



Overlap of the distribution of black petrel (*Procellaria parkinsoni*) with New Zealand trawl and longline fisheries

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EXECUTIVE SUMMARY

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EXECUTIVE SUMMARY

Black petrel, *Procellaria parkinsoni*, has been identified as the New Zealand endemic seabird species that is most at risk from incidental captures in commercial fisheries. The goal of this project was to use available data to estimate the overlap of New Zealand black petrel with commercial trawl and longline fisheries.

The main black petrel colony is on Great Barrier (Aotea) Island in Hauraki Gulf. Black petrel attend the island from October to May, migrating to the coast of South America during the austral winter. During the breeding season, they forage on the shelf edge, principally along the north-east coast between East Cape and North Cape. Data on black petrel abundance at sea are available from counts made by government fisheries observers of seabirds behind fishing vessels between 2004–05 and 2012–13; from sightings made by a tour operator during birdwatching trips in Hauraki Gulf and to Kermadec Islands between 2004 and 2012; and from high-resolution Global Positioning System (GPS) tracking of 15 birds carried out during the 2012–13 breeding season. All of these data sets have limitations: the observer data contain mistaken identifications, the sightings data from the birdwatching tours are mainly focused inside Hauraki Gulf, and there are only limited high-resolution GPS tracks available.

To generalise from these data to obtain an overlap with fishing effort, boosted regression trees were used to model the data. Boosted regression trees are insensitive to outliers, and are able to represent complex interactions between variables, due to the hierarchical structure of the trees. Two models were fitted, a simple “lat-long” model that related black petrel abundance to latitude and longitude (as well as the count type, method, and breeding season), and a habitat model that related abundance to variables that may be relevant to black petrel (distance from Great Barrier Island, water depth, sea-surface height, sea-surface temperature anomaly, and chlorophyll-*a* concentration) instead of latitude and longitude. When tested using a ten-fold cross-validation procedure, the lat-long model explained more of the underlying variation in the data. This model was selected as the best model, with results from the habitat model available for sensitivity analysis.

Both models showed a peak in the black petrel abundance on the shelf edge (peaked at around 1000 m water depth), to the north of Great Barrier Island. This finding is consistent with previously published tracking data that were not used in this study. When compared with the observations, the lat-long model was able to explain much of the variation in black petrel abundance between regions and fishing methods. The overlap with trawl and longline fisheries was calculated from the black petrel abundance estimated at each fishing event. When compared with the overlap derived from the distribution used in a recent risk assessment of commercial fisheries to New Zealand seabirds, overlap with bottom-longline fisheries decreased in Hauraki Gulf, and increased towards the shelf break. Overlap with inshore trawl fisheries decreased, while overlap with bluenose bottom-longline fisheries (which are mainly on the shelf break) increased. When compared with observed captures, there appeared to be low overlap on the East Coast North Island, south of East Cape. There were no seabird abundance observations made by fisheries observers on bottom-longline vessels in this area. Both models (the lat-long model and the habitat model) gave similar overlaps for the main fisheries in the region.

Although there were limitations with the source data sets, the boosted regression tree models provided a method for estimating overlap between black petrel and commercial fisheries. This overlap will be used in a revision of the risk assessment to allow a better estimate of the capture of black petrel in poorly observed small-vessel trawl and longline fisheries.

1. INTRODUCTION

Black petrel, *Procellaria parkinsoni*, is a New Zealand endemic seabird species, with around 1200 pairs breeding annually on Great Barrier Island (Aotea Island) and Little Barrier Island (Te Hauturu-o-Toi) (ACAP 2009). It was identified as the seabird species most at risk of population decline as a result of incidental captures in commercial fisheries within New Zealand waters (Richard & Abraham 2013).

From counts within census grids at the Great Barrier Island colony, it appears that the number of breeding pairs of black petrel decreased between 2000–01 and 2011–12 (Bell et al. 2013), although there was an apparent increase in the number of breeding pairs in 2012–13, and demographic modelling of the population did not provide clear evidence for a population change over this period (Francis & Bell 2010).

A goal of the “National Plan of Action – 2013 to reduce the incidental catch of seabirds in New Zealand fisheries” (NPOA) is that “incidental mortality of seabirds in New Zealand fisheries is at or below a level that allows for the maintenance at a favourable conservation status or recovery to a more favourable conservation status for all New Zealand seabird populations” (Ministry for Primary Industries 2013). The risk assessment of commercial fisheries to New Zealand seabirds is part of the process used to establish progress towards this goal. Nevertheless, there is considerable uncertainty in the calculation of the risk. A key input is an estimate of the number of birds that are caught in fisheries. Estimation of these captures depends on an estimate of the overlap of the distribution of black petrel with fisheries. The previous risk assessment used a spatial distribution of black petrel that was derived from expert opinion and heuristic rules. Using available data to refine the distribution will improve the understanding of the overlap between black petrel and New Zealand fisheries, and in turn, will allow our understanding of the risks posed to black petrel by commercial fisheries to be refined.

Several sources of data are available to assess the distribution of black petrel. First, government observers on board commercial fishing vessels have conducted counts of seabirds at the back of vessels since 2004, providing a data set on the distribution of seabirds in New Zealand (Richard et al. 2011). Second, a seabird specialist and tour operator (Chris Gaskin) has been recording the abundance of seabirds during birdwatching trips in Hauraki Gulf and at Kermadec Islands. These data are expected to be of high quality, with accurately identified seabird species; however, the distribution of the observations is limited in its spatial extent. Third, there has been some Global Positioning System (GPS) tracking of birds breeding on Great Barrier Island, providing high-resolution data on the foraging of black petrel (Bell et al. 2013).

A statistical modelling approach, boosted regression trees (Elith et al. 2008), was used to map the distribution of black petrel. Two approaches were tried, one that used latitude and longitude as predictive variables, and one that used variables of potential ecological relevance (such as sea surface height, or distance from Great Barrier Island). From the modelled distribution the overlap between fishing effort and black petrel abundance may be calculated. This overlap will be used to recalculate the risk to black petrel from New Zealand commercial fisheries.

2. METHODS

2.1 Breeding periods

The breeding periods of black petrel were defined as follows, based on Imber (1987). Pre-laying period: October–November; incubation period: December–January; chick-rearing period: February–May; non-breeding period: June–September.

The birds are present at the colony during the pre-laying, incubation, and the chick-rearing periods. In the non-breeding period, the birds migrate to close to the coast of South America (Spear et al. 2005). For this study, there were assumed to be no black petrel in New Zealand waters during the non-breeding period.

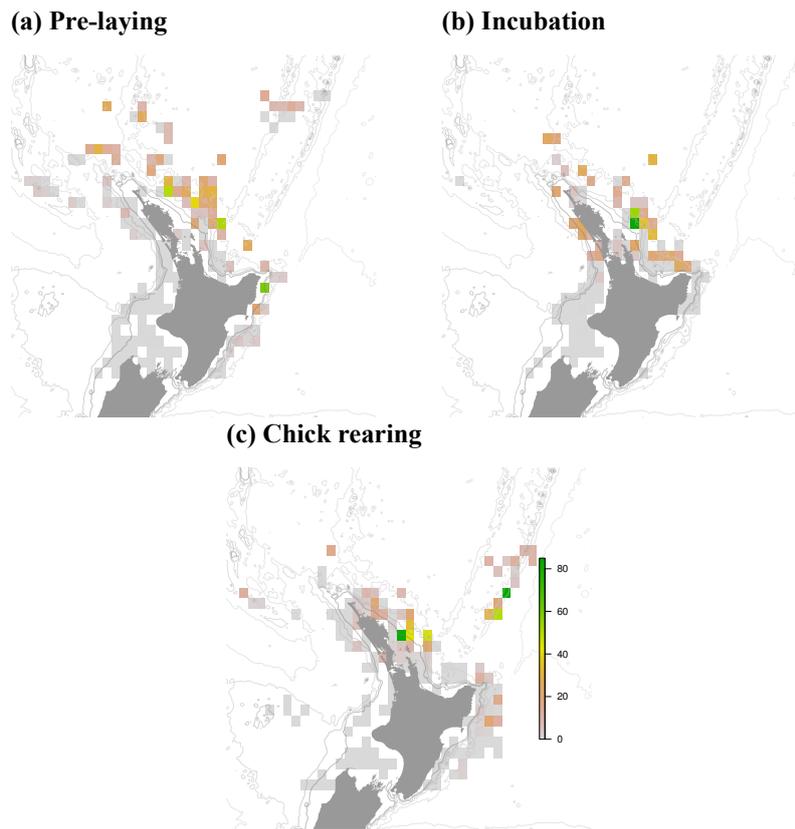


Figure 1: Mean count of black petrel (on a 0.2° grid) as recorded by observers on board commercial fishing vessels between January 2004 and December 2012, for the three breeding periods considered in the analysis.

2.2 Count data

2.2.1 Observer counts

Beginning in 2004, government fisheries observers carried out counts of seabirds behind fishing vessels for the Department of Conservation Conservation Services Programme (CSP) (Richard et al. 2011). For these bird counts, observers recorded the number of seabirds behind the vessel by species or species group. In inshore trawl fisheries, counts were conducted during daylight hauls, with a haul defined as the time between the trawl doors surfacing and the net hitting the stern ramp or being lifted from the water. In offshore trawl fisheries, the counts were typically made during the first daylight haul of each day. In longline fisheries, counts were undertaken during observations of every daylight set and haul, at the start, middle, and end of setting and hauling.

These counts are a valuable source of information on the abundance of black petrel around fishing vessels. The counts were made throughout New Zealand fisheries, across all seasons. A key limitation of the data, however, is that there are misidentifications. Observers have variable experience and skill at identifying seabirds. Some records of black petrel may be of other similar species such as Westland petrel, white-chinned petrel, or other dark-coloured birds of similar size. Tracking of black petrel using GPS has indicated that they rarely forage south of 40° South. For this reason, we assumed that identifications of black petrel further south than this latitude were errors. We restricted the analysis to waters north of 40° South, omitting 358 counts where black petrel were reported. Similarly, there were 151 counts during the non-breeding season where black petrel were recorded. No other data source suggested that black petrel was present during this period, and these counts were also considered misidentifications.

After the data preparation, the dataset included a total of 13 533 counts carried out by observers between 2004 and 2012 (Table 1). Black petrel were recorded in 715 (5.28 %) of these counts (Figure 1).

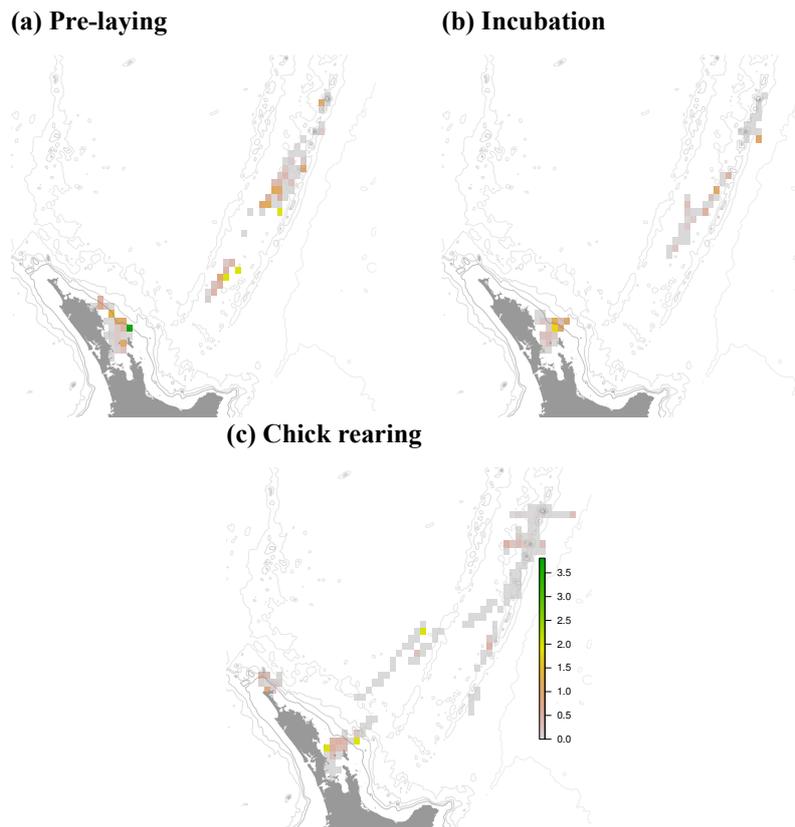


Figure 2: Mean number of black petrel (on a 0.2° grid) recorded during pelagic birdwatching tours between January 2004 and December 2012, for the three breeding periods considered in the analysis.

