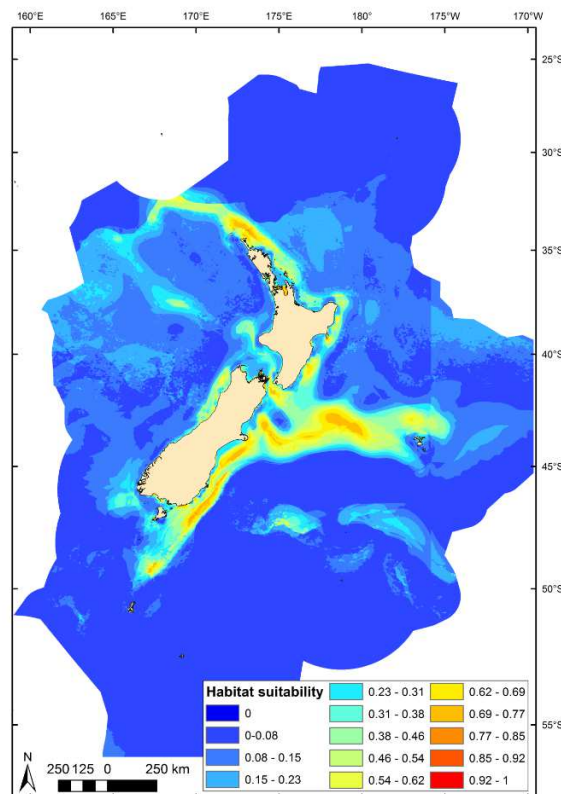


Habitat models of southern right whales, Hector's dolphin, and killer whales in New Zealand

Prepared for Trans-Tasman Resources Limited

October 2013



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Cover image: Habitat suitability predictions for killer whales from the habitat use model with bias grid correction

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Executive summary

Trans-Tasman Resources Ltd (TTR) proposes to extract iron sands from the seabed in the South Taranaki Bight (STB), approximately 22-35 km offshore in water depths of 25-45 m. The proposed mining activities will affect the seafloor community at the extraction sites, while the sediment plume associated with the discharge of tailings sediment back to the seafloor has the potential to affect pelagic and benthic ecosystems downstream. Cetaceans (whales and dolphins), as important high level predators in marine systems, may be impacted by these activities.

A preliminary assessment of cetacean distribution in the region identified the presence of three endangered species: southern right whales (*Eubalaena australis*), Hector's dolphins (*Cephalorhynchus hectori* and the sub-species Maui's dolphin *C.H. maui*), and killer whales (*Orcinus orca*). There were two objectives of the present study. First, to create New Zealand wide species distribution models for southern right whales, Hector's dolphins, and killer whales using all available sightings data to date. Second to use the model outputs to determine the suitability of marine habitats in the STB, specifically the areas likely to be affected by mining activities, for these three species.

Distribution models of the three species around New Zealand were generated using incidental presence-only sightings data. Maximum entropy modelling (Maxent) was implemented to relate species distribution to a variety of environmental predictor variables including bathymetry, dissolved organic matter, winter sea surface temperature, sea surface temperature gradient, suspended particulate matter, primary productivity, tidal current, and the 95th percentile of wave height (representing extreme wave/storm events). Distribution models were created for habitat within the 350 m isobath of the New Zealand mainland coast for southern right whales and Hector's dolphins as a function of their coastal distribution patterns. The killer whale model extent included the New Zealand extended continental shelf due to the broad distribution of this species. Seasonality was not incorporated into these models due to lack of sufficient data across seasons, so results represent a yearly average for Hector's dolphins and killer whales. The southern right whale model was limited to winter months when this species uses coastal habitats.

The data incorporated into the models were not collected through standardized surveys. Therefore, the distribution of these incidental sightings were subject to observer bias (more sightings where more people were looking for them). Observational bias can negatively impact model accuracy and predictive capabilities. Bias was detected in the spatial distribution of Hector's dolphin and killer whale incidental sightings. Therefore, a bias grid was incorporated into the models of Hector's dolphin and killer whale distribution that down-weighted areas with increased presence locations. No bias was detected in the spatial distribution of incidental southern right whale sightings.

Model results of southern right whale distribution patterns determined that the most influential predictor variables of habitat use patterns were bathymetry, dissolved organic matter, and the 95th percentile of wave height. The spatial predictions of southern right whale habitat based on this model identified sheltered coastal habitats as having the highest habitat suitability during winter. Low habitat suitability for southern right whales was predicted at and adjacent to TTR's proposed project area. A coastal strip within 5 km of the shoreline, had low

to moderate suitability for this species suggesting that individuals may use this area as a migration corridor.

The results from the Hector's dolphin model identified that suspended particulate matter, dissolved organic matter, the 95th percentile of wave height, and winter sea surface temperature were the most important predictor variables of their habitat use patterns. The spatial predictions of Hector's dolphin distribution based on model results demonstrated a relatively good match with known areas of sub-population distributions and identified one area from which Hector's dolphins may have been historically extirpated. The modelling established that habitat suitability for Hector's dolphins in the proposed project area was low. However, coastal areas inshore of the proposed project area were predicted to have average to above average suitability as habitat for Hector's dolphin.

The model of killer whale habitat use patterns determined that sea surface temperature gradient was the most influential determinant of distribution, followed by primary productivity, dissolved organic matter, and suspended particulate matter. Low habitat suitability for killer whales was predicted in the proposed TTR project area. A band of average to above average habitat suitability for killer whales, corresponding to an area of increased sea surface temperature gradient, begins approximately 8 km seaward of the proposed project area.

In summary, the proposed project area in the STB appears to be of low suitability for all three species of threatened cetaceans. Areas of increased habitat suitability for Hector's dolphins and southern right whales lie close inshore and may be increasingly used as the New Zealand populations of these species recover. An area of average to above average habitat suitability for killer whales begins approximately 8 km seaward of the proposed project area.

1 Introduction

Trans-Tasman Resources Ltd (TTR) proposes to extract iron sands from the seabed in the South Taranaki Bight (STB), approximately 22-35 km offshore in water depths of 25-45 m. The proposed mining activities will affect the seafloor community at the extraction sites, while the sediment plume associated with the discharge of tailings sediment back to the seafloor has the potential to affect pelagic and benthic ecosystems downstream. Cetaceans (whales and dolphins), as important high level predators in marine systems, may be impacted by these activities.

An initial examination of cetacean distribution in the STB (MacDiarmid et al. 2010) relied on two datasets of opportunistic sightings of cetacean species: (1) The Department of Conservation (DOC) cetacean sightings data, and (2) a dataset compiled by Martin Cawthorn of incidental cetacean sightings by transiting cargo ships. These two datasets provide 64 records of 13 different cetacean species sighted between February 1980 and December 2007 within the STB. Three of these species, the southern right whale (*Eubalaena australis*), the Hector's dolphin (*Cephalorhynchus hectori*) (including the sub-species Maui's dolphin, *Cephalorhynchus hectori maui*), and the killer whale (*Orcinus orca*) are listed as nationally endangered or critical (Baker et al. 2010). Current population estimates of these species in New Zealand are low (Baker et al. 2010) and their use of areas near TTR's proposed project area are unknown.

The objectives of this study were to:

1. Create New Zealand wide species distribution models for southern right whales, Hector's dolphins, and killer whales using all available sightings data to date.
2. Use the model outputs to determine the suitability of marine habitats in the STB, specifically the areas likely to be affected by mining activities, for these three species.

Development of New Zealand wide species distribution models enables the use of all available sightings data, thereby increasing model accuracy and reliability. Species distribution models are increasingly used to address numerous questions in conservation biology, ecology and evolution (Guisan & Thuiller 2005). Predictive distribution models can contribute to an understanding of a species habitat use patterns. For species where there is a lack of occurrence data in specific areas, species distribution models can support conservation efforts through the potential identification of critical habitats and assessment of potential risks (Gregr 2011). Indeed, to conserve a threatened species, its ecological niche must first be described in order to understand its habitat preferences and survival requirements (Soberón 2007).

Previous studies have been conducted in New Zealand on the distribution patterns of southern right whales and Hector's dolphins utilizing a range of methods (e.g., Brager et al. 2003, Clement et al. 2010, Patenaude & Baker 2001). However, these studies explored relationships between environmental variables and species distribution on relatively small scales, such as within single bays. No study on killer whale distributions patterns in New Zealand has been previously conducted. In this study, we generate large-scale distribution models of these three threatened species throughout their range in New Zealand waters. We compiled nearly 4000 sightings of these three species recorded between 1970 and 2011 and related these data to

environmental variables. We implement novel habitat layers that represent the New Zealand marine environment that have never before been related to the distribution of these species. From these distribution models we predict the distribution for each species. Predictions of Hector's dolphin and southern right whales were limited to within the 350 m isobaths of the New Zealand mainland coast based on the limits of their distribution patterns (Figure 2-1). The southern right whale model was further limited to winter months when they are coastally distributed as a function of their migration cycle. The model of killer whale distribution patterns extended to the limits of the New Zealand Extended Continental Shelf, the area over which the country has jurisdiction of the seafloor, because sightings data were distributed across this range into depths greater than 750 m (Figure 2-1).

1.1 Background information on Hector's and Maui's dolphins

Genetic studies have determined four sub-populations of Hector's dolphins (Pilcher et al. 1998), including the distinct sub-species Maui's dolphin (Baker et al. 2002). Hector's dolphin and Maui's dolphins are endemic to New Zealand and considered among the rarest mammal species in the world (Du Fresne 2010). Their distribution is restricted to the coastal zone, (Bräger et al. 2002, Slooten et al. 2004, Slooten et al. 2005). The Maui's dolphin population is distributed along the western coast of North Island, potentially including the TTR proposed project area, and has a population estimate of just 55 individuals greater than 1 year-old (95% CI = 48 to 69; Hamner et al. 2012). Two recent Hector's or Maui's dolphin deaths have been recorded in the STB: (1) an individual was incidentally caught in a gill net on 2 January 2012 off Mt. Egmont, Taranaki and (2) a beach cast individual was discovered on 25 April 2012 at Opunake, Taranaki. The three Hector's dolphin sub-populations inhabit the east, west and southern coasts of South Island and have a combined population estimate of approximately 7000 (Slooten et al. 2004). It is difficult to visually distinguish between Hector's and Maui's dolphins. However, DNA genotyping of individuals suggest that both South Island Hector's dolphins and North Island Maui's dolphins use the South Taranaki Bight (Hamner et al. 2012a, Hamner et al. 2012b). Therefore, the distribution patterns of both sub-species in New Zealand and near the TTR proposed project area are examined in this report (collectively called Hector's dolphins unless otherwise noted).

1.2 Background information on Southern right whales

The southern right whale is distributed across all ocean basins in the southern hemisphere (Townsend 1935). However, whaling between the 18th and 20th centuries reduced these populations to near extinction (Dawbin 1986, Smith et al. 2012), including an estimate of just 90 surviving individuals in 1925 for the New Zealand population (Jackson et al. 2011). Today, this population is estimated at 900 whales, however this estimate includes fewer than a dozen reproductive females around New Zealand (Patenaude 2002). Southern right whales are predominantly encountered in coastal waters during calving over winter months (Bannister 2011, Dawbin 1986) and during the remainder of the year they occur in offshore habitats used as foraging grounds (Torres et al. 2011). During the winter months, females with calves frequent sheltered, coastal waters (Elwen & Best 2004a, Elwen & Best 2004b, Patenaude & Baker 2001). Although the majority of the New Zealand southern right whale population is limited to sub-Antarctic waters (Carroll et al. 2011a) coastal sightings around mainland New Zealand have been recorded with increased frequency over the past decade, indicating

possible recovery and re-colonization of historic wintering grounds (Carroll et al. 2011b, Carroll et al. 2013).

1.3 Background information on killer whales

Killer whales have a broad global distribution and are found in all oceans of the world (Ford 2009). Killer whales also have a broad diet including fish, rays, marine mammals and sharks (Constantine et al. 1998, Ford 2009, Visser 1999, Visser et al. 2000). Consequently, killer whales have been found to inhabit a range of habitats from deep pelagic waters to coastal areas (Baird & Dill 1995, Ford 2009, Iniguez 2001). The entire New Zealand killer whale population is small (mean = 119 ± 24 SE) and known to be broadly distributed around both North and South islands (Visser 2000). Little is known about killer whale distribution or habitat use patterns and, hence, conservation managers have little knowledge about their population status in different areas or exposure to various anthropogenic threats.

2 Methods

2.1 Data and study area

Distribution data for the three cetacean species were obtained from four sources: (1) The New Zealand Department of Conservation (DOC) database of verified incidental cetacean sightings by various sources including DOC staff, fishermen, and the public (Department of Conservation 2012); (2) Incidental cetacean sightings recorded by transiting ships between New Zealand and overseas ports collated between 1979 and 1999¹; (3) The New Zealand Ministry of Fisheries database of cetacean sightings recorded by observers aboard fishing vessels (Comprehensive Observer Database (COD); Ministry of Fisheries 2011); (4) Opportunistic cetacean sightings recorded by scientists from the National Institute for Water and Atmospheric research (NIWA)².

Sightings compiled in the DOC dataset derive from multiple sources including the public, scientific research, and DOC employees. All sightings in the DOC dataset are validated (1-5, high to low confidence) and only sightings with a confidence rating between 1 and 3 were included in this analysis. The time period of these DOC sightings data range from 1970 to 2011, though most sightings were recorded between 1999 and 2011. The Cawthorn data were collected by ship captains trained by Mr Cawthorn and all sightings were verified by Mr Cawthorn. These Cawthorn data were collected between 1979 and 1999, with most data recorded between 1980 and 1987. The COD cetacean sightings were recorded by trained fisheries observers aboard inshore fishing vessels between 2009 and 2011. The NIWA sightings are all verified by Dr Torres either through photos or videos taken in the field, or by verbal descriptions of the observations. The time period of the NIWA sightings ranges from 2007 to 2011.

A portion of Hector's dolphin sightings from the DOC database derived from aerial surveys along the North Island west coast (n=52). Although more than 8000 sightings of these three species were collected from 1960 to 2011 and recorded in these databases, only half of

¹ Unpublished data, Martin Cawthorn, May 2009, Cawthorn & Associates, Plimerton, New Zealand

² Unpublished data, Leigh Torres, January 2012, National Institute of Water and Atmospheric Research, Ltd. Wellington, New Zealand

these sightings were retained for analysis in the distribution models. We removed duplicate sightings between databases, sightings with imprecise location and date information, and spatial duplicates. A spatial duplicate is when more than one record from the same species occurred in the same 1 km grid cell. Spatial duplicates skew models towards the environmental conditions found in those cells (Elith et al. 2010). The final dataset used for analyses included 3298 Hector's dolphin sightings, 210 southern right whale sightings, and 475 killer whale sightings.

In order to maximize the sample size of sightings used in the models, we did not limit the temporal range of data implemented in the models. With this approach our data set spans 51 years and the assumption is made that environmental patterns across the study region and the species-environment relationships have not changed during this period. Moreover, because the abundance of southern right whales and Hector's dolphins has likely changed over this time period (recovering or declining due to anthropogenic impacts, respectively), the wide temporal range of data used allows the models to assess all potential suitable habitats for the species, not just those used during one time period.

Due to the coastal distribution of Hector's dolphins around mainland New Zealand (Brager et al. 2003), species distribution models for this species were generated within the 350 m isobaths of mainland New Zealand (Figure 2-1). Additionally, the majority of southern right whale sightings in our dataset were coastal and recorded in winter months during their calving season. Therefore, we only used sightings recorded between May and September and generated a distribution model for southern right whales within the 350 m isobath of the New Zealand mainland coast during winter. Sightings of killer whales extended to depths of nearly 800 m allowing the distribution model to encompass the extended continental shelf.

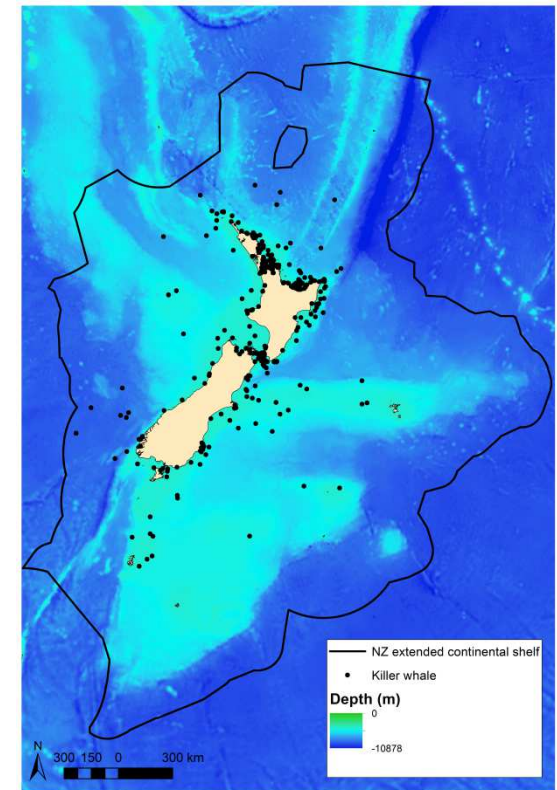


Figure 2-1: Distribution of incidental sightings of southern right whales, Hector's dolphins, and killer whales used in distribution models. The blue areas in the first two panels represent habitat less than 350 m that was used as the modelling extent. The black line in the third panel illustrates the extended continental shelf used as the extent for the killer whales model; regional bathymetry is illustrated.

2.2 Environmental data

Selection of environmental variables that are functionally relevant to species is an important phase of any species modelling process (Guisan & Zimmermann 2000). Environmental variables of significance for Hector's dolphins and killer whales likely represent proxies for their prey distribution. Direct information on the distribution of Hector's dolphin and killer whale prey across their entire range are non-existent. The distribution of Hector's dolphins has been found to be influenced by water clarity, temperature and depth (Brager et al. 2003). Habitat use patterns of killer whales have been associated with relatively cold waters, and variable depths based on location ranging from shallow waters along coastlines to deep offshore areas (Baird & Dill 1995, Constantine et al. 1998, Matkin et al. 2007). Environmental variables of significance for southern right whales likely represent good calving areas which offer protection from predators (killer whales and sharks) and calm, shallow waters (Elwen & Best 2004a, Elwen & Best 2004b, Payne 1986, Thomas 1987).

