Characterising surface longline fishing fleet behaviour in relation to leatherback bycatch

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Contents

Tables

Figures

Executive summary

Leatherback turtles (*Dermochelys coriacea*) are the most frequently reported turtle bycatch in New Zealand commercial surface longline fisheries. Leatherback turtles are protected under the Wildlife Act 1953. This project updated the fishery captures of leatherbacks in New Zealand waters up to, and including, the 2022–23 fishing year and attempted to identify any temporal changes in fishing practices and/or catch composition associated with changes in leatherback bycatch.

Most surface longline fishing effort targeted southern bluefin tuna (*Thunnus maccoyi*), followed by bigeye tuna (*T. obesus*), and swordfish (*Xiphias gladius*). The surface longline fishery started in northern waters around October and moved south as the season progressed and waters warmed, returning to more northern waters as winter approached. In summer months, the southern bluefin tuna fishery extended to the southeast of the South Island, while the swordfish fishery occurred on the southeast North Island and west coast South Island. Bigeye tuna catches were centred further north, rarely extending beyond the Bay of Plenty and East Cape.

Leatherback captures have been centred in the Bay of Plenty. The leatherback spatial ‘hotspot’ and season (the ‘hotspot’) occurred between latitudes of 36° S and 38°S from January to April. Bigeye tuna, and then swordfish fishing, had the greatest spatial and temporal overlap with the leatherback hotspot. The southern bluefin tuna fishery had very little overlap. About 75% of the bigeye tuna catch, 80% of the swordfish catch, and almost all the southern bluefin tuna catch, ware taken outside of the leatherback hotspot. The greatest leatherback captures were reported from 2021 when fishing effort was relatively low, but more focused on the east coast North Island than usual.

The fisheries characterisation using reported commercial catch and effort data indicated the strongest interaction was between leatherbacks and the fishery targeting bigeye tuna. An alternative analysis based on clustering of catch compositions produced a different result, with the strongest association being between leatherbacks and swordfish. This difference was because the reported target species did not always accurately describe the catch composition. The catch composition analyses did not isolate the Bay of Plenty region as a specific fishery subunit, meaning there was nothing apparently unique about the fishing in and around the leatherback hotspot.

A Generalised Additive Model (GAM) was developed to investigate the potential reasons for trends in leatherback captures in 2021. The GAM analysis was updated to 2023 with additional environmental and fisheries variables included and restricted to the east coast North Island. The updated GAM explained more of the variability in leatherback bycatch probability, but with a different set of predictor variables. The variables used were proximity to steep sea surface temperature (SST) gradients (fronts), mixed-layer depth, water depth, strength of the west-to-east current, number of hooks between floats (an alias for fishing depth), number of light sticks used between floats, and moon phase. Further GAMs predicting leatherback occurrence and fish catch rates from environmental conditions found the closest association was between leatherbacks and swordfish. A close association between swordfish catch rates and leatherback captures is consistent with international leatherback capture mitigation focusing on swordfish target fisheries.

Comparison of vessels reporting and not reporting leatherbacks was made and found the greatest difference was in location fished. Overall, fishing location was the most persistent and important factor determining the likelihood of a vessel capturing a leatherback.

1 Introduction

Five species of sea turtle are recorded from New Zealand waters, and all are protected under the Wildlife Act 1953. All sea turtles are listed on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species as threatened species (Critically Endangered, Endangered, or Vulnerable) (IUCN 2024). Leatherback (*Dermochelys coriacea*) and green turtles (*Chelonia mydas*) have been the marine reptiles most frequently reported as bycatch in New Zealand commercial fisheries, likely reflecting a higher occurrence in New Zealand waters (Godoy 2016, Dunn et al. 2022). Turtle conservation has been successful in arresting population declines for many turtle populations globally, but the western Pacific leatherback population remains one of the few cases were there has been a steep and continued decline (Hays et al. 2024).

Most leatherbacks occurring in New Zealand waters probably originate from the western Pacific leatherback population. These leatherbacks breed on beaches in the southwest Pacific, including the Solomon Islands, and winter-nesting turtles in Indonesia (Benson et al. 2011, Pete Waldie, TNC, unpublished data). The total regional population is poorly estimated but is likely to be just over 1000 females nesting annually and has been declining at an estimated rate of 6% per year (Benson et al. 2020, Martin et al. 2020). The main known anthropogenic threat to leatherback turtles in the New Zealand region is commercial fishing, with most reported interactions being with surface longline (SLL) fisheries off the northeast North Island during summer-early autumn (Dunn et al. 2022). Despite a reduction in the size of the domestic SLL fleet, reported and estimated interactions with leatherbacks increased after 2014, with a peak of 50 reported captures in the 2021 fishing year (Dunn et al. 2022, Dunn et al. 2023).

Statistical models of the leatherback probability of capture found an increase in bycatch with increasing SST from a constant-over-time spatial pattern of monthly SST (Dunn et al. 2023). This meant the increase in leatherback bycatch could be explained by the SLL fleet moving into warmer areas where the probability of leatherback capture was higher. Capture mitigation measures might therefore include restricting fishing in leatherback ‘hotspot’ times and areas. However, the implementation of any closed areas would likely not be straightforward, because spatial and temporal ‘hotspots’ or turtle distribution and capture may be spatially and temporally patchy and ephemeral (Siders et al. 2024), and there could be costs and unintended consequences of closures that ultimately hinder conservation efforts (Dunn et al. 2023).

This project builds upon CSP project INT2021-03 (Review of commercial fishing interactions with marine reptiles) and subsequent research by NIWA (Dunn et al. 2023). This project was designed to consider the relationship between leatherback turtles, fisher behaviour, and fish species caught in the SLL fisheries and help inform the development of mitigation measures for this fishery. The specific objectives of the project were:

- Describe the temporal patterns in the distribution of SLL fishing effort by target species and leatherback bycatch off the North Island east coast (FMA1, FMA2);
- Evaluate the spatial and temporal patterns of SLL fishing effort by target species relative to biological and environmental predictors of leatherback bycatch;
- Evaluate the SLL catch in the region by species and weight for vessels reporting interactions with leatherbacks and those not reporting any leatherback interactions;
- Identify any temporal changes in fishing practices and/or catch composition associated with changes in leatherback bycatch.

2 Methods

2.1 Data collation

2.1.1 Observer data

The Centralised Observer Database (COD) contains data collected by observers on fishing vessels and is managed by NIWA for Fisheries New Zealand (FNZ). The database was searched for all records containing the three-letter species codes for leatherbacks and associated fishing event data up to the end of 30 September 2023.

These records are hereafter referred to as 'observed' leatherback records and sets. The Observer Programme also provided photographs and diary notes taken by observers. All observer records were checked ('groomed') by hand, evaluating each record for plausibility by comparing the consistency of data provided for that event (e.g., location consistent with depth), and consistency with adjacent records (Dunn et al. 2022). Photographs taken by the observers were used to evaluate record accuracy, including species identification and condition.

2.1.2 Commercial data

The Enterprise Data Warehouse database managed by FNZ contains surface longline catch and effort data received from commercial fishers. The database was searched for all leatherback records up to the end of 30 September 2023. Associated data extracted included date, latitude, longitude, Fisheries Management Area (FMA), Fisheries General Statistical Area, fishing method, target species, fishing depth, fishing duration, total hook count, light stick count, and number of floats. Gear location was taken as the reported start location. The same data fields were extracted for all fishing events, regardless of whether a leatherback was caught, to allow comparison between events that caught leatherbacks and events that did not. These records are hereafter referred to as 'reported' leatherback records and sets. Since late 2008, fishers have been reporting protected species captures mainly on Non-Fish Protected Species Catch Returns (NFPS), with the first marine reptile record being dated 18 February 2009. Commercial fishery catch and effort data were groomed to replace obviously incorrect or missing values following the same procedure reported in Dunn et al. (2022).

2.1.3 Combined leatherback capture data set

The commercial and observer reports of leatherback interactions were combined to provide a single groomed data set containing all records, with any duplication between the commercial fisher and observer data removed. Where unique capture records were reported by both the commercial fisher and the observer, primacy was given to the observer data. Fishing year was referred to as the year-ending, e.g., 2011 for the 1 October 2010 to 30 September 2011 fishing year.

2.1.4 Environmental data

Environmental data were collated and allocated by nearest date and location to the catch and effort data. The variables followed Dunn et al. (2023), with the addition of moon phase (illumination) and further temperature gradient and current variables (Table 2-1).

Table 2-1: The variables considered in analyses of leatherback capture probability for the surface longline fishery. Form in generalised additive model (GAM) is either as a categorical factor, or as a continuous variable fitted with a cubic spline smoother. AVISO2 data were at a 0.25-degree latitude and longitude resolution. The Roemmich and Gilson Argo climatology were at a 1-degree latitude and longitude resolution (Roemmich & Gilson, 2009).