2.2.2 Birdwatching counts

Data from privately operated birdwatching tours between 2004 and 2012 were also used. Regular counts were carried out by a birdwatching tour operator (Chris Gaskin, Kiwi Wildlife Tours NZ), who has extensive experience at identifying seabirds at sea. In contrast to records by fisheries observers, these identifications are likely to be accurate. Nevertheless, these counts covered a small spatial extent, with around two thirds of them carried out in Hauraki Gulf, and one third carried out during trips to Kermadec Islands.

The data from these birdwatching trips were in ranges (1, 2–9, 10–49, 50–99, 100–499, 500–999, or 1000+ birds), rather than being point estimates. The lower end of the range was used for the modelling. This biases the sightings low, and should be considered when comparing the abundance from the sightings with the abundance from observer count data. In addition to black petrel abundance, and location, the sightings data also contained a record of whether there was chumming for birds at the time an observation was made.

Omitting counts made during the non-breeding season, during which no black petrel was seen, this data set included 4171 counts, with black petrel identified in 367 (8.8 %) of them (Table 1, Figure 2).

2.2.3 GPS tracking data

Between December 2012 and February 2013, i-Got-U™GPS loggers were attached to breeding birds at Great Barrier Island (by E. Bell; Wildlife Management International Limited, T. Dennis, Auckland University, and T. Landers, Auckland Council). The tracks from 15 loggers were recovered, consisting of 36 534 locations recorded around 1-minute apart. Only the track locations from the chickrearing period were kept, as only fractions of tracks were retrieved during the incubation stage. The tracks were

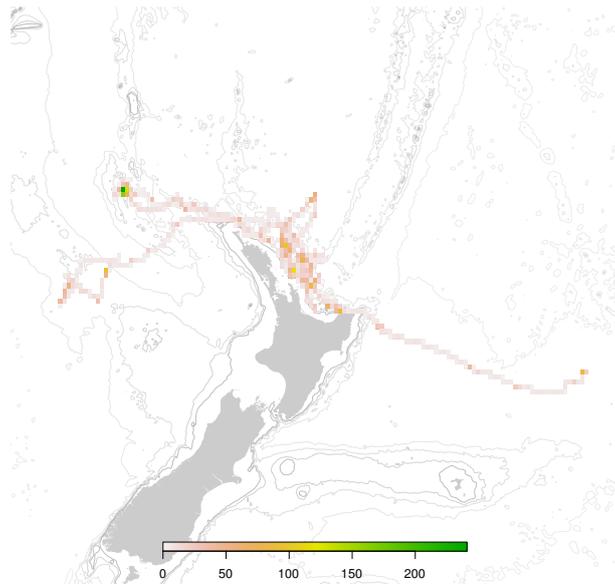


Figure 3: Maps of tracking data of black petrel using Global Positioning System (GPS) loggers, between December 2012 and February 2013. The number of GPS fixes (recorded every 5 minutes) contained in each 20 km grid cell is shown.

resampled so that any two successive locations were separated by a minimum of 5 minutes, resulting in 6491 locations (Figure 3).

These locations were then converted to pseudo-counts, by spatially aggregating them on a projected grid of 20-km resolution, extending from 160°E to 190°E and from 57°S to 24°S. Each grid cell contained the number of locations falling into it, resulting in 27 597 pseudo-counts for the chick-rearing period, with 403 (1.46%) of them being positive (Table 1).

Additionally to GPS data loggers, the tracks from 87 light-recording Global Location Sensing (GLS) tags were available (Bell et al. 2011). Nevertheless, the location accuracy of these loggers is low and not appropriate for habitat modelling at the scale of New Zealand, and we did not include them in the analysis. Previous GPS tracking was carried out in February 2006 (Freeman et al. 2010), with data from nine tracks being retrieved. These data were not available, and were not included in the analysis.

2.3 Model variables

To assess the distribution of black petrel, a number of time-invariant variables were considered (see Appendix A, Figure A-1):

- Position (°). The position of each record in degrees latitude and longitude.
- Distance from Great Barrier (km). The distance from Great Barrier Island was calculated, as this island is the breeding ground of 95% of the black petrel population (ACAP 2009). The minimum distance over sea was chosen, as black petrel are unlikely to fly over land. This variable was obtained using cost distance modelling with the software Geographic Resources Analysis Support System (GRASS; Neteler et al. (2012)).
- Ocean depth (m). Ocean depth was obtained from the National Institute of Water and Atmospheric Research (NIWA) bathymetry dataset (Charting Around New Zealand (CANZ) 2008)
- Sea-floor slope (degrees). The slope of the ocean floor was derived from the bathymetry using the software QuantumGIS (QGIS Development Team 2009).

Table 1: Summary of the data used to estimate the distribution of black petrel in New Zealand. For each count type, method, and breeding period, the table gives the total number of observed counts (“Total counts”), the number of observed counts where black petrel was present (“Presences”), and the mean and maximum number of black petrel over all counts within that stratum. Observer data included bottom longlining (BLL), surface longlining, and trawling between 2004–05 and 2012–13; birdwatching tours included counts while chumming and without chum between 2004 and 2012; Global Positioning System (GPS) data were from tracking of breeding birds during the chick-rearing period in the summer of 2012–13.)

Count type	Method	Period	Total counts	Presences	Mean black petrel	Max black petrel
Observers	BLL	Pre-egg	635	0	0.00	0
		Incubation	299	38	1.32	60
		Chick	916	264	4.36	150
	SLL	Pre-egg	108	77	14.54	100
		Incubation	128	97	23.01	100
		Chick	1035	62	0.81	150
	Trawl	Pre-egg	2722	129	0.53	80
		Incubation	2057	29	0.24	50
		Chick	5633	19	0.06	60
Birdwatching	Chum	Pre-egg	67	35	1.87	50
		Incubation	88	58	1.98	50
		Chick	40	32	2.35	10
	No chum	Pre-egg	1344	95	0.17	50
		Incubation	1139	63	0.14	10
		Chick	1493	84	0.10	10
GPS tracking	GPS	Chick	27597	403	0.21	241

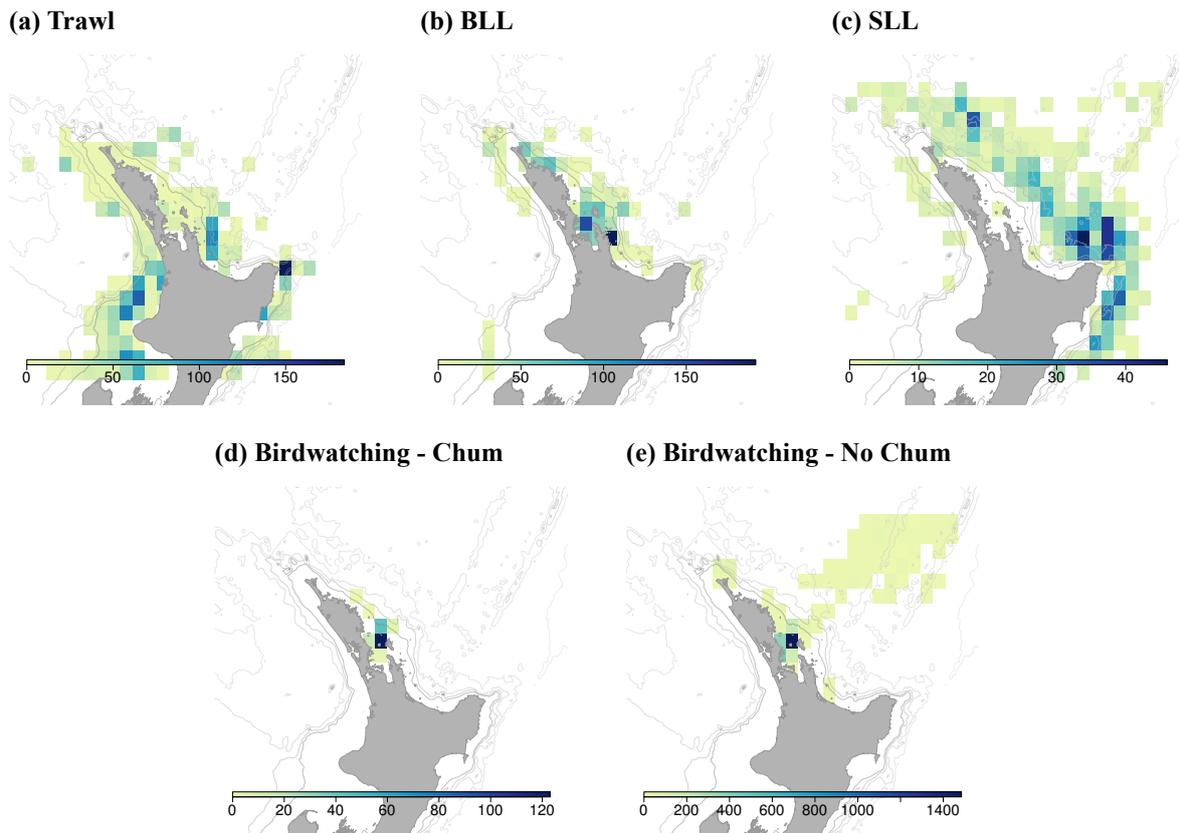


Figure 4: Distribution of the number of counts of black petrel across the different data sets, used to predict the distribution of this species in New Zealand waters. Data sets included observer counts in trawl, bottom-longline (BLL) and surface-longline (SLL) fisheries; and counts during birdwatching tours with and without the use of chum.

Additionally, a number of time-varying oceanographic variables were considered (see Appendix A, Figures A-2 to A-6):

- Chlorophyll (mg m^{-3}). The monthly oceanic concentration of chlorophyll-*a* was used as an index of ocean primary productivity, likely to influence the distribution of black petrel food sources (mostly squid and fish ACAP 2009). The concentration of chlorophyll-*a* can be high near the coast, and the value was therefore truncated at a maximum of 1.5 mg m^{-3} .
- Sea-surface height (m). The monthly mean of the sea-surface height anomaly, derived from satellite altimetry data.
- Current speed (m s^{-1}). The daily geostrophic velocity anomaly, derived from satellite altimetry data.
- Sea-surface temperature ($^{\circ}\text{C}$). The sea-surface temperature from satellite data.
- Sea-surface temperature anomaly ($^{\circ}\text{C}$). The sea surface temperature, with the seasonal mean removed.

All oceanographic variables were obtained from the data portal CoastWatch (<http://coastwatch.pfeg.noaa.gov>) provided by the United States National Oceanic and Atmospheric Administration (NOAA), with the exception of the geostrophic velocity anomaly, which was produced by Ssalto/Duacs and distributed by Aviso, with support from Cnes (<http://www.aviso.oceanobs.com/duacs/>). The concentration of chlorophyll-*a* (Chl*a*) was obtained from the science quality AQUA/MODIS dataset, sea surface height (SSH) from the science quality AVISO dataset, sea surface temperature (SST) from the Advanced Very-High Resolution Radiometer dataset. The SSH and SST seasonal anomalies were derived by calculating the deviation from the mean value since 2004, which was obtained for each breeding period. The two components *u* and *v* of the geostrophic velocity anomaly were used to calculate the speed, $\sqrt{u^2 + v^2}$.

