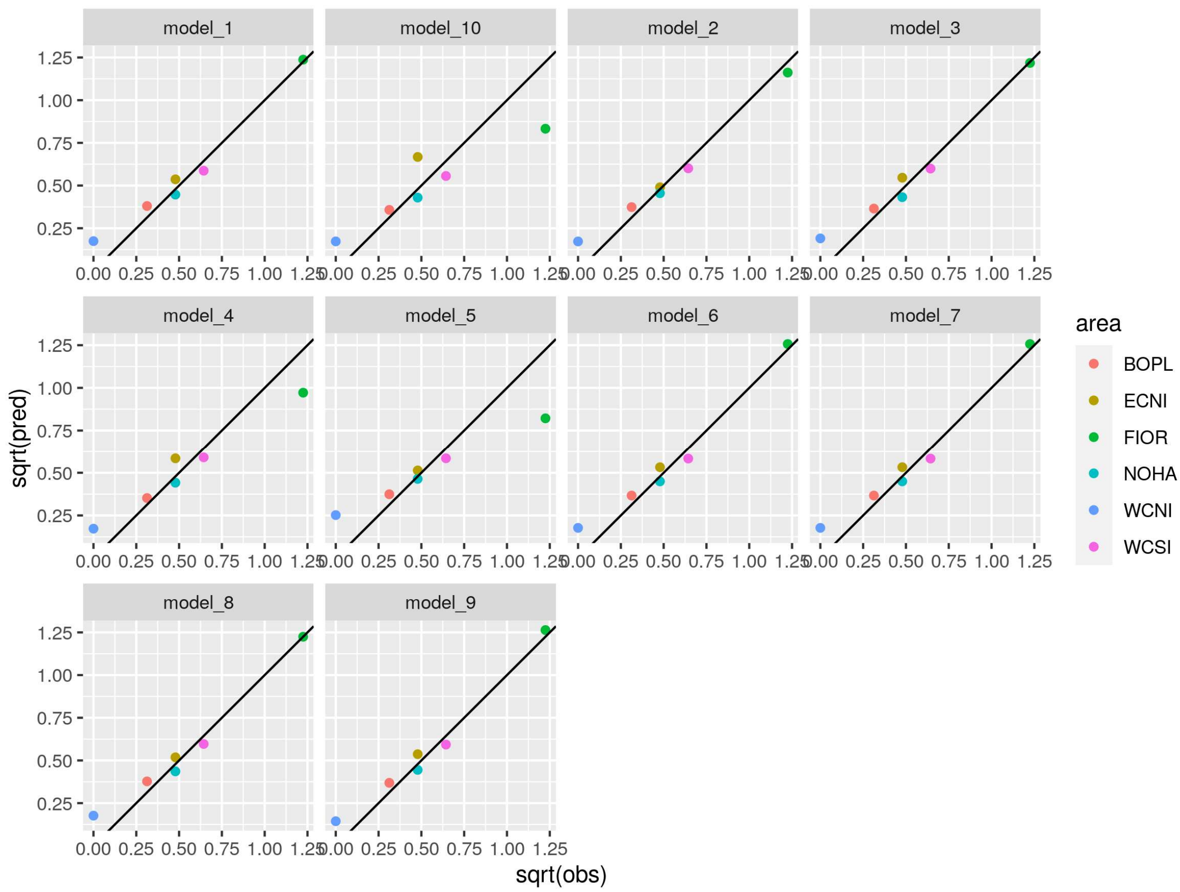

Figure 21: Mean square-root predicted (sqrt(pred)) vs. mean square-root observed (sqrt(obs)) captures in each area for top-10 models fitted to all seabird captures where model fits included variables with ≥ 20% data completeness (Table 7).

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

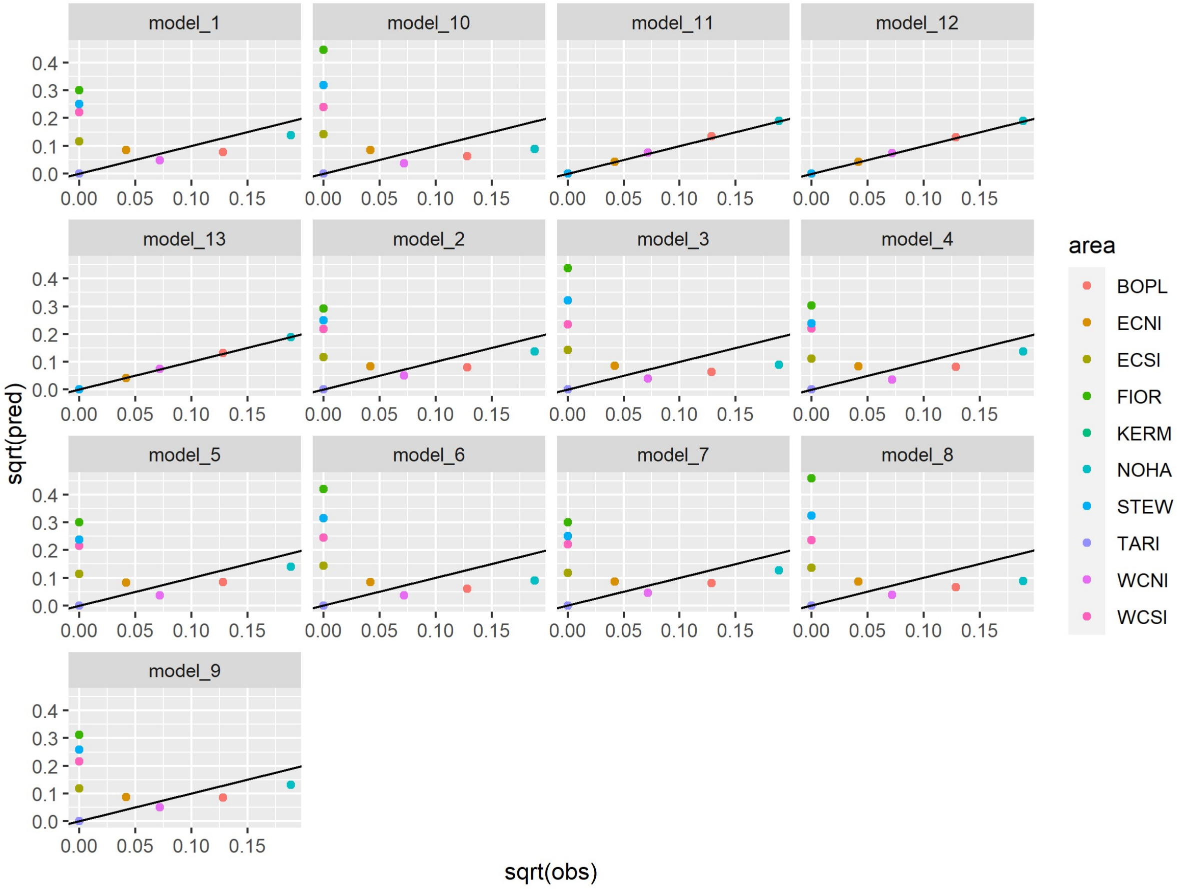

Figure 22: Mean square-root predicted (sqrt(pred)) vs. mean square-root observed (sqrt(obs)) observed black petrel captures in each area for top-13 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with 100% data completeness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

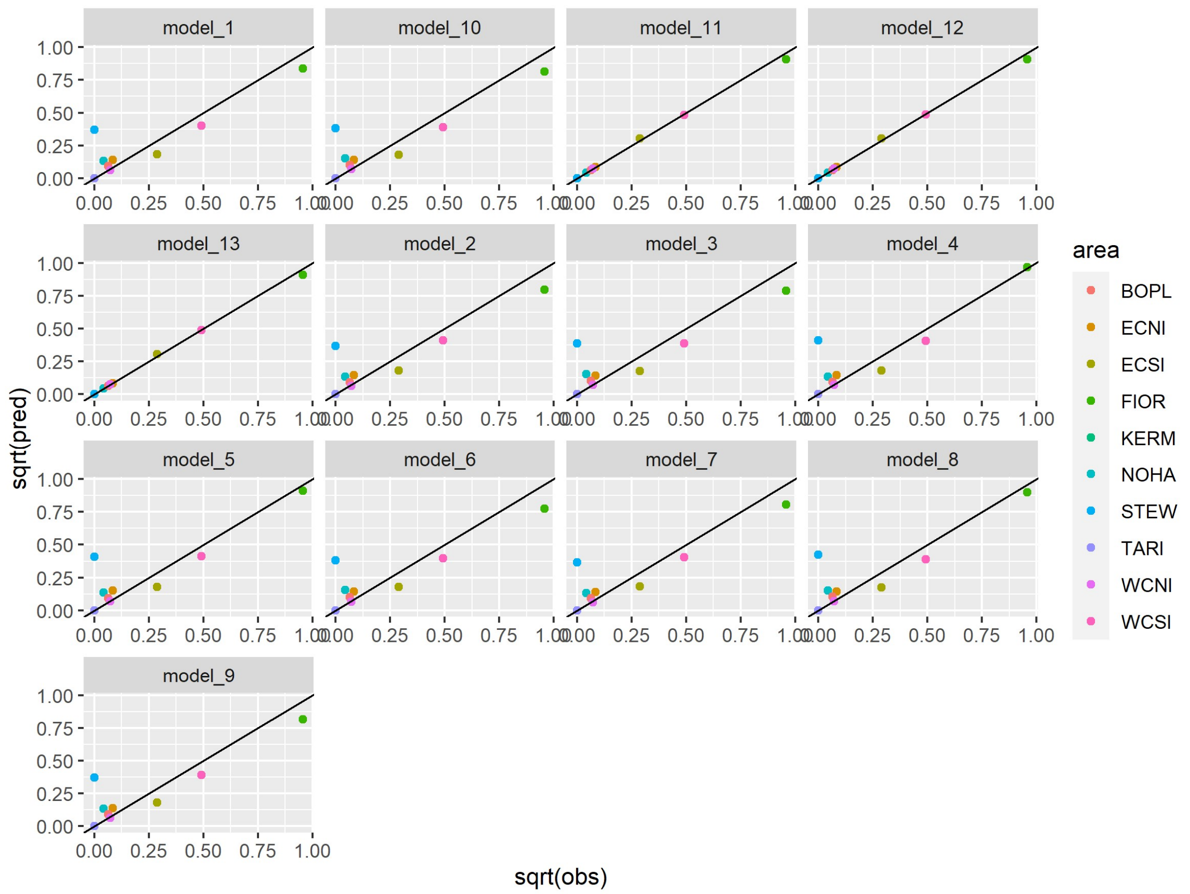

Figure 23: Mean square-root predicted (sqrt(pred)) vs. mean square-root observed (sqrt(obs)) white-capped albatross captures in each area for top-13 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with 100% data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