Variable label	Source	Description
chla	Chlorophyll-a concentration between 1997–2021 (monthly, 9 km) produced by blending SeaWiFS (NASA, 2018a) and MODIS-Aqua (NASA, 2018b) observations using the overlap period (Pinkerton et al. 2021, Gall et al. 2022).	Open ocean chlorophyll-a (mg/m^3). This will be dubious close to the shore (within ~5 km). Correlation with kd490.
SST OI v2.1	Optimal-interpolation ocean product (OI-SST v2.1; Reynolds et al. 2007, Huang et al. 2021) at 0.25°lat x 0.25°lon, monthly	SST (°C)
SST-monthly	MODIS-Aqua default sst product at 4 km (NASA OBPG 2020, Kilpatrick et al. 2015, 2019)	SST (°C)
SST-climatology	See Gall et al. (2022)	Monthly climatological SST (i.e., average January, February etc) (°C)
SST-anomaly	See Gall et al. (2022)	Monthly anomaly in SST (i.e., difference between SST-monthly and SST4-climatology) (°C)
kd490	Open-ocean diffuse downwelling irradiance attenuation at 490 nm (Kd490) product from MODIS-Aqua and SeaWiFS (Clark 1997) (9km, monthly) blended as Pinkerton et al. (2021), Gall et al. (2022)	Diffuse attenuation at 490 nm (proxy for the reciprocal of water clarity) (m^{-1}). Excluded from final models as no data for 2021.
par	Open-ocean PAR product (9km, monthly) from MODIS-Aqua and SeaWiFS (Frouin & Pinker 1995, Frouin et al. 2012) blended as Pinkerton et al. (2021), Gall et al. (2022)	Average daily incident irradiance at sea surface (Einstein/m^2/d). Correlated with temp.
vgpm	Vertically Generalised Production Model (VGPM, Behrenfeld & Falkowski 1997) based on MODIS-Aqua and SeaWiFS (sourced from Oregon State University[1], 9km, monthly) and blended as Pinkerton et al. (2021).	Model of primary production (mgC/m^2/d). Chla preferred in final models. Correlated with eppley and mld.
café	Carbon, Absorption, and Fluorescence Euphotic-resolving model (CAFE, Silsbe et al. 2016). based on MODIS-Aqua and SeaWiFS (sourced from Oregon State University[1], (9km, monthly) and blended as Pinkerton et al. (2021).	Models of primary production (mgC/m^2/d). Chla preferred in final models
cbpm	Carbon Based Production Model (CBPM, Behrenfeld et al. 2005, Westberry et al. 2008) based on MODIS-Aqua and SeaWiFS (sourced from Oregon State University[1], 9km, monthly) and blended as Pinkerton et al. (2021).	Models of primary production (mgC/m^2/d). Chla preferred in final models

Variable label	Source	Description
eppley	Eppley-modified VGPM (Eppley 1972, Behrenfeld & Falkowski 1997) based on MODIS-Aqua and SeaWiFS (sourced from Oregon State University[1], 9km, monthly) and blended as Pinkerton et al. (2021).	Models of primary production (mgC/m^2/d). Chla preferred in final models
SSTgrad_OISST	Magnitude of the 2-dimensional spatial gradient of OI-SST v2.1 (Reynolds et al. 2007, Huang et al. 2021)	Spatial gradient in SST as indicative of fronts.
SSTgrad	Derived from MODIS-Aqua default sst product at 4 km	Spatial gradient in SST as indicative of fronts.
mld0p030	Depth at which there is potential density difference of 0.030 kg m^{-3} from the surface. Based on GLBu0.08 hindcast results (using hycom, fnmoc, soda, tops: Metzger et al. 2007, Chassignet et al. 2007, Wallcraft et al. 2009) sourced from Oregon State University ocean productivity (9km, monthly)	Mixed layer depth (m) on two different criteria for changes in potential density (0.03 kg/m^3). Correlated with other mld, and vgpm.
mld0p125	As for mld0p030 but with potential density difference of 0.125 kg/m^3 from the surface (9km, monthly)	Mixed layer depth (m) on two different criteria for changes in potential density (0.125 kg/m^3). Correlated with other mld, and vgpm.
temp100m	Roemmich and Gilson Argo climatology	Temperature at 100m. Correlated with other temp.
temp200m	Roemmich and Gilson Argo climatology	Temperature at 200m. Correlated with other temp.
TimeVaryingEastwardCurrents	AVISO	Zonal current (u) (time-varying eastward currents). Positive values indicate stronger to the east.
TimeVaryingNorthwardCurrents	AVISO	Meridional current (v) (time varying northward currents). Positive values indicate stronger to the north.
EKE	AVISO	Eddy Kinetic Energy, calculated as $0.5(u^2 + v^2)$
Umean_geo	AVISO	Mean u (mean eastward current); variable over space but not time
Vmean_geo	AVISO	Mean v (mean northward current); variable over space but not time
Seabed depth	NIWA	NIWA New Zealand bathymetry updated to 250 m resolution, 2016, based on Mitchell et al. (2012)
Seabed depth	NOAA	Smith and Sandwell 8.2 NOAA global bathymetry dataset

Variable label	Source	Description
Total number of hooks	Ministry for Primary Industries	Reported number of hooks per set
Number of floats	Ministry for Primary Industries	Total number of hooks / (number of floats -1) gives the number of hooks between floats, which is an alias for fishing depth (e.g., Peatman et al. 2023)
Longline length	Ministry for Primary Industries	In nautical miles
Number of light sticks	Ministry for Primary Industries	Number of light sticks / (number of floats -1) gives the number of light sticks between floats
Vessel length	Ministry for Primary Industries	Registered total vessel length (m)
Vessel power	Ministry for Primary Industries	Registered vessel power (kW)
Esun	Cosine of solar zenith angle based on Kirk (1994) and corrected for nautical twilight (solar elevation >12° below horizon).	Intensity of incident irradiance on the sea-surface in the absence of clouds (zero at night, 1 if sun is directly overhead) [note: in relative units and not scaled by mean extraterrestrial solar irradiance]
Eprop	Esun as proportion of maximum daily Esun (day) and as proportion of minimum absolute daily Esun (night)	Proportion of maximum daily incident irradiance (1=solar midday; 0= dawn/dusk; negative when the sun is below the horizon)
Echange	Rate of change of Esun (h-1)	Rate of change of incident light (no clouds) to differentiate between dawn and dusk
EMoonPhase	Moon phase based on Meeus (1991) implemented in IDL by W. Landsman, September 1997, from the NASA ASTRO library (accessed March 2024)	Illuminated fraction of Moon's disk ($0.0 < k < 1.0$), $k = 0$ indicates a new moon, $k = 1$ a full moon
Emoon	Moon position based on Meeus (1991) implemented by W. Landsman, September 1997, from the NASA ASTRO library (accessed March 2024), and assuming moon albedo 0.12	Sea-surface moon irradiance in absence of clouds (same units as Esun)

1. Oregon State University Ocean Productivity project, http://sites.science.oregonstate.edu/ocean.productivity/index.php.
2. AVISO gridded products: http://www.aviso.oceanobs.com/en/data/products/sea-surface-height-products/global/index.htm
3. NOAA bathymetry: https://ferret.pmel.noaa.gov/LAS_docFiles/smith_sandwell_v8_2.html.

2.2 Data analyses

2.2.1 Fishery characterisation

The fishery characterisation is important as it sets the resolution at which the overlap between the fishery and leatherbacks is evaluated (leatherback hotspot area). The characterisation for the commercial catch and effort data was completed using two different methods:

1. Using the fishery descriptors as recorded in the event-by-event catch and effort data, such as start latitude, month, and target species. This is a more detailed version of the characterisation completed by Dunn et al. (2022).

2. Clustering events using the fishers' reported species catch composition. This identification of fishery subunits that share a common exploitation pattern (often called "métiers") is a relatively new method to New Zealand but often completed overseas (e.g., Cubillos et al. 2022). The advantage of this analytical method is that it may identify fishing patterns that fishers did not describe or were not aware of (e.g., because they did not do it themselves).

The clustering was done using CLARA (Clustering LARge Applications), which is an extension of PAM (Partition Around Medioids) specifically designed to efficiently handle large datasets (Kassambara 2017). CLARA works by selecting a random sample of the data, applying PAM to the sample, and repeating this process multiple times retaining the sub-set for which the mean (or sum) is minimal. The optimal number of clusters *k* is selected based on the minimum dissimilarity measure, using the average silhouette method over a range of possible values for *k* (Kaufman and Rousseeuw 2009). A "large" dataset is considered to have more than a few thousand records; here we clustered catch weights for 40 species and 37 657 events. Leatherback captures were not included in the catch weights (i.e., clustering procedure), so they did not influence the identification of fisheries.