The sea surface height and geostrophic velocity were used to capture the impact of currents and their interaction with undersea features, which can influence food availability and seabird foraging areas (Nel et al. 2001). Sea-surface temperature has also been shown to influence foraging areas of seabirds (Guinet et al. 1997), and its seasonal anomaly was therefore also considered. Every environmental variable was converted to a grid, of the same extent and resolution (20 km) as the grid used for GPS tracking pseudo-counts, leading to a single grid for each of the time-invariant variables (e.g., distance to coast, depth), or a series of monthly gridded values for the time-dependent variables. The value of environmental variables at the time and location of each seabird observation was extracted from the gridded data.

For making predictions from the models, a single grid per breeding period was prepared for each environmental variable, with the value of each grid being the average value for all dates within the corresponding breeding period.

In addition to the environmental variables, three other variables were included in the models. The type of counts (from observers, from birdwatching tours, and from GPS tracking) was included, as the observation process differed between the three types, with fishing vessels expected to attract more birds than pelagic birdwatching trips, and the pseudo-counts from GPS tracking were also of a different nature. A variable “method” was defined that included both the fishing method and the count type. The fishing method (trawl, bottom longline, and surface longline) is important as some fishing practices may attract birds more than others. The method for birdwatching counts was set to whether chum was used to attract birds or not. For the GPS data, the method was set to a single value, GPS. Taken together, the method of any record could have the value trawl, bottom longline (BLL), surface longline (SLL), chum, no chum, or GPS. Finally the breeding period was also included, as birds are expected to forage differently depending on the stage of reproduction, with the foraging range expected to be large during the pre-laying stage, but smaller during the chick-rearing period, as chicks are fed frequently.

2.4 Modelling

We used boosted regression trees (Elith et al. 2008) to relate the counts to the environmental variables. This technique is used for species habitat modelling (De'Ath 2007, Leathwick et al. 2008, Roura-Pascual et al. 2009), as it combines the benefits of two statistical algorithms (regression trees and boosting), gives accurate predictions, and allows the modelling of complex relationships (Ridgeway 1999). Regression trees (Breiman et al. 1984) relate the response variable to the predictors by recursive binary splits, choosing the predictors and split points in order to minimise prediction errors. Regression trees are insensitive to changing scales in the values of the predictors, they are insensitive to outliers, and interactions are automatically modelled due to the hierarchical structure of the trees (Breiman et al. 1984, Elith et al. 2008). Nevertheless, a single regression tree generally over-fits the data, or represents relationships as overly smooth. Boosting alleviates these limitations by iteratively developing multiple regression trees and combining them into a model ensemble. Regression trees are sequentially fitted to a training set of the data, growing the tree progressively, until the deviance reaches a minimum.

We fitted boosted regression trees to the count data, assuming a Poisson distributed error, using the R “dismo” package (Hijmans et al. 2013) and the function “gbm.step”, with a learning rate of 0.01, and a bag fraction of 0.5. A ten-fold cross-validation approach was used to evaluate the fit of the trees. The birdwatching data were divided into trips (defined as sequential days of seabird sighting effort), and each observer and birdwatching trip was then randomly assigned to one of the ten folds. The tracking data had been converted to pseudo-counts, and the pseudo counts (number of points within a 0.2° cell) were randomly allocated to the folds. This allocation does not reflect the structure of the track data (made of only 15 tracks), and so the model may tend to over-fit the track data.

Two models were then fitted to the data. A simple model, the “lat-long” model that had latitude, longitude as covariates (as well as breeding season, fishing method, and count type), and a habitat model that used environmental variables rather than latitude or longitude. We also varied the tree complexity parameter of the boosted regression trees with values of 1, 10, and 20, to assess its impact on model performance. The habitat model was fitted in two stages, firstly the full set of variables were fitted with the three different tree complexities, and then a reduced set that had an average variable importance of larger than 5% was chosen. The reduced set of variables were the fishing method (including whether the data were GPS data, or birdwatching data with or without chum), the breeding period, and the following five environmental variables: distance to Great Barrier Island, depth, sea surface temperature anomaly, sea-surface height and chlorophyll-*a*. The other variables had an importance of less than 5%.

Model performance was assessed from the prediction of the models on the cross-validation hold-out data. The residual deviance of a model with a Poisson-distributed error is:

$$\text{Deviance} = \sum_i y_i \log\left(\frac{y_i}{u_i}\right) - (y_i - u_i), \quad (1)$$

with y_i and u_i being the observed and predicted count, respectively. The null deviance is the same, except that the predicted count u_i is set to the mean of the observations. The model performance was assessed by calculating the proportion of deviance explained (one minus the ratio of the residual deviance to the null deviance).

2.5 Overlap with fisheries

Fisheries data from the Ministry for Primary Industries (MPI) were used for calculating the overlap of the distribution of black petrel with commercial fisheries. The data were records of fishing effort from the MPI *warehouse* database, and observer data from the Centralised Observer Database administered by NIWA. The methods for preparing the data were the same as those used for the estimation of protected species captures (Abraham et al. 2013, Thompson et al. 2013), with the time period extended to include the 2012–13 fishing year. The same areas were used as in the estimation of incidental captures of seabirds (Abraham et al. 2013) (see Appendix B, Figure B-7).

Summaries of the data to the end of the 2012–13 fishing year, including records of seabird bycatch, are

publicly available from the Protected Species Captures database (<https://data.dragonfly.co.nz/psc/>). The same data sources were also used for the seabird risk assessment (Richard & Abraham 2013).

From the black petrel distribution (see Figure 4) and the fisheries data, overlap with a fishing event was calculated by predicting the number of birds that would have been counted by observers at the location and date of the event, and with the same fishing method. The overlap was then summed to obtain overlap for different aggregates. The overlap was calculated for longline and trawl fishing, using the same fisheries that were defined in the risk assessment (Richard & Abraham 2013), with the difference that overlap was separately estimated for swordfish and tuna fishing. This measure of overlap has the units of a product of a number of birds and a number of fishing events, and so overlap has units “birds events” (more specifically, “birds tows” for trawl fishing and “birds sets” for longline fishing).

3. RESULTS

By using the overall proportion of deviance explained as a measure of model fit, the best model was the lat-long model, with an intermediate tree complexity of 10 (see Table 2 for a summary of the performance of the two models considered for assessing the distribution of black petrel in New Zealand waters). For all tree complexities, the lat-long model explained more of the deviance in the observer counts than the habitat model. The lat-long model also explained more of the deviance in the tracking data for intermediate and high tree complexities, and of the deviance in the birdwatching tour counts for low tree complexity.

At the regional scale, the lat-long model reproduced the main features of the observed data, shown in the comparison of the mean estimated and mean observed abundance of black petrel (Figure 5). The estimates were derived from the estimated mean value of the Poisson distribution at the same time and place as each of the (pseudo-)counts, and the correlation between the estimates and observations was high ($r^2 = 0.93$; 95% c.i.: 0.84 to 0.97). The highest mean abundances were recorded by observers behind surface-longline vessels (close to 20 black petrel in the Northland and Hauraki Gulf region), with lower abundances behind bottom-longline and trawl vessels. This variation may have been due to the different location of these fisheries, as much as their different propensities to attract black petrel. There were no observer counts from bottom-longline vessels from the East Coast North Island region. There was wide variation in the mean pseudo-counts from the GPS tracking data. The highest mean abundance from the tracking data was in the Bay of Plenty region. Interpretation of the mean pseudo-counts from the GPS data was somewhat confounded, as variation between regions reflected the number of zeros that were generated when forming the pseudo-counts. The highest regional mean abundance from the birdwatching tours sightings data was around 2, with observations made following chumming in the Northland and Hauraki Gulf region. Regional mean sightings made without chumming were all low (less than 0.5 birds).

Table 2: Summary of the performance of the six models considered to assess the distribution of black petrel in New Zealand waters. The proportion of deviance explained is shown as percentages for the three type of data considered in the models (counts from observers, from birdwatching tours, and pseudo-counts from Global Positioning System (GPS) tracking), and overall. The row that is highlighted in bold indicates the model that explains the most deviance.

Variables	Tree complexity	Deviance explained			
		Observer	Birdwatching	GPS	Overall
Habitat	1	48.10	13.51	42.69	47.93
	10	49.11	19.11	48.26	50.72
	20	47.29	18.46	48.18	49.69
Lat/long	1	48.97	14.01	36.98	46.33
	10	52.31	15.93	62.86	57.69
	20	47.66	15.36	66.37	56.45

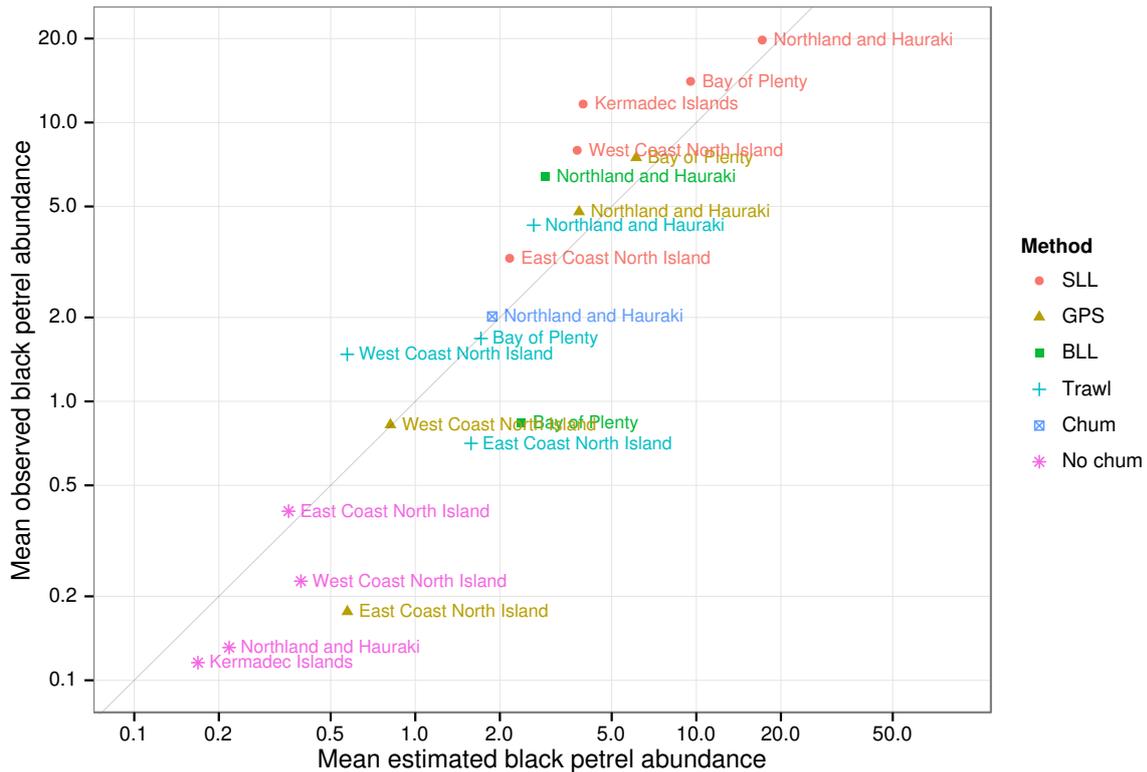


Figure 5: Comparison between the mean estimated and mean observed abundance of black petrel, by area and data set. Estimates are from the lat-long model used to assess the distribution of black petrel in New Zealand waters. The different data sets included observer count data from different fishing methods (BLL: bottom longline, SLL: surface longline, and trawl), sightings data from birdwatching tours (Chum, No chum), and Global Positioning System (GPS) tracking data. Data were restricted to the areas shown here, which include all data from within New Zealand’s Exclusive Economic Zone that were used in the analysis. Data are plotted on a base-ten logarithmic scale, with the one-to-one line shown. GPS data from the Kermadec Islands are not shown, as there were no observed black petrel in this area.