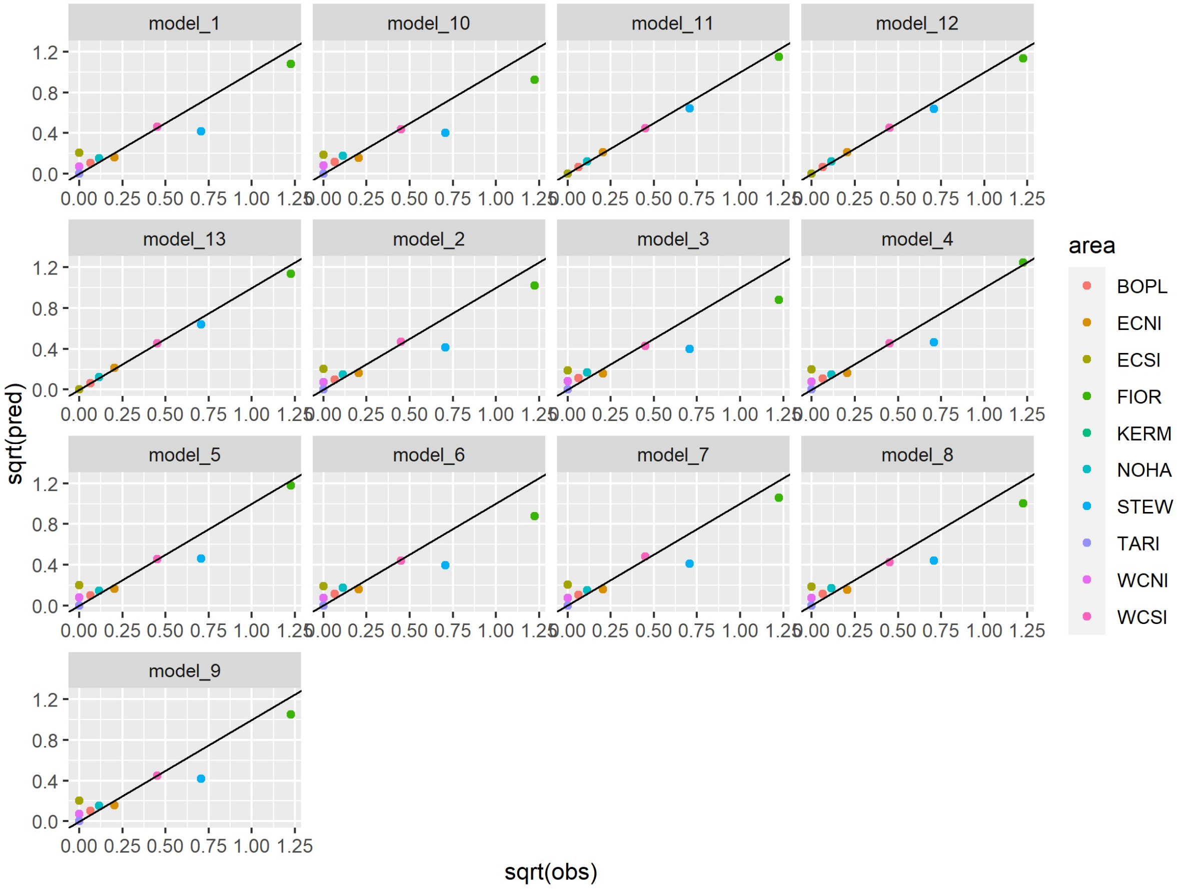

Figure 24: Mean square-root predicted (sqrt(pred)) vs. mean square-root observed (sqrt(obs)) Buller's albatross captures in each area for top-13 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with 100% data completeness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

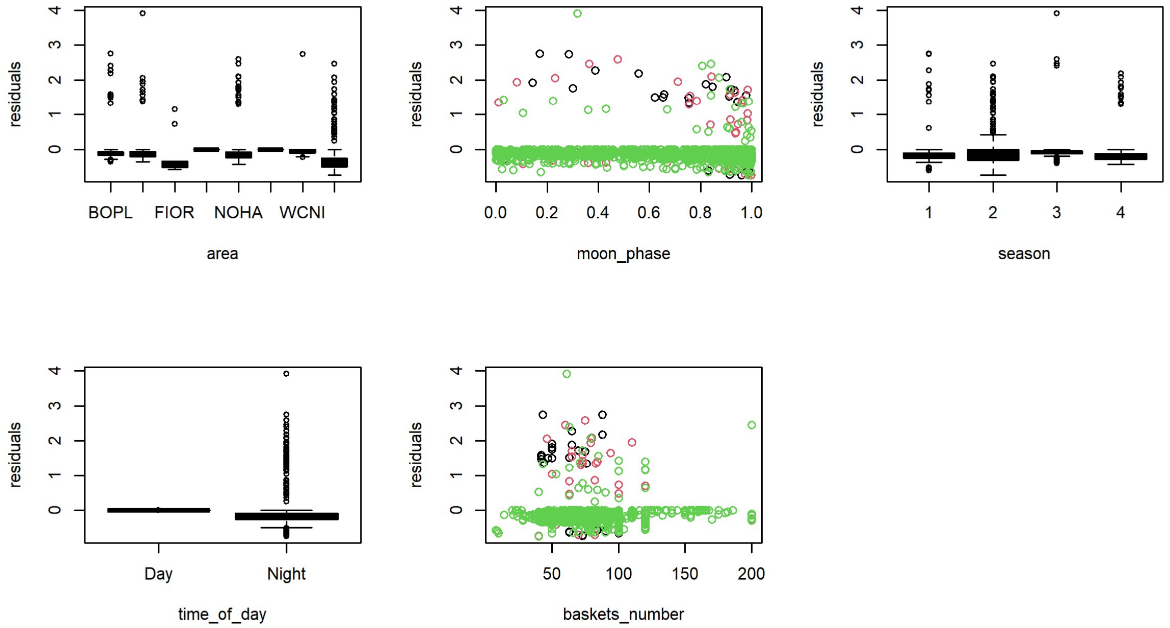

Figure 25: Residuals vs predictors from top multi-species seabird captures model (model 1) where model fits included variables with ≥ 75% data completeness (Table 12).

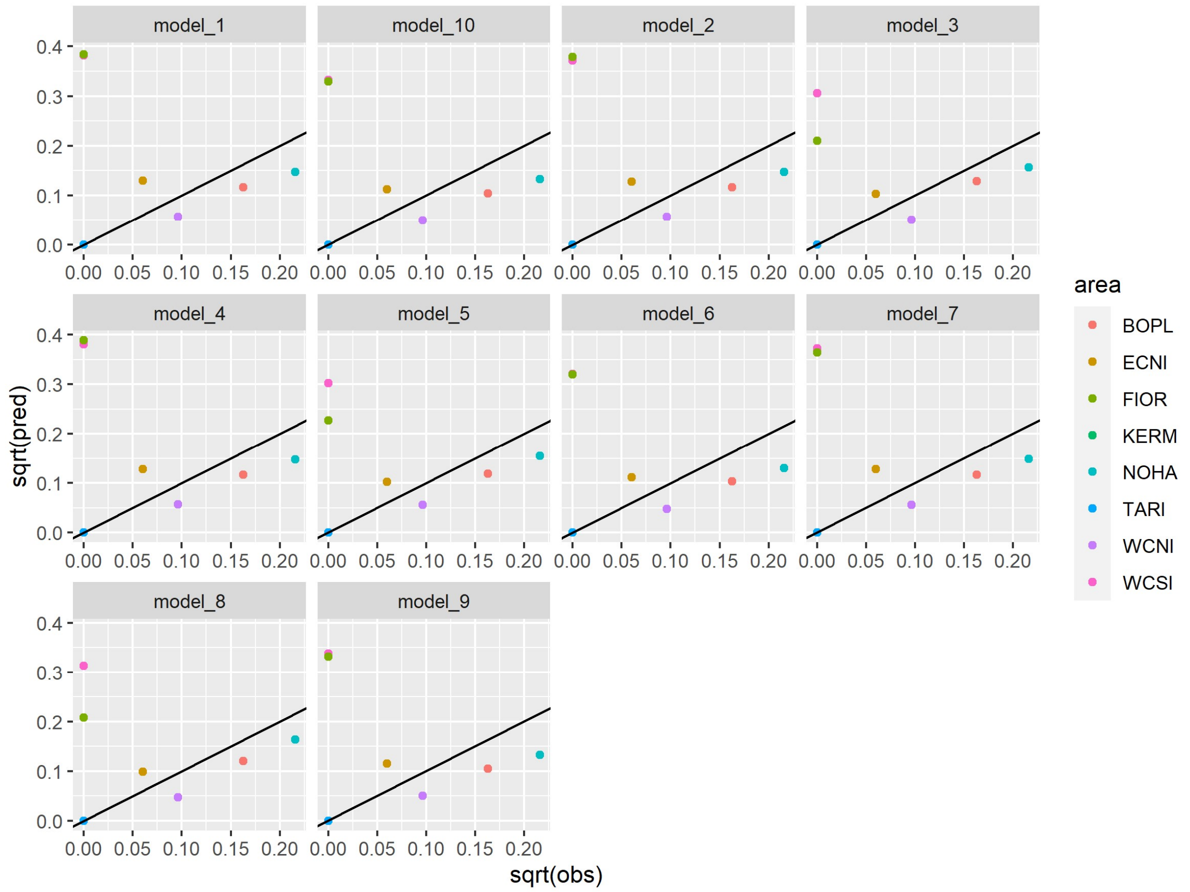

Figure 26: Mean square-root predicted (sqrt(pred)) vs. mean square-root observed (sqrt(obs)) black petrel captures in each area for top-10 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with ≥ 75% data completeness (Table 12).