The location of the highest probability of capturing leatherbacks, or the 'hotspot', was evaluated using cluster analysis using rpart in R. The model predicted leatherback capture using all surface longline fishing records 2007–08 to 2022–23 and in FMA 1 and FMA 2, and was offered the variables latitude, longitude, day of year, month, and seabed depth. Splitting was done using the Poisson method with 10-fold cross validation, with a requirement for at least 20 observations in any terminal group (which was greatly exceeded), and complexity parameter (cp) of 0.008.

2.2.2 Analyses of leatherback turtle and fish captures and environmental conditions

The identification of environmental variables best predicting leatherback captures were investigated following Dunn et al. (2023). The dataset consisting of surface longline catch and effort records over the fishing years 2008 to 2023. All fishing events sampled by Ministry for Primary Industries (MPI) observers, in addition to commercial records for eight specific vessels were included in the dataset. The commercial records for the eight vessels were included because they had reported at least one leatherback capture in every year fished. The collated environmental variables are summarised in Table 2-1. A dataset of 8610 surface longline fishing events (mean=539 events per year^{-1}, range=389–706 events per year^{-1}), and 183 leatherback interactions in 156 longline fishing events between 2008 and 2023 were used.

Leatherback captures were modelled using a binomial (occurrence only) generalised additive model (GAM). We used the restricted maximum likelihood method (REML) for automated selection of smoothing parameters to select a ‘base’ model using the *mgcv* library (Wood 2017) in R (R Core Team 2022). The *gam.check* function was used to assess model fit by visually evaluating residual plots and running diagnostic tests to ensure adequate basis dimensions for each smooth. We then checked for competing models that might describe the data equally well by manually adding and/or replacing correlated or related variables in the base model. We considered the model to show no improvement if REML improved by less than 1, additional deviance explained <0.5%, and the additional term had a *p-value* >0.001; these criteria were used to favour a parsimonious rather than complex model.

The predicted effect of each variable was plotted over the observed range with all other variables fixed at their median values. The influence of each variable on the year trend was shown as the mean predicted value from that variable for each year divided by the overall mean predicted for that variable (Bentley et al. 2012).

We repeated the GAM for important target species identified from the fishery characterisation, albacore (*Thunnus alalunga*), bigeye tuna (*Thunnus obesus*), southern bluefin tuna (*Thunnus maccoyii*), along with sunfish (*Mola mola*) as a potential proxy of leatherback presence (Mosnier et al. 2019), and the important bycatch species blue shark (*Prionace glauca*), moonfish (*Lampris guttatus*), mako (*Isurus oxyrinchus*), and porbeagle (*Lamna nasus*). Like leatherback turtles, lamnid sharks such as porbeagle and mako have the capacity to conserve metabolic heat (Bernal et al. 2001).

The GAM analyses by Dunn et al. (2023) were conducted to evaluate possible reasons for the 2021 peak in leatherback captures, but also allowed past temporal trends in leatherback captures to be predicted. We used the Dunn et al. (2023) model, fitted to the east coast North Island region only (FMAs 1 and 2) and using data 2008 to 2021, to test how well the model predicted the captures observed for 2022 and 2023. This was a test (albeit limited) of the predictive ability and assumptions of the Dunn et al. (2023) model.

2.2.3 Differences between vessels reporting and not reporting leatherbacks

It is a legal requirement in New Zaland for fishers to report bycatch of turtles, but it is not illegal to accidently catch them. Because only a small proportion of the surface longline fishing fleet reported almost all of the leatherback captures, with one vessel accounting for 40.4% of all captures, Dunn et al. (2023) suspected non-reporting of leatherbacks by commercial fishers might have taken place. Currently, bycatch mitigation efforts in the surface longline fisheries has focused primarily on seabird interactions, and it is possible leatherback captures were not given the same attention. Observer coverage of the east coast North Island surface longline fisheries has been historically low and at the wrong time of year to observer turtle captures (Godoy 2016; Dunn et al., 2023).

A simple comparison was made for the vessels that regularly reported leatherback bycatch (at least 10 across all years, 2008 to 2023), and those vessels that have never reported bycatch. The leatherback capture rate by vessels having both observed and unobserved trips in the leatherback bycatch hotspot area and season (defined in Section 2.2.1) were also compared. A commercial record was considered “observed” if there was a record for that vessel on that day in the observer dataset.

This analysis should be treated with some caution because there is no explicit link between the observer and commercial catch and effort databases. For example, records were found in the observer data that could not be linked to any record in the commercial data, even after widening the date selection.

3 Results

3.1 Characterisation of the surface longline fishery

The surface longline fisheries were dominated by three reported target species – southern bluefin tuna (*Thunnus maccoyii*), bigeye tuna (*T. obesus*), and swordfish (*Xiphias gladius*) (Table 3-1). Generally, the fishery has started in northern waters in October and extended south as the season progressed, peaking in southern areas between February and May, and then returned the more northern waters as winter approached (Table 3-2). Leatherback captures have been centred predominantly at latitudes of 36° to 38° S during January to April. Within this characterisation we define this the leatherback bycatch 'hotspot'. Captures have not occurred in the southern fished regions (>45° S) (Table 3-3).

Table 3-1: Fishing effort, as number of events, for surface longline fisheries around New Zealand by fishing year and reported target species. Fishing year shown as year ending.

Fishing year	Albacore	Bigeye	Southern bluefin	Swordfish	Pacific bluefin	Yellowfin	Other
2008	2	1 050	725	131	25	7	19
2009	11	1 634	922	45	14	1	5
2010	25	1 362	1 279	147	22	1	4
2011	15	1 692	1 001	185	9	0	10
2012	0	1 346	1 229	195	13	0	0
2013	8	1 027	1 259	319	33	0	4
2014	4	852	1 239	212	15	0	0
2015	0	467	1 214	540	12	0	0
2016	23	759	1 376	520	25	0	3
2017	4	587	1 362	447	21	0	0
2018	0	706	1 405	474	23	3	0
2019	4	500	1 542	197	29	1	0
2020	7	465	1 535	198	43	0	1
2021	5	409	1 085	339	9	4	1
2022	41	233	1 007	143	0	0	1
2023	0	474	1 087	211	10	2	5

The closest correspondence between the leatherback bycatch hotspot and fishery catches is fisheries that reported targeting bigeye tuna (Table 3-14). This fishery started in more northern waters in spring (September), extending south to the southeast North Island coast in summer (January/February) but with the peak remaining at about 37°–38° S, and retreated northwards again as winter (~June) approached. The catch rates for bigeye tended to be similar throughout the season (Table 3-5). Of the bigeye tuna catch, 24.4% has been taken in the leatherback hotspot region and season.

The fishery for swordfish follows a similar pattern to bigeye but extended further south and later into the year (Table 3-6), with relatively high catch rates around 37°–38° S from January to April, extending south to 38°–39° S from March until June (Table 3-7). The extension south resulted in a reduced overlap with leatherbacks, with 17.9% of swordfish catch in the leatherback hotspot area and season.

Table 3-2: Number of surface longline fishing events by latitude and month for 2008–2023. Latitudes are floored, so a latitude of 38°S means >37°S to 38°S. Darker shading of cells indicates higher values. No. vessels, the number of vessels using surface longline at least once during the fishing years 2008–2023.

	Latitude (°S)																				
Month	**49**	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**40**	**39**	**38**	**37**	**36**	**35**	**34**	**33**	**32**	**31**	**30**	**No. vessels**
10												3	15	21	100	164	35	33	16	9	48
11	3	12		3	2		1					43	68	177	513	133	21	7	1		59
12	1	10	33	7	2		3		2	3	17	332	396	264	219	48	14	1			71
1		22	11	19	NA	1	4	8	55	121	142	745	385	258	322	41	15				85
2	11	64	151	58	1	10	38	22	170	245	360	617	341	303	375	100	15				91
3	2	100	202	193	16	75	311	254	182	385	776	632	366	331	450	251					92
4		9	142	412	70	209	517	193	155	392	461	542	354	345	397	281	9				86
5			3	466	475	364	738	271	333	875	696	509	201	216	246	205	49	3	1		78
6				9	102	232	930	370	111	777	903	1 017	534	104	186	163	35	4			55
7						6	554	384	57	55	270	888	1 330	474	301	379	135	14	1	3	29
8						4	178	327	26	5	18	324	737	524	662	518	265	106	3		33
9							2	11	3	7	7	31	95	118	363	280	144	70	11	5	34
No. vessels	5	12	17	23	29	36	52	48	63	70	72	81	82	75	71	64	52	27	9	1	

Table 3-3: Number of leatherback turtles reported by latitude and month for 2008–2023. Latitudes are floored, so a latitude of 38°S means >37° S to 38° S. Darker shading of cells indicates higher values. The blue box indicates an area and time of high leatherback reports and includes 63.4% of all reports.