The habitat model allowed exploration of the relationship between environmental variables and black petrel abundance (see Figure 6 for the marginal effect of each variable, with the effects of the other variables being integrated out; see Friedman 2001). (As regression trees are inherently non-linear, the response may vary for different values of the other parameters.) In the habitat model, distance to Great Barrier Island was the most important variable, with the highest black petrel abundance within 500 km of the island, and with a strong decrease in abundance between 500 and 1200 km distance from the island. Water depth was the next most important variable, with a non-linear relationship between this variable and black petrel abundance. The abundance was low in shallow waters (less than around 200 m depth), peaked at the shelf break (around 1000 m depth) and then decreased to 2000 m depth, with no change beyond this distance. Relative abundance was highest in observer counts around surface-longline vessels, and was lowest in counts by birdwatching tours without chumming (supporting the results from the lat-long model and the raw data illustrated in Figure 5). The next most important variable was sea surface height, with a peak in abundance at around 0.7 m (corresponding with the East Auckland Current, see Figure A-3), and low abundance for sea surface heights of 0.6 m or less. The sea surface temperature anomaly generally had a weak effect. There was a sharp peak at the lowest anomalies (less than -2.5°C); however, there was limited data in this range, so this peak had a low influence on the predictions. The effect of chlorophyll-*a* peaked at around 0.13 mg m^{-3} , with a decline in abundance at concentrations less than 0.08 mg m^{-3} , indicative of low black petrel abundance in oceanic water. The influence of breeding period on the abundance was low.

From the two models, distribution maps were derived for each of the three breeding periods when black petrel are present in New Zealand waters (Figure 7). In both models, the predicted abundance of black petrel was highest on the shelf edge, offshore from Great Barrier Island. In the habitat model, the peak in the estimated black petrel abundance was more narrowly focused on the shelf edge, particularly in the chick-rearing and guard stage. In both models, there was low estimated abundance in shallow water on the shelf. The tartan effect in the lat-long model was caused by the model using lines of constant latitude and longitude to extrapolate away from the data. The marked latitudinal gradient at around the latitude of Great Barrier Island was not apparent in the habitat model, and it may be that the variables within the habitat model did not distinguish well between waters north and south of the Great Barrier Island latitude.

Although breeding period was available to both models, in the lat-long model, the spatial pattern was almost independent of the season (at least for the bottom-longline fisheries shown here). In the habitat model, there was an overall change in the abundance between the seasons. While the season itself had only a weak effect (Figure 6), this change may have been related to seasonal changes in the time-dependent variables (sea surface height, chlorophyll-*a*, and sea surface temperature anomaly).

Many of the apparent differences in the distributions occurred away from fisheries data, and were less apparent when the overlap with fishing effort from 2010–11 to 2012–13 was calculated (Figure 8). Maps of overlap for two main fisheries and breeding periods (surface longlining during the pre-laying period, and bottom longlining during the incubation and chick rearing period) showed that the highest overlaps occurred offshore from Great Barrier Island. There was a clear offshore shift in the overlap with bottom-longline fisheries, when compared with the overlap used in the recent risk assessment (Richard & Abraham 2013). Although the distribution of black petrel was shifted toward the shelf break, there remained some overlap within Hauraki Gulf for bottom-longline fisheries, reflecting the distribution of fishing effort.

The fishing method was included as a variable in fitting the boosted regression tree. The distribution of interactions between black petrel and other fisheries were not simple re-scalings of the distributions for bottom-longline fisheries. When calculating the overlap of the distribution with the fisheries, the fishing method was included with the other predictor variables (including the breeding period) to produce a specific prediction at the time and location of the fishing events.

When averaged by breeding period and fishery, the mean annual overlaps from the habitat model and the lat-long model were similar, but contained some marked differences with the overlap that was used in the

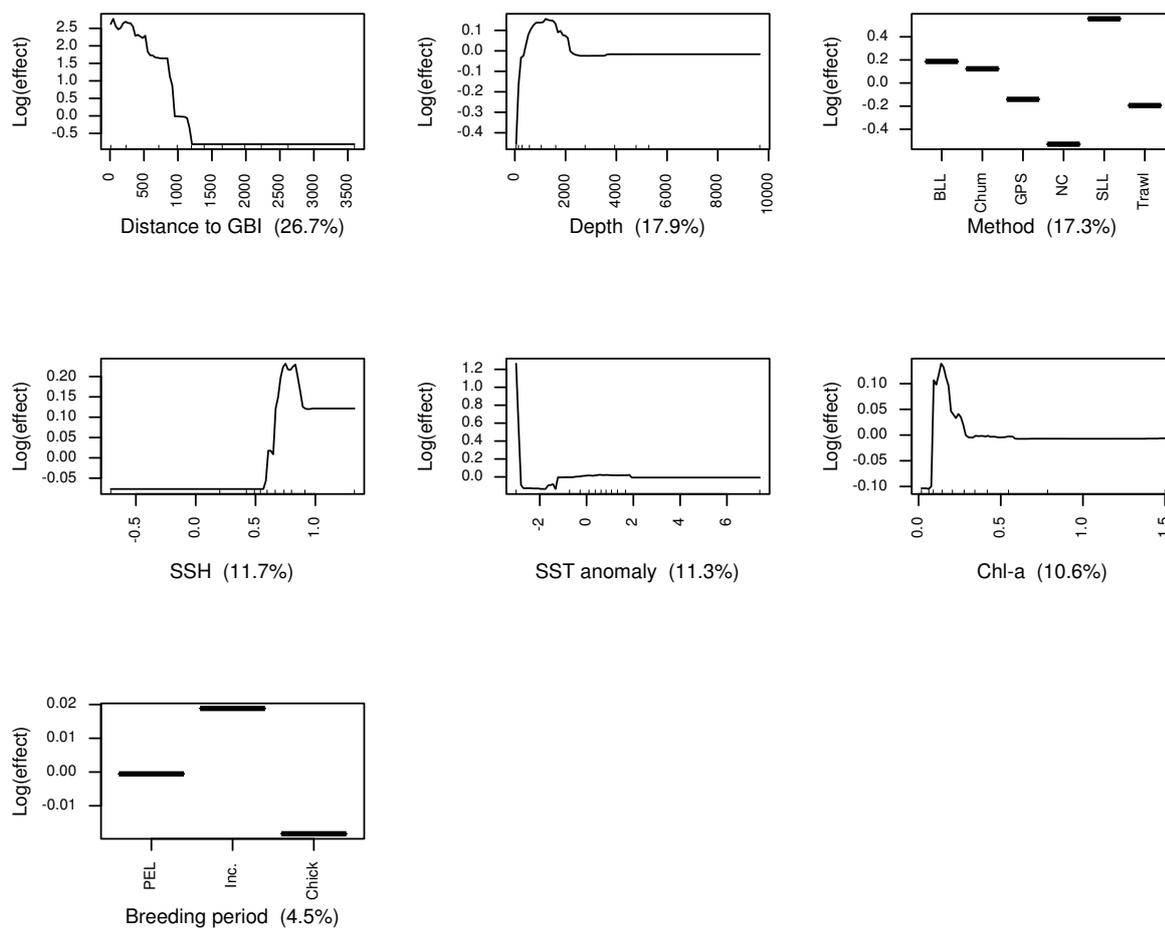


Figure 6: Effect of environmental variables on the distribution of black petrel in New Zealand waters, as estimated by the habitat model. For each variable in the model the plots show the logarithm of the marginal effect, with the effect of the other variables being integrated out. Variables included distance to Great Barrier Island (GBI), water depth, data collection method (during commercial fishing: BLL, bottom longlining; SLL, surface longlining, trawl; GPS tracking; birdwatching tours using chum or no chum (NC)), sea surface height (SSH), sea surface temperature (SST) anomaly, concentration of chlorophyll-*a* (Chl-*a*), and the breeding period of black petrel (PEL: pre-egg laying; Inc.: Incubation; Chick: Guard and chick rearing). Numbers in parentheses are the relative importance of each variable (%). Inward ticks on the *x*-axis indicate deciles of the data used for the modelling.

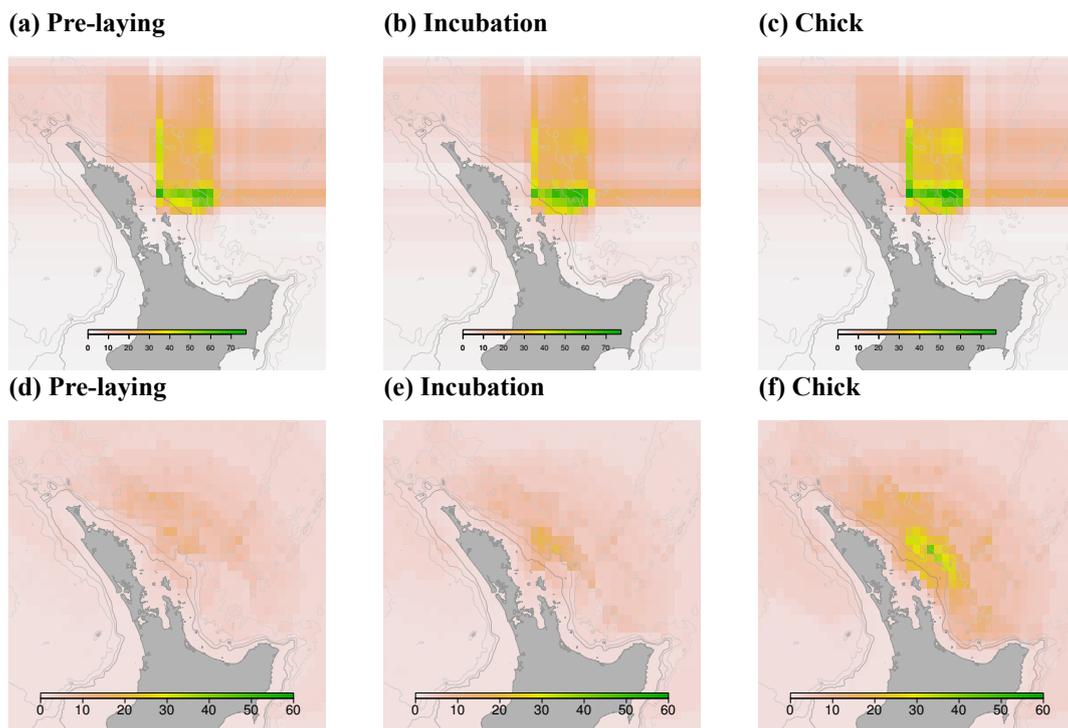


Figure 7: Distribution of black petrel in New Zealand, as predicted by a model including latitude and longitude (a–c) and by a model including environmental variables (d–f), for each for the three breeding periods. Both models were fitted to counts made by observers on fishing vessels, to counts from birdwatching tours, and to pseudo-counts from Global Positioning System (GPS) tracking data. Each distribution represents the number of black petrel that an observer would count behind a bottom-longline fishing vessel.