We selected a core of seven environmental variables based on previous studies that demonstrated functional relevance to the occurrence of the three cetacean species. These included winter sea surface temperature (sstwin), sea surface temperature gradient (sstgr), sea surface primary productivity (vgpm), the 95th percentile of annual average wave height that indicates extreme events (hsmn95), dissolved organic matter (disorg), suspended particulate matter (susp), and tidal current velocity (tidcurr; see Table 2-1 for descriptions of each variable and Appendix A and Appendix B for graphic representations of each variable). These dynamic environmental datasets represent temporal periods that are not entirely congruent with the cetacean sightings data (1970-2011). Therefore the assumption is made that the environmental variation represented in these datasets has not changed over the time period of the study. These environmental layers represent average conditions across the study area, rather than intermittent variations.

Bathymetry in the coastal environment can be highly correlated with biologically important environmental variables. These correlations may cause the functional response of species to biological variation (such as primary productivity) to be masked by the dominance of bathymetry. Therefore, we included bathymetry (bathyme) in the modelling procedure of southern right whales and Hector's dolphins as a secondary step in order to assess results and species-environment relationships with and without this potentially dominant factor. Winter sea surface temperature was included as a predictor variable in annual models of species distribution to identify the response of species to habitats with contrasting, extreme temperatures.

These environmental factors were implemented in the models for their potential functional relevance to the ecological distribution of the three cetacean species. Gradients in bathymetry, water temperature, dissolved organic matter, suspended particulate matter and tidal current likely influence prey distribution and aggregations for Hector's dolphins and killer whales. Water temperature, wave height, dissolved organic matter, suspended particulate matter, and tidal current may influence the selection of coastal habitats by southern right whales with calves who seek areas with low predation risk, enhance cryptic conditions, and require low energetic demands.

Killer whales in New Zealand range widely (Figure 2-1) and likely forage upon different prey when in different habitats. We attempted to control for this potential broad-scale variation in

habitat use patterns by distinguishing between coastal and offshore sightings of killer whales. Those sightings between shore and the 200 m isobaths were classified coastal, and otherwise were classified offshore (see Appendix B for spatial representation of the population (popln) layer). With this approach, if killer whales prefer different habitat characteristics between coastal and offshore habitats the model identifies such patterns and uses the information to improve predictive capacity of habitat suitability maps. Additionally, this method removed the need to include bathymetry in the model as a predictor variable because the population layer derived from this depth layer. Due to correlations with many variables, bathymetry can often mask other important species-environment relationships that may be more functionally relevant to the distribution patterns. Therefore, bathymetry was not included in the killer whale model.

Table 2-1: Description of environmental variables used in the predictive modelling analysis. Units and sources of each variable are given.

Variable	Description	Units	Reference
Dissolved organic matter (disorg)	Modified Case 2 inherent optical property algorithm applied to modified Case 2 atmospheric corrected SeaWiFS ocean colour remotely sensed data for the New Zealand region	aDOM (443) m ⁻¹	Pinkerton and Richardson, 2006
Suspended particulate matter (susp)	Based on SeaWiFS ocean colour remote sensing data. Indicative of total suspended particulate matter concentration	g m ⁻³	Pinkerton and Richardson, 2006
Sea surface temperature gradient (sstgr)	Smoothed annual spatial estimated from 96 months of remotely sensed SeaWiFS data	°C km ⁻¹	Hadfield, 2002
Sea surface temperature winter (sstwin)	Statistical analysis of 8 years of remotely sensed SST data from months between May and August	°C	Hadfield, 2002
Surface water primary productivity (vgpm)	Vertically generalized productivity model based on net primary productivity estimated as a function of remotely sensed chlorophyll, irradiance, and photosynthetic efficiency estimated from remotely sensed sea-surface temperature	mg C m ⁻² d ⁻¹	Behrenfield and Falkowski, 1997; Tracey et al. 2011
Tidal current velocity (tidcurr)	Maximum depth-averaged tidal current velocity estimated by interpolating outputs from the New Zealand region tide model	m s ⁻¹	Walters et al., 2001; Hadfield et al., 2002
Depth (bathyme)	Depth at the seafloor interpolated from contours generated from various bathymetry sources, including multi-beam and single-beam echo sounders, satellite gravimetric inversion and others	m	CANZ, 2008
95 th percentile of annual average wave height (hsmn 95)	The EEZ scale wave climatology has been based on information derived from NIWA hindcast of biggest swell wave conditions in the NZ region	m	Gorman, 2011

The layers of sea surface temperature were calculated from a satellite dataset available from the National Institute of Water and Atmospheric Research (NIWA) SST Archive (Hadfield et al. 2002). The measures of dissolved organic matter and suspended particulate matter were also derived from satellite imagery and provide indirect measures for the physical and chemical influence of river discharges (Pinkerton & Richardson 2006). The 95th percentile of the annual average wave height was estimated from NIWA's hindcast model of swell wave conditions covering the south western Pacific and Southern Oceans (Gorman 2011). The 95th percentile of wave height was implemented in these models to examine habitat use patterns during extreme wave and storm events when animals are most in need of protected waters. Tidal current velocity was taken from a tide model of the New Zealand region (Hadfield et al. 2002, Walters et al. 2001). Depth was taken from the Charting Around New Zealand (CANZ) bathymetry series (CANZ 2008). Surface water primary productivity was based on net primary productivity estimated as a function of remotely sensed chlorophyll, irradiance, and photosynthetic efficiency (Behrenfeld & Falkowski 1997, Tracey et al. 2011). Each variable was gridded at a 1 x 1 km resolution in ArcGIS 9.3 and mapped in a World Mercator projection (central meridian 100°E, standard parallel -41°S). Each cetacean sighting was assigned a value of each of these environmental layers based on geographic location.

2.3 Analysis

Our cetacean sighting dataset did not include absence data (locations where animals were not encountered). Therefore, we implemented presence-only statistical models to analyse distribution patterns relative to environmental variability. Evaluations of species distribution models have shown that maximum entropy modelling (Maxent) outperforms other presence-only modelling packages in terms of predictive power (Elith et al. 2006). Maxent uses environmental data at locations of species observation in comparison to environmental variability in the background data to describe the distribution of a species. The background data were a large number of points ($n > 10000$) randomly selected from within the study region during the modelling procedure, and provided a sample of available habitat to a species in a region (Phillips et al. 2006). Maxent associated species distribution to each environmental variable and used these species-environment relationships to generate maps of predicted distribution patterns for each species. Each Maxent model was constructed by calculating a raw probability value $p(x)$ for each grid cell x , such that the total of all cell probabilities summed to one. This value was then scaled logarithmically using the equation

$$c p(x)/(1 + c p(x))$$

where c is the exponential of the entropy of the raw distribution, resulting in a relative probability of occurrence ranging from zero to one. The probability of occurrence can be interpreted as an estimate of the probability of presence under a similar level of sampling effort as that used to obtain the known occurrence data (Phillips & Dudík 2008).

Our datasets of cetacean sightings were not collected through systematic surveys and therefore the recorded observations of the Hector's dolphins and killer whales were biased by observer effort (see Figure 2-1). Sightings of Hector's dolphins were clustered in four coastal locations (primarily Banks Peninsula) and the sightings of killer whales were predominantly near shore. No spatial bias was evident in the distribution of southern right whale sightings that were relatively evenly distributed around the coasts. Biases existed because a majority of observations were collected along maritime pathways, and near towns

or harbours. Biased sampling in environmental space remains the most difficult source of error to detect, and correct for, when using presence-only models (Elith et al. 2011). To detect bias, records can be mapped in geographical and/or environmental space to determine which regions or environmental characteristics have been poorly sampled. For optimal model predictive capacity Maxent requires an unbiased sample (Phillips et al. 2009). However, such survey-quality data for southern right whales, Hector's dolphins and killer whales across the whole of New Zealand was unavailable. Therefore, our aim was to produce a model that accounted for this bias and provided the best predictions of Hector's dolphin and killer whale distributions.

The optimal method to compensate for bias is to incorporate the processes that drive the bias into the model, e.g. taking into account the location of maritime pathways and proximity to towns and harbours (Hijmans et al. 2000). Alternatively, a model that describes the geographic distribution of the bias can be used to create a bias grid for Maxent following the methods of Elith et al. (2010). This bias grid enables Maxent to choose the background samples in areas of increased sample bias, thus down-weighting the influence of areas with increased sampling effort. We generated four Hector's dolphin models: one without bias compensation, two models with attempts to remove bias using the two different approaches (processed based of geographically determined), and a fourth model with the preferred bias that also included bathymetry. Two killer whale models were developed: one without bias compensation and one with that account for geographic bias. It was assumed that due to the offshore distribution of killer whales the anthropogenic-based processed based factors of bias were not relevant. The process based bias grids included two factors that may describe the processes driving the bias: a weighted layer of human population density and a distance to harbour layer. The models with geographic-bias incorporated a grid to down-weight areas with increased presence. Bias grids were calculated by first generating density grids of sightings using a kernel smoothing function across the study region. These density grids were then used to weight the sightings according to its spatial location so that sightings in areas of high density were down-weighted and sightings in areas of low density were up-weighted. Model performance was assessed by comparing the discrimination ability of the spatial predictions (ability to predict absence and presence habitat) and the jack-knifed variable contribution to the model (see below for explanation of jack-knifing).

For all species, we ran the Maxent models using ten-fold cross-validation that aggregates results from ten models based on ten random selections of occurrence data. This approach allowed model results to be based on ten randomly selected portions of the data and model performance to be assessed by with-held portions of the data (Phillips et al. 2006). To assess model performance we used the area under the curve (AUC; Fielding & Bell 1997). AUC is calculated by summing the area under a receiver operating characteristic (ROC) curve, and measures the model's ability to discriminate between areas where the species is present (sensitivity) and areas where the species is absent (specificity; Elith et al. 2006, Tittensor et al. 2009). AUC ranges from 0 to 1; a value of 1 indicates perfect discrimination, values of 0.5 indicate predictive performance that is no better than random, and values less than 0.5 indicate model predictions that are worse than random. However, the optimal model for each species was ultimately determined by balancing high AUC with realistic spatial predictions and species-environmental relationships relative to previously documented in the literature.

Each environmental variable's influence on a model can be assessed by its per cent contribution. However, these per cent contribution values are not absolute (Phillips & Dudík 2008) and can be misleading when assessing the roles of highly correlated environmental variables that can be surrogates for each other. Thus, to identify the relative importance between the correlated variables a jack-knifing procedure was used. This procedure compares the relative importance of each variable by examining the drop in the AUC when each variable is used in isolation and when the variable's unique information is omitted from the model (Phillips et al. 2006).

Each Maxent model produces response curves that illustrate the functional relationship between the species occurrence and the environmental predictor variables. The curves show the marginal effect of changing one variable relative to the average effect of all other predictor variables. Therefore, these curves must be interpreted with caution when using correlated variables because model results may depend on correlations that are not evident in the curves, such as when the model implements sets of variables that change together.

Predictions of species distribution were produced by applying the calculated models to each grid cell of environmental layers, resulting in probabilities of occurrence between zero (lowest) and one (highest). These habitat suitability maps were estimated using a logistic link function that was scaled so that the number of background points used in the Maxent model did not affect probabilities (Elith et al. 2010, Phillips et al. 2006).

3 Results

As expected, based on contrasting ecology and life history strategies, the habitat use models identified different predictor variables as the most influential of each species' distribution (Table 3-1). According to per cent contribution to the model, the distribution of Hector's dolphins was most strongly influenced by suspended particulate matter concentration, southern right whale distribution by bathymetry, and killer whale distribution by the sea surface temperature gradient. Bathymetry was only included as a predictor variable in the southern right whale model, and the Hector's dolphin and killer whale models that incorporated bias grids delivered the best performance and spatial predictions (Table 3-2).

Table 3-1: Mean and standard error of per cent contribution of predictor variables derived from models of Hector's dolphin, southern right whale and killer whale.

Variable	Southern right whale	Hector's dolphin	Killer whale
bathyme	84.17 ± 2.17	Not included in model	Not included in model
disorg	0.73 ± 0.09	5.49 ± 0.56	0.51 ± 0.41
hsmn95	3.89 ± 1.53	7.31 ± 0.46	5.58 ± 1.52
sstgr	3.05 ± 0.52	9.94 ± 0.38	41.40 ± 2.87
sstwin	2.69 ± 0.84	12.47 ± 0.24	2.85 ± 1.03
susp	0.91 ± 1.15	52.08 ± 0.50	2.35 ± 0.18
tidcurr	3.37 ± 0.57	8.62 ± 0.41	3.75 ± 0.38
vgpm	1.14 ± 0.14	4.06 ± 0.56	29.87 ± 3.06
popln	Not included in model	Not included in model	13.69 ± 2.28

Table 3-2: Comparison of model performance based on AUC from 10 cross-validated model runs. Model selected in bold. Core environmental variables included sstwin, sstgr, vgpm, hsmn95, disorg, susp, tidcurr (see Table 2-1 for details). Processes of bias incorporated a weighted layer of human population density and a distance to harbour layer into the Hector's dolphin model only. Bias grid incorporated a layer that down-weighted areas with increased sightings into the Hector's dolphin and killer whale models. A layer of bathymetry was incorporated into the southern right whale and Hector's dolphin models. NA = not applicable.

	Southern right whale	Hector's dolphin	Killer whale
Core environmental variables	0.921 ± 0.028	0.987 ± 0.018	0.979 ± 0.002
Processes of bias incorporated	NA	0.986 ± 0.004	NA
Bias grid incorporated	NA	0.973 ± 0.008	0.950 ± 0.0135
Bathymetry incorporated	0.931 ± 0.032	0.974 ± 0.005	NA

3.1 Southern right whale

All of the core environmental variables included in the model of southern right whale distribution influenced the habitat suitability of whales. However, when we added the bathymetry (bathyme) layer to our model, the AUC from the cross-validated model increased from 0.921 to 0.931 (Table 3-2) and bathymetry had the highest relative contribution to the model (84.2%), with the seven others environmental variables contributing a lower percentage (<4 %, Table 2). The jack-knife of variable contribution confirmed that, in addition to bathymetry, four other layers influenced the distribution of southern right whale distribution: dissolved organic matter (disorg), wave height (hsmn95), suspended particulate matter (susp), and tidal current velocity (tidcurr; Figure 3-1). Thus, bathymetry is not the only environmental parameter to explain the distribution of southern right whales, as other variables continued to improve the model.

The omission of each variable in turn from the model did not decrease the AUC considerably (Figure 3-1), indicating that no variable contributed a substantial amount of predictive capacity that was not contributed by the other variables. These results demonstrate the presence of correlations between the predictor variables (i.e., dissolved organic matter and suspended particulate matter; Appendix A), yet the model was able to distinguish the most significant determinants of whale distribution.

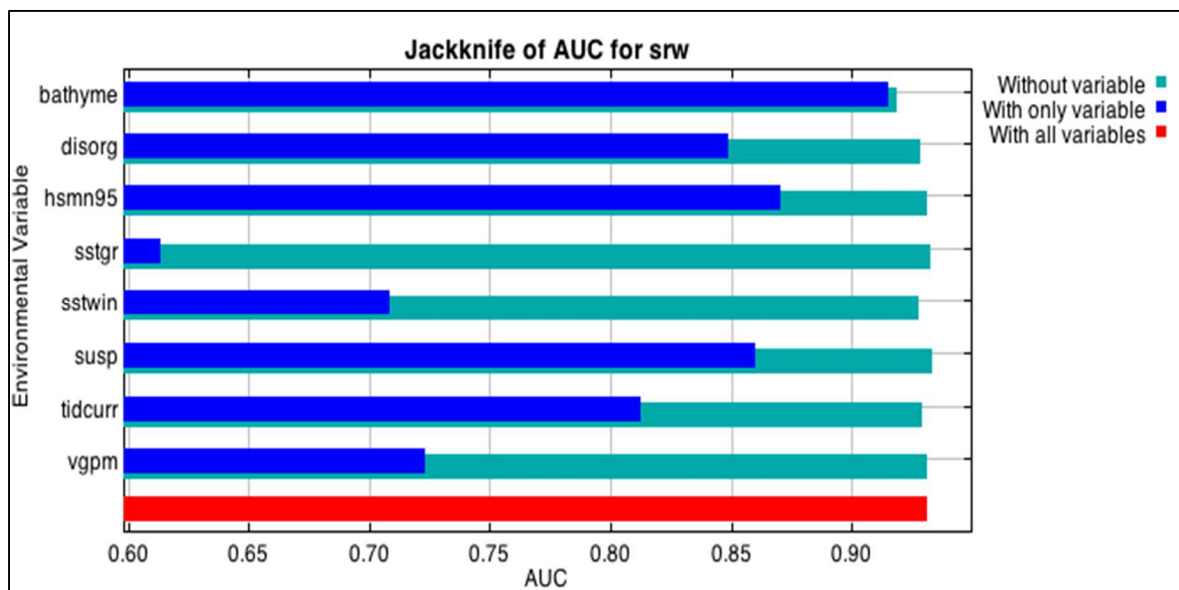


Figure 3-1: Jack-knife of AUC from the southern right whale (srw) model derived for the core environmental variables selected. Dark blue bars show the AUC value when each environmental variable is used in isolation, and therefore indicates the level of predictive contribution by each variable. Light blue bars illustrate the AUC value when each variable is omitted and therefore shows the amount of information that is not captured by other variables. Values shown are averages over 10 replicate runs.