	Latitude (°S)																			
Month	**49**	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**40**	**39**	**38**	**37**	**36**	**35**	**34**	**33**	**32**	**31**	**30**
10												0	0	0	1	0	0	0	0	0
11	0	0		0	0		0					1	0	0	5	1	0	0	0	
12	0	0	0	0	0		0		0	0	0	3	2	2	1	0	0	0		
1		0	0	0		0	0	0	0	1	0	31	9	1	3	0	0			
2	0	0	0	0	0	0	1	0	0	1	1	21	14	4	1	0	0			
3	0	0	0	0	0	1	1	0	0	0	5	34	9	7	0	0				
4		0	0	0	0	0	1	2	0	1	2	20	11	2	2	1	0			
5			0	0	0	0	1	0	0	2	3	4	2	4	1	2	1	0	0	
6				0	0	0	1	0	0	0	0	5	0	1	0	0	0	0		
7						0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
8						0	0	0	0	0	0	1	0	0	1	0	1	0	0	
9							0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 3-4: Estimated catch (t) of bigeye tuna by surface longline by latitude and month for 2008–2023. Latitudes are floored, so a latitude of 38°S means >37° S to 38° S. Darker shading of cells indicates higher values. The blue box indicates an area and time of high leatherback reports (see Table 3-3) and includes 24.4% of all bigeye catches.

	Latitude																			
Month	**49**	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**40**	**39**	**38**	**37**	**36**	**35**	**34**	**33**	**32**	**31**	**30**
10												0	1.1	1.5	12.2	17.1	5.2	4.9	2.0	1.2
11	0	0		0	0		0					6.1	3.7	20.8	76.5	13.2	1.4	0.1	0	
12	0	0	0	0	0		0		0	0	0.4	45.2	34.7	24.1	22.6	4.1	0.1	0.1		
1		0	0	0		0	0	0	17.2	15.8	15.1	70.3	33.0	25.8	32.7	2.4	0.2			
2	0	0	0	0	0	0	0	0.3	6.2	9.9	18.1	63.6	39.7	36.5	47.3	15.0	0.4			
3	0	0	0	0	0	0	0	0.1	2.9	22.4	43.2	76.6	33.9	44.7	69.6	34.2				
4		0	0	0.1	0	0	0	0	2.3	19.1	30.9	57.7	26.0	25.7	50.6	35.1	0.1			
5			0	0	0	0	0.3	0.1	2.1	12.7	13.2	24.6	7.2	10.2	14.8	14.5	0.8	0.1	0	
6				0	0	0	0	0	0.2	1.8	2.0	16.5	9.6	4.5	15.3	25.6	6.6	0		
7						0	0	0	0	0	0.7	5.1	9.5	11.4	19.1	47.4	17.8	0.9	0.3	0.2
8						0	0	0	0	0	0	1.7	13.4	18.3	40.1	35.6	27.6	12.4	0.5	
9							0	0	0	0	0	0.3	5.8	13.9	39.9	17.7	11.7	9.3	2.8	1.8

Table 3-5: Estimated catch rate (t per 1000 hooks) of bigeye tuna by surface longline, where the reported target species is bigeye tuna, by latitude and month for 2008–2023. Latitudes are floored, so a latitude of 38°S means >37° S to 38° S. Darker shading of cells indicates higher values. The blue box indicates an area and time of high leatherback reports (see Table 3-3).

	Latitude																			
Month	**49**	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**40**	**39**	**38**	**37**	**36**	**35**	**34**	**33**	**32**	**31**	**30**
10													0		0	0.04	0	0.1		
11														0		0	0.03	0	0	
12											0	0.07	0.08	0.04	0.08	0.05	0			
1								0	0.01	0.01	0.07	0.08	0.07	0.12	0.16	0.05	0			
2						0	0	0	0	0.01	0.05	0.09	0.07	0.07	0.12	0.22	0.1			
3						0	0	0	0	0.02	0.02	0.09	0.05	0.05	0.11	0.13				
4						0	0	0	0.01	0.03	0.02	0.06	0.03	0.05	0.13	0.06	0.01			
5						0	0	0	0	0.01	0.01	0.03	0.03	0.06	0.04	0.04	0.01	0.03		
6						0	0	0	0	0	0	0.01	0	0.04	0.05	0.11	0.05	0		
7							0	0			0	0.02	0	0.05	0.03	0.12	0.07	0.03	0.25	0.08
8							0	0	0					0.09	0.04	0.02	0.03	0	0.15	
9														0	0.03	0.04	0.05	0.2	0.22	0.11

Table 3-6: Estimated catch (t) of swordfish by surface longline by latitude and month for 2008–2023. Latitudes are floored, so a latitude of 38° S means >37° S to 38° S. Darker shading of cells indicates higher values. The blue box indicates an area and time of high leatherback reports (see Table 3-3) and includes 17.9% of all swordfish catches.

	Latitude																			
Month	**49**	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**40**	**39**	**38**	**37**	**36**	**35**	**34**	**33**	**32**	**31**	**30**
10												0	0.3	0.2	6.0	11.3	3.4	3.9	3.8	2.1
11	0	0		0	0		0					1.7	2.0	11.7	25.8	9.6	2.0	1.5	0.5	
12	0	0	0	0	0		0		0	0	0.5	31.6	45.6	33.4	14.4	8.3	7.3	0.8		
1		0	0	0		0.3	0.2	0.3	7.5	12	14.0	193.0	97.7	77.4	71.8	7.5	8.6			
2	0	0	0	0	0	0.8	10.6	5.9	50.2	89.9	86.5	182.0	104.0	111.0	105.0	24.0	5.1			
3	0	0	0	0	1.0	14.2	113.0	130.0	76.5	122.0	262.0	214.0	137.0	109.0	102.0	95.3				
4		0	0	0.4	4.3	33.0	115.0	56.7	45.7	109.0	144.0	159.0	93.9	135.0	94.1	94.8	8.2			
5			0	2.1	7.3	29.2	117.0	83.6	42.3	137.0	191.0	155.0	69.7	83.2	62.4	63.3	30.9	4.4	0.2	
6				0	0.4	13.3	63.0	41.2	13.3	114.0	166.0	122.0	59.1	33.1	63.7	27.5	6.9	0.6		
7						0.3	17.7	19.6	1.4	5.7	36.8	58.9	84.6	61.0	63.0	58.7	26.3	1.8	0.5	1.2
8						0	2.8	7.4	1.1	0.4	1.7	13	23.9	55.2	84.8	54.9	32.2	18.7	1.3	
9							0	0	0	0	0	2	2.9	3.0	19.8	20.7	17.5	10.0	4.1	1.0

Table 3-7: Estimated catch rate (t per 1000 hooks) of swordfish by surface longline, where the reported target species is swordfish, by latitude and month for 2008–2023. Latitudes are floored, so a latitude of 38°S means >37° S to 38° S. Darker shading of cells indicates higher values. The blue box indicates an area and time of high leatherback reports (see Table 3-3).

	Latitude																			
Month	**49**	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**40**	**39**	**38**	**37**	**36**	**35**	**34**	**33**	**32**	**31**	**30**
10													0		0	0.24	0	0.15		
11														0.2		0.08	0.21	0.32	0.45	
12											0	0.23	0.25	0.54	0.16	0.45	0.56			
1								0	0.06	0.05	0.17	0.47	0.44	0.49	0.41	0.35	0.68			
2						0.16	0.29	0.31	0.56	0.6	0.41	0.39	0.4	0.6	0.52	0.46	0.52			
3						0.36	0.5	0.59	0.55	0.56	0.69	0.54	0.62	0.39	0.5	0.59				
4						0.02	0.45	0.44	0.46	0.68	0.53	0.63	0.6	0.73	0.56	0.57	1.11			
5						0	0.41	0.62	0.37	0.4	0.59	0.81	0.75	0.78	0.6	0.68	0.81	1.38		
6						0	0.37	0.43	0.33	0.65	0.53	0.63	0.55	0.69	1.03	0.43	0.5	0		
7							0	0.19			0.16	0.26	0.31	0.47	0.96	1.17	1.16	0.22	0.42	0.5
8							0.16	0.21	0.02					0.39	0.7	0.73	0.2	0	0.6	
9														0	0	0.49	0.62	0.2	0.39	0.67

Few southern bluefin were caught (0.1% of catch) in the leatherback bycatch hotspot area, and season (Table 3-8) and catch rates there were very low (Table 3-9). The fishery started in summer (February/March), predominantly off the southeast South Island, with some effort off the west coast South Island. Fishing started to move northwards as autumn approached, with some fishing off the southeast North Island from April, and most fishing effort occurring off the west coast South Island in June. By July, fishing was predominantly off the west coast South Island and northeast North Island. The southern bluefin fishery therefore missed the leatherbacks by being further south during the summer, and only in more northern waters in autumn and winter when leatherback captures (and presumably leatherback occurrence) were relatively rare.