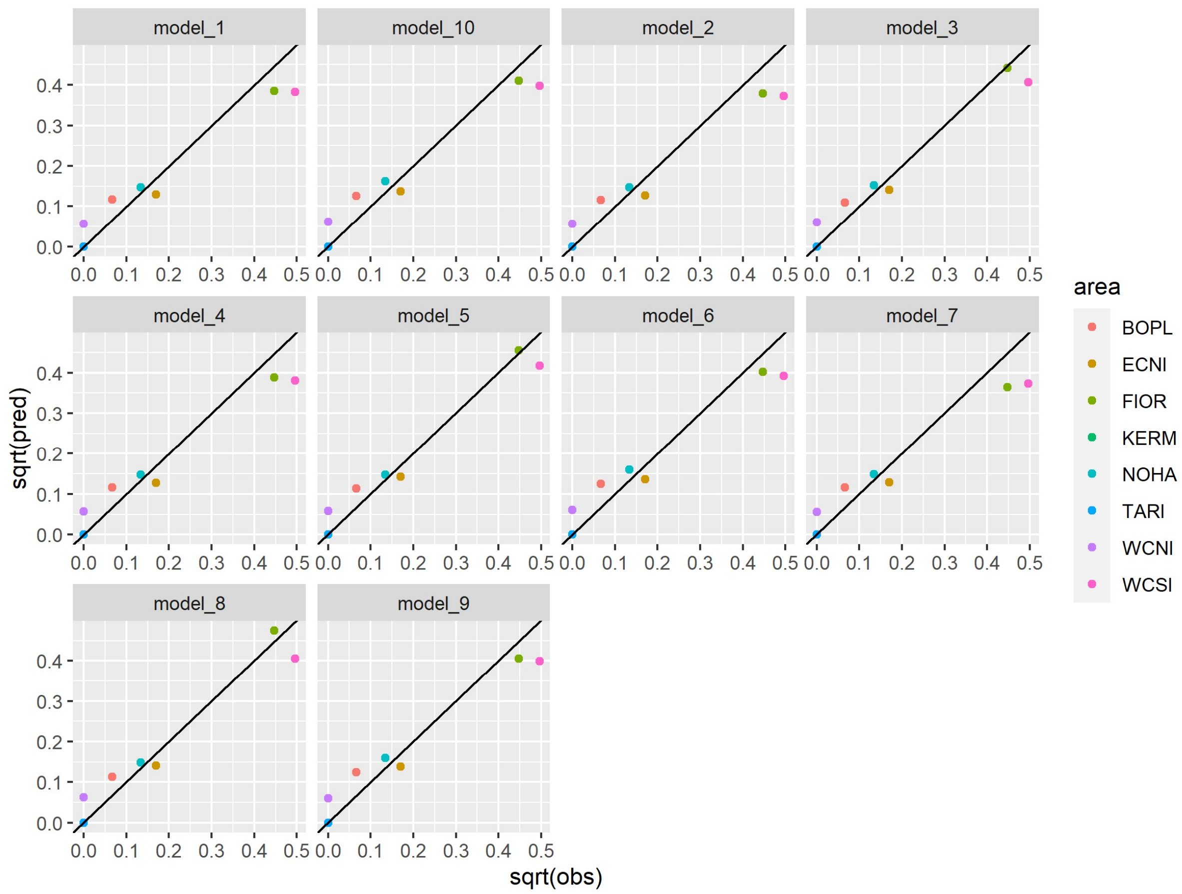

Figure 27: Mean square-root predicted (sqrt(pred)) vs. mean square-root observed (sqrt(obs)) Buller's albatross captures in each area for top-10 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with ≥ 75% data completeness (Table 12).

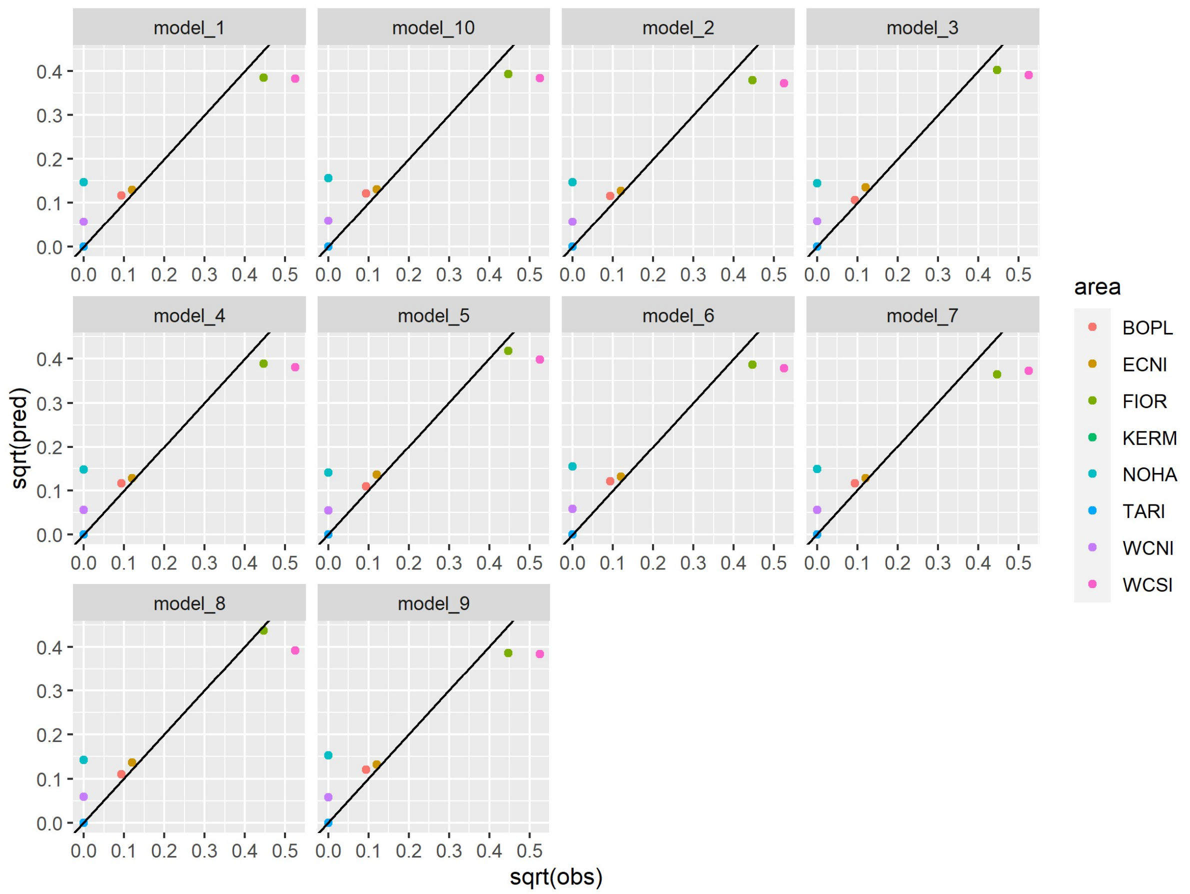

Figure 28: Mean square-root predicted (sqrt(pred)) vs. mean square-root observed (sqrt(obs)) white-capped albatross captures in each area for top-10 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with ≥ 75% data completeness (Table 12).

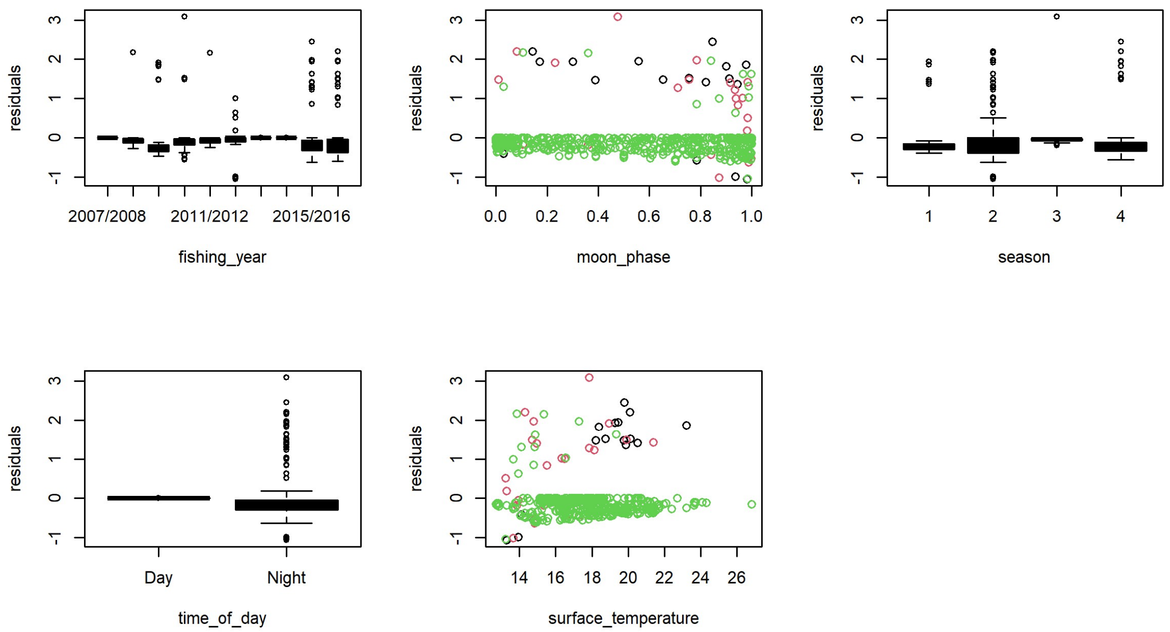

Figure 29: Residuals vs predictors from top multi-species seabird captures model (model 1) where model fits included variables with ≥ 60% data completeness (Table 13).

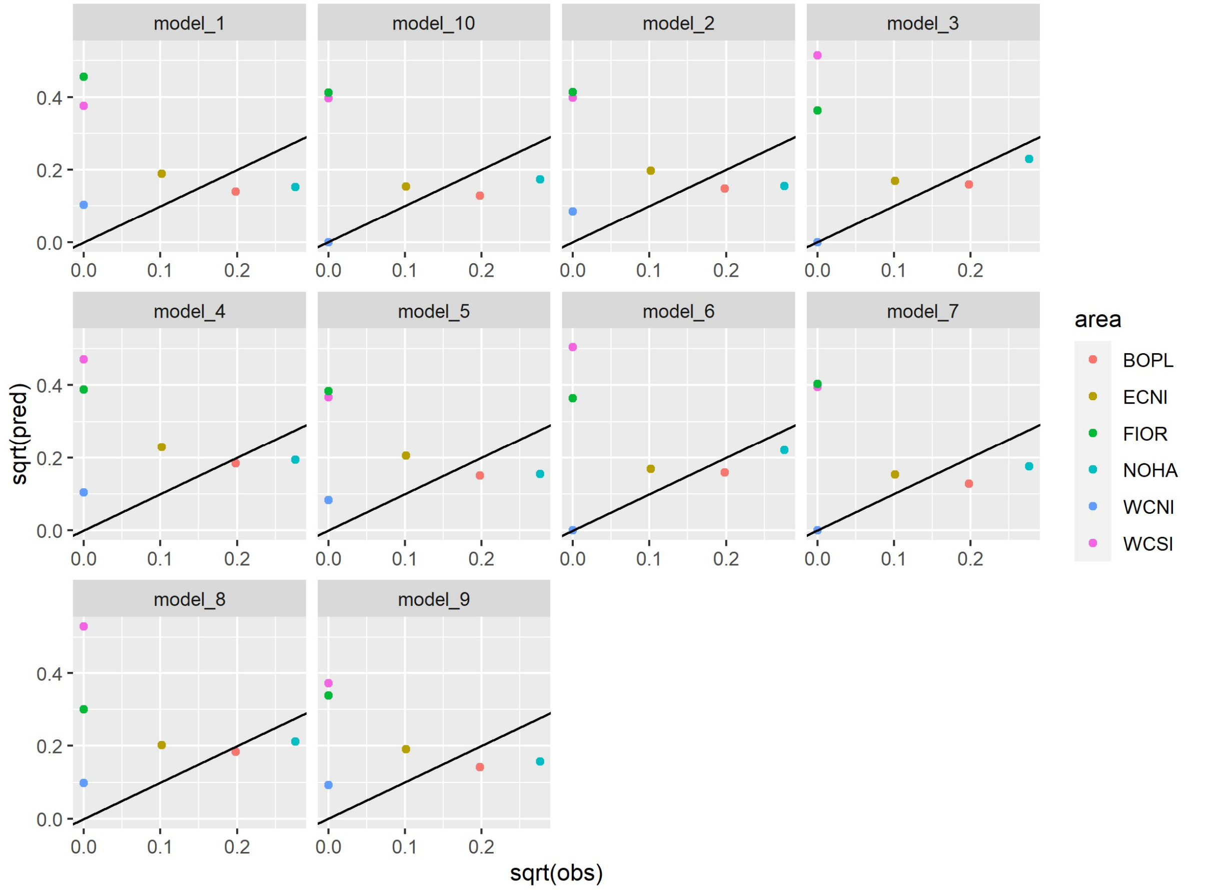

Figure 30: Mean square-root predicted (sqrt(pred)) vs. mean square-root observed (sqrt(obs)) black petrel captures in each area for top-10 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with ≥ 60% data completeness (Table 13).