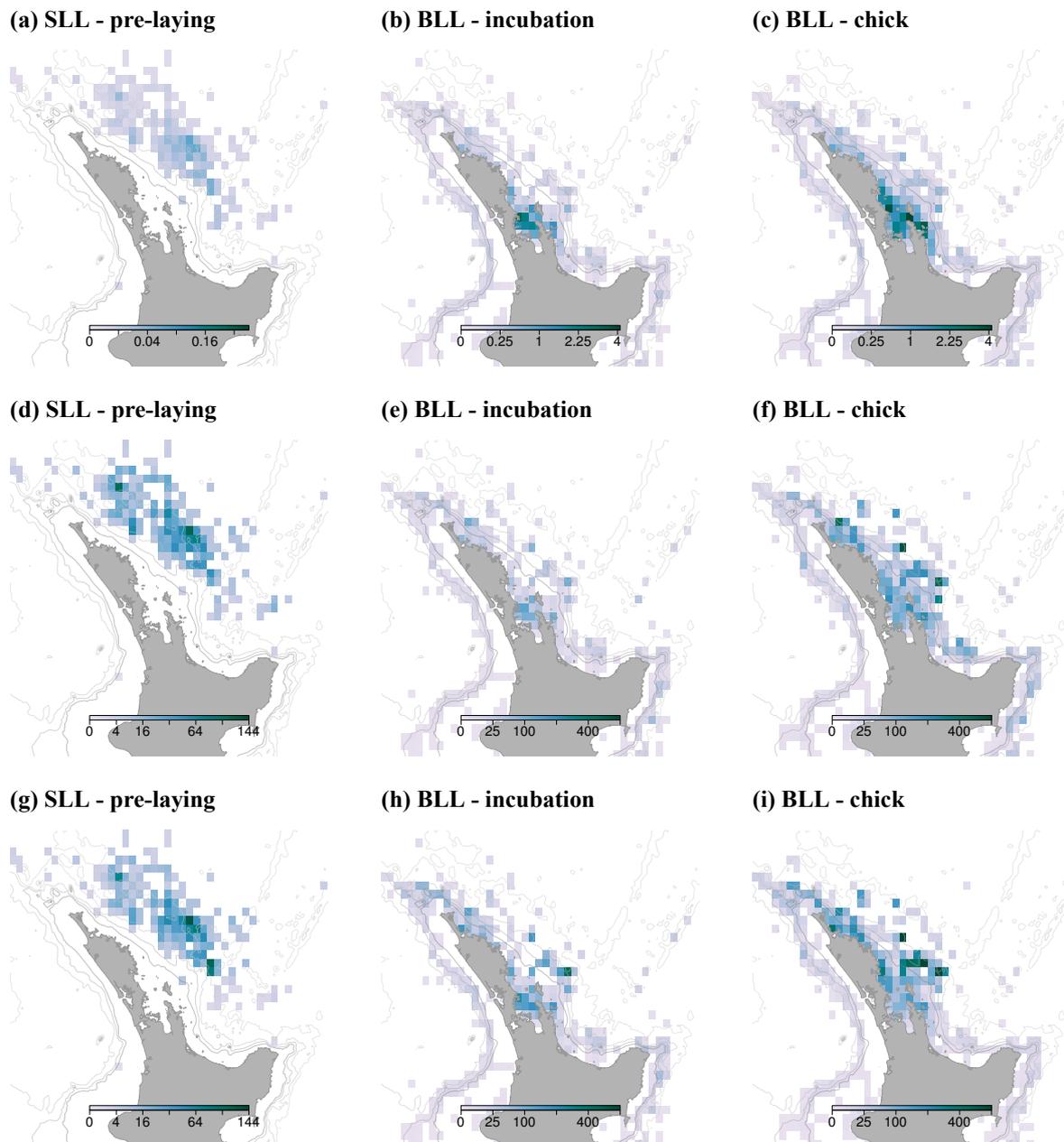


Figure 8: Overlap between the distribution of black petrel in New Zealand and the mean annual fishing effort of the last three years (2010–11 to 2012–13). The distributions were obtained from (a–c) the recent risk assessment of commercial fisheries to seabirds (Richard & Abraham 2013), (d–f) the predictions from a model including environmental variables, and (g–i) the predictions from a model including latitude and longitude instead. Both models were fitted to counts made by observers on fishing vessels, to counts from birdwatching tours, and to pseudo-counts from Global Positioning System (GPS) tracking data. The predictions were made on observer count data. Overlaps are shown for the three combinations of fishing method and breeding period during which most captures have been observed (SLL: surface longline; BLL: bottom longline).

recent risk assessment (Richard & Abraham 2013)(Table 3). In particular, the overlap of black petrel with bluenose and snapper bottom-longline fishing was between 10% and 20% of the total overlap for trawl and longline fisheries (with effort measured by fishing event), whereas when using distributions from the recent risk assessment (Richard & Abraham 2013), the overlap with snapper fisheries was 27.8%, and the overlap with the bluenose fisheries was only 3.8% (Table 3). The bluenose fisheries were active at the shelf break, and this increase in overlap with bluenose fisheries was due to the shift in distribution away from shallow water. The proportion of the total overlap associated with inshore trawl fisheries decreased from 49% (Richard & Abraham 2013) to around 25%, while the proportion of the total overlap associated with surface-longline fisheries increased from around 3% (Richard & Abraham 2013) to between 19% and 27% (depending on the model). This decrease was also associated with the shift in the distribution away from shallow water.

3.1 Relationship between overlap and fisheries

A key question was whether this overlap relates to the captures of black petrel. An assumption of the risk assessment was that, within fisheries, there is a proportional relationship between observed overlap and captures, with the proportionality constant being the vulnerability.

For the lat-long model with the best fit to the data, the highest observed overlap with an individual fishery and period was with the deepwater trawl fishery during the pre-egg-laying period (see Table 4 for a summary of the observed overlap, and Figure 9 for the relationship between observed overlap and different fisheries). There were no observed captures associated with this fishery. This lack of observed captures reflected the low vulnerability to capture of birds by deepwater trawl fisheries (Richard & Abraham 2013). In all other cases, average annual overlaps of over 100 bird events were associated with observed captures. It appears that, for the same overlap, there were likely to be more captures in bottom-longline fisheries than in surface-longline fisheries. This finding implied a higher vulnerability of black petrel to being caught in bottom-longline than in surface-longline fisheries. There were three bottom-longline-fisheries-period combinations that had over five observed captures, but which had low overlap. These captures were in bottom-longline fishing on the East Coast of North Island. There had been a total of 23 captures in this region in bottom-longline fisheries targeting hāpuku and bluenose. Nevertheless, there had been few observations of seabird abundance in bottom fisheries in this region.

The proportion of overlap that had been observed was low (less than 5%) across all the fisheries and periods that had observed captures. In inshore trawl fisheries, the observed overlap was less than 1% of the total overlap.

Table 3: Overlap between the distribution of black petrel and fisheries, from three distributions: the distribution used in the recent risk assessment of commercial fisheries to seabirds (Richard & Abraham 2013), predicted by a model including environmental variables, and predicted by a model including latitude and longitude instead. Both models were fitted to counts of observers on board commercial fishing vessels, to counts from birdwatching tours, and to pseudo-counts from Global Positioning System tracking. Overlap was calculated on the mean annual total fishing effort between 2010–2011 and 2012–2013. Overlap is the product of a number of birds, and a number of fishing events, and so has units “birds events”. The percentage of the total overlap by all fisheries during all seasons is represented for each model. Only the fisheries responsible for 90% of the total overlap within each fishing method are shown.

Method	Fishery	Distribution	Pre-laying	Incubation	Chick rearing	All seasons	
Trawl	Inshore	Risk assessment	13.27	12.88	22.86	49.00	
		Habitat model	6.42	5.87	13.48	25.77	
		Lat/long model	7.91	8.97	9.97	26.86	
	Deepwater	Risk assessment	0.48	0.28	0.63	1.39	
		Habitat model	1.16	0.49	1.11	2.76	
		Lat/long model	1.11	0.28	0.85	2.24	
	Scampi	Risk assessment	1.12	1.08	1.56	3.75	
		Habitat model	0.72	0.76	1.20	2.68	
		Lat/long model	0.79	0.08	1.20	2.07	
	Middle depth	Risk assessment	0.46	0.39	0.91	1.77	
		Habitat model	0.60	0.45	0.89	1.94	
		Lat/long model	0.46	0.17	0.46	1.09	
	BLL	Snapper	Risk assessment	6.94	6.80	14.00	27.75
			Habitat model	2.78	3.12	8.91	14.81
			Lat/long model	3.97	4.95	9.12	18.03
Bluenose		Risk assessment	1.05	0.90	1.60	3.55	
		Habitat model	1.73	1.90	9.37	12.99	
		Lat/long model	4.63	2.98	8.88	16.48	
Hāpuku		Risk assessment	0.46	0.30	0.54	1.29	
		Habitat model	0.66	0.55	1.89	3.10	
		Lat/long model	1.81	1.02	2.54	5.37	
Ling		Risk assessment	0.62	0.38	0.58	1.58	
		Habitat model	0.72	0.28	1.73	2.74	
		Lat/long model	0.67	0.41	0.80	1.88	
SLL		Bigeye tuna	Risk assessment	0.41	0.82	1.90	3.13
			Habitat model	5.82	9.15	11.28	26.24
			Lat/long model	4.06	6.98	8.73	19.77

Table 4: Overlap between the distribution of black petrel and fisheries for the main overlapping fisheries for each of three breeding periods and all seasons, between 2003–04 and 2012–13. Shown are the number of observed captures of black petrel, the mean annual overlap with observed fishing effort (Obs. overlap), the mean annual overlap with all fishing effort (Total overlap), and the percentage of the total overlap that was observed (Prop. observed). Overlap data presented here were produced from the distribution of black petrel from the lat-long model, fitted to counts of observers on board commercial fishing vessels, to counts from birdwatching tours, and to pseudo-counts from Global Positioning System tracking. Only target fisheries responsible for 90% of the total overlap within each fishing method are shown.

Method	Fishery	Period	Obs. captures	Obs. overlap	Total overlap	Prop. observed
Trawl	Inshore	Pre-egg	0	11	3 439	0.31
		Incubation	0	9	3 457	0.27
		Chick	2	96	7 273	1.32
		All seasons	2	116	14 169	0.82
	Deepwater	Pre-egg	0	196	533	36.78
		Incubation	0	13	266	4.83
		Chick	0	38	687	5.57
		All seasons	0	247	1 485	16.63
	Scampi	Pre-egg	0	54	370	14.63
		Incubation	0	16	373	4.17
		Chick	1	52	554	9.42
		All seasons	1	122	1 297	9.40
	Middle depth	Pre-egg	0	115	364	31.70
		Incubation	0	16	242	6.63
		Chick	0	34	474	7.07
All seasons		0	165	1 080	15.27	
BLL	Bluenose	Pre-egg	0	0	798	0.00
		Incubation	9	16	1 260	1.23
		Chick	12	124	6 471	1.91
		All seasons	21	139	8 530	1.63
	Snapper	Pre-egg	0	9	1 501	0.57
		Incubation	5	71	1 724	4.13
		Chick	23	159	4 629	3.43
		All seasons	28	238	7 854	3.04
	Hāpuku	Pre-egg	0	0	358	0.02
		Incubation	10	2	384	0.47
		Chick	6	30	1 634	1.81
		All seasons	16	32	2 376	1.33
SLL	Bigeye tuna	Pre-egg	8	144	2 997	4.80
		Incubation	1	144	3 373	4.27
		Chick	1	82	4 528	1.81
		All seasons	10	370	10 898	3.39

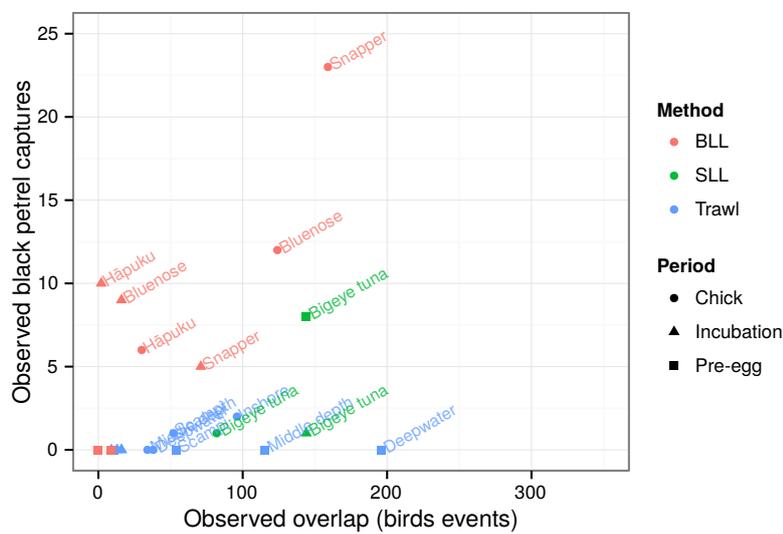


Figure 9: Relationship between mean annual observed overlap and observed captures of black petrel, based on data between 2003–04 and 2012–13. Points are the total observed captures and the mean annual overlap for different fisheries and breeding periods, including bottom-longline (BLL), surface-longline (SLL) and trawl fisheries. Overlap data were derived from a model including latitude and longitude. Only target fisheries responsible for 90% of overlap within each fishing method for the last three years are shown.