Sunfish are thought to often co-occur with leatherbacks, but sunfish bycatch was more similar to swordfish and extended further south than the leatherback turtle hotspot area and season (Table 3-10). Only 12.3% of the sunfish bycatch was taken in the leatherback bycatch hotspot area and season.

Overall, about 32% of the fishing effort (by number of events) in 2023 took place between 36° S and 38° S (Table 3-11) and of this effort, about 39% took place in January to April 2023 (Table 3-12). This meant about an average of 12% of the overall effort took place in the leatherback hotspot area, ranging from 7–15% and without clear trend over the period 2008–2023. The total fishing effort (by number of events) was lower over the last three years, and the number of vessels about half the number of ten years previous (Table 3-11), although for the hotspot latitude effort in 2021 was slightly above average (Table 3-12). The number of vessels also decreased recently with around five ‘core’ vessels dominating the catches from the hotspot region and was lower during the summer months (Table 3-13).

A spatial axis provided an alternative method of viewing the fishery (Figure 3-1–Figure 3-3). The seasonal southerly extension of the fishery around the North Island was apparent, and although some fishing remained in the leatherback bycatch hotspot area throughout the year, there have been numerous other fishing locations in each month. The importance of more northerly fishing grounds seemed to have declined a little over time, and effort was most pronounced in the hotspot between 2015 and 2019. When viewed in this way, the peak of leatherback captures in 2021 was not associated with a clear change in spatial distribution of effort around the North Island. However, the percentage of the overall number of fishing events occurring off the North Island was relatively high in 2021 and reached a time-series peak for 37–38°S (at 24% of events; average 15%; see latitude labelled “38” in Table 3-11).

Table 3-8: Estimated catch (t) of southern bluefin tuna by surface longline by latitude and month for 2008–2023. Latitudes are floored, so a latitude of 38° S means >37° S to 38° S. Darker shading of cells indicates higher values. The blue box indicates an area and time of high leatherback reports (see Table 3-3) and includes 0.1% of all southern bluefin tuna catches.

	Latitude																			
Month	**49**	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**40**	**39**	**38**	**37**	**36**	**35**	**34**	**33**	**32**	**31**	**30**
10												0	0.5	0.1	1.2	2.4	0.2	1.4	0	0.1
11	0.3	0.5		0.1	0		0					0.3	0.3	1.8	3.1	0.5	0	0	0	
12	0	0.4	1.5	0	0		0		0	0	0	0.5	1.4	0.6	0.5	0	0	0		
1		1.8	0.2	1.8		0	0.2	0.3	0.1	0.5	0.1	2.4	0.8	0.3	0.7	0	0			
2	2.8	33.4	52.4	13.6	0.1	1.7	3.1	1.3	0.6	2.2	0.1	0.5	0.2	0.1	0.6	0	0			
3	1.5	89.7	142	94.8	12.8	28.0	74.6	54.1	12.4	0.3	0.8	1.7	1.2	1.8	0.5	0.6				
4		7.9	70.7	273	58.9	137.0	242.0	59.2	16.1	11.8	8.3	5.9	1.1	1.0	1.4	0.2	0			
5			1.4	444	470.0	303.0	321.0	62.8	66.5	201.0	134.0	32.0	10.6	3.5	1.8	0.5	0	0	1.1	
6				2.4	86.4	189.0	601.0	210.0	83.2	381.0	372.0	449.0	174.0	10.6	10.4	7.2	0.4	0		
7						3.7	487.0	349.0	53.4	18.5	153.0	602.0	777.0	200.0	111.0	96.0	23.0	0.6	0	0
8						0.8	104.0	205.0	6.9	0.3	2.3	202.0	382.0	160.0	110.0	106.0	56.4	17.0	0	
9							0.5	3.4	0.3	1.9	1.3	9.0	18.0	23.5	32.3	21.4	9.2	1.3	0.1	0.2

Table 3-9: Estimated catch rate (t per 1000 hooks) of southern bluefin tuna by surface longline, where the reported target species is southern bluefin tuna, by latitude and month for 2008–2023. Latitudes are floored, so a latitude of 38° S means >37° S to 38° S. Darker shading of cells indicates higher values. The blue box indicates an area and time of high leatherback reports (see Table 3-3).

	Latitude																			
Month	**49**	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**40**	**39**	**38**	**37**	**36**	**35**	**34**	**33**	**32**	**31**	**30**
10												0	0.14	0	0.03	0	NA	0	0	
11	0.1	0.04										0		0	0.01	0	0			
12	0	0.04	0.05	0					0	0	0	0	0	0	0	0				
1		0.08	0.02	0.09			0.05	0.08	0	0	0.01	0.03	0							
2	0.29	0.53	0.36	0.25	0.25	0.36	0.15	0.19	0.03	0	0	0								
3	0.65	0.84	0.75	0.54	0.83	0.38	0.32	0.36	0.28	0	0	0	0	0.36	0	0				
4		0.92	0.53	0.66	0.34	0.67	0.49	0.38	0.14	0.07	0.07	0.03	0	0	0					
5			0.18	0.45	0.37	0.37	0.34	0.25	0.22	0.26	0.27	0.14	0.12	0.02	0.4				1.1	
6				0.29	0.37	0.38	0.45	0.42	0.55	0.54	0.46	0.51	0.38	0.25	0.09					
7						0.8	0.87	0.95	0.91	0.43	0.61	0.76	0.65	0.46	0.57	1.21	0.68			
8						0.62	0.63	0.63	0.3	0.06	0.14	0.73	0.63	0.38	0.28	0.4	0.61	0.57	0	
9							0.31	0.33	0.15	0.28	0.2	0.34	0.2	0.31	0.14	0.2	0.21	0.23		

Table 3-10: Estimated catch (t) of sunfish as a bycatch in surface longline by latitude and month for 2008–2023. Latitudes are floored, so a latitude of 38° S means >37° S to 38° S. Darker shading of cells indicates higher values. The blue box indicates an area and time of high leatherback reports (see Table 3-3) and includes 12.3% of all sunfish catches.

	Latitude																			
Month	**49**	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**40**	**39**	**38**	**37**	**36**	**35**	**34**	**33**	**32**	**31**	**30**
10												0	1.3	1.2	14	13.5	2.5	2.8	1.3	1.3
11	0	0		0	0		0					0.2	1.2	15.7	80.2	17.4	1.4	0.1	0	
12	0	0	0	0	0		0		0	0	0.2	18.1	26.5	30.0	18.4	1.7	0.7	0		
1		0	0	0		0	0	0	0.3	3.6	6.2	44.0	31.1	17.2	21.5	0.9	0.3			
2	0	0	0	0	0	0.1	2.3	3.4	7.3	22.9	32.5	32.8	21.3	17.0	27.5	5.8	0.2			
3	0	0	0	0	0.3	3.4	18.2	20.2	18.8	64.6	98.2	49.0	27.4	17.2	26.3	9.2				
4		0	0	0	0.6	6.6	16.2	13.5	10.0	74.3	54.8	32.5	29.2	36.9	24.2	10.7	0			
5			0	1.0	2.7	2.4	6.7	3.7	13.9	67.4	43.9	33.1	14.6	34.1	23.2	10.7	1.4	0	0	
6				0	0.3	0.8	4.4	1.5	2.0	20.8	22.4	51.1	25.5	4.5	30.3	16.9	6.0	0		
7						0	0.8	1.2	0.7	0.6	2.1	17.7	43.1	30.1	30.1	53.9	18.7	1.6	0	0
8						0	0.3	0.7	0	0.1	0.4	3.8	26.0	15.2	55.2	72.4	33.2	13.3	0	
9							0	0	0	0	0	0.7	6.3	7.7	27.6	39.1	13.3	7.2	0.2	0

Table 3-11: Number of surface longline fishing events by latitude and fishing year for 2008–2023. Fishing years labelled by year ending. Latitudes are floored, so a latitude of 38° S means >37° S to 38° S. Darker shading of cells indicates higher values. No. vessels, the number of vessels using surface longline at least once.