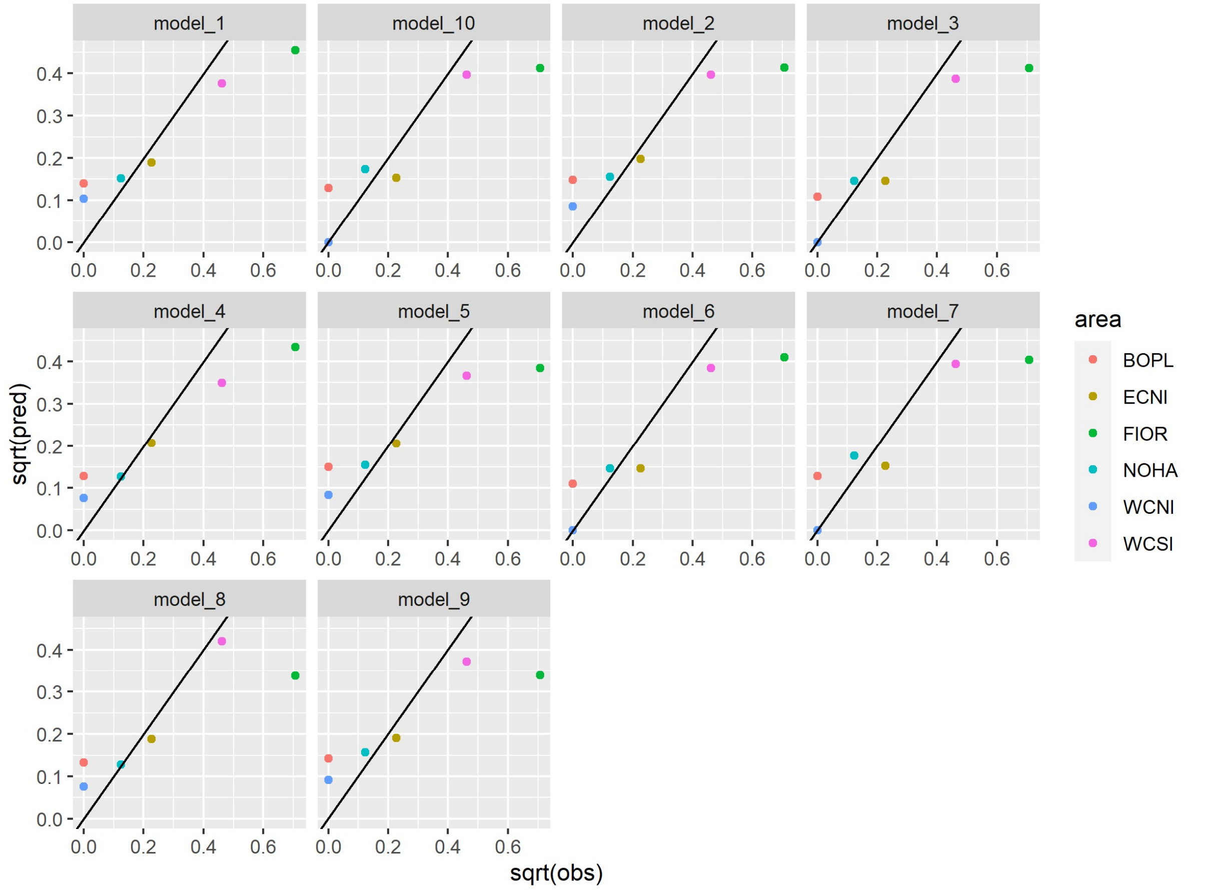

Figure 31: Mean square-root predicted (sqrt(pred)) vs. mean square-root observed (sqrt(obs)) Buller's albatross captures in each area for top-10 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with ≥ 60% data completeness (Table 13).

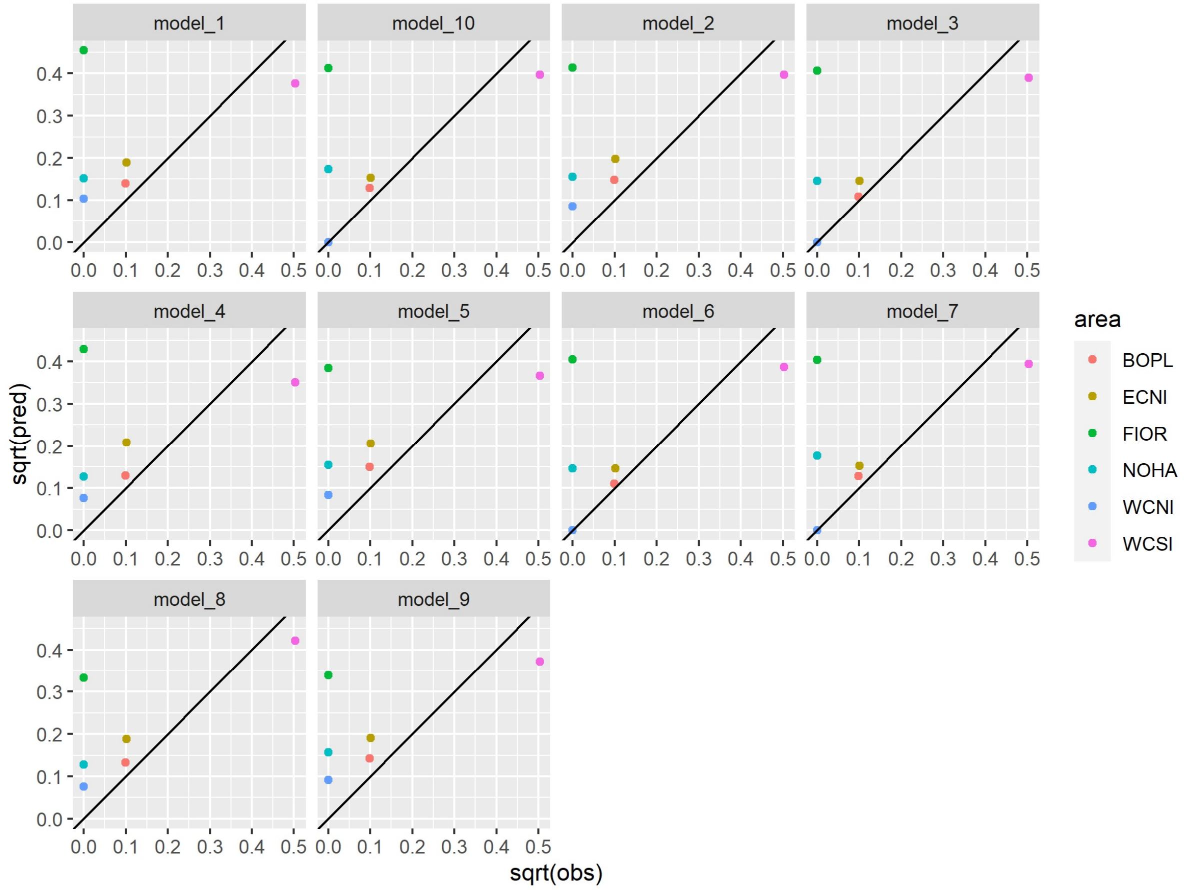

Figure 32: Mean square-root predicted (sqrt(pred)) vs. mean square-root observed (sqrt(obs)) white-capped albatross captures in each area for top-10 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with ≥ 60% data completeness (Table 13).

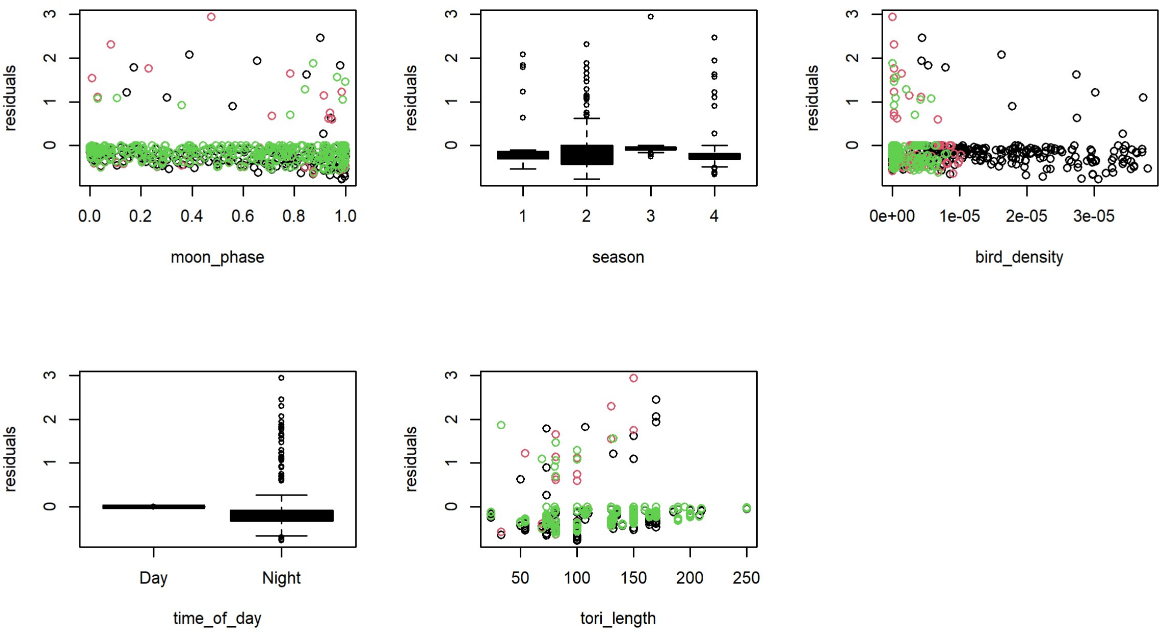

Figure 33: Residuals vs predictors from top multi-species seabird captures model (model 1) where model fits included variables with ≥ 20% data completeness (Table 14).