4. DISCUSSION

4.1 Summary of the modelling

The goal of this study was to develop understanding of the distribution of black petrel that would be a suitable input into the seabird risk assessment (Richard & Abraham 2013). Data were available from a range of sources (observer counts, sightings during birdwatching tours, and GPS tracking data). All of these data had limitations: the observer counts included misidentifications, birdwatch data were spatially restricted, and available tracking data were limited. The aim of this study was to pool these data from different sources to overcome some of the shortcomings of each individual data set. Analyses based on tracking data alone are often limited, as only a single component of the population (such as breeding birds) is typically measured. The observer counts are a direct measure of the quantity of interest: the number of black petrel associated with fishing vessels. Not only do they include all life-stages, but they also account for the attraction of black petrel to the fishing activity.

Boosted regression trees were used as the modelling technique to synthesise these count data. Regression trees are non-parametric, and have the advantage that they are able to represent interactions in the data. It was expected that a habitat model, based on variables that were considered to be relevant to black petrel, would be able to explain the distribution of this species. Nevertheless, a simple model (the lat-long model) that had latitude and longitude as the covariates in the boosted regression tree best explained the variation in the data. Because this lat-long model did not include covariates that are related to black petrel ecology, it should not be used for extrapolating far away from the data. As the seabird count data were collected by observers during commercial fishing activities, these data are appropriate for an analysis of black petrel overlap with fisheries.

Although the habitat model performed less well at explaining variation in the data, it allowed exploration of the relationship between the model effects and black petrel abundance. Distance from Great Barrier Island and water depth were the two most important covariates. Black petrel abundance increased close to the island, with no further decrease beyond around 1000 km distance from the island. Black petrel were also found to have highest abundance on the shelf edge, with a peak in abundance at around 1000 m water depth.

A limitation of the regression trees was that the data were assumed to be Poisson distributed. In reality, the count data were over-dispersed. In future analyses, if possible, we recommend that a model structure is used that allows for overdispersion. A suitable model structure could be a hierarchical Generalised Additive Model (GAM), that includes those covariates that were identified by the boosted regression tree as important. The GAM allows for a non-linear relationship between the covariates and black petrel abundance, and would also allow for an overdispersed distribution (such as a negative binomial) to be estimated from the data. The hierarchical structure would be used to account for the sampling structure of the data (from observer trips, and individual GPS tracks). Depending on the model structure, it may also be possible to account for limitations such as observer misidentification, or for the grouping of birdwatch sightings data into ranges. This kind of statistical modelling was not possible with the boosted regression trees. Additional covariates related to the observer counts (such as time of day, whether the fishing event was a set or a haul, or the experience of the observers), may also be included in a structured model.

The analysis of the distribution was limited by the available data. Inshore fisheries have been relatively poorly observed, and so there have only been sporadic observer counts of seabird abundance behind inshore fishing vessels. An increase in observer coverage in this area, partly in response to the very-high risk of black petrel from fisheries mortalities, will improve the dataset considerably. In the bottom-longline snapper fishery, observer coverage in 2013–14 has already increased (N. Walker, pers. comm.). Furthermore, more GPS tracking data were collected in the summer of the 2013–14 fishing year, and the observer programme that includes the recording of counts of seabirds associated with fishing vessels continues. As more data are collected, understanding of the distribution of black petrel will improve.

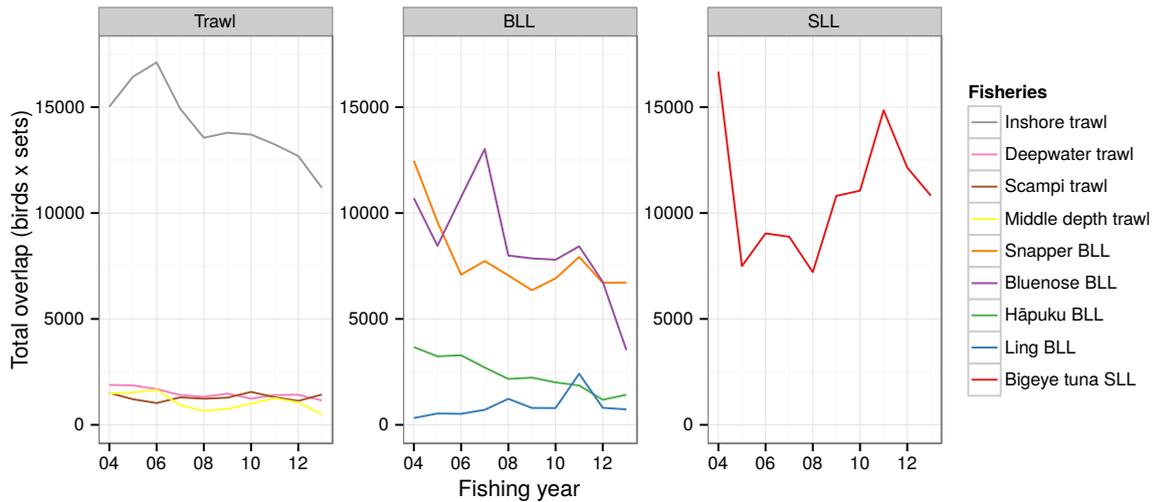


Figure 10: Variation of total overlap between black petrel and target fisheries from 2003–04 to 2012–13, by fishery. Overlap data were derived from a model including latitude and longitude. Only target fisheries responsible for 90% of overlap within each fishing method for the last three years are shown (BLL: bottom longline; SLL: surface longline).

4.2 Overlap with fisheries

The observer counts are a direct measure of the number of birds behind fishing vessels, and the overlap (with units of number of birds multiplied by the number of fishing events) has a direct interpretation as the total number of birds that are around fishing vessels during fishing events. There are limitations on this interpretation: the observer counts are made at a point in time and so are not a measure of the total number of birds that interact with the vessel for the duration of the event. No attempt was made to measure turnover (whether individual birds are staying with the vessel throughout the event, or whether some birds leave and others arrive during the fishing). From this point of view, the observer count is a lower estimate of the number of birds interacting with the fishing vessel. In contrast, however, the observer counts only record presence of the birds at the back of the vessel, and no attempt is made to quantify the nature of the interaction.

Considering the total overlap over the period between 2003–04 and 2012–13, there were differences across different fisheries (Figure 10). The overlap with inshore trawl fisheries was around 15 000 birds sets, compared with snapper and bluenose bottom-longline fisheries, where the overlap was around 10 000 and 5 000 birds sets, respectively. For surface-longline fisheries, the overlap was around 10 000 birds sets.

In recent years, there have been declines in the level of overlap in all the fisheries that overlap most strongly with black petrel. The total overlap has decreased from around 89 000 birds events in 2003–04 to around 45 000 birds events during the 2012–13 fishing year. Assuming that incidental captures are proportional to overlap (and not considering any changes in the population over this period, as they are not represented in this analysis), the incidental captures of black petrel will have approximately halved over this period. The decline is most marked in the bottom-longline fishery targeting bluenose. Overlap with this fishery has fallen from over 20 000 birds sets in 2003–04 to less than 5 000 birds sets in 2012–13. As the effort declines, black petrel captures should correspondingly decrease. If black petrel are strongly associating with fishing vessels, however, then the number of black petrel behind vessels would increase as the fishing effort declined. The observer count data are not yet sufficient to detect any trends in abundance.

For this study, the motivation for quantifying the overlap of black petrel with commercial fishing was to allow extrapolation from captures on observed fishing to captures on all fishing, for the purpose of

updating the recent seabird risk assessment (Richard & Abraham 2013). It is recommended that the overlap derived from the lat-long model, which best represented the data, is used as the base case. The overlap from the habitat model may be used as an alternative, to explore the sensitivity of the analysis to different assumptions on overlap between black petrel and fisheries. While there were limitations with all the data sets, these data-based fishery overlaps provide a better basis for the risk assessment than the heuristically generated map that was previously used by Richard and Abraham (2013). To reduce uncertainty in the distribution and in the estimates of black petrel captures, further observer coverage in fisheries with recorded interactions is recommended. In particular, observations in bottom-longline fisheries on the East Coast of North Island would help to resolve the discrepancy between the apparently low overlap in this area, and the high proportion of observed captures that have occurred there.

5. ACKNOWLEDGMENTS

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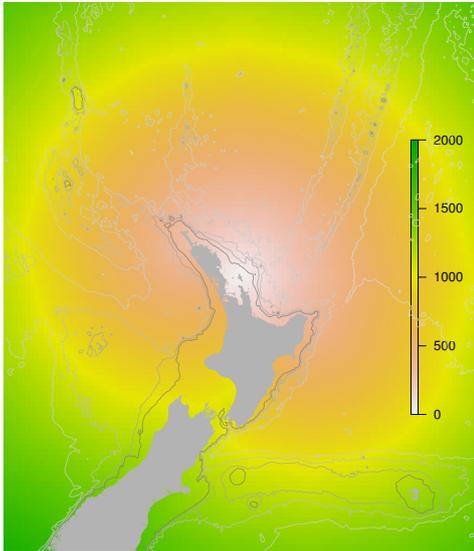
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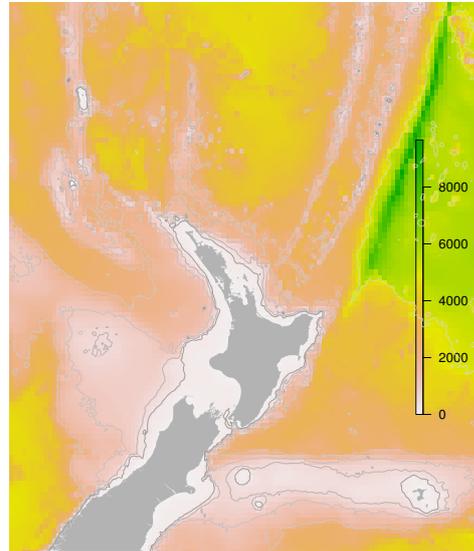
APPENDIX A Variables included in the habitat model

A.1 Time-invariant variables

(a) Distance to Great Barrier Island



(b) Depth



(c) Slope

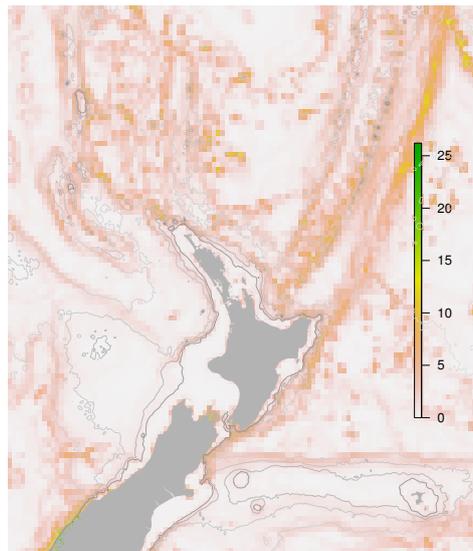
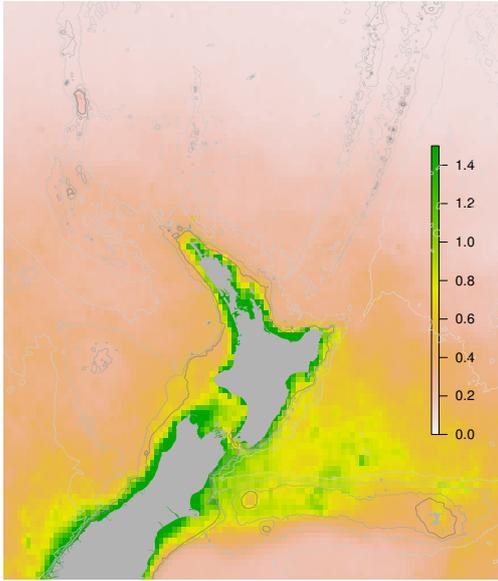


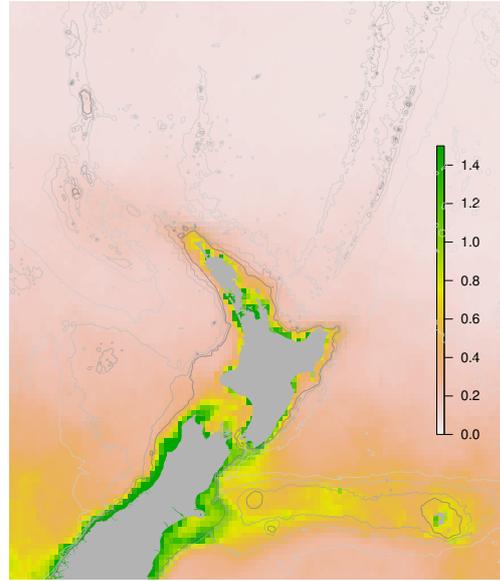
Figure A-1: Time-invariant variables used as covariates in the habitat model to estimate the overlap between the distribution of black petrel and commercial fisheries. The variables were (a) distance to Great Barrier Island (km), avoiding land, (b) water depth (m), and (c) seafloor slope (degrees).