	Latitude																					
Fishing year	**49**	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**40**	**39**	**38**	**37**	**36**	**35**	**34**	**33**	**32**	**31**	**30**	**Total**	**No. vessels**
2008				69	93	28	33	39	10	105	243	368	226	106	326	242	47	21			1 956	37
2009				30	87	65	110	78	55	122	315	382	320	260	357	358	57	23	8	4	2 631	39
2010				49	91	10	165	67	120	304	504	281	395	302	298	192	45	11	4	2	2 840	42
2011				40	80	29	95	38	101	269	352	343	258	389	472	164	210	65	7		2 912	42
2012				16	53	78	310	188	96	299	160	227	339	224	320	293	128	46	5	1	2 783	44
2013			2	13	42	115	332	86	55	223	328	280	286	399	246	190	36	16			2 649	40
2014				6	21	92	324	188	74	223	170	203	304	308	137	234	29	9			2 322	39
2015				17	7	66	213	225	141	129	105	298	490	196	205	105	30	6			2 233	34
2016					5	60	283	198	73	218	280	423	527	189	287	145	13		1		2 702	33
2017					11	151	287	84	40	242	141	367	324	186	409	135	40	3	1		2 421	32
2018				48	22	56	162	148	65	194	228	495	368	213	381	185	33	2	4	7	2 611	34
2019		16	88	154	17	102	207	110	95	144	190	469	290	76	193	76	35	3			2 265	30
2020	4	62	167	141	26	25	306	92	32	159	228	434	157	79	216	86	17	17	1		2 249	28
2021	3	3	67	199	1	8	135	104	32	85	178	433	242	86	159	82	5	10			1 832	28
2022		63	72	175	27	1	224	79	27	76	117	275	136	46	63	40	1	1	1		1 424	24
2023	10	73	146	210	85	15	90	116	78	73	111	405	160	76	65	36	11	5	1	3	1 769	20

Table 3-12: Number of surface longline fishing events by month and fishing year (2008–2023), for the two degrees of latitude 36° S to 38° S (categories labelled 37 and 38 in the previous tables). Fishing years labelled by year ending. Darker shading of cells indicates higher values.

	Month												
Fishing year	**10**	**11**	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Total**
2008			41	86	93	47	59	58	62	141	6		593
2009		1	51	58	40	29	49	100	249	120	1		698
2010	3	5	68	71	58	50	76	26	111	188	13	1	670
2011		13	66	131	61	54	62	48	79	73	5	1	593
2012		3	31	70	103	100	46	25	71	96	20		565
2013		9	37	74	87	110	26	25	26	159	3	1	557
2014		1	36	66	51	67	51	16	8	148	59	2	505
2015			50	87	71	72	37	55	73	215	117	7	784
2016		5	68	102	81	90	91	41	113	117	197	39	944
2017	7	1	49	38	8	34	71	53	126	169	118	17	691
2018	1	5	47	75	72	86	38	41	173	213	96	12	859
2019		10	66	71	35	61	58	23	166	199	52	13	754
2020	4	11	29	41	47	20	55	68	110	84	108	14	591
2021		16	40	79	64	44	79	46	79	113	112	3	675
2022		7	9	46	43	35	33	7	54	84	84	9	411
2023	2	24	40	32	42	85	60	65	44	94	70	7	565

Table 3-13: Number of vessels fishing using surface longlines by month and fishing year (2008–2023), for the two degrees of latitude 36° S to 38° S (categories labelled 37 and 38 in the previous tables). Fishing years labelled by year ending. Darker shading of cells indicates higher values. No. vessels, the number of vessels using surface longline at least once. No. vessels 75% (90%), the number of vessels accounting for at least 75% (90%) of the reported catch summed for all species.

	Month														
Fishing year	**10**	**11**	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**No. vessels**	**No. vessels 75%**	**No. vessels 90%**
2008			6	8	9	9	11	10	18	23	4		17	6	10
2009		1	8	9	5	6	9	17	22	22	1		15	5	8
2010	2	3	7	8	10	9	11	8	22	26	6	1	17	6	9
2011		1	12	13	14	11	14	13	15	19	4	1	23	8	12
2012		2	6	9	12	12	9	7	17	17	7		18	7	10
2013		4	6	9	13	12	9	8	10	22	3	1	19	7	10
2014		1	6	7	5	11	10	5	4	19	14	1	13	6	9
2015			6	7	9	8	7	12	13	19	17	2	11	5	7
2016		2	6	7	10	10	12	6	14	19	20	13	18	5	8
2017	1	1	6	5	4	6	9	8	16	21	16	4	12	6	8
2018	1	1	8	8	11	11	6	12	22	23	17	2	19	7	13
2019		3	10	9	4	6	6	5	21	19	14	2	12	3	5
2020	1	3	6	5	5	4	8	11	14	17	13	4	10	4	5
2021		2	5	9	7	3	11	10	14	13	13	2	16	5	10
2022		2	4	6	5	4	5	3	11	12	10	2	9	3	5
2023	1	2	5	8	6	9	8	7	8	12	9	2	14	5	8

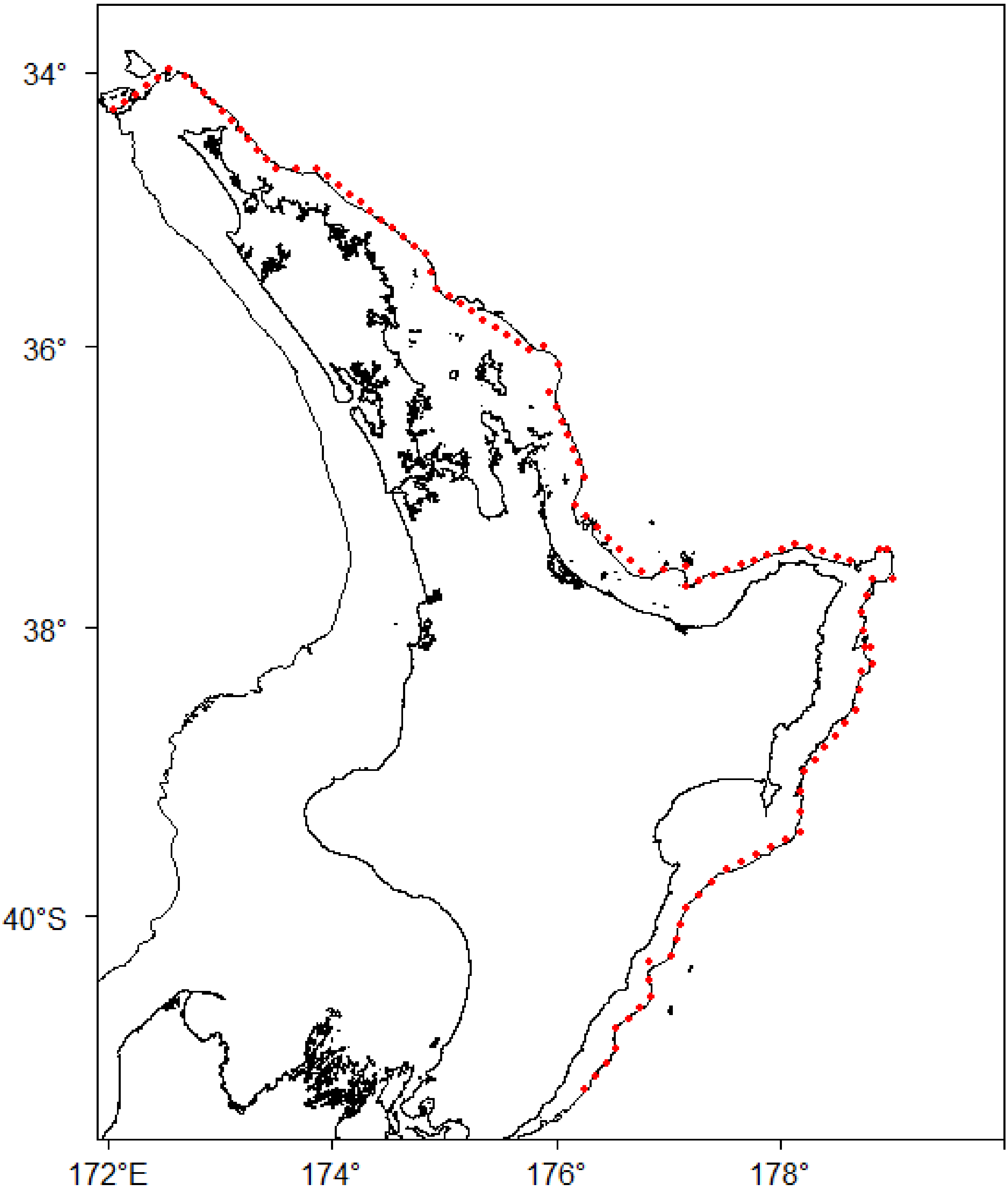

Figure 3-1: The 200 m isobath (black line) and the location of axis positions roughly following the 200 m isobath (red points, regular positions on lines drawn by hand following the isobath) around the east coast of the North Island.