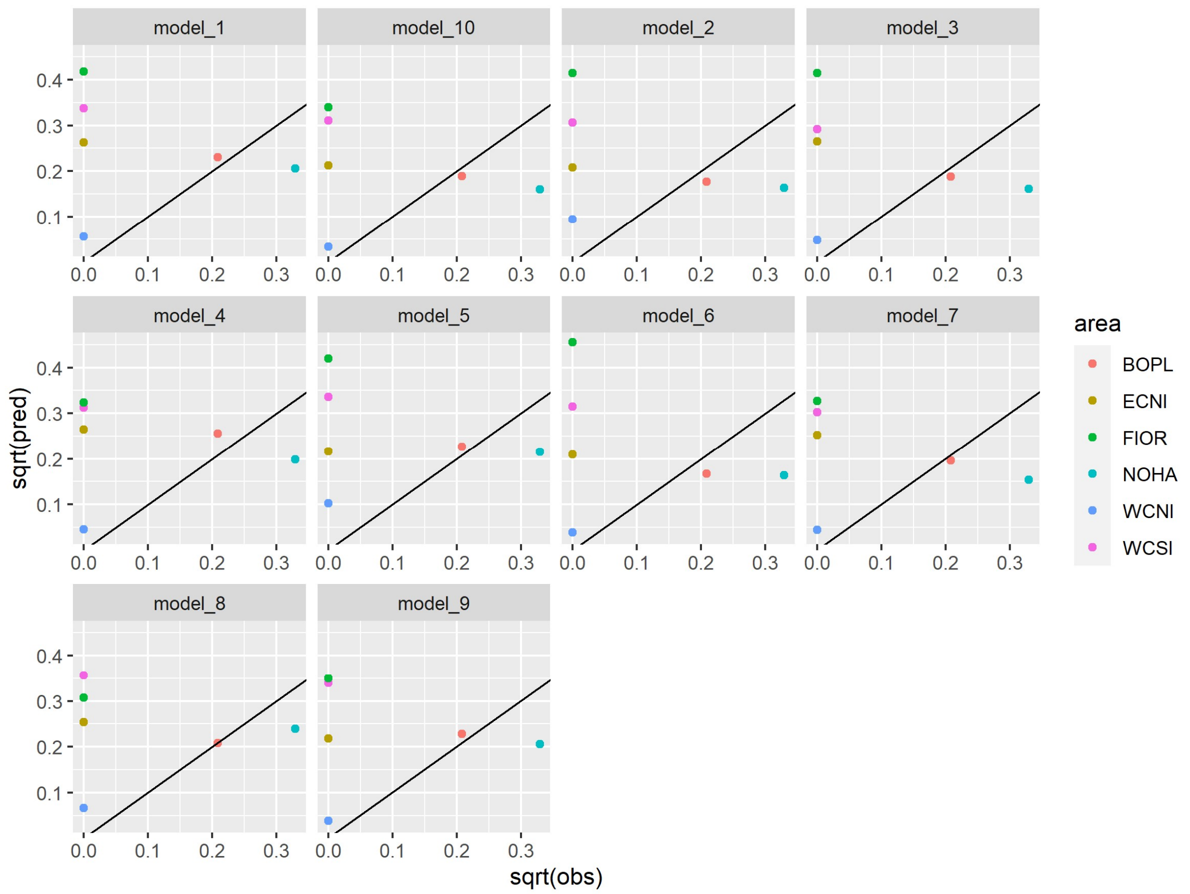

Figure 34: Mean square-root predicted (sqrt(pred)) vs. mean square-root observed (sqrt(obs)) black petrel captures in each area for top-10 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with ≥ 20% data completeness (Table 14).

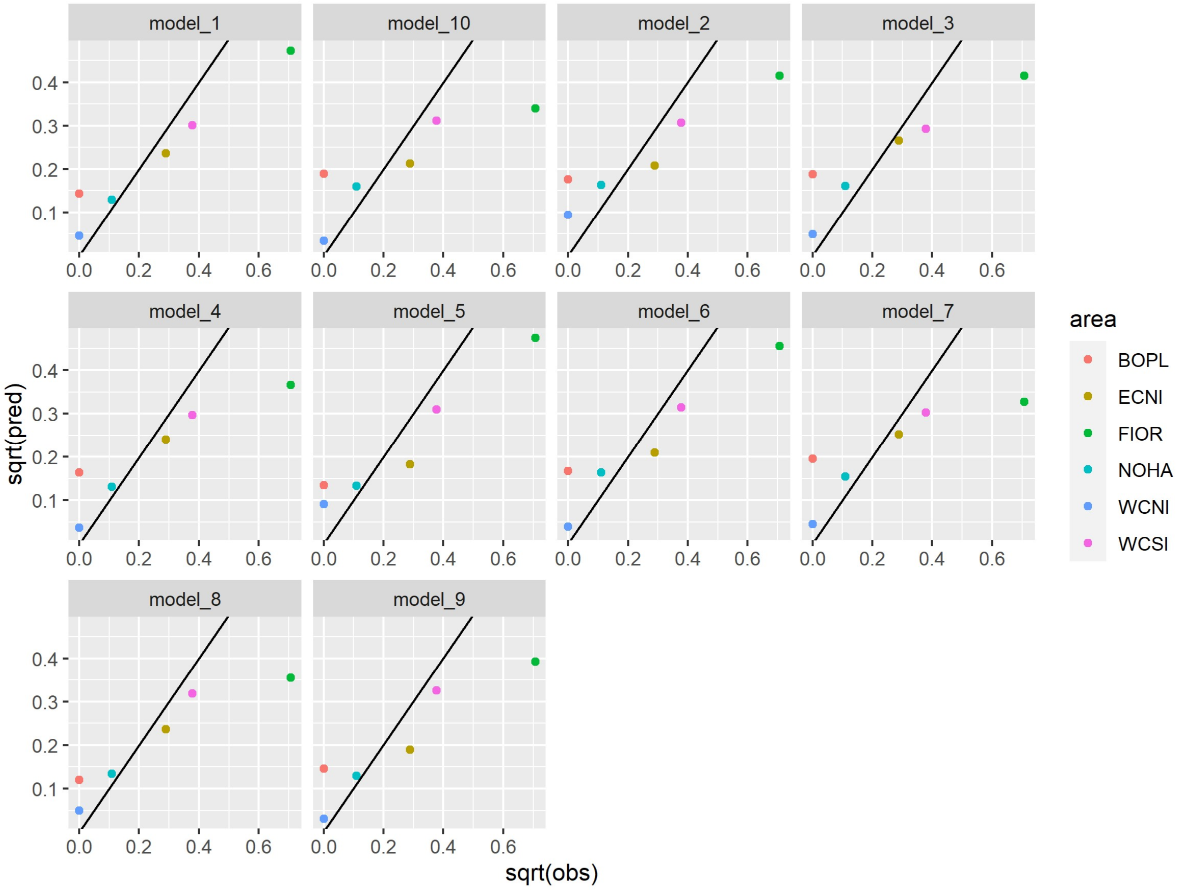

Figure 35: Mean square-root predicted (sqrt(pred)) vs. mean square-root observed (sqrt(obs)) Buller's albatross captures in each area for top-10 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with ≥ 20% data completeness (Table 14).

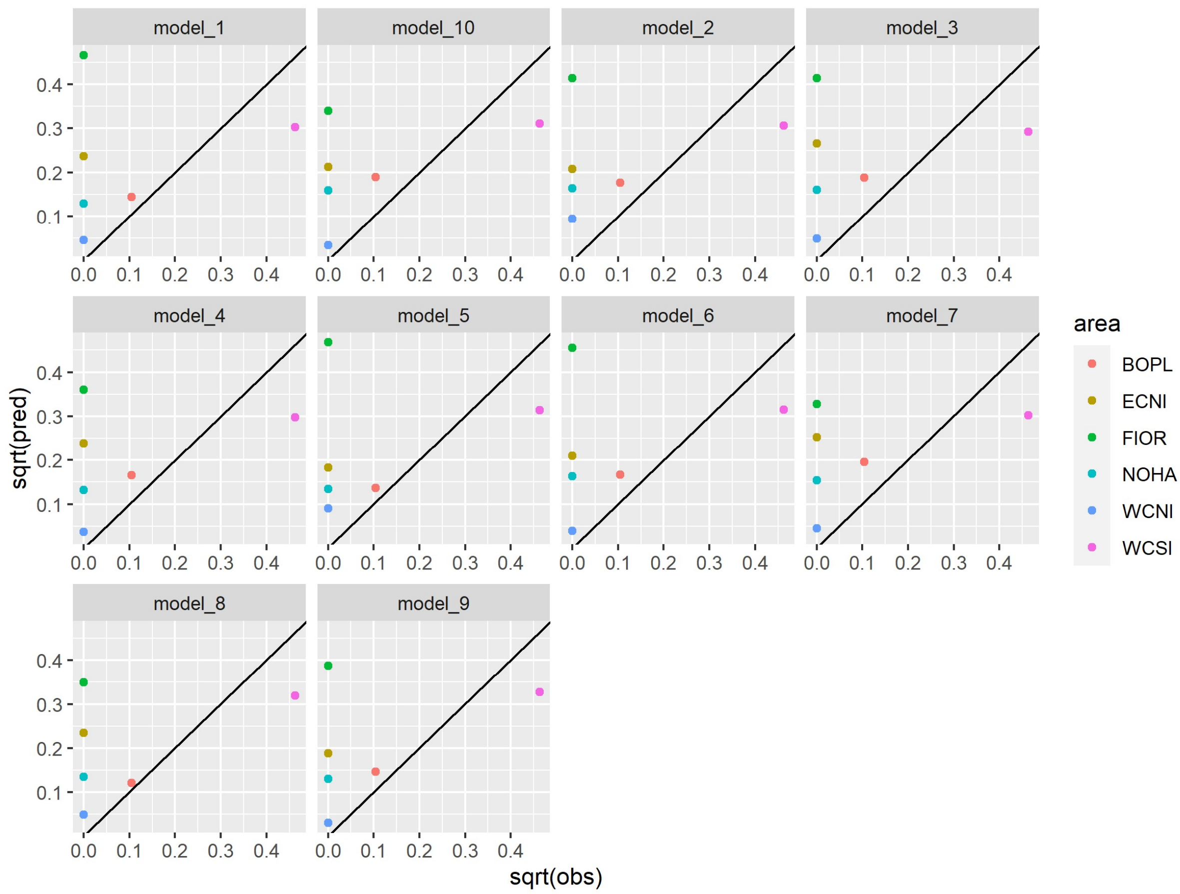

Figure 36: Mean square-root predicted (sqrt(pred)) vs. mean square-root observed (sqrt(obs)) observed white-capped albatross captures in each area for top-10 multi-species models fitted to black petrel, white-capped albatross, and Buller's albatross captures where model fits included variables with ≥ 20% data completeness (Table 14).