The response curves produced by the model of southern right whale distribution (Figure 3-2) illustrate that habitat suitability was highest in areas with shallow water (< 20 m), low wave heights during extreme events (between 0 and 2 m), high concentrations of dissolved organic matter (> 0.2 m⁻¹), and with tidal current velocity greater than 1 m/s. The spatial predictions of southern right whale distribution (Figure 3-3) based on model results illustrate their preference for shallow, coastal waters around New Zealand during winter months. The prediction map indicates several areas with relatively high habitat suitability (P) (P > 0.7), including protected harbours and bays along the north-west and east coasts of North Island (Figure 3-4), in the Golden Bay, Marlborough Sounds and Cook Strait regions of the South Taranaki Bight (Figure 3-5), and the south and south east coasts of the South Island (Figure 3-6). These are all locations where southern right whales have been historically sighted during the winter calving season (Carroll et al. 2013).

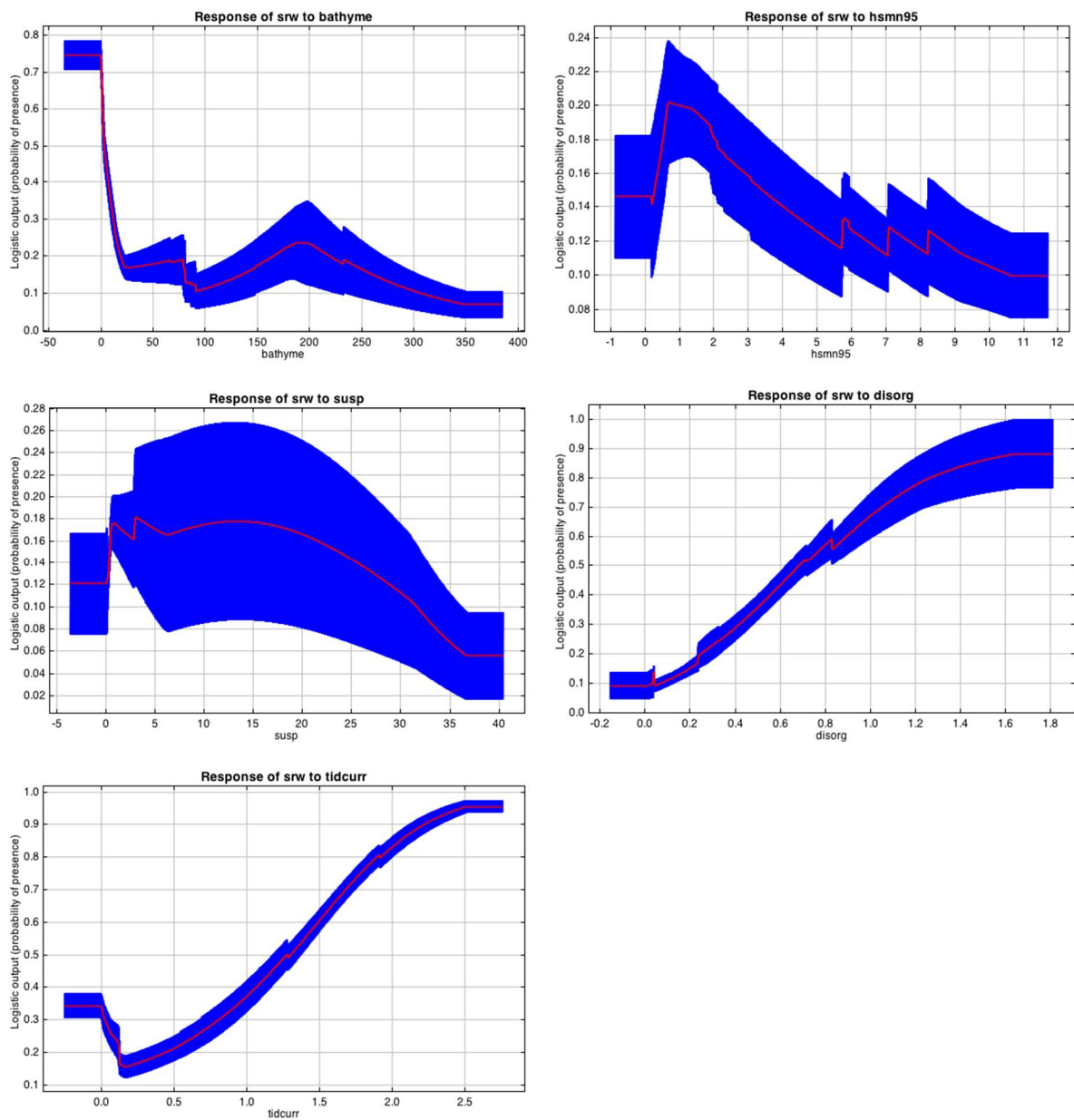


Figure 3-2: Response curves of the top five environmental predictor variables from the southern right whale distribution model. The curves show how the logistic prediction changes relative to variation in the focal environmental variable, keeping all other environmental variables at their average sample value. Red lines are the mean response of the 10 replicate Maxent runs and the blue areas are \pm one standard deviation. Note that the scale of the y-axes is not consistent between plots.

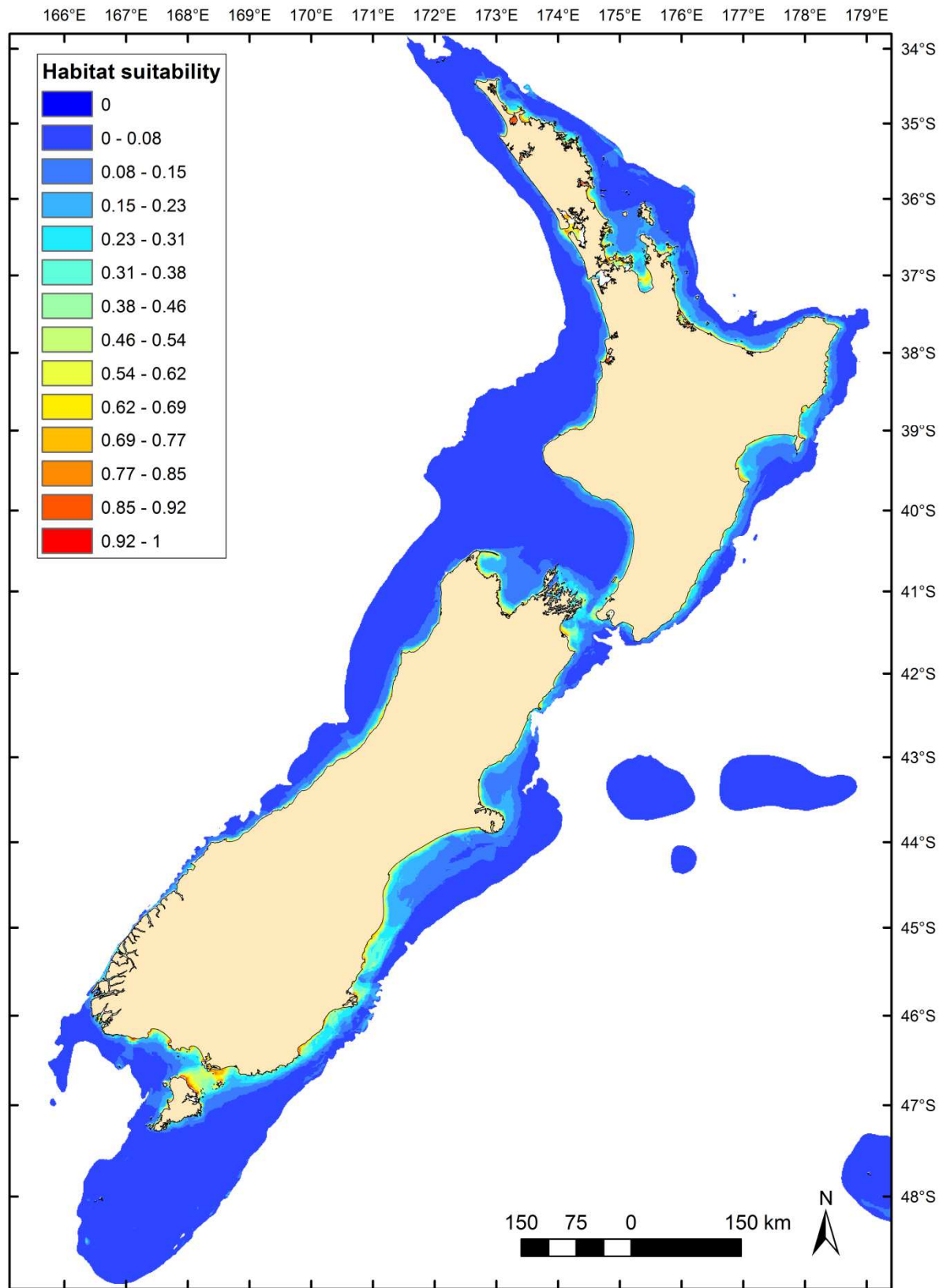


Figure 3-3: Winter habitat suitability predictions for southern right whales derived from the habitat use model. Full extent of model within the 350 m isobaths of mainland New Zealand. The habitat suitability index is a logistic output from the Maxent model (warm colours showing the highest habitat suitability).

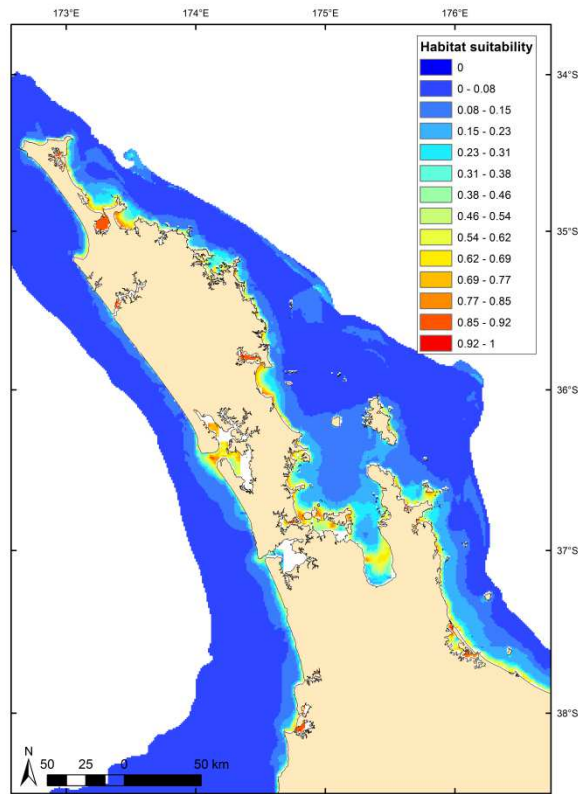


Figure 3-4: Winter habitat suitability predictions for southern right whales in the northern North Island region derived from the habitat use model. The habitat suitability index is a logistic output from the Maxent model (warm colours showing the highest habitat suitability).

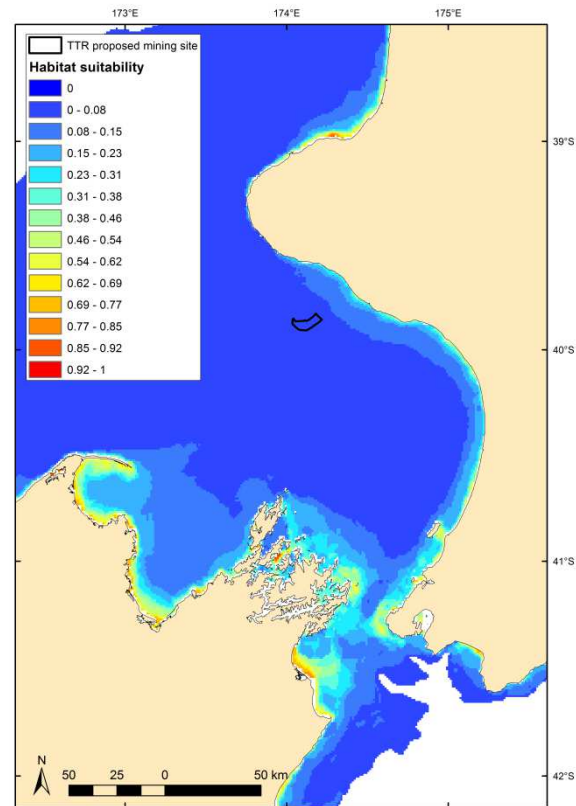


Figure 3-5: Winter habitat suitability predictions for southern right whales in the South Taranaki Bight, Marlborough sounds, and Cook Strait region. Predictions derived from the habitat use model. TTR proposed project area outlined in black. The habitat suitability index is a logistic output from the Maxent model (warm colours showing the highest habitat suitability).

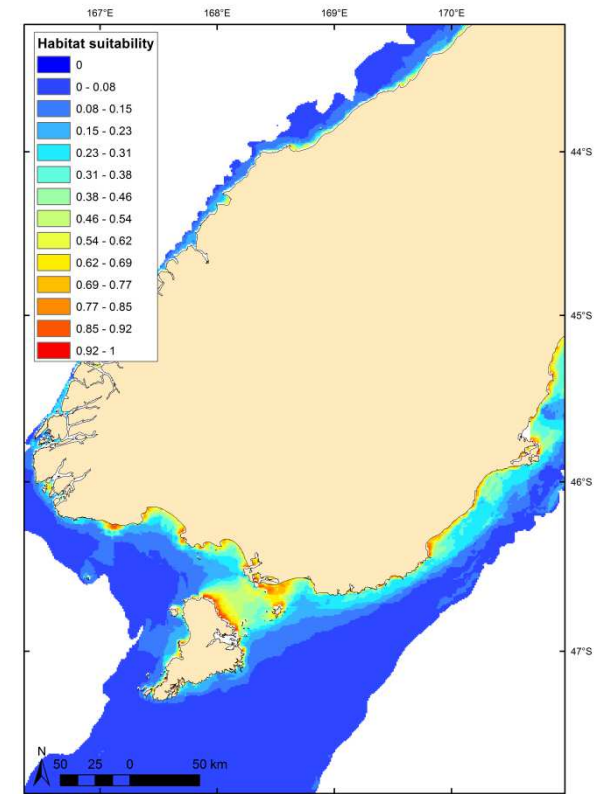


Figure 3-6: Winter habitat suitability predictions for southern right whales along the south and southeast coasts of the South Island derived from the habitat use model. The habitat suitability index is a logistic output from the Maxent model (warm colours showing the highest habitat suitability).

3.1.1 Suitability of habitat for southern right whales in the STB

The predicted suitability of habitat for southern right whales in the STB during winter months was generally low ($P < 0.08$; Figure 3-5). The coastal region of the Bight had slightly increased predicted habitat suitability ($P < 0.38$), including the coastal areas inshore of the TTR proposed project area (Figure 3-7). The highest predicted habitat suitability for southern right whales in the TTR proposed project area was $P = 0.072$. Only a few southern right whale sightings have been recorded in the northern region of the STB. This low level of sightings is possibly due to low observer effort in the region, historical extirpation from the region, naturally low prevalence, or a combination of these factors. The persistent low to moderate level ($P < 0.54$) of predicted habitat suitability along the coast of the STB may reflect a migration pathway that southern right whales use while transiting to more suitable wintering grounds to the north or south. Southern right whale cows are known to 'hug' shorelines while migrating with calves in order to avoid predators (Elwen & Best 2004a).

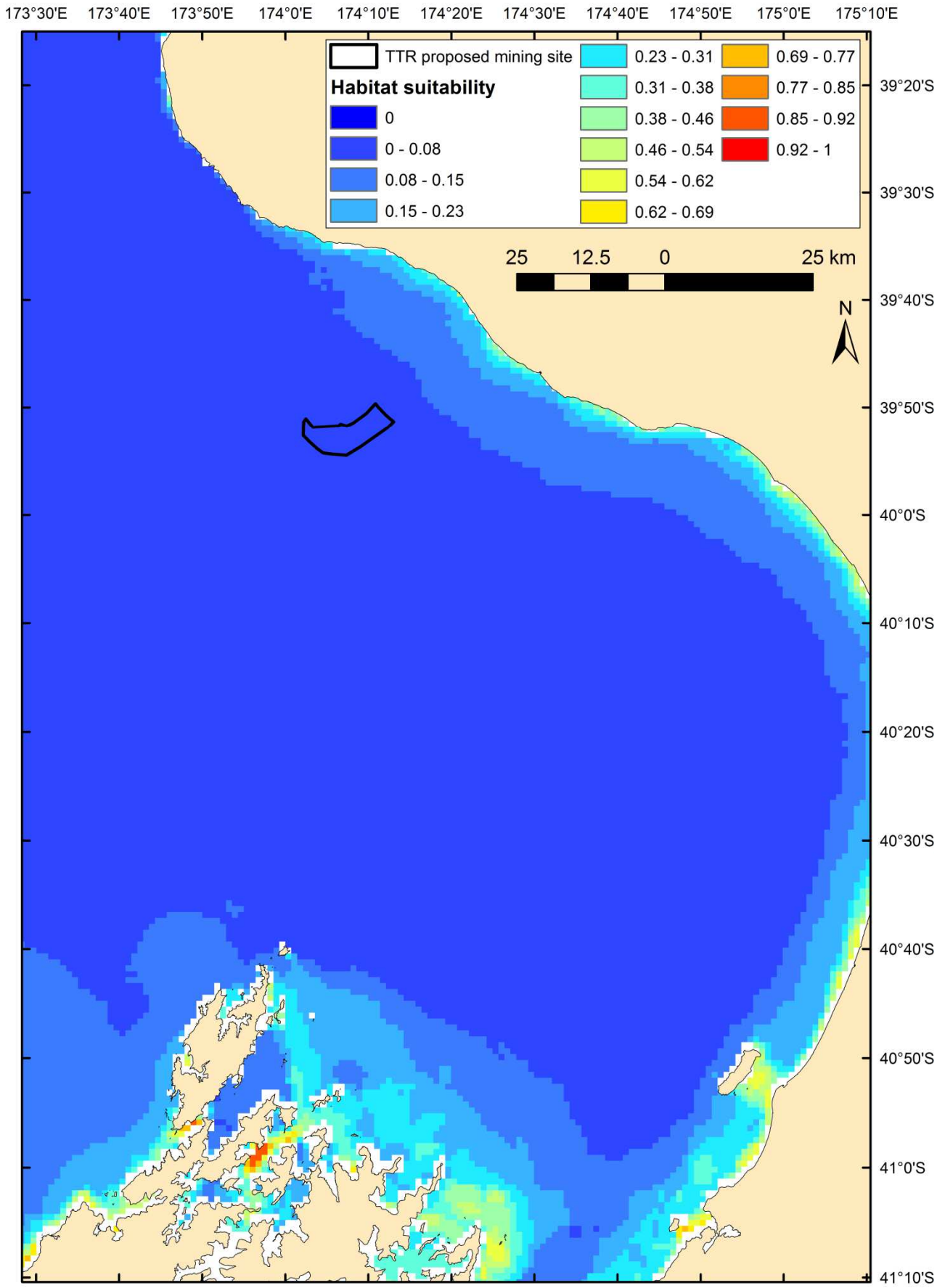


Figure 3-7: Habitat suitability predictions for southern right whales in the South Taranaki Bight derived from the habitat use model. TTR proposed project area outlined in black. The habitat suitability index is a logistic output from the Maxent model (warm colours showing the highest habitat suitability).