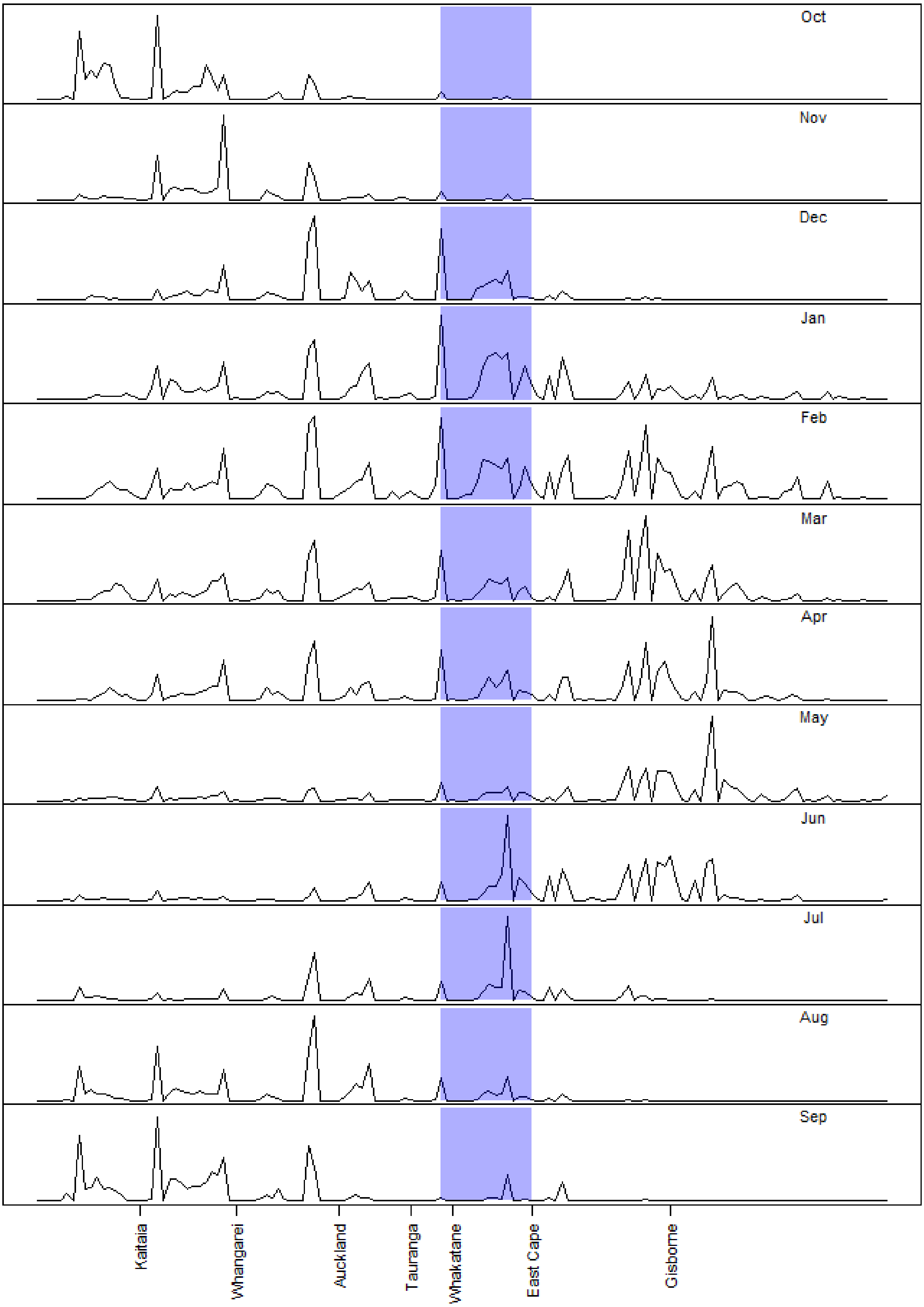

Figure 3-2: The relative distribution of surface longline fishing events as allocated to the nearest axis position (see Figure 3-1), by month, summed for all fishing years (2008–2023). The leatherback bycatch hotspot is indicated by the purple stripe.

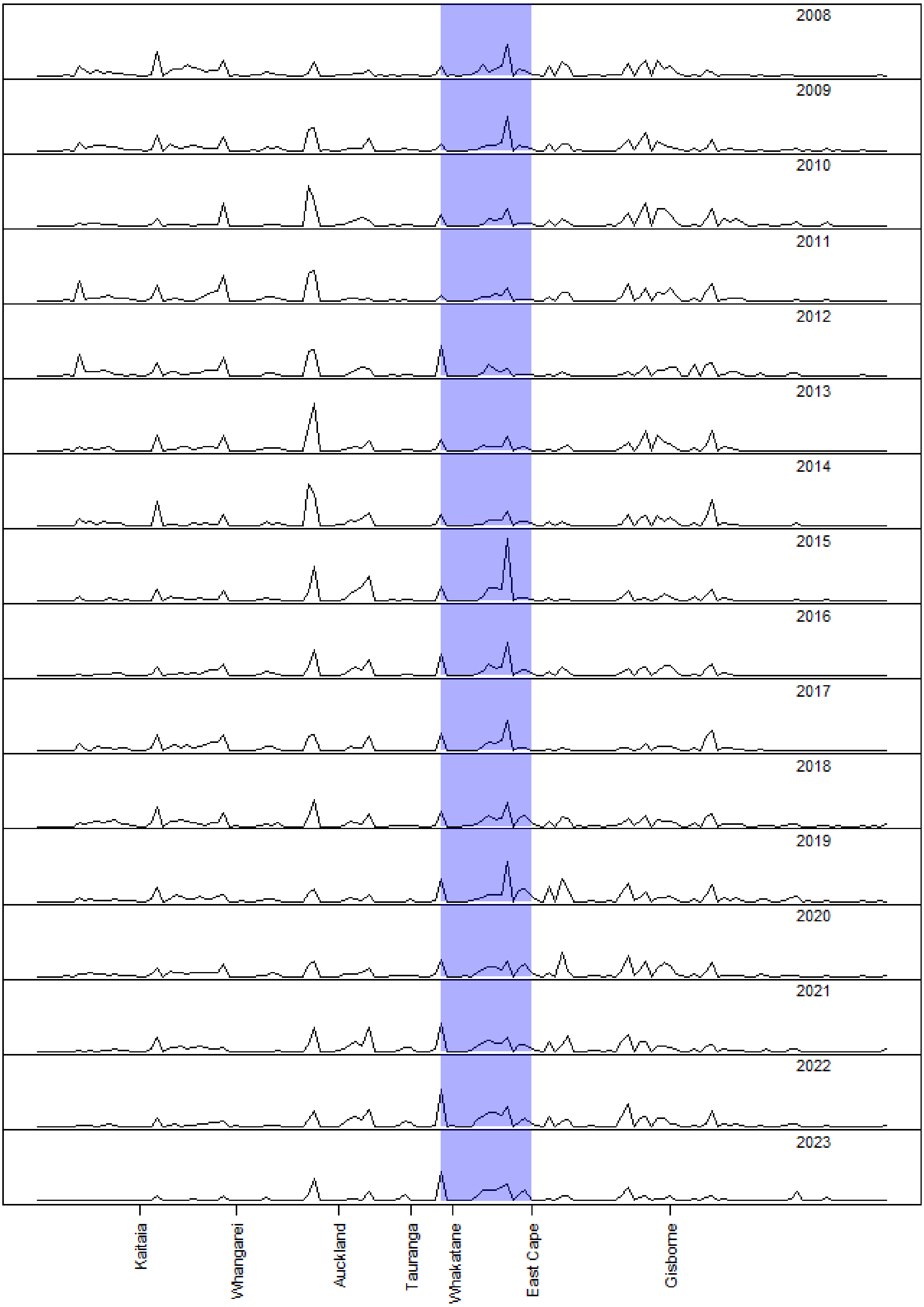

Figure 3-3: The relative distribution of surface longline fishing events by fishing year (2008–2023) as allocated to the nearest axis position (see Figure 3-1). The leatherback hotspot is indicated by the purple stripe.

The cluster analysis on the leatherback bycatch using latitude, longitude, depth, and season, identified eight terminal groups. The groups were first split by season (split at day of year 117.5). Within 1 January to 28 April, the observations were then split by latitude and longitude, with the highest probability of capture in the coastal waters east of Great Barrier Island and Coromandel (south of 35.725 S and west of 176.333° E; 0.170 leatherbacks per 1000 hooks), with the next highest probability of capture in the southern Bay of Plenty (south of 37.264° S and 176.333–178.503° E; 0.095 leatherbacks per 1000 hooks), followed by the central Bay of Plenty (east of 176.333°E and north of 37.264° S; 0.040 leatherbacks per 1000 hooks), then east of East Cape (37.264–38.325° S and east of 178.503° E; 0.022 leatherbacks per 1000 hooks) (Figure 3-4). The next highest probability of capture was inshore (depth <1615 m) between 29 April and 31 December (0.018 leatherbacks per 1000 hooks; Figure 3-4).