APPENDIX E: PREDICTIVE CHECKING FOR NEW ZEALAND FUR SEAL CAPTURES MODEL

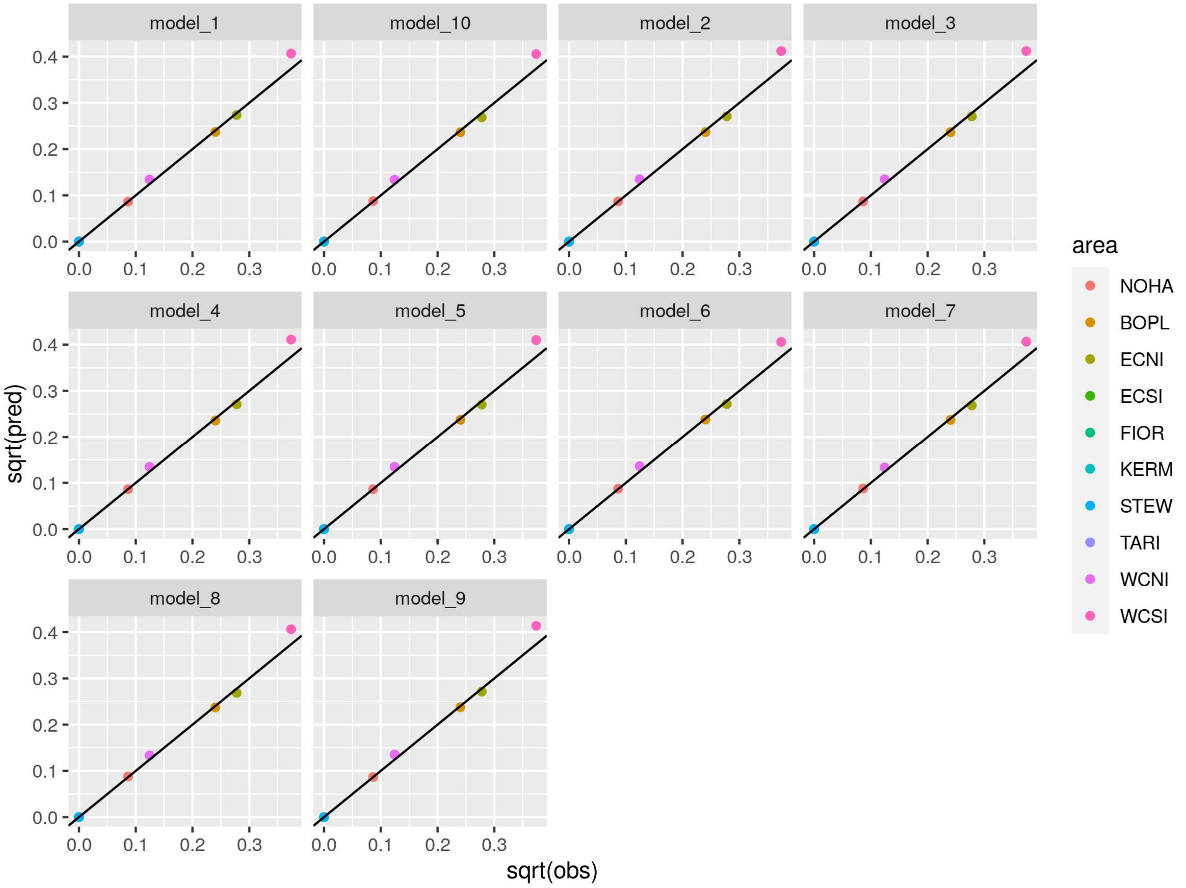

Figure 37: Mean square-root predicted (sqrt(pred)) vs. mean square-root observed (sqrt(obs)) New Zealand fur seal captures in each area for top-10 models where model fits included variables with 100% data completeness (Table 18).

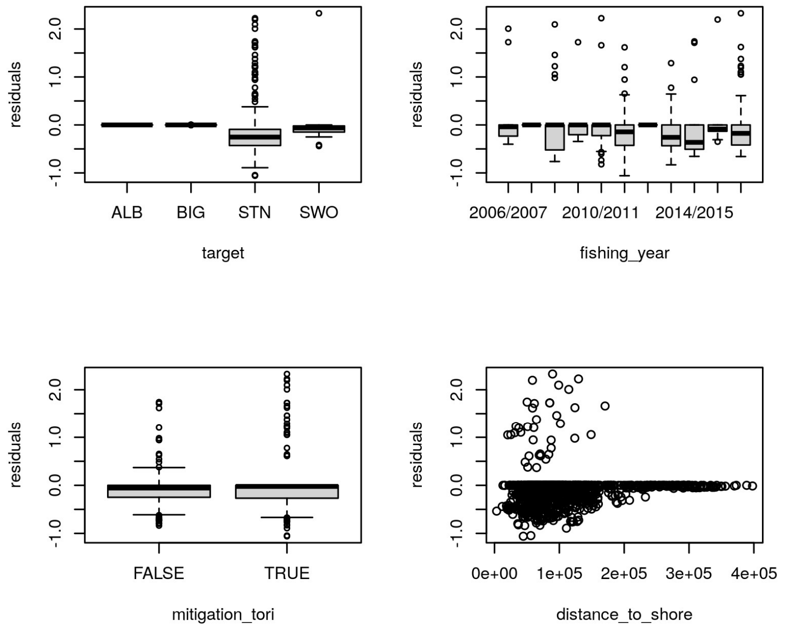

Figure 38: Residuals vs predictors from top New Zealand fur seal captures model (model 1) where model fits included variables with ≥ 75% data completeness (Table 19).

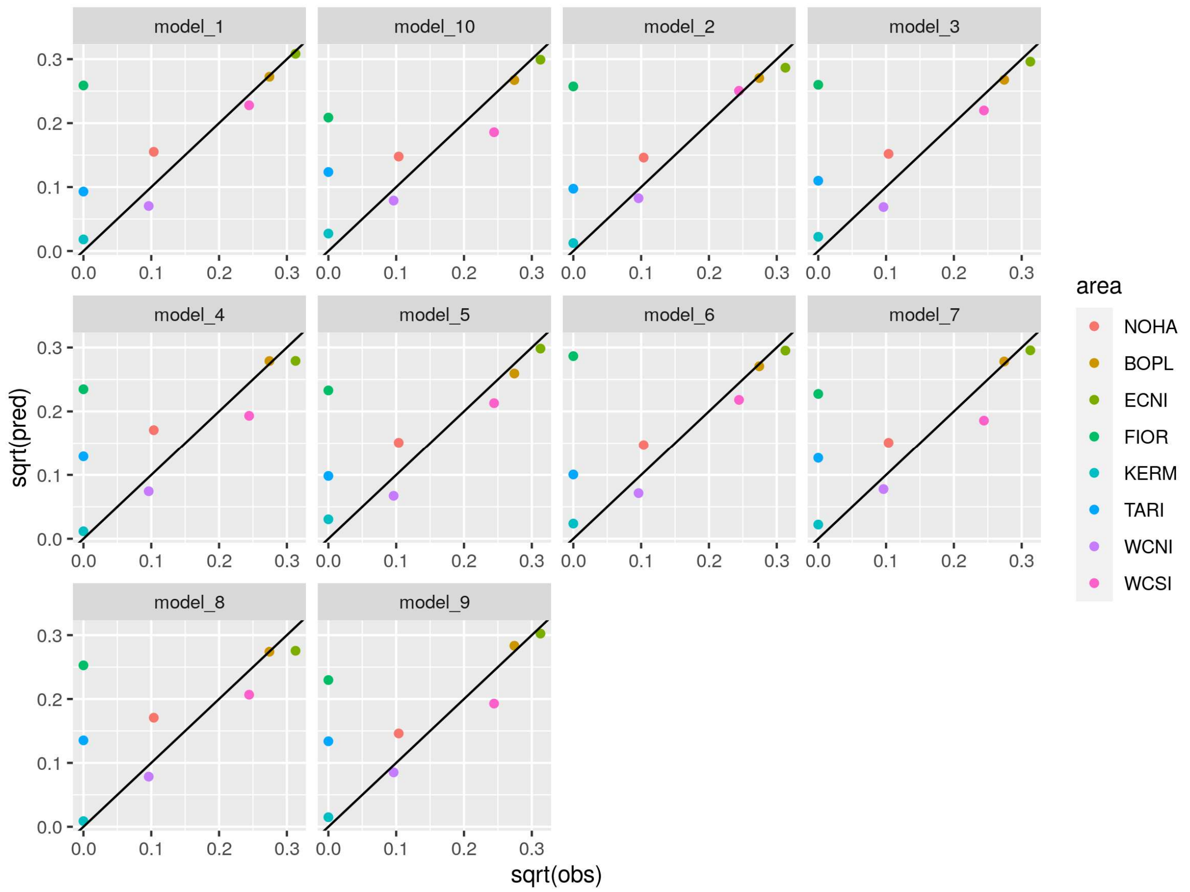

Figure 39: Mean square-root predicted (sqrt(pred)) vs. mean square-root observed (sqrt(obs)) New Zealand fur seal captures in each area for top-10 models where model fits included variables with ≥ 75% data completeness (Table 19).

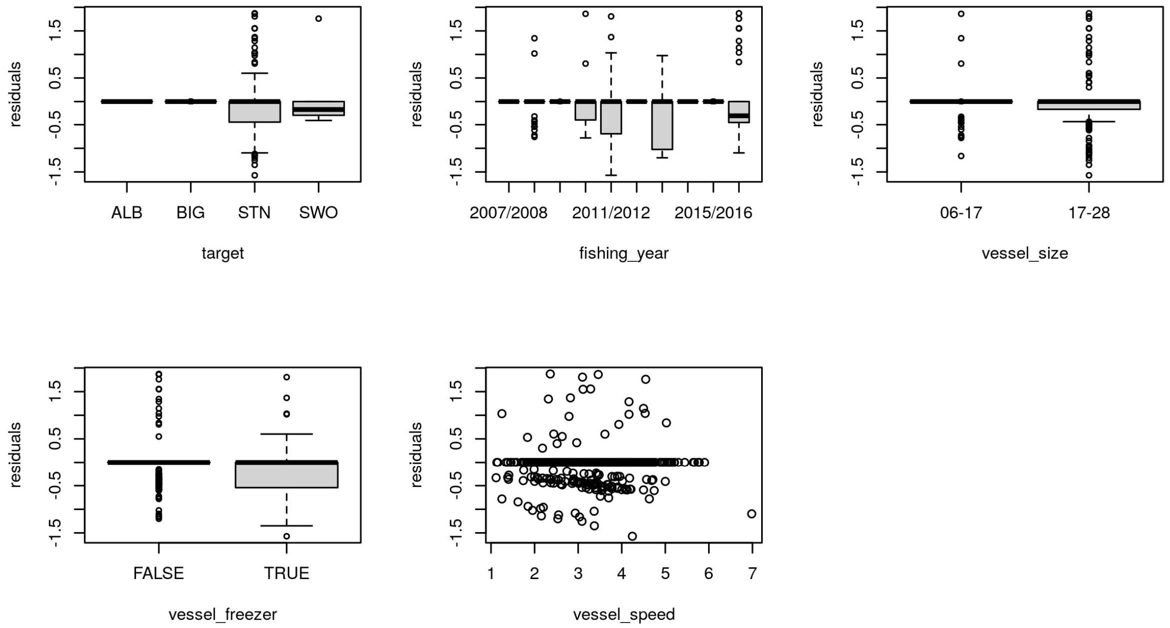

Figure 40: Residuals vs predictors from top New Zealand fur seal captures model (model 1) where model fits included variables with ≥ 60% data completeness (Table 20).