3.2 Hector's dolphin

As expected, the Hector's dolphin model without bias correction did not generate realistic predictions of distribution (Figure 3-8). The model predicted high habitat suitability ($P > 0.6$) in direct relationship to the density of incidental sightings (see Figure 2-1), without much application of environmental correlates. Areas which were oversampled in our incidental sightings dataset were reflected as areas of increased suitability. This approach created an unrealistic strip of moderate habitat suitability along the majority of New Zealand's coastline.

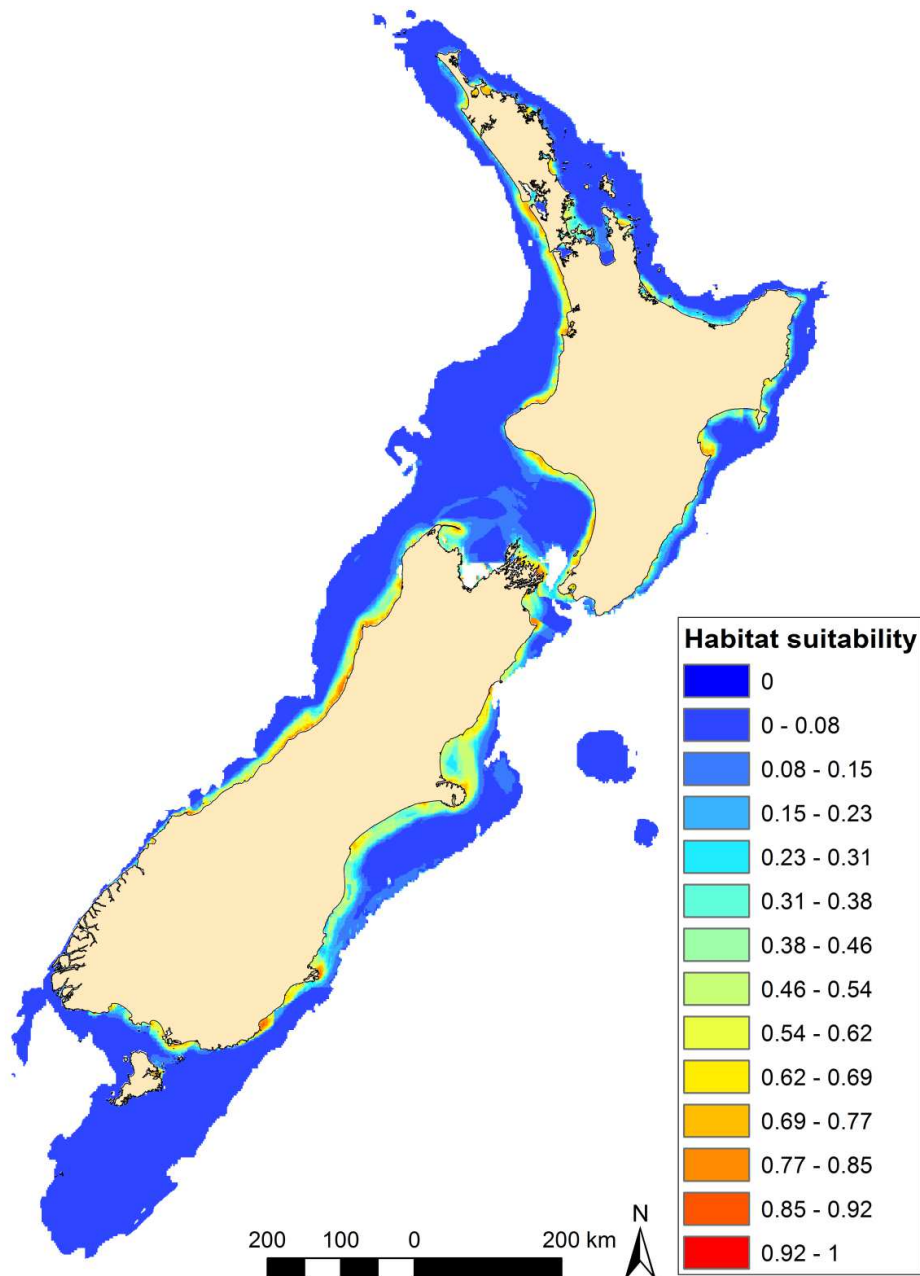


Figure 3-8: Habitat suitability predictions for Hector's dolphin derived from the habitat use model without the use of a bias grid. The habitat suitability index is a logistic output from the Maxent model (warm colours showing the highest habitat suitability).

The first approach for correcting bias in the Hector’s dolphin sighting data entailed the generation of a model with the core environmental variables, and the distance to harbour (harb), and human population density (wtpop) layers (AUC = 0.986;). The jack-knife of variable contribution revealed that harb and wtpop had small contributions to the model (Figure 3-9), indicating that these two parameters do not sufficiently explain bias in the distribution of sightings data.

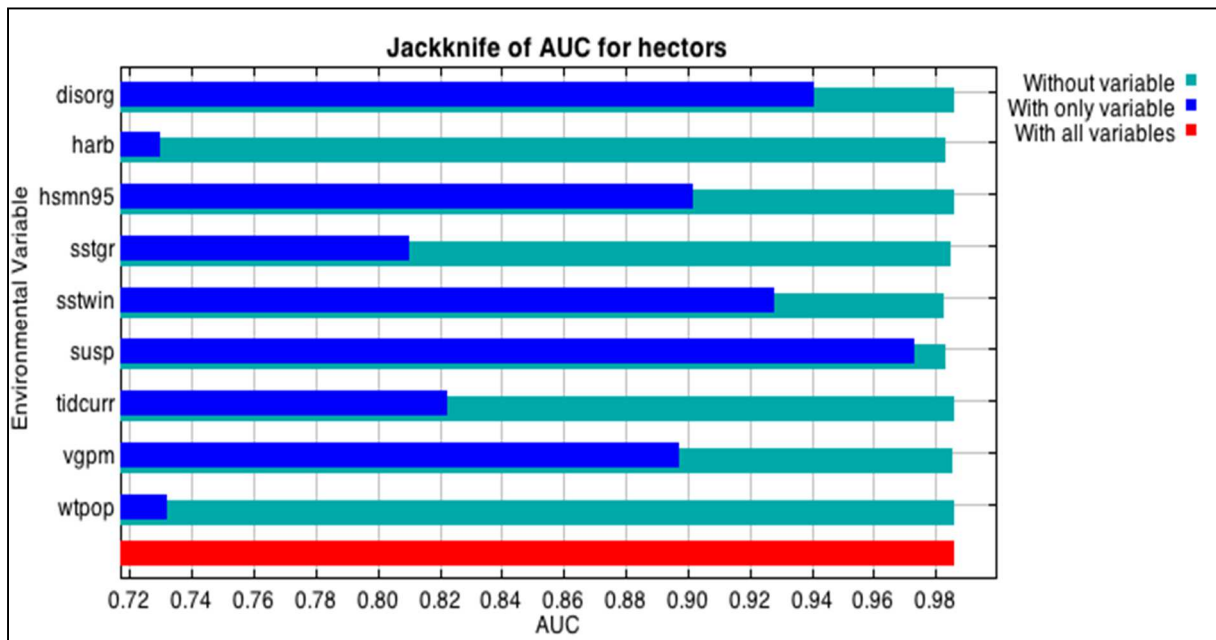


Figure 3-9: Jack-knife of AUC from the Hector’s dolphin model including the core environmental variables plus the layers of distance to harbor (harb) and human population density. Dark blue bars show the AUC value when each environmental variable is used in isolation, and therefore indicates the level of predictive contribution by each variable. Light blue bars illustrate the AUC value when each variable is omitted and therefore shows the amount of information that is not captured by other variables. Values shown are averages over 10 replicate runs.

The second, and more successful, approach to minimizing observation bias in the sightings data, incorporated the bias grid into the model of Hector’s dolphin distribution. Incorporating bathymetry into this model as a predictor variable did not improve model performance (Table 3-2). Therefore, results from the Hector’s dolphin distribution model with a bias grid and without bathymetry are presented. This model produced relatively high performance based on cross-validated models (AUC = 0.973; Table 3-2) and spatial predictions that more accurately reflected the species occurrence patterns. Based on the jack-knife analysis, this model determined that five primary environmental variables influenced habitat suitability: suspended particulate matter concentration (susp), dissolved organic matter (disorg), 95th percentile of wave height (hsmn95), winter sea surface temperature (sstwin), and primary productivity (vgpm) (Figure 3-10).

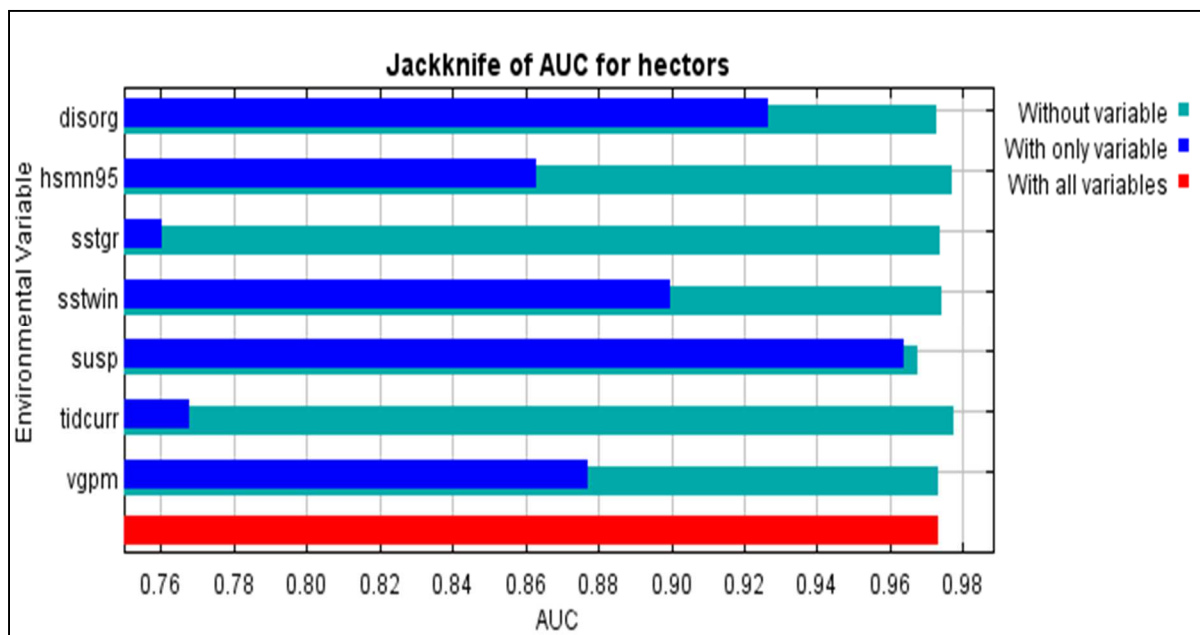


Figure 3-10: Jack-knife of AUC from the Hector's dolphin model using the bias grid for the core environmental variables. Dark blue bars show the AUC value when each environmental variable is used in isolation, and therefore indicates the level of predictive contribution by each variable. Light blue bars illustrate the AUC value when each variable is omitted and therefore shows the amount of information that is not captured by other variables. Values shown are averages over 10 replicate runs.

Response curves of species presence/absence relative to these five environmental predictors indicate the functional response of Hector's dolphins to habitat variability (Figure 3-11). The primary factor that influenced Hector's dolphin distribution were suspended particulate matter and dissolved organic matter. The response curve between Hector's dolphin presence/absence and suspended particulate matter indicated increased habitat suitability at lower levels of suspended particulate matter ($P > 0.4$ when $\text{susp} = 8 \text{ g m}^{-3}$). However, the relationship with dissolved organic matter indicated a bi-modal distribution with habitat suitability high in habitats with low ($P > 0.5$ when $\text{disorg} < 0.1 \text{ m}^{-1}$) and high ($P > 0.9$ when $\text{disorg} > 1.6 \text{ m}^{-1}$) concentrations of dissolved organic matter. Bi-modal peaks in response curves were also evident relative to winter sea surface temperature where Hector's dolphin habitat suitability increased in colder ($P > 0.6$ for water between 6 and 9°C) and warmer ($P > 0.6$ for water between 18 and 20°C) waters, but was low at intermediate temperatures ($P < 0.05$ for temperatures between 10 and 18°C). Hector's dolphin habitat suitability also increased in habitats with high rates of primary productivity ($P > 0.35$ when $\text{vgpm} = 2000 \text{ mgCm}^{-2}\text{d}^{-1}$). Hector's dolphins showed a slight preference for sheltered areas during extreme wave events, but habitat suitability stayed low ($P > 0.1$ when $\text{hsmn95} < 1 \text{ m}$).

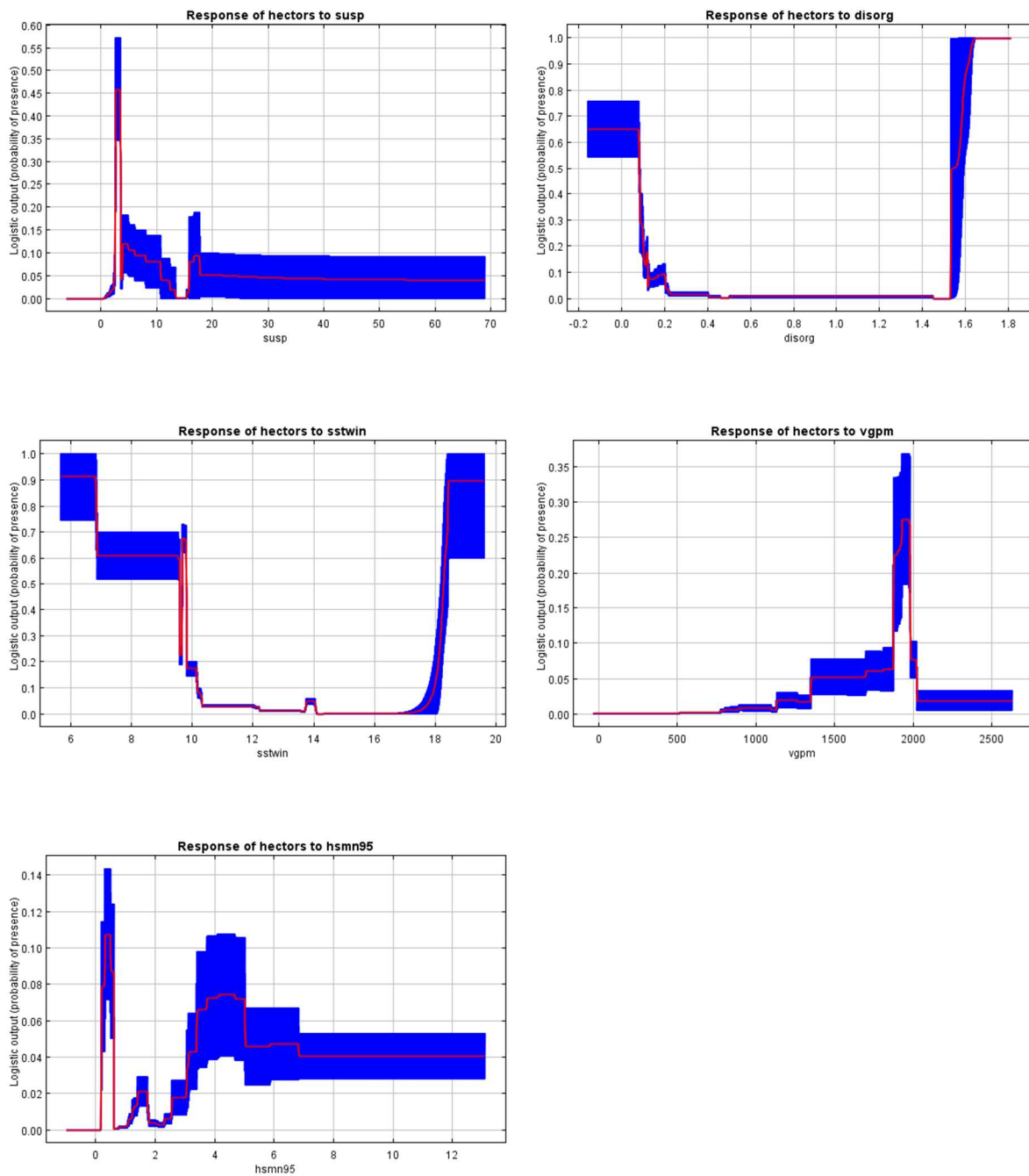


Figure 3-11: Response curves of the top five environmental predictor variables derived from the Hector's dolphin distribution model with bias grid. The curves show how the logistic prediction changes relative to variation in the focal environmental variable, keeping all other environmental variables at their average sample value. Red lines are the mean response of the 10 replicate Maxent runs and the blue areas are \pm one standard deviation. Note that the scale of the y-axes is not consistent between plots.