A.2 Chlorophyll-a

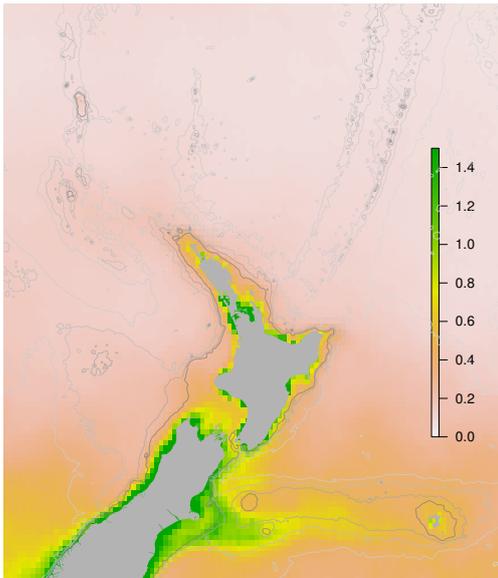
(a) Pre-laying



(b) Incubation



(c) Chick rearing



(d) Non-breeding

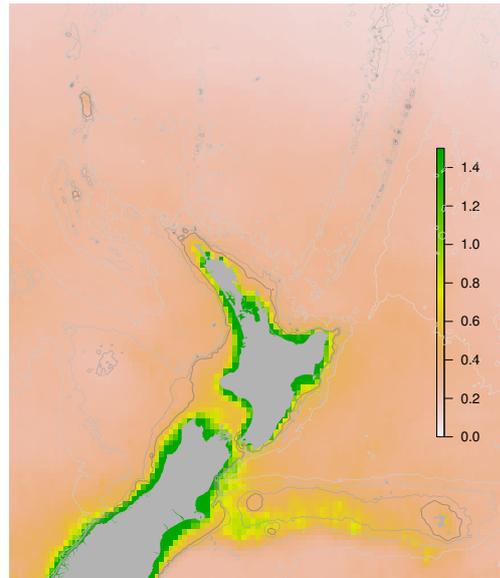
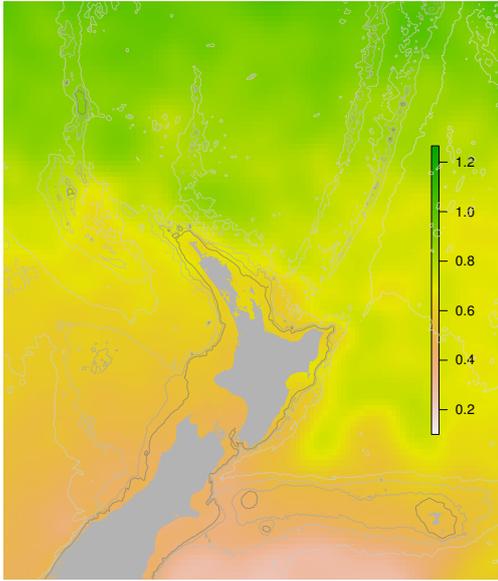


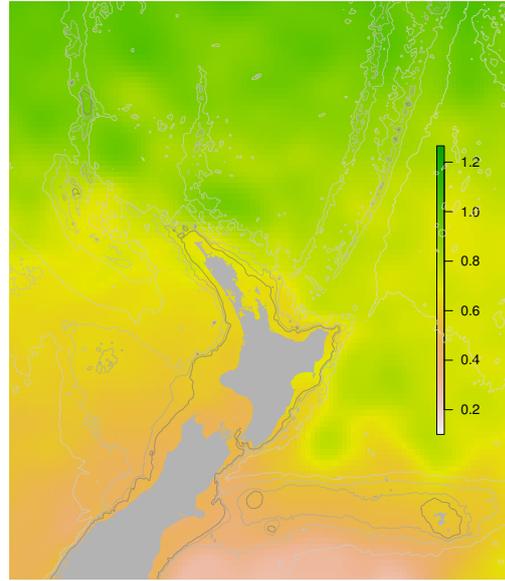
Figure A-2: Map of chlorophyll-a concentration (mg m^{-3}), averaged within each of the four breeding periods of black petrel.

A.3 Sea surface height

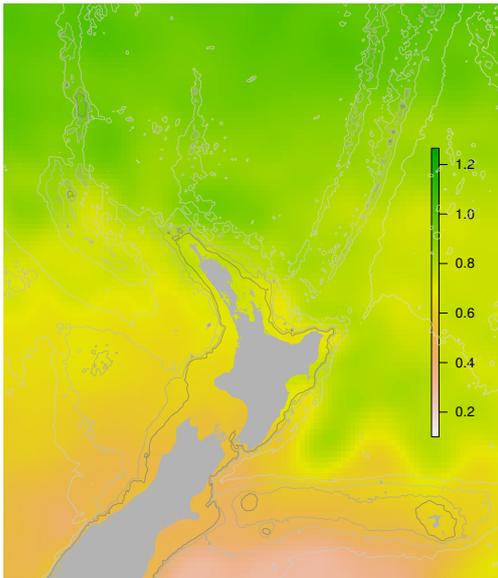
(a) Pre-laying



(b) Incubation



(c) Chick rearing



(d) Non-breeding

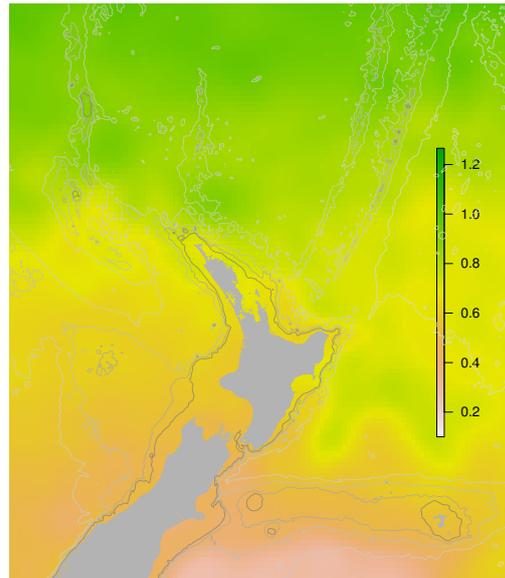
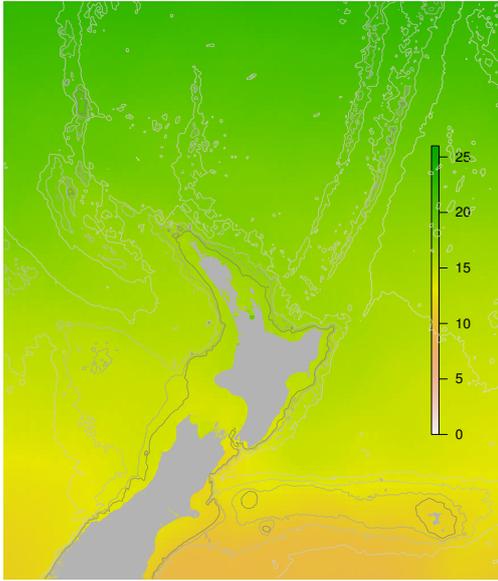


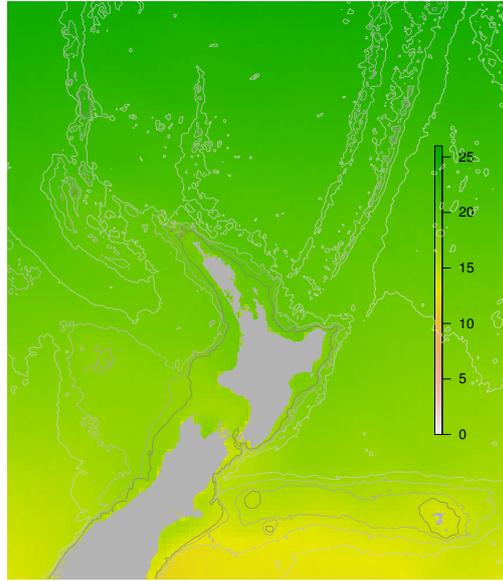
Figure A-3: Map of sea surface height (m), averaged within each of the four breeding periods.

A.4 Sea surface temperature

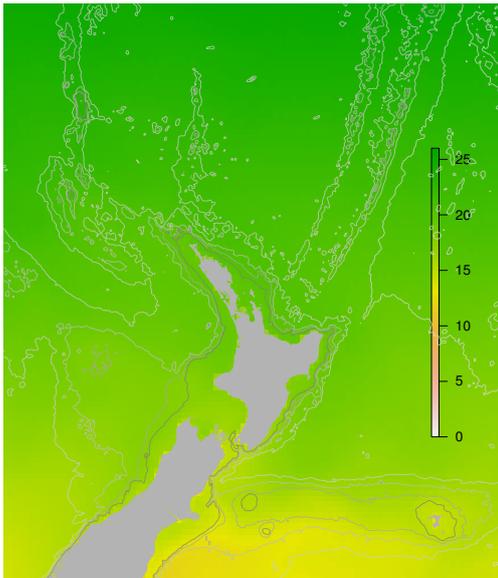
(a) Pre-laying



(b) Incubation



(c) Chick rearing



(d) Non-breeding

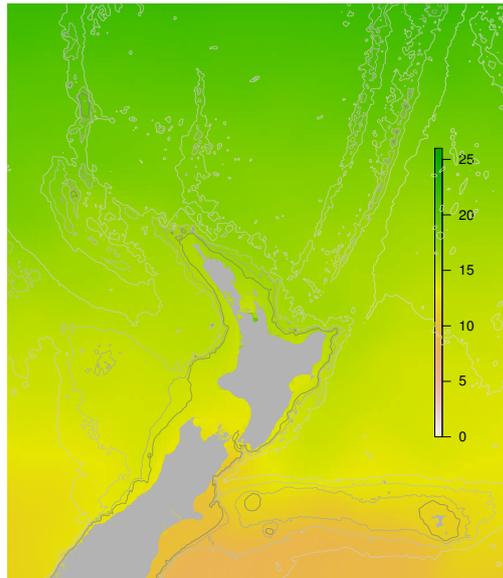
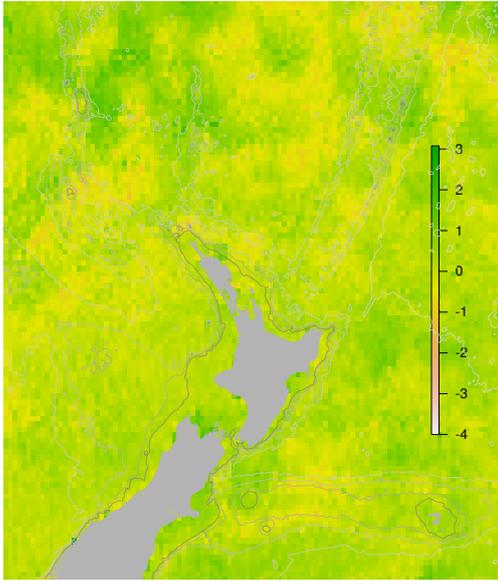


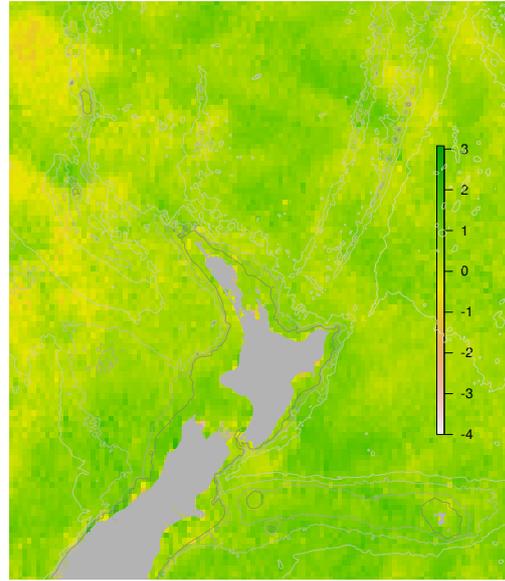
Figure A-4: Map of sea surface temperature (°C), averaged within each of the four breeding periods of black petrel.