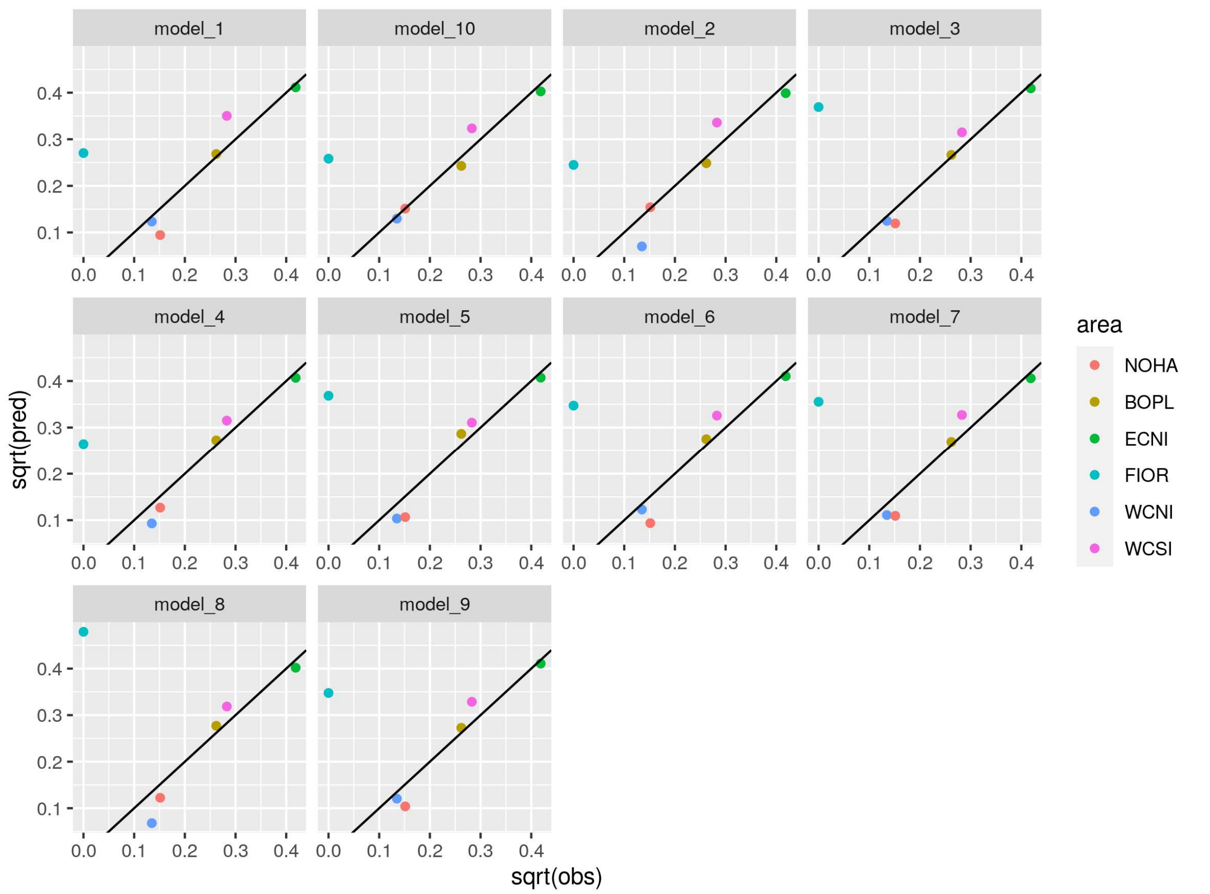

Figure 41: Mean square-root predicted (sqrt(pred)) vs. mean square-root observed (sqrt(obs)) New Zealand fur seal captures in each area for top-10 models where model fits included variables with ≥ 60% data completeness (Table 20).

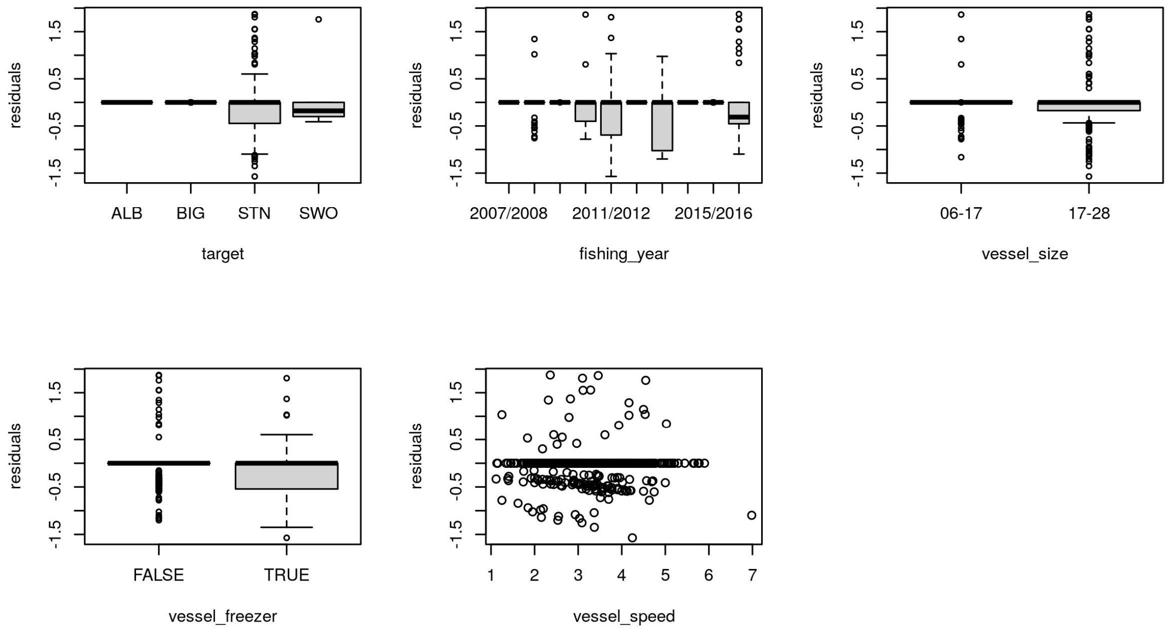

Figure 42: Residuals vs predictors from top New Zealand fur seal captures model (model 1) where model fits included variables with ≥ 20% data completeness (Table 21).

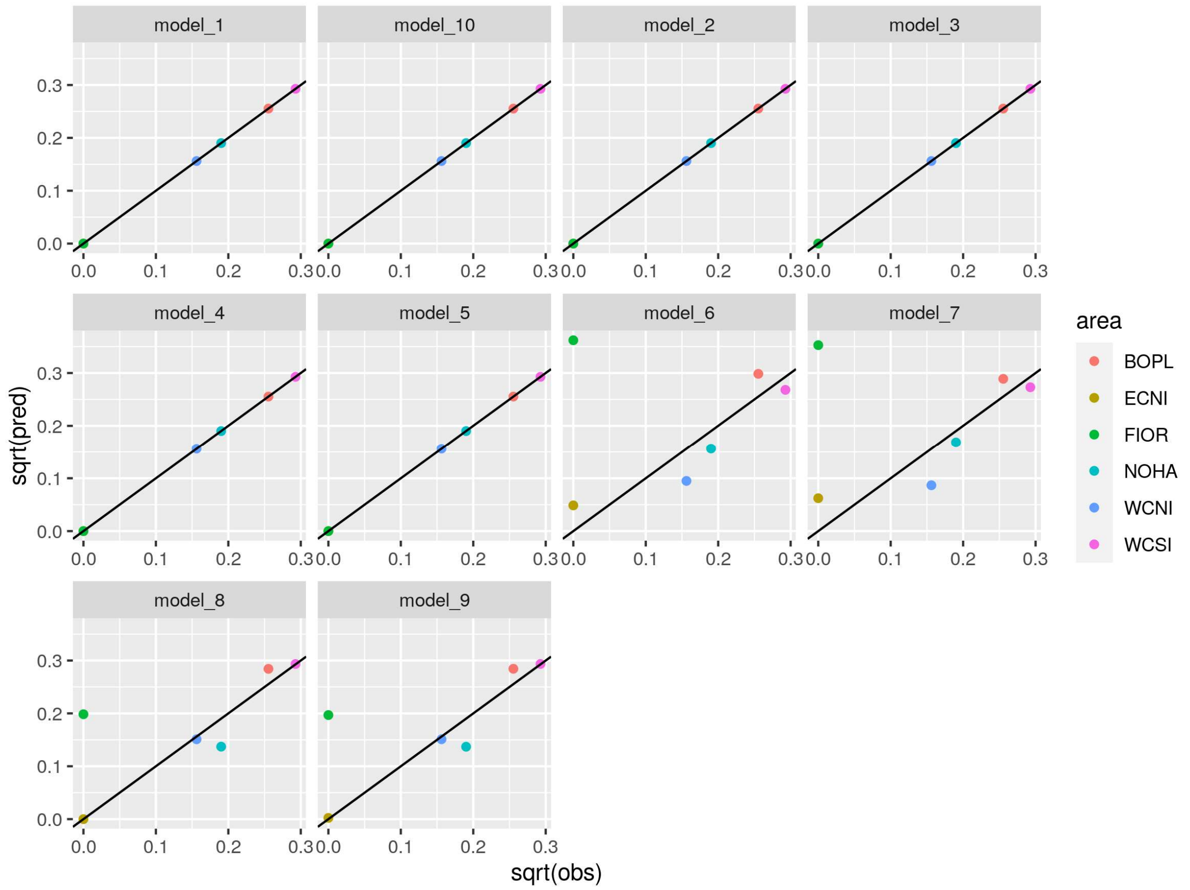

Figure 43: Mean square-root predicted (sqrt(pred)) vs. mean square-root observed (sqrt(obs)) New Zealand fur seal captures in each area for top-10 models where model fits included variables with ≥ 20% data completeness (Table 21).