The spatial predictions of Hector's dolphin habitat suitability based on model results illustrated a relatively good match with known areas of sub-populations (Figure 3-12). In contrast to the model without bias correction (Figure 3-8), this model distinguished five different areas with relatively high habitat suitability ($P > 0.7$): the west coast North Island (Figure 3-13), the west coast South Island (Figure 3-14), the east coast South Island (Figure 3-15), the south coast South Island (Figure 3-16), and the Bay of Plenty region (Figure 3-17). Habitat in Clifford and Cloudy Bays in northeast South Island, where a population of Hector's dolphins is known to reside (Du Fresne & Mattlin 2009), also had pockets of high predicted presence ($P > 0.7$).

High Hector's dolphin habitat suitability was predicted along the northwest coast of North Island (Figure 3-13) between Kaipara Harbour and Kawhia Harbour. Off the west coast of South Island (Figure 3-14), medium to high habitat suitability is predicted along the coast from just north of Westport where predicted presence is high ($p > 0.8$) to Jackson Bay. Along the east coast of South Island large areas of high Hector's dolphin presence were predicted around Banks peninsula and along Canterbury Bight (Figure 3-15). Particularly high probabilities of presence ($P > 0.8$) were predicted around the north-east part of Banks peninsula and near Timaru Harbour in southern Canterbury Bight. The south coast of South Island was characterized by localized pockets of high predicted presence in Te Waewae, Colac, Toetoes and Porpoise bays (Figure 3-16). All of these regions are known areas of Hector's or Maui's (west coast North Island) sub-populations; predictions of high habitat suitability in these regions lend credibility to model predictions and validation. However, the model also predicted high habitat suitability for Hector's dolphins in an area where Hector's dolphins are not known to currently occur: the Bay of Plenty and the Hauraki Gulf (Figure 3-17). These high rates of predicted Hector's dolphin presence are due to extrapolation of environmental characteristics from areas with high presence to areas with similar environmental values. Although a limited number of sightings included in our model dataset were from the Bay of Plenty ($n=1$) and around East Cape ($n=10$), there are currently no resident sub-populations in these regions and it has been suggested that the distribution of Hector's dolphins prior to human arrival in New Zealand did not extend to these regions (Russell 1999). High habitat suitability in an area not known as Hector's dolphin habitat may indicate (1) the absence of important environmental variables from our model that may better explain distribution, or (2) model results may be accurate and these areas identified as suitable habitats represent currently underutilized areas that may be re-colonized if Hector's dolphin sub-populations are allowed to recover.

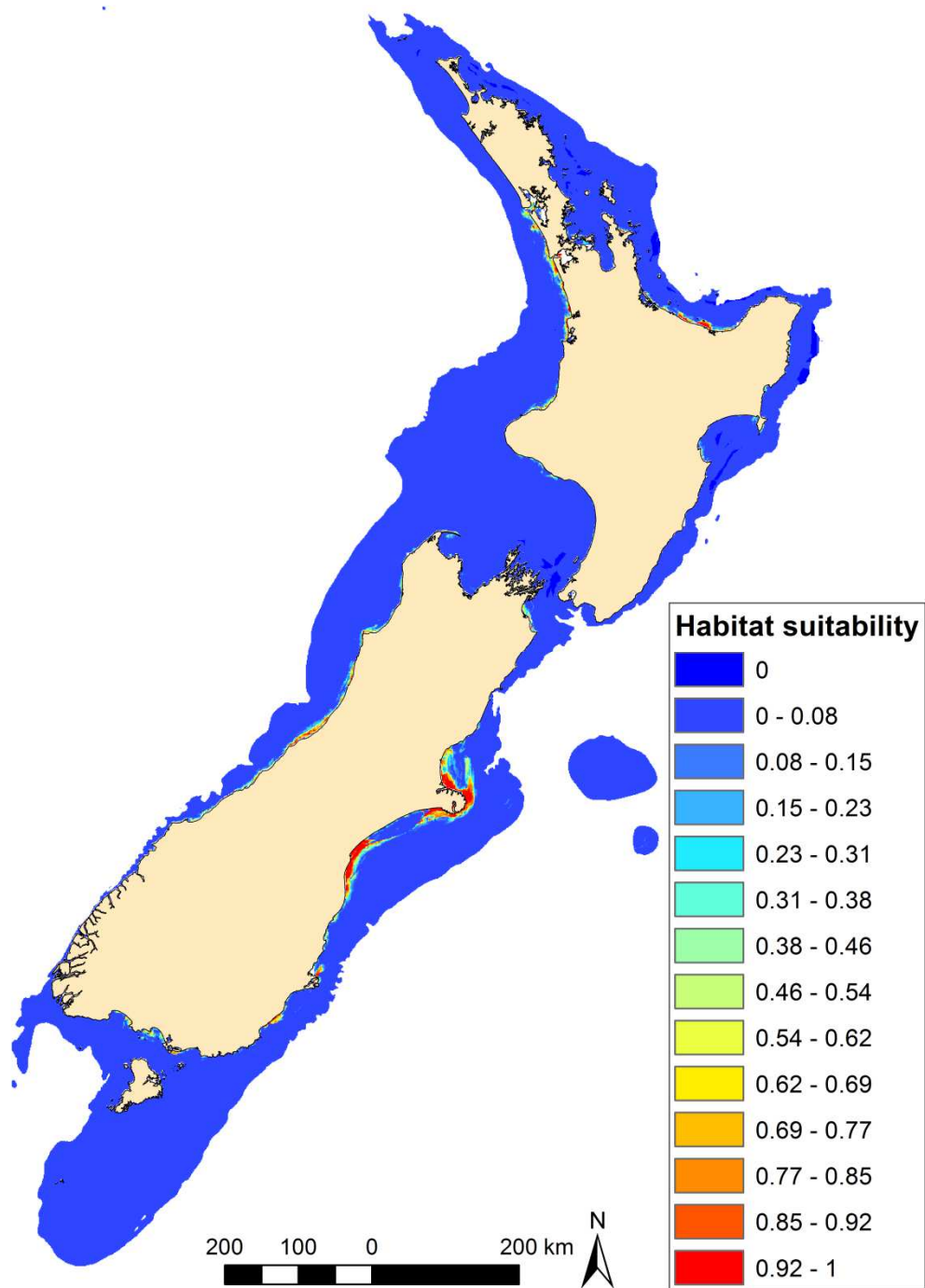


Figure 3-12: Habitat suitability predictions for Hector's dolphins derived from the habitat use model with bias correction. The habitat suitability index is a logistic output from the Maxent model (warm colours showing the highest habitat suitability).

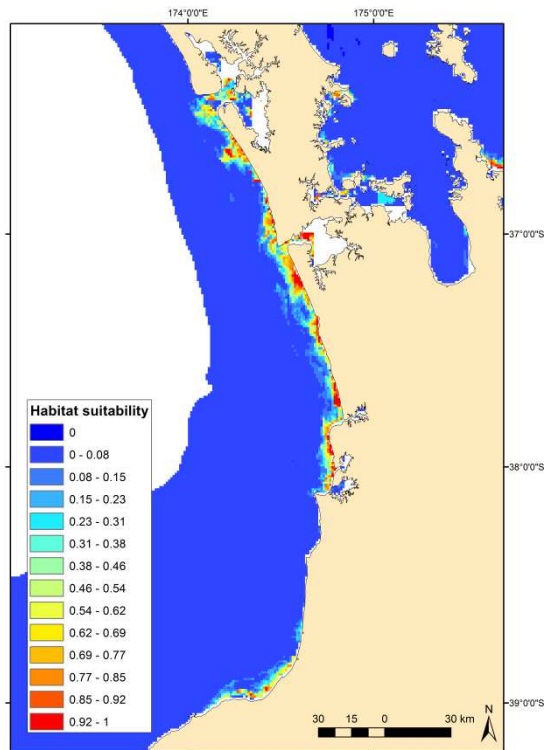


Figure 3-13: Habitat suitability prediction of Hector's dolphin for the west coast North Island area. Predictions derived from the habitat use model with bias correction. The habitat suitability index is a logistic output from the Maxent model (warm colours showing the highest habitat suitability).

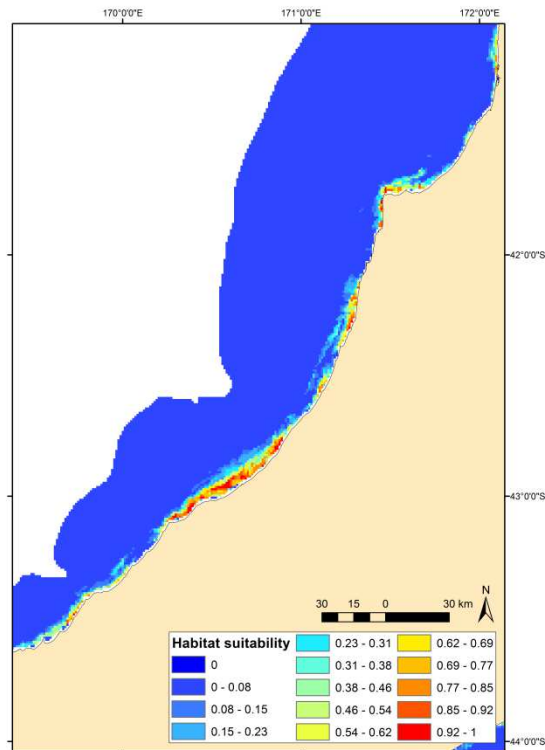


Figure 3-14: Habitat suitability prediction of Hector's dolphin for the west coast South Island area. Predictions derived from the habitat use model with bias correction. The habitat suitability index is a logistic output from the Maxent model (warm colours showing the highest habitat suitability).

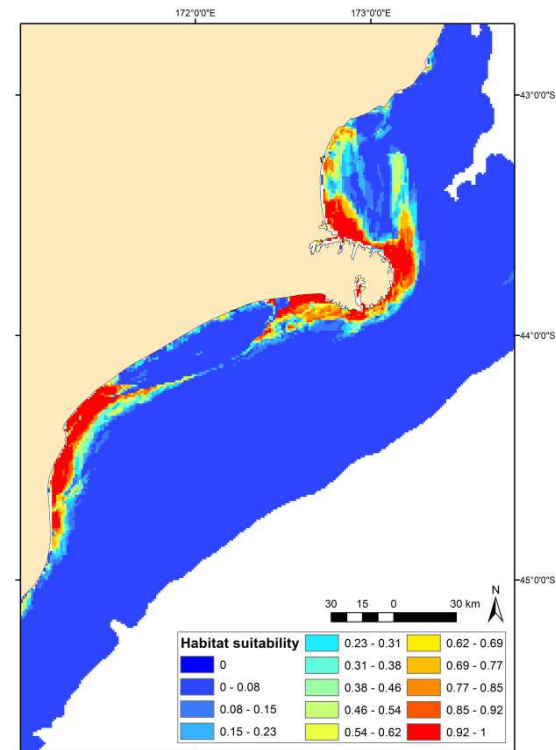


Figure 3-15: Habitat suitability prediction of Hector's dolphin for the east coast South Island area. Predictions derived from the habitat use model with bias correction. The habitat suitability index is a logistic output from the Maxent model (warm colours showing the highest habitat suitability).

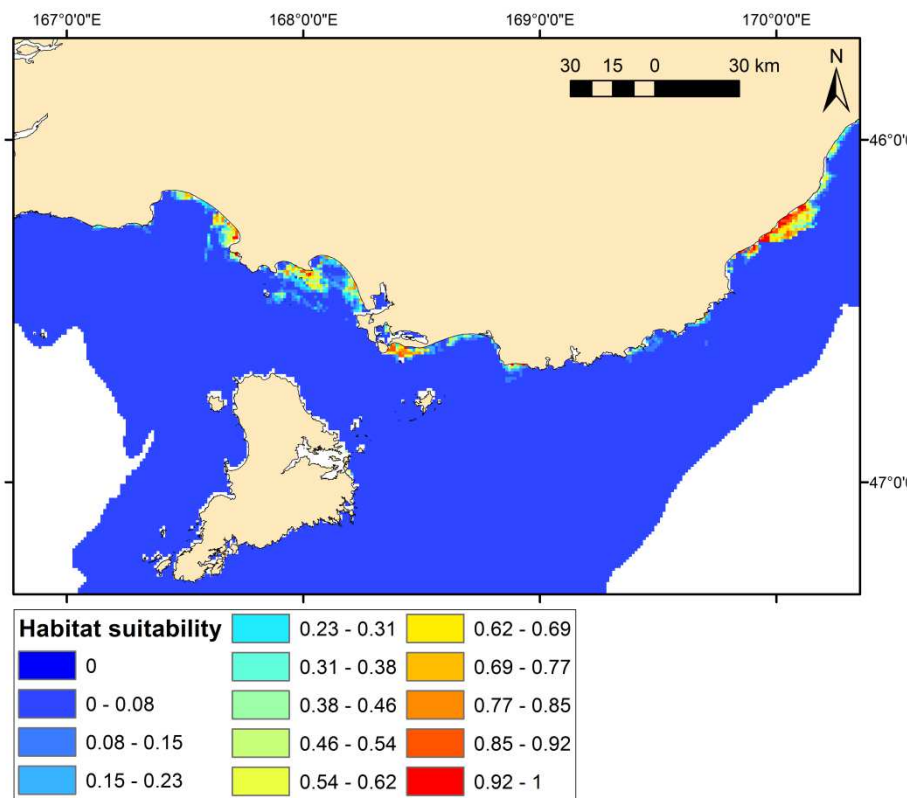


Figure 3-16: Habitat suitability prediction of Hector's dolphin for the south coast South Island area. Predictions derived from the habitat use model with bias correction. The habitat suitability index is a logistic output from the Maxent model (warm colours showing the highest habitat suitability).

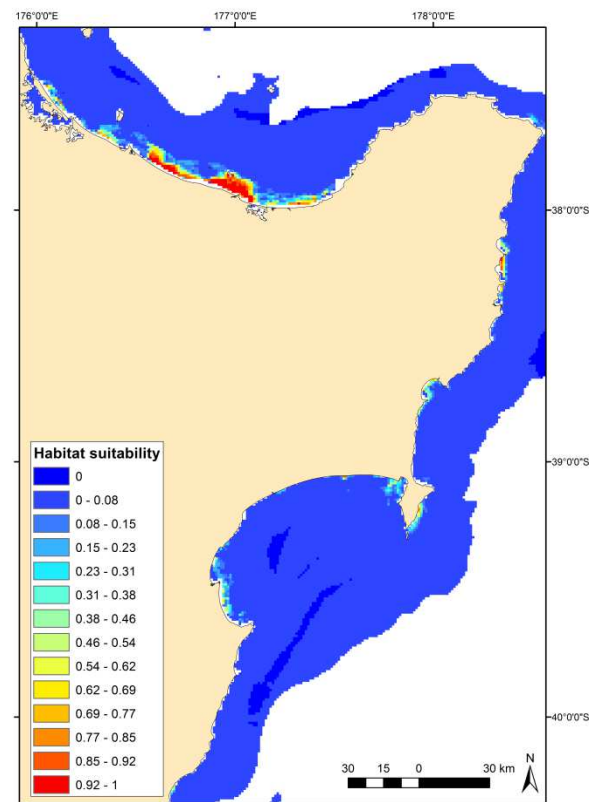


Figure 3-17: Habitat suitability prediction of Hector's dolphin for Bay of Plenty and Hawke's Bay area. Predictions derived from the habitat use model with bias correction. The habitat suitability index is a logistic output from the Maxent model (warm colours showing the highest habitat suitability).

3.2.1 Predicted suitability of habitat for Hector's dolphin in the STB

The predicted suitability of habitat for Hector's dolphin in the STB was generally low ($P < 0.08$; Figure 3-18). However, pockets of increased habitat suitability ($P > 0.46$) were predicted in the coastal region to about 8 km offshore adjacent to the TTR proposed project area (Figure 3-20). The highest predicted habitat suitability for Hector's dolphin in the TTR proposed project area is $P = 0.0004$. Three 1 km² grid cells along the coast had predicted habitat suitability of 0.8 or greater. Although no Hector's dolphin sightings have been recorded along the coastal strip south of Cape Egmont (possibly due to low observer effort, historical extirpation from habitat, naturally low prevalence, or a combination of these factors), according to model results based on over three thousand sightings of Hector's dolphins across their entire range, the habitat characteristic of certain areas in the coastal region inshore of the proposed TTR mining site provide average to above average habitat suitability for Hector's dolphins. This result indicates that if Hector's dolphins were to re-occupy this region there is an average to above average chance a Hector's dolphin would use this coastal habitat.

An examination of Figures 3-17 through 3-22 helps to describe the processes that cause this coastal area to have increased habitat suitability. The Hector's dolphin habitat suitability model predicted a positive relationship between Hector's dolphin occurrence and dissolved organic matter, so that as dissolved organic matter increases the habitat suitability of Hector's dolphins is predicted to increase. Dissolved organic matter was the most influential variable in the model and shows high values in the coastal area (Figure 3-23). Winter sea surface temperature (Figure 3-25) and primary productivity (Figure 3-26) show little to no variation in this region and likely had little influence on the predicted habitat suitability. The shape of the coastal area predicted to have increased Hector's dolphin habitat suitability, including the pocket of low habitat suitability near 39° 45' S and 174° 25' E (Figure 3-21), is likely driven by the range of the 95th percentile of wave height (Figure 3-24) which shows variation consistent with the shape of this pocket. The habitat model predicted a bimodal relationship between Hector's dolphin presence and the 95th percentile of wave height, meaning that Hector's dolphin presence is predicted to be higher at low levels of extreme wave heights (< 1 m), low at wave heights between 1 and 3 m, and then higher at wave heights above 3 m (Figure 3-11). This layer of the 95th percentile of wave height is a model derived prediction (Gorman 2011) and is highly dependent on local bathymetry which is less well described for shallow areas, and therefore may be prone to unrealistic variation at in shallow areas and at finer scales such as examined here. Additionally, the bi-modal nature of the response curve between Hector's dolphin presence and the 95th percentile of wave height may not be realistic; the second peak in Hector's dolphin presence does not serve an obvious ecological function.