A.5 Sea surface temperature anomaly

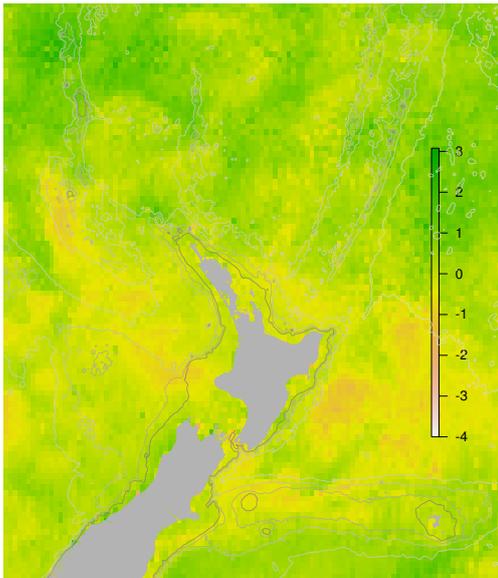
(a) Pre-laying



(b) Incubation



(c) Chick rearing



(d) Non-breeding

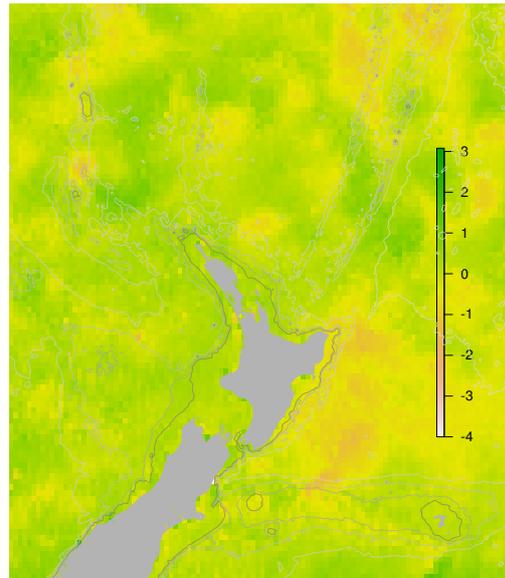
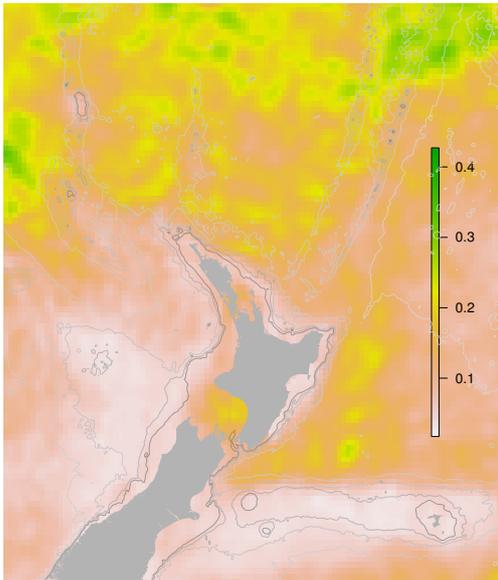


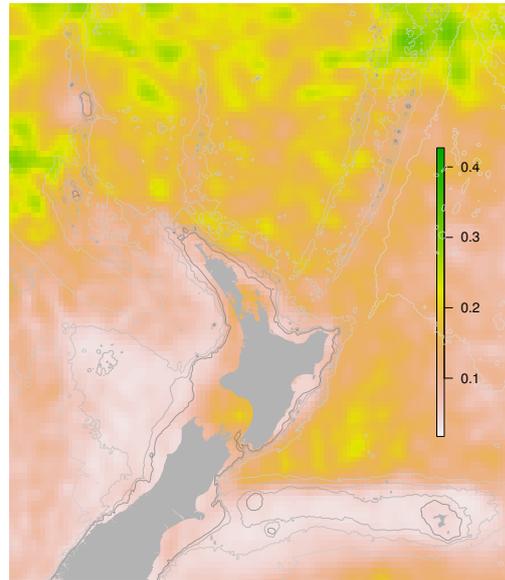
Figure A-5: Map of the sea surface temperature anomaly ($^{\circ}\text{C}$), averaged within each of the four breeding periods.

A.6 Geostrophic current

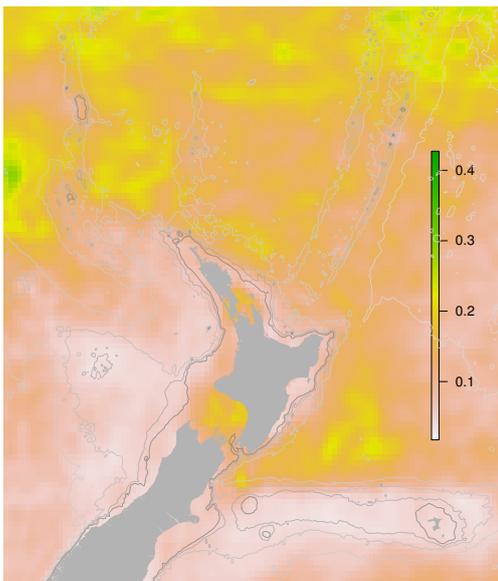
(a) Pre-laying



(b) Incubation



(c) Chick rearing



(d) Non-breeding

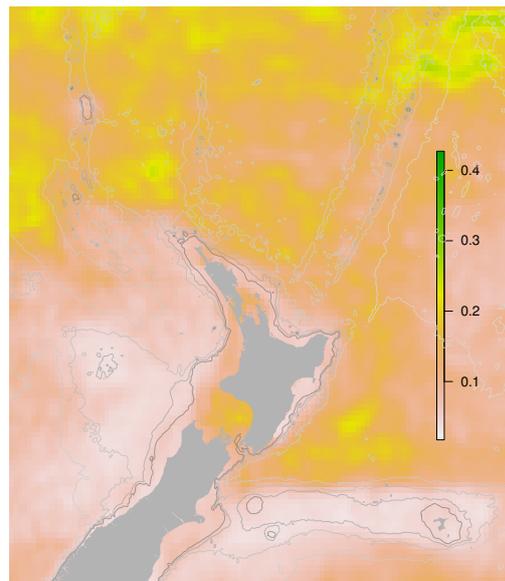


Figure A-6: Map of geostrophic current speed (m s^{-1}), averaged within each of the four breeding periods of black petrel.

A.7 Variable importance

Table A-1: Importance of variables in each of the habitat models to estimate the overlap between the distribution of black petrel and commercial fisheries. A preliminary analysis considered all variables before selection. Variables are sorted by decreasing mean importance (GBI, Great Barrier Island; Method, fishing and data collection method; Depth, water depth; SST, sea surface temperature; SSH, sea surface height; Chl-*a*, chlorophyll-*a* concentration in the water column; OGC, current speed; slope, seafloor slope; count type—observer, birdwatching, or GPS).

Variable	Tree complexity			Mean
	TC=1	TC=10	TC=20	
Distance to GBI	44.78	23.18	22.98	30.31
Method	40.50	14.39	10.85	21.91
Depth	4.78	14.58	15.89	11.75
SST anomaly	4.41	9.54	9.93	7.96
SSH	2.43	9.36	10.23	7.34
Chl- <i>a</i>	0.76	8.15	8.84	5.92
OGC	0.07	5.43	6.77	4.09
Slope	1.19	5.32	5.00	3.84
SSH anomaly	0.01	4.96	4.81	3.26
Breeding period	0.93	3.87	3.19	2.66
Count type	0.16	1.22	1.51	0.96

Table A-2: Variable importance in the habitat model to estimate the overlap between the distribution of black petrel and commercial fisheries, after removing the least important variables. Variables are sorted by decreasing importance (GBI, Great Barrier Island; Depth, water depth; Method, data collection method; SSH, sea surface height; SST, sea surface temperature; Chl-*a*, chlorophyll-*a* concentration in the water column).

Variable	Importance
Distance to GBI	26.71
Depth	17.92
Method	17.27
SSH	11.71
SST anomaly	11.25
Chl- <i>a</i>	10.62
Breeding period	4.52

APPENDIX B Areas used

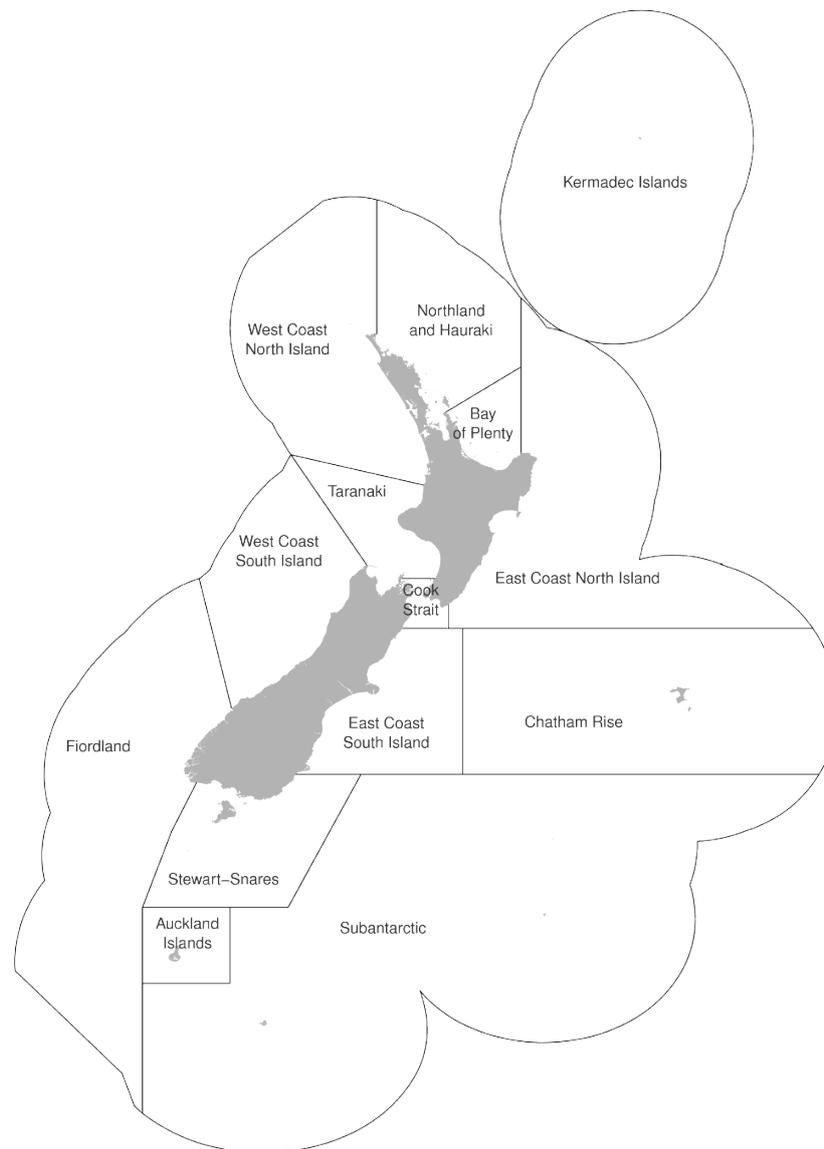


Figure B-7: Areas in New Zealand's Exclusive Economic Zone, used for summarising protected species captures (see Abraham et al. 2013). The northern areas, East Coast North Island, Kermadec Islands, Bay of Plenty, Northland and Hauraki, and West Coast North Island, were used in the present study to summarise the observed and estimated abundance of black petrel.