APPENDIX F: PREDICTIVE CHECKING FOR TURTLE CAPTURES MODEL

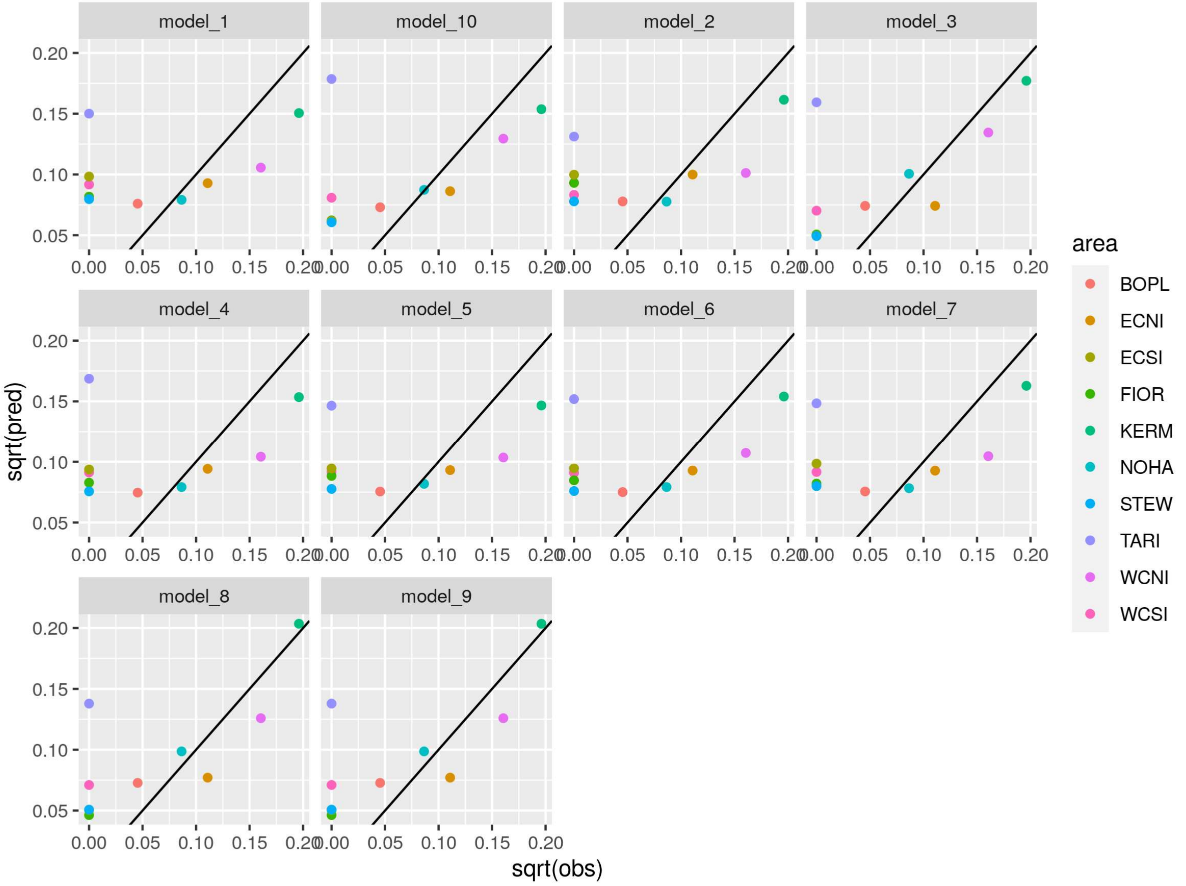

Figure 44: Mean square-root predicted (sqrt(pred)) vs. mean square-root observed (sqrt(obs)) turtle captures in each area for top-10 models fitted to turtle captures where model fits included variables with 100% data completeness (Table 25).

APPENDIX G: DATA HISTOGRAMS

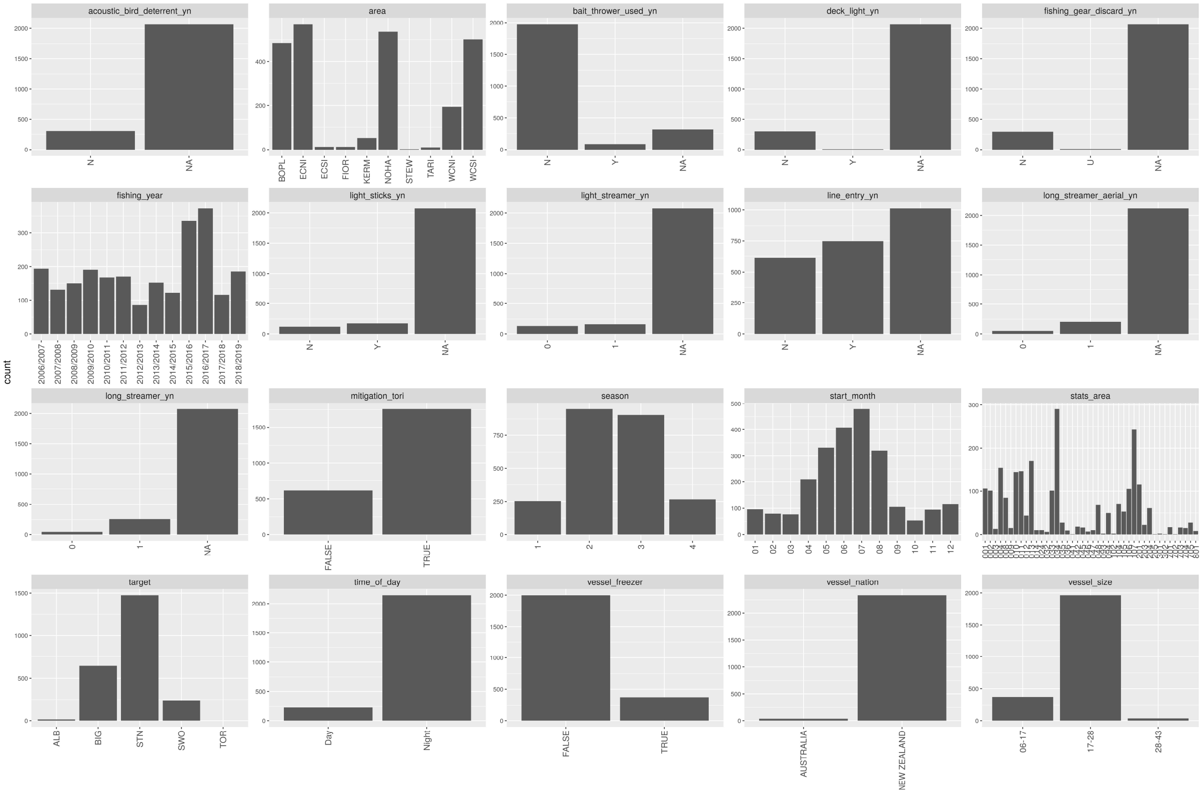

Figure 45: Histograms of categorical variables.

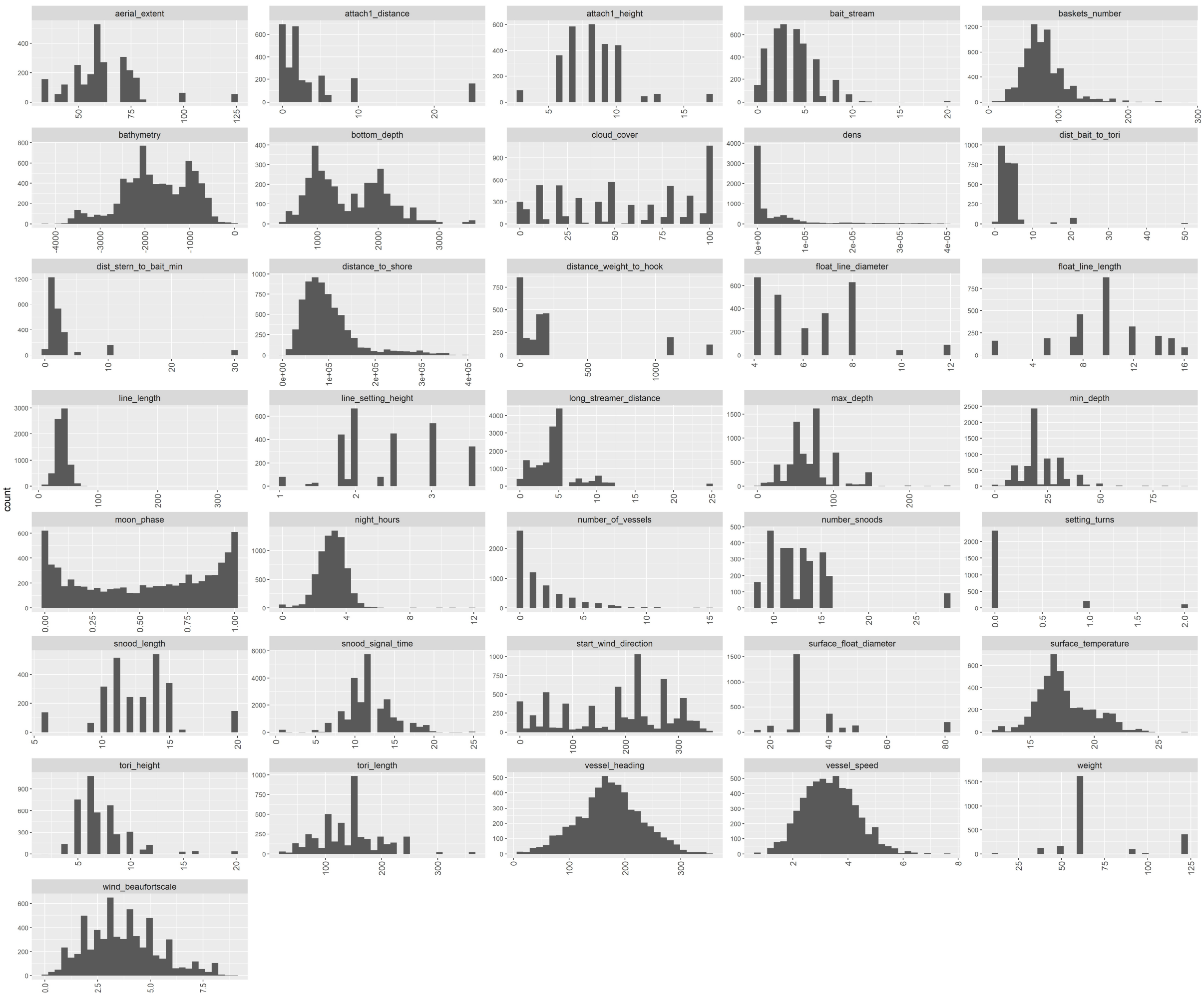

Figure 46: Histograms of continuous variables.