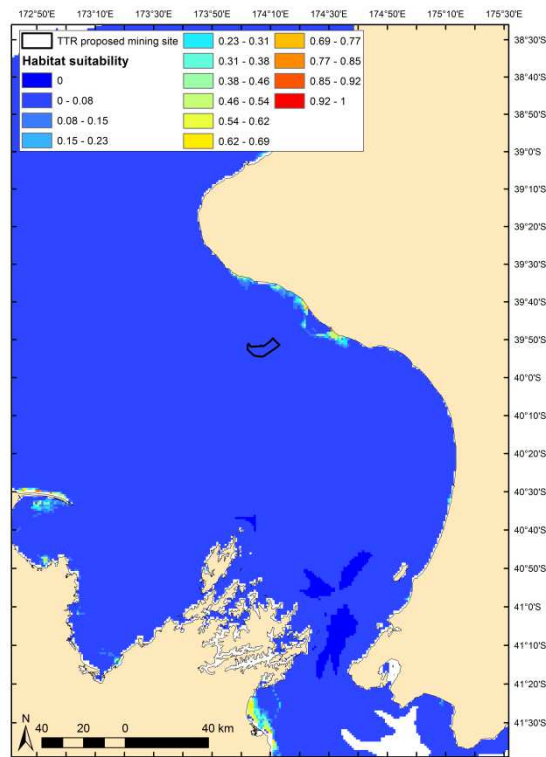


Figure 3-18: Prediction of habitat suitability for Hector's dolphin in the South Taranaki Bight. TTR proposed project area outlined in black. Predictions derived from the habitat use model with bias correction. The habitat suitability index is a logistic output from the Maxent model (warm colours showing the highest habitat suitability).

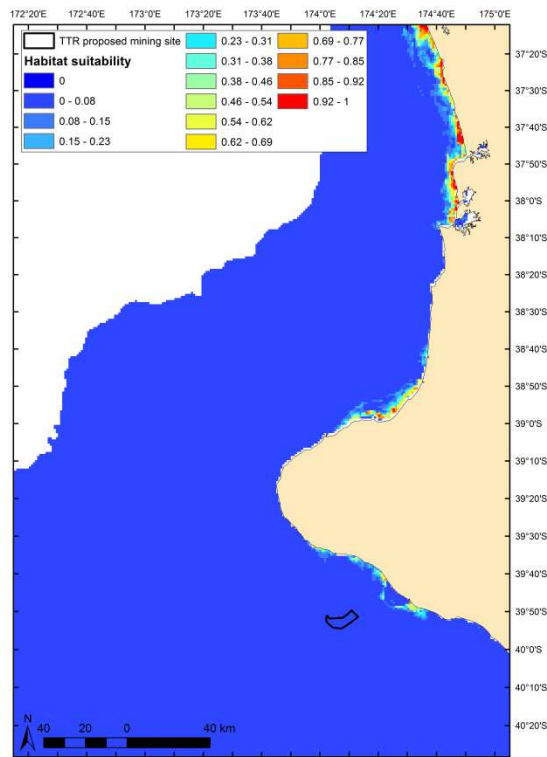


Figure 3-19: Prediction of habitat suitability for Hector's dolphin in the North and South Taranaki Bights. TTR proposed project area outlined in black. Predictions derived from the habitat use model with bias correction. The habitat suitability index is a logistic output from the Maxent model (warm colours showing the highest habitat suitability).

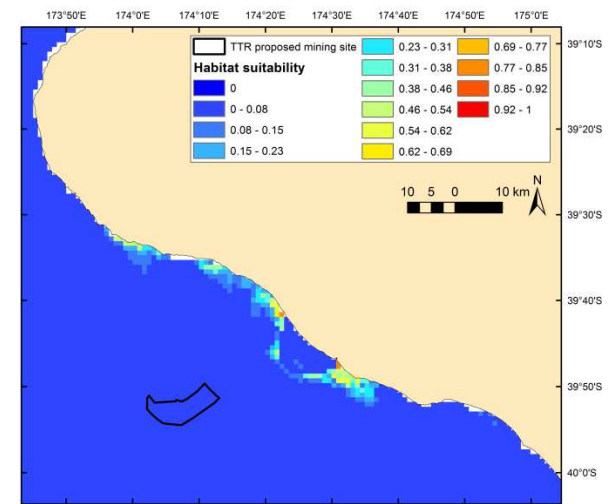


Figure 3-20: Enlargement of prediction of habitat suitability for Hector's dolphin inshore of the TTR proposed project area. TTR proposed project area outlined in black. Predictions derived from the habitat use model with bias correction. The habitat suitability index is a logistic output from the Maxent model (warm colours showing the highest habitat suitability).

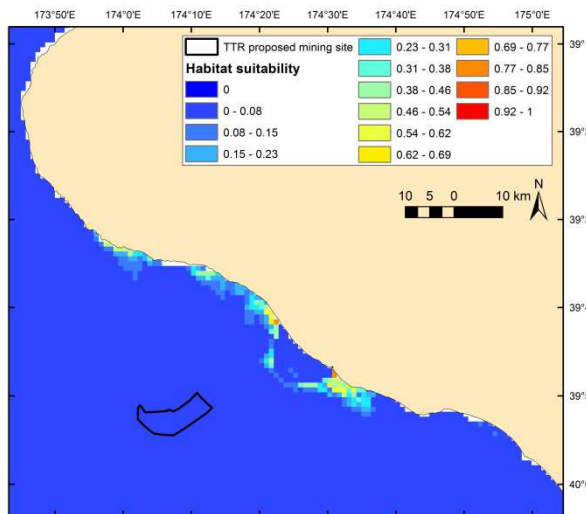


Figure 3-21: Predicted Hector's dolphin habitat suitability near the TTR proposed project area. Predictions derived from the habitat use model with bias correction. The habitat suitability index is a logistic output from the Maxent model (warm colours showing the highest habitat). TTR proposed project area outlined in black.

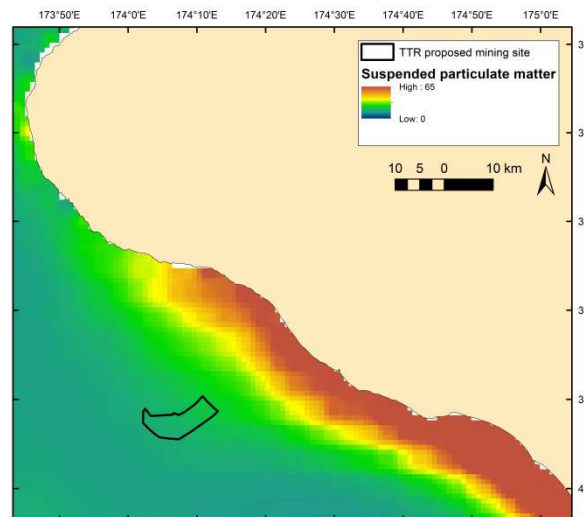


Figure 3-22: Suspended particulate matter near the TTR proposed project area. This layer of environmental data was included in the habitat suitability models. TTR proposed project area outlined in black.

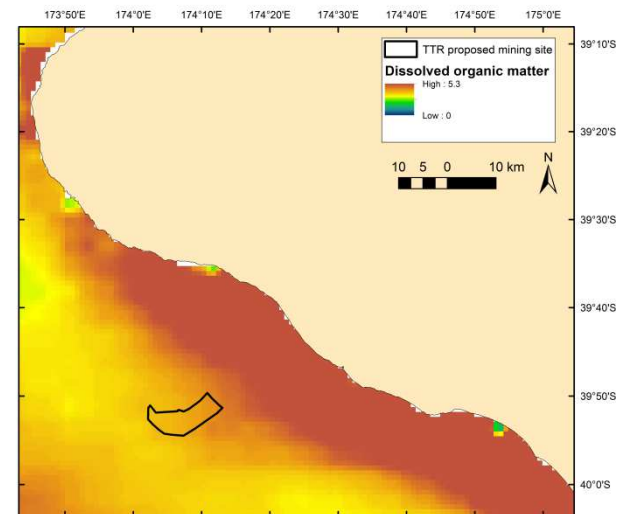


Figure 3-23: Dissolve organic matter near the TTR proposed project area. This layer of environmental data was included in the habitat suitability models. TTR proposed project area outlined in black.

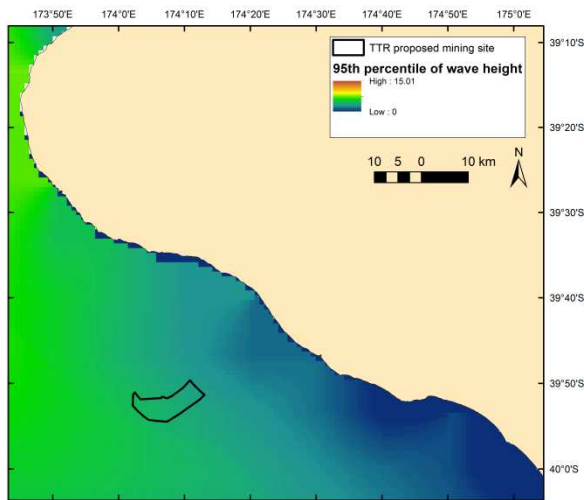


Figure 3-24: The 95th percentile of wave height near the TTR proposed project area. This layer of environmental data was included in the habitat suitability models. TTR proposed project area outlined in black.

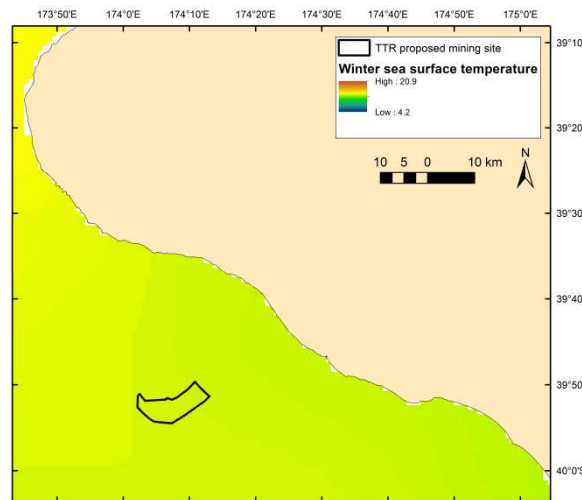


Figure 3-25: Winter sea surface temperature near the TTR proposed project area. This layer of environmental data was included in the habitat suitability models. TTR proposed project area outlined in black.

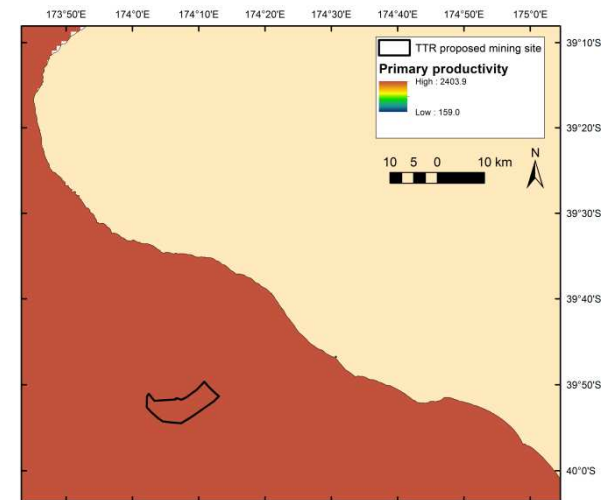


Figure 3-26: Primary productivity near the TTR proposed project area. This layer of environmental data was included in the habitat suitability models. TTR proposed project area outlined in black.

3.3 Killer whales

The spatial prediction calculated from killer whale habitat model without bias correction (Figure 3-27) was unable to distinguish multiple areas of high habitat suitability ($P > 0.62$). Regions off Northland and the Bay of Plenty with high habitat suitability ($P > 0.75$) was a function of the high density of sightings in this area (Figure 2-1). Although the performance based on AUC was higher without the bias grid (AUC = 0.979; (Table 3.2) relative to with the bias grid (AUC = 0.95), this model did not generate realistic predictions of distribution nor species-environment relationships. Therefore, we implemented a bias grid into the modelling process to down-weight the influence of areas with increased sampling effort.

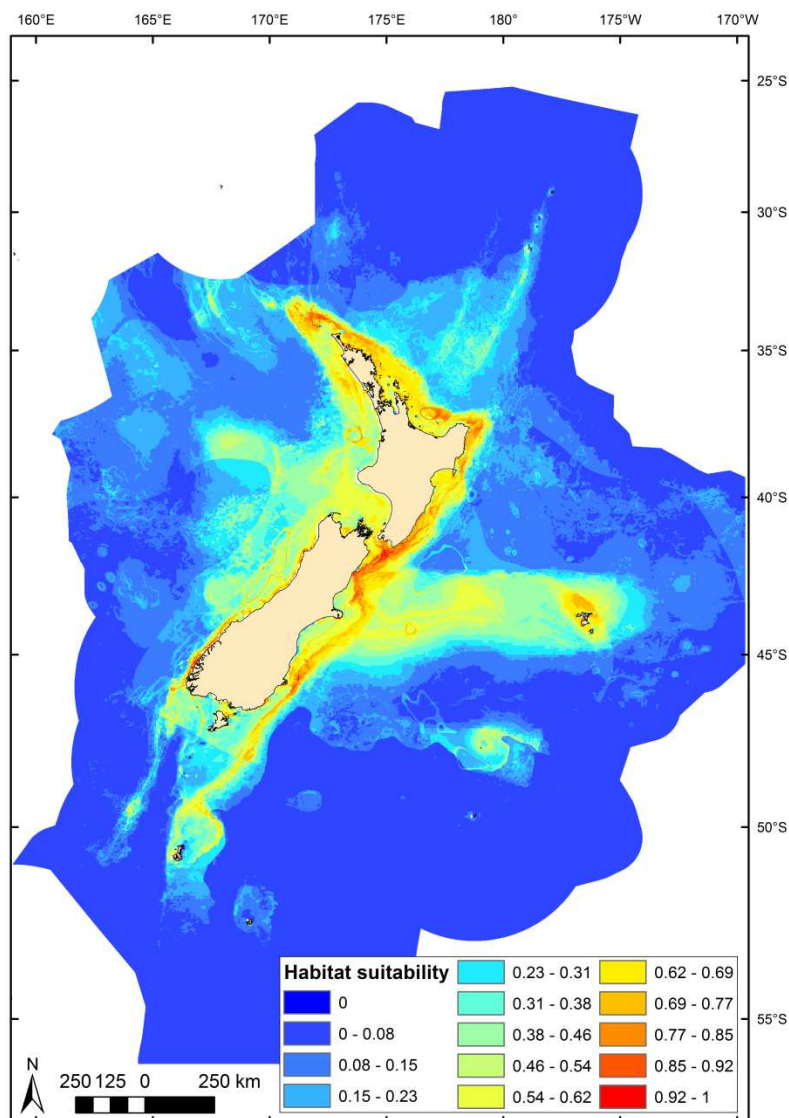


Figure 3-27: Habitat suitability predictions for killer whales derived from the habitat use model without the use of a bias grid. The habitat suitability index is a logistic output from the Maxent model (warm colours showing the highest habitat suitability).

The use of a bias grid in the modelling process was successful in minimizing observation bias in the sightings data. This model produced relatively high performance based on cross-validated models (AUC = 0.95; Table 3.2) and spatial predictions that more accurately reflected the species occurrence patterns. Based on the jack-knife analysis, this model determined that four primary environmental variables influenced habitat suitability for killer whales: sea surface temperature gradient (sstgr), primary productivity (vgpm), dissolved organic matter (disorg), and suspended particulate matter (susp; Figure 3-28). In particular, sea surface temperature gradient appears to have a significant influence on the distribution patterns of killer whales. Not only does it contribute the most explanatory power to the model, but without this variable in the model, the total AUC value declines significantly. This result indicates that the spatial relationship between killer whale distribution and sea surface temperature gradient is not sufficiently captured with any other predictor variable. Population (popln) was not one of the top five predictor variables and its explanatory power in the model was redundant in other variables (light blue bars in Figure 3-28). Therefore the model indicates that killer whale habitat preferences are similar when in coastal (within 200 m isobaths of shore) and offshore regions.

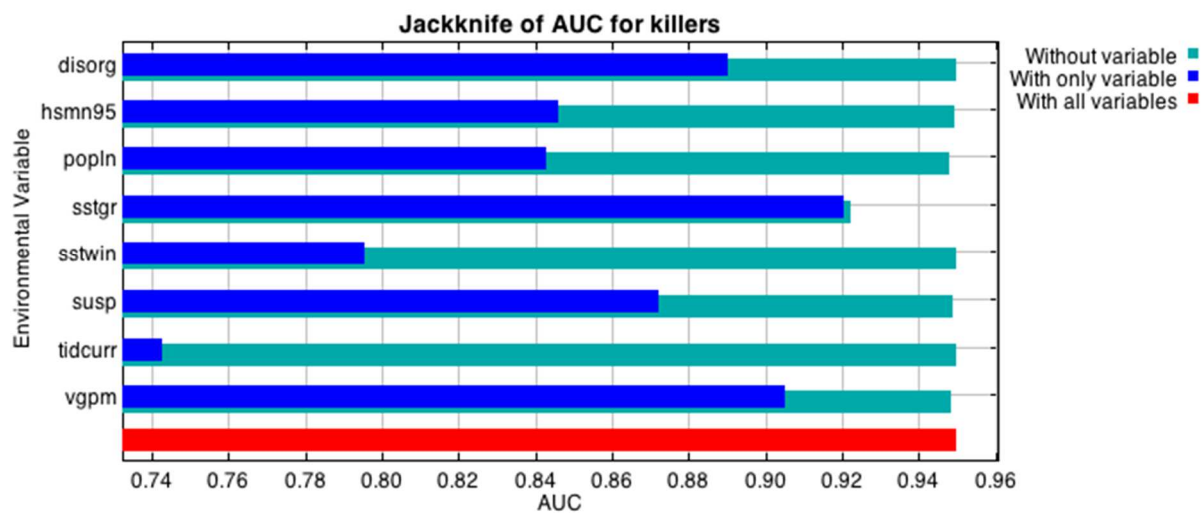


Figure 3-28: Jack-knife of AUC from the killer whales model using the bias grid for the core predictor variables. Dark blue bars show the AUC value when each environmental variable is used in isolation, and therefore indicates the level of predictive contribution by each variable. Light blue bars illustrate the AUC value when each variable is omitted and therefore shows the amount of information that is not captured by other variables. Values shown are averages over 10 replicate runs.

Response curves of species presence/absence relative to these four environmental variables indicate the functional response of killer whales to habitat variability (Figure 3-29). The relationship of killer whale presence to sea surface temperature gradient illustrates increased suitability of habitats with relatively high temperature gradients ($P > 0.75$ when $sstgr > 0.01$ °C km⁻¹). Relatively tight confidence intervals are maintained throughout the functional relationship. A non-linear relationship between killer whale habitat suitability and primary productivity (vgpm) is evident in this response curve; suitability rapidly increases where vgpm is between 200 and 500 mg C m⁻² d⁻¹, then gradually declines but P stays above 0.60. The relationships between killer whale presence and dissolved organic matter (disorg) and suspended particulate matter (susp) are very similar and this likely reflects their spatial correlation (evident in spatial plots of layers in Appendix B). In both response curves, killer

whale habitat suitability spikes just above zero and high suitability ($P > 0.85$) is maintained at all greater values of dissolved organic matter (disorg) or suspended particulate matter (susp).

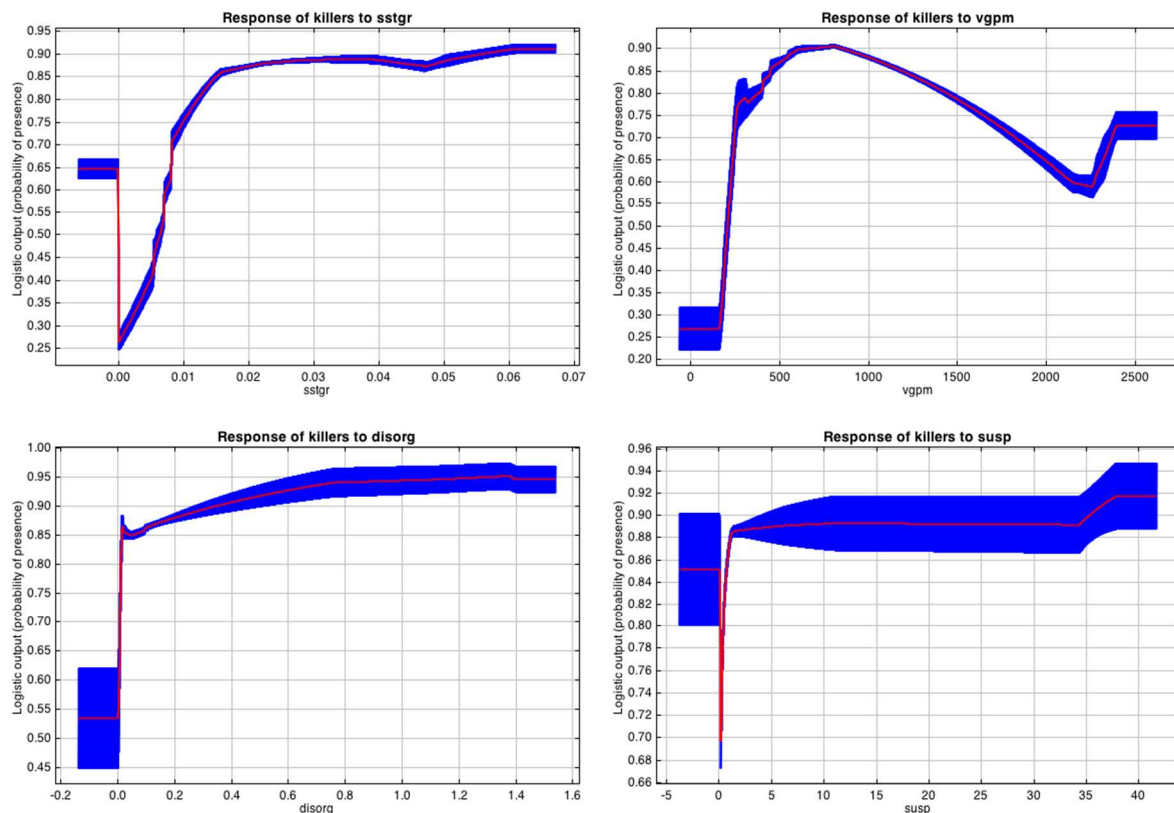


Figure 3-29: Response curves of the top four environmental variables derived from the killer whale distribution model with bias grid. The curves show how the logistic prediction changes relative to variation in the focal environmental variable, keeping all other environmental variables at their average sample value. Red lines are the mean response of the 10 replicate Maxent runs and the blue areas are \pm one standard deviation. Note that the scale of the y-axes is not consistent between plots.

The spatial prediction of killer whale distribution based on model results (Figure 3-30) illustrated a few coastal areas with high habitat suitability ($P > 0.75$): the southern Hauraki Gulf (Figure 3-31), the Mahia Peninsula, Marlborough Sounds and Golden Bay (Figure 3-32), and the southeast tip of South Island and Te Waewae Bay on South Island (Figure 3-33). The remaining areas of high suitability habitat for killer whale presence are predicted to be in offshore areas including off the northeast tip of Northland (Figure 3-31), over Chatham Rise, offshore of Banks Peninsula and Canterbury Bight (Figure 3-30 and Figure 3-32), and along the shelf break along the Otago coast (Figure 3-33). Interestingly, despite slope and bathymetry not being included as environmental parameters in the model, these regions correspond to the 200 m shelf break along the east coast. Additionally, areas with lesser yet above average habitat suitability ($P > 0.5$ and < 0.75) also correspond to this physical bathymetric feature. The variable included in the model that does explain this distribution is sea surface temperature gradient. The spatial variation of sea surface temperature gradient (see plot in Appendix B) illustrates areas of increased gradient along these shelf breaks.

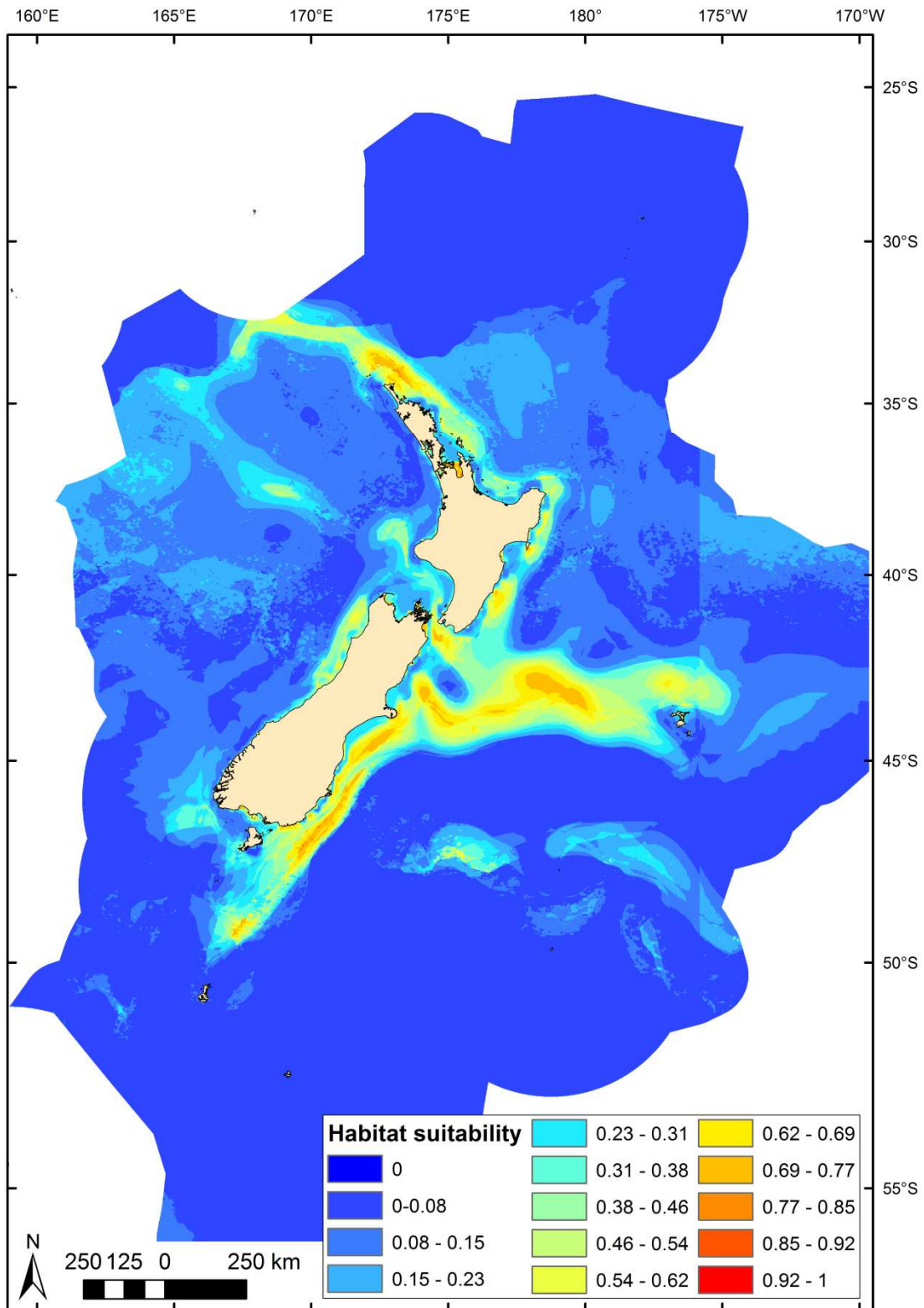


Figure 3-30: Habitat suitability predictions for killer whales from the habitat use model with bias grid correction. The full extent of model within New Zealand's extended continental shelf is displayed. The habitat suitability index is a logistic output from the Maxent model (warm colours showing the highest habitat suitability).

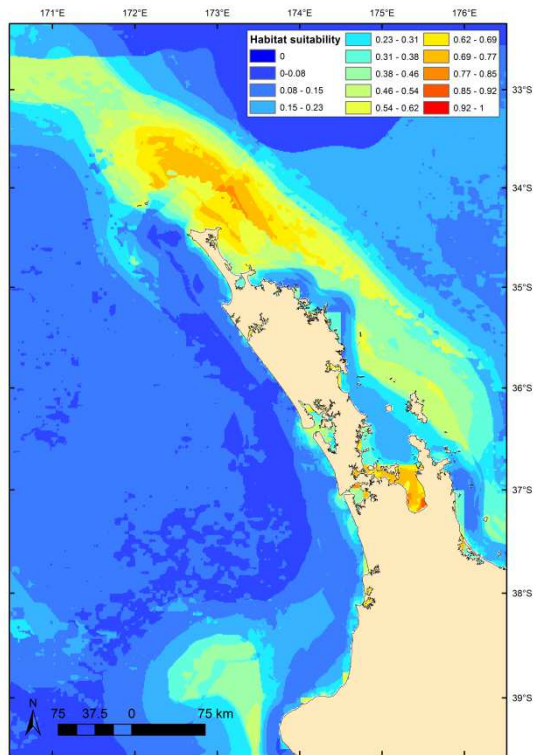


Figure 3-31: Habitat suitability predictions for killer whales in the northern North Island region derived from the habitat use model with bias correction. The habitat suitability index is a logistic output from the Maxent model (warm colours showing the highest habitat suitability).

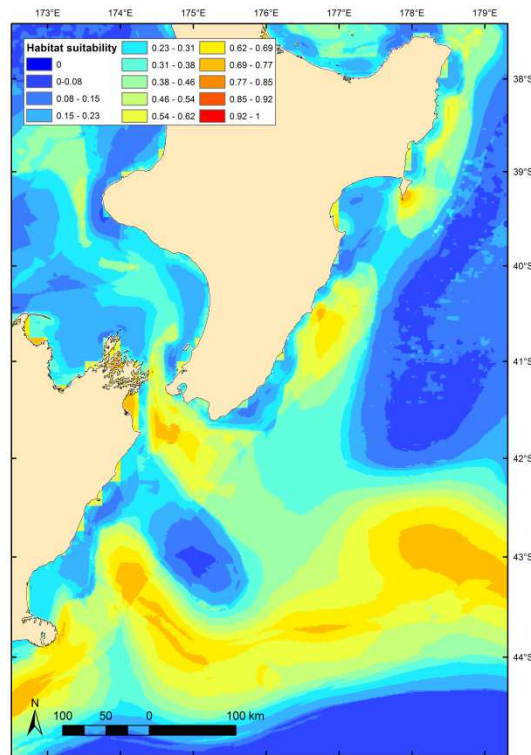


Figure 3-32: Habitat suitability predictions for killer whales around middle New Zealand the western Chatham Rise derived from the habitat use model with bias correction. The habitat suitability index is a logistic output from the Maxent model (warm colours showing the highest habitat suitability).

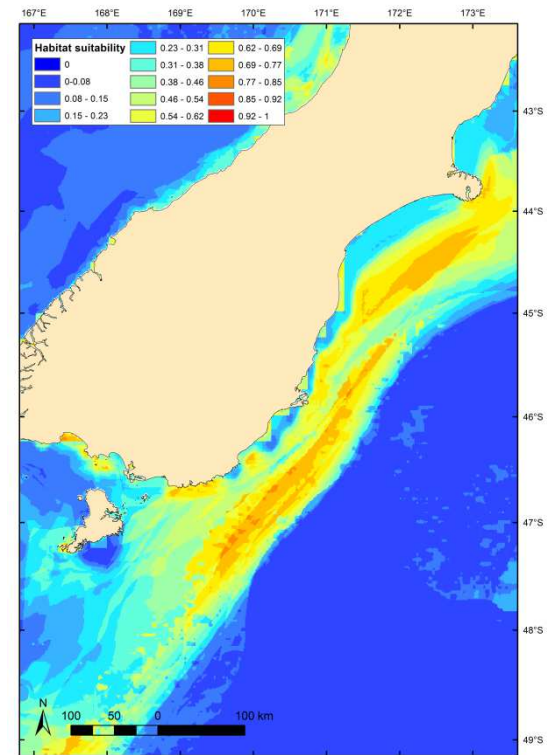


Figure 3-33: Habitat suitability predictions for killer whales along the southeast coast of the South Island derived from the habitat use model with bias correction. The habitat suitability index is a logistic output from the Maxent model (warm colours showing the highest habitat suitability).

3.3.1 Predicted suitability of habitat for killer whales in the STB

The predicted habitat suitability for killer whales in the STB ranges from low to moderate ($0.08 > P < 0.62$; Figure 3-34). The band of increased habitat suitability (yellow areas in Figure 3-34) corresponds to an area of increased sea surface temperature gradient (see Appendix B) and begins approximately 8 km seaward of the proposed project area. Killer whales may be using this habitat as a foraging ground as it is known to have increased abundance of prey fish such as Kahawai (*Arripis trutta*) and school shark (*Galeorhinus galeus*) (MacDiarmid et al. 2013). Close to shore in this region there is generally decreased killer whale habitat suitability. The highest predicted habitat suitability for killer whales in the TTR proposed project area is $P = 0.29$.

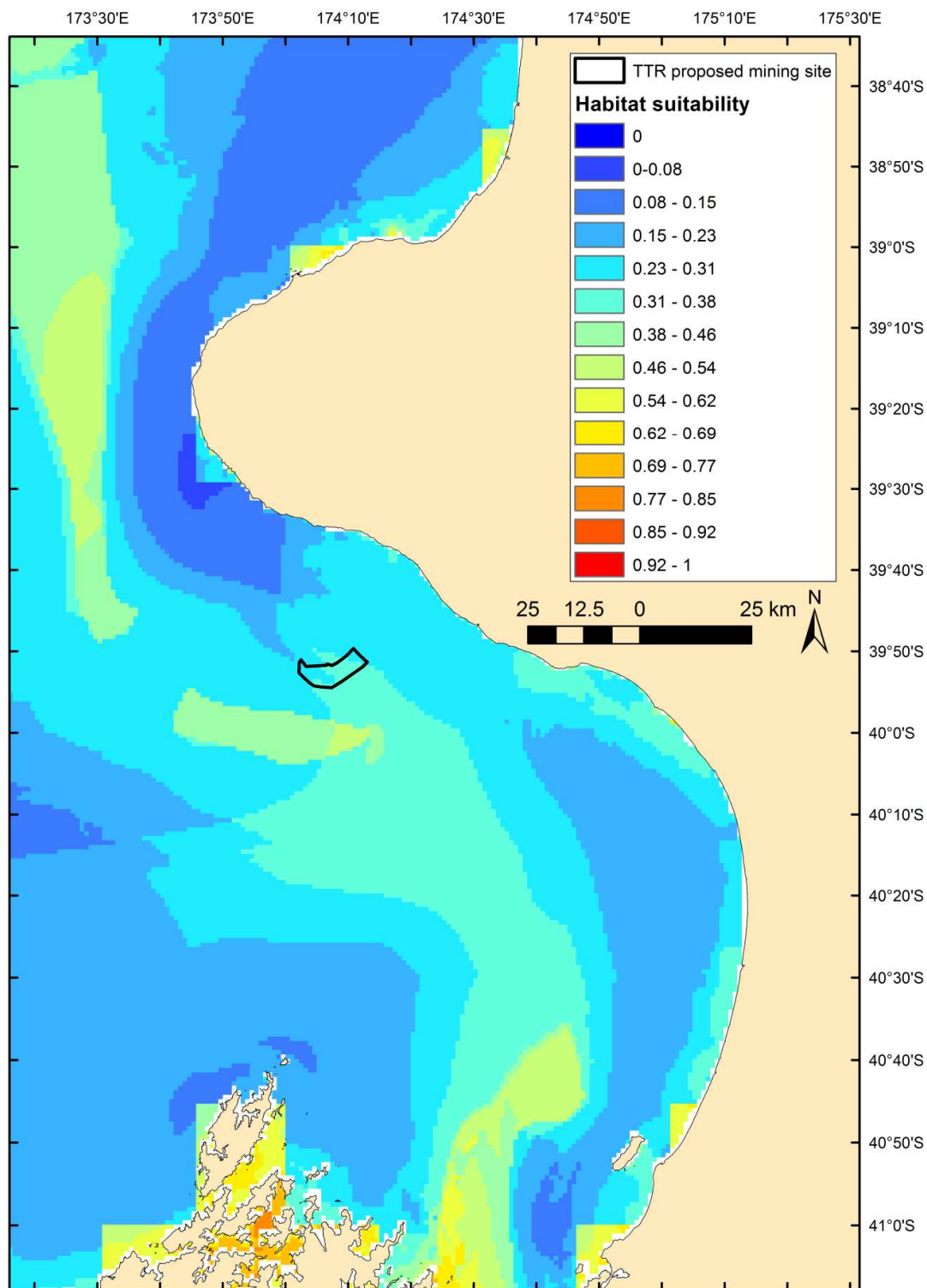


Figure 3-34: Habitat suitability predictions for killer whales in the North and South Taranaki Bights derived from the habitat use model with bias correction. TTR's proposed project area is outlined in black. The habitat suitability index is a logistic output from the Maxent model (warm colours showing the highest habitat suitability).

4 Discussion

This study related a suite of environmental variables with the spatial patterns of incidental sightings of three endangered cetacean species in New Zealand (southern right whale, Hector's dolphin, and killer whales). Maximum entropy modelling (Maxent) was implemented due to the presence-only nature of the data. A bias grid was included as a predictor variable in the Hector's dolphin and killer whale models in order to account for the spatial bias of the incidental sightings. These methods generated models with relatively high performance (AUC>0.9; Table 3.2) and produced realistic broad-scale predicted habitat suitability maps. The high AUC values associated with the models may be explained by three non-exclusive factors: the selection of relevant environmental covariates in the models, limited spatial extents of the models that fostered relatively 'simple' models, and adequate sample sizes and distribution of sightings data.

While these models are a first of their kind for these species in New Zealand and offer a robust step-forward in our understanding of their distribution and habitat use patterns, the spatial predictions should not be considered absolute, but rather as mathematical approximations based on the best available data and methods. Unfortunately, independent datasets are not available to validate the model predictions.

4.1 Southern right whale

The model of southern right whale habitat suitability predicts that during winter months suitable habitat is shallow areas near shore with high rates of dissolved organic matter, and sheltered from big waves. These results support the ecological needs of southern right whales during this phase when cows with calves select habitats that reduce calf energetic demands and injury risk (i.e., low wave energy to struggle against) and limit predation risk (lower abundance of predatory sharks and killer whales near shore) in order to increase calf survival rates (Elwen & Best 2004a). These model-derived results are coincident with findings from field surveys of southern right whales during the calving season that showed a preference by this species for calm, shallow habitats that are protected from wind and swell (Carroll et al. 2011b, Elwen & Best 2004b, Patenaude & Baker 2001). The functional ecological relationships between southern right whale distribution, dissolved organic matter and suspended particulate matter is unclear; these species-environment relationships are likely due to a correlation between proximity to shore and increased dissolved organic matter from river run-off and suspended particulate matter (Table 2.2 and Appendix A). Therefore, these environmental parameters may not functionally influence the distribution of southern right whales, but they do provide increased predictive capacity of habitat suitability.

Southern right whale preference for nearshore, shallow habitats is illustrated in the predicted habitat suitability map (Figure 3-3). Hot spots of preferred winter habitat for southern right whales are sheltered bays and harbours around the coast including the north-west and east coasts of North Island (Figure 3-4), in Golden Bay, Marlborough Sounds, Cook Strait region (Figure 3-5), and the south and south east coasts of the South Island (Figure 3-6). These areas are all characterized by shallow depths and small wave heights (Appendix A) and were historically key areas of shore based whaling and bay whaling by anchored whaling vessels in the period 1830-1845 (Carroll et al. 2013). Additionally, the predictions of habitat suitability appear higher on the east coasts of each island in areas that are more sheltered against the predominant west-southwest direction of swell and winds in New Zealand (Pickrill & Mitchell

1979). The southern right whale population in New Zealand is presently 3% of its historical level and growing at 4.6% per annum (Jackson et al. 2011). As this population recovers, the habitat suitability model suggests that the occurrence of southern right whale cows and calves in winter will increase in these preferred habitats.

4.2 Hector's dolphin

Implementation of the bias grid into the Hector's dolphin distribution model produced spatial predictions of species occurrence that, with one exception, are consistent with the known broad-scale distributions patterns of the four described sub-populations (Baker et al. 2002, Pilcher 2002): North-West population on the North Island (especially outside the Kaipara, Manukau, and Kawhia harbours, and the Waikato River mouth), and East (Banks peninsula and Canterbury Bight), West and South populations on the South Island. The exception is the identification of highly suitable habitat for Hector's dolphins in the Bay of Plenty. Only limited sightings of Hector's dolphins have been made in this area in the recent period and our results suggest either the absence of important environmental variables from our model that may better explain distribution, or this species may have been once present in this region and subsequently extirpated. However, further research is required to test this hypothesis.

The model of Hector's dolphin habitat suitability predicts that preferred areas are those with high concentrations of dissolved organic matter and high primary productivity. These results correspond with existing knowledge of Hector's dolphin ecology, determined through *in situ* habitat use studies, showing a preference by this species for turbid waters. Bräger et al. (2003) found that most Hector's dolphins were encountered in waters with low clarity (Secchi disk visibility <4m). Other studies have determined increased occurrence of Hector's dolphins near river mouths (Brager & Schneider 1998, Clement et al. 2010). Increased Hector's dolphin occurrence near shore and river mouths may be due to increased abundance of targeted prey items and increased hunting efficiency in turbid waters due to echolocation capabilities that enable the ability to detect and surprise prey in waters with low visibility (Brager et al. 2003, Clement et al. 2010).

The model also identified that areas with low levels of suspended particulate matter and dissolved organic matter are highly suitable for Hector's dolphins. This contrasting result with Hector's dolphin preference for waters with high levels of dissolved organic matter and primary productivity may be explained by the targeting of different target prey items in different water masses. Similarly we suggest that the bi-modal relationships between Hector's dolphin habitat preference and dissolved organic matter, and suspended particulate matter, are due to different target prey items with contrasting habitat preferences. The bi-modal relationship of Hector's dolphin and winter sea surface temperature may be due to contrasting temperatures along east and west coasts and North and South Islands. Additionally, this preference for both cold and warm waters may be due to documented seasonal variation in habitat and distribution patterns showing increased presence in relatively deeper, offshore waters in winter (Rayment et al. 2010) leading to biannual differences in habitat preferences. Alternatively, the variable response curve relative to winter sea surface temperature may be due to the failure of an annual model to account for seasonal changes in water temperature and subsequent impacts on prey and predator

distributions. Additionally, the sample size of sightings was likely not equivalent between seasons and therefore could affect this relationship.

4.3 Killer whales

Incorporation of the bias grid into the killer whale habitat use model generated a spatial prediction that was realistic and corresponded to the distribution of the raw sightings data (Figure 2-1 and Figure 3-30). Moreover, the species-environment relationships are ecologically reasonable (Figure 3-29). Areas of steep sea surface temperature gradients (sstgr) are known to aggregate primary (chlorophyll) and secondary (zooplankton) productivity that attracts (fish; Etnoyer et al. 2004, Owen 1981) that are targeted by killer whales. This functional relationship between killer whales and sea surface temperature gradient is echoed by a similar relationship with primary productivity (vgpm). Killer whale habitat use is predicted to increase in areas with relatively high primary productivity. Ideally, independent sightings (sightings not included in the modelling process) could be used to validate the predictive capacity of the spatial distribution maps, but these data are unavailable. Little is known about the distribution or habitat use patterns of killer whales around New Zealand, especially in offshore waters.

Overall, the spatial prediction of killer whale distribution resulted in fewer areas of high habitat suitability ($P > 0.8$) compared to the southern right whale or Hector's dolphin models. This is likely due to the larger extent that was modelled for killer whales that covers much greater habitat variation. Similarly, killer whales range over a wider variety of habitat characteristics and likely cue into different environmental factors based on location and target prey item. This environmental and behavioural variation challenges a single habitat model to determine consistent areas of high habitat suitability since killer whales are highly dynamic animals that may prefer different habitat features at separate locations at various times of the year.

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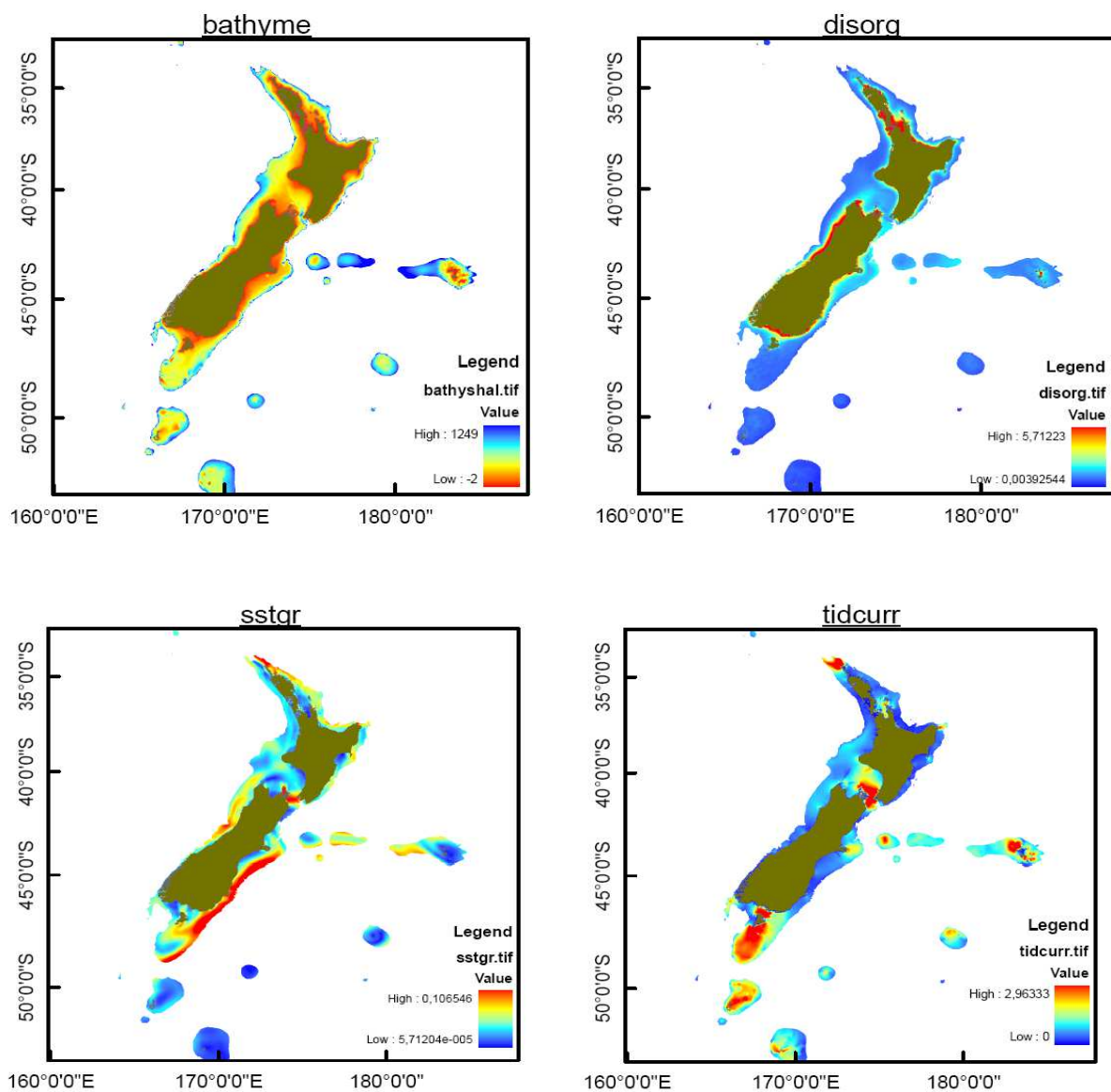
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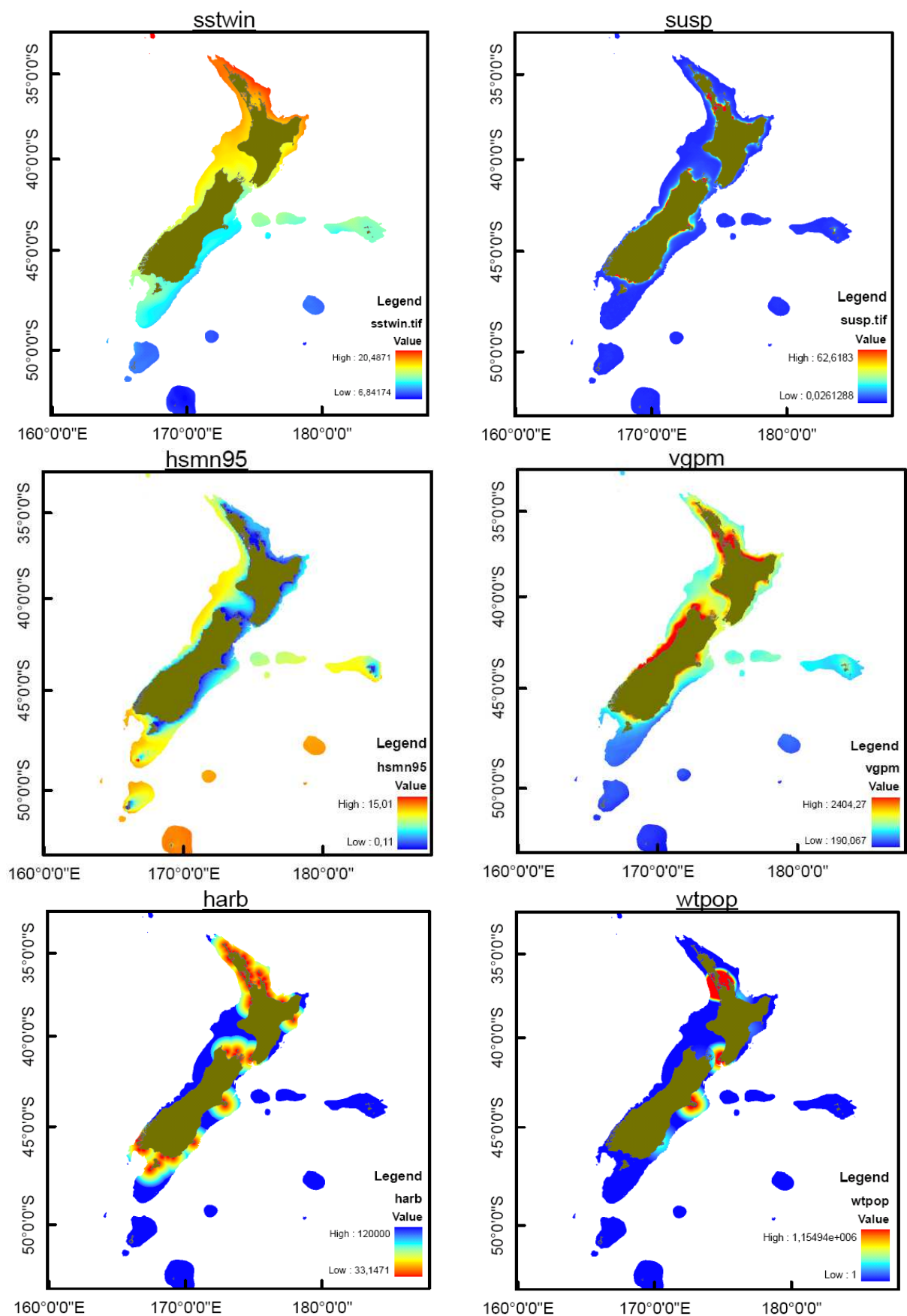
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Appendix A Maps of environmental layers used in habitat modelling analyses of southern right whales and Hector's dolphins

Spatial illustration of environmental layers used in habitat modelling analyses of southern right whales and Hector's dolphins within the 350 m isobaths: bathymetry (bathyme), dissolved organic matter (disorg), sea surface temperature gradient (sstgr), tidal current velocity (tidcurr), winter sea surface temperature (sstwin), suspended particulate matter (susp), 95th percentile of wave height (hsmn95), primary productivity (vgpm), distance to harbor (harb) and population density (wtpop).





Appendix B Maps of environmental layers used in habitat modelling analyses of killer whales

Spatial illustration of environmental layers used in habitat modelling analyses of killer whales within New Zealand's extended continental shelf: bathymetry (bathyme), dissolved organic matter (disorg), sea surface temperature gradient (sstgr), tidal current velocity (tidcurr), winter sea surface temperature (sstwin), suspended particulate matter (susp), 95th percentile of wave height (hsmn95), primary productivity (vgpm), and binary population designation (popln).