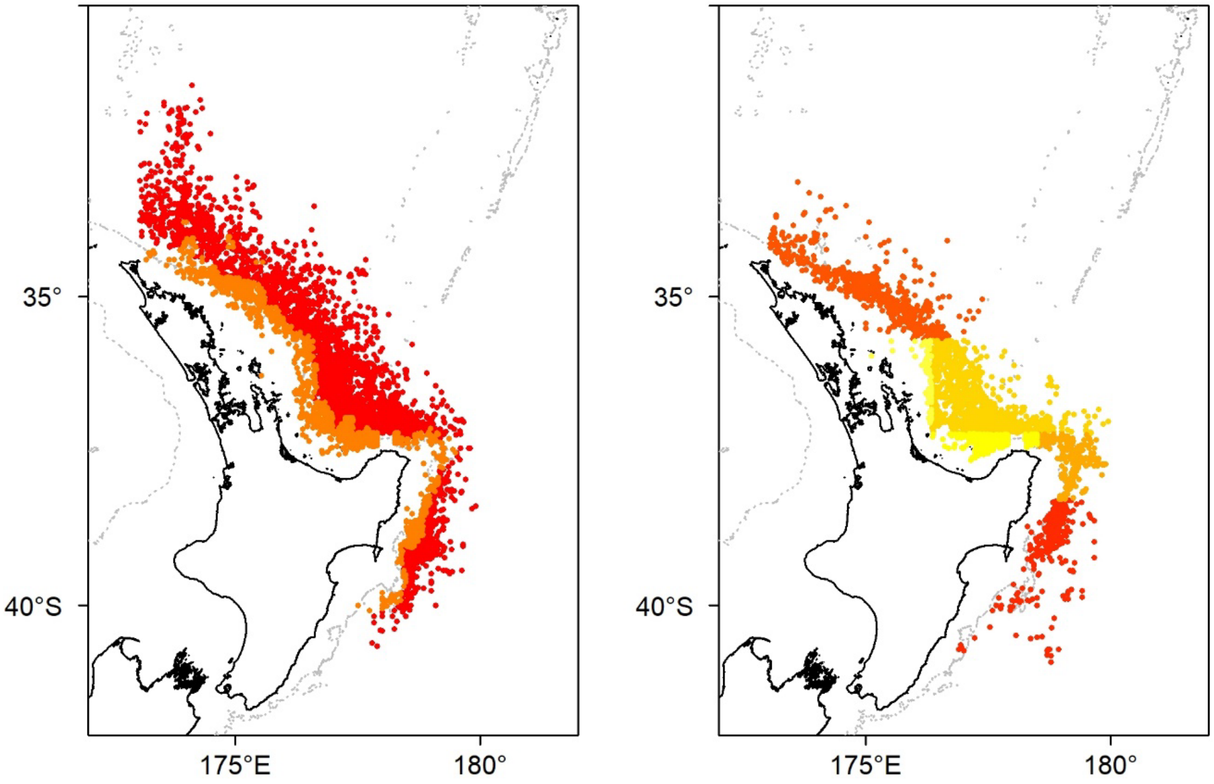

Figure 3-4: Leatherback capture in 0.1° latitude and longitude cells from cluster analyses. Left panel, 29 April to 31 December. Right panel, 1 January to 28 April. Cells are shaded using heat colours to show the probability of leatherback captures (lowest is dark red, highest is bright yellow).

3.2 Clustering of the surface longline fishery

Clustering groups together records (surface longline fishing events) that had a similar composition of catch weight by species. The optimal number of clusters (*k*) selected by CLARA was three (Figure 3-5). Results are presented for three clusters (Section 3.2.1) and six clusters (Section 3.2.2, as the best option for a more resolved/detailed clustering).

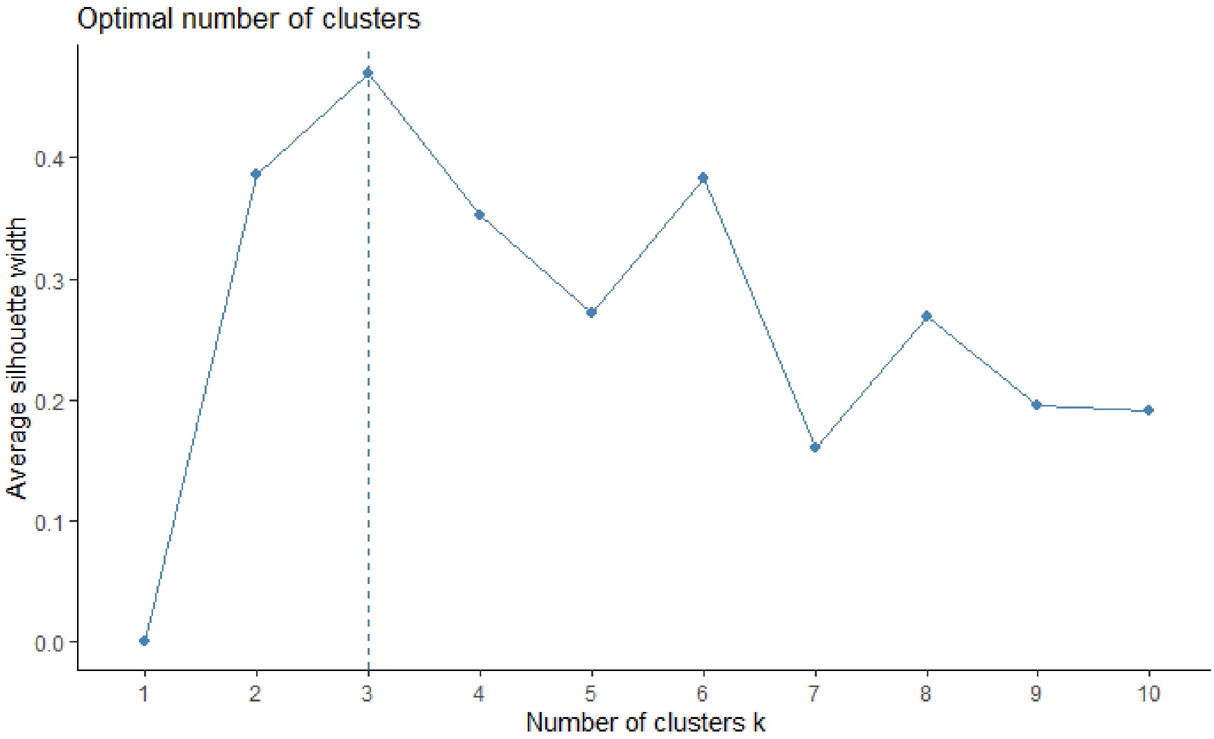

Figure 3-5: Average silhouette (quality of clustering) by number of assumed clusters. The vertical broken line indicates the optimal number of clusters.

Three clusters

The overlap between the top three clusters was substantial (Figure 3-6), indicating there was considerable overlap in catch composition between the clusters. The depth distributions of the three clusters were similar (between 510 and 532 m), but the SST in Cluster 3 was the coolest at 15.4°C, compared to 17.1° and 18.7°C (Table 3-14).

Cluster 1 targeted primarily bigeye tuna, then southern bluefin tuna (Table 3-14), but most catch and the highest catch rate was of swordfish, followed by blue shark, southern bluefin tuna, albacore, and bigeye tuna (Table 3-15). This fishery was relatively prolonged in seasonal duration, effort was centred in March (Table 3-16) and in the warmest water (Table 3-14). Effort declined over time, but this fishery remained the largest of all the clusters (Table 3-17). Cluster 1 was located of the east North Island, notably in the Bay of Plenty (especially in 2021), west coast South Island, and southeast South Island (especially in 2023) (Figure 3-7). Cluster 1 caught the greatest number of leatherbacks (n=212), with 0.82 leatherback per 100 events or 0.90 leatherbacks per 100 000 hooks (Table 3-18).

Cluster 2 occurred later in the year than Cluster 1, with effort peaking in May (Table 3-16) and in slightly warmer SST (Table 3-14). The Cluster 2 fishery targeted southern bluefin tuna and some bigeye tuna (Table 3-14), but caught similar amounts of swordfish as bluefin, relatively little bigeye, and predominantly blue shark (Table 3-15). Effort decreased considerably since 2020 and was almost absent in 2023 (Table 3-17). Cluster 2 was located mostly on the east coast North Island, and primarily on the west coast South Island in more recent years (Figure 3-8). This fishery caught 22 leatherbacks, with 0.37 leatherback per 100 events or 0.34 leatherbacks per 100 000 hooks (Table 3-18)

Cluster 3 targeted (Table 3-14) and caught (Table 3-15) predominantly southern bluefin tuna from autumn into winter (Table 3-16). Effort had been steadily increasing to a peak in 2023 (Table 3-17). Cluster 3 was located predominantly off the east coast North Island and west coast South Island (Figure 3-7). This fishery very rarely caught leatherbacks, with only one leatherback reported, and 0.02 leatherback per 100 events or 0.01 leatherbacks per 100 000 hooks (Table 3-18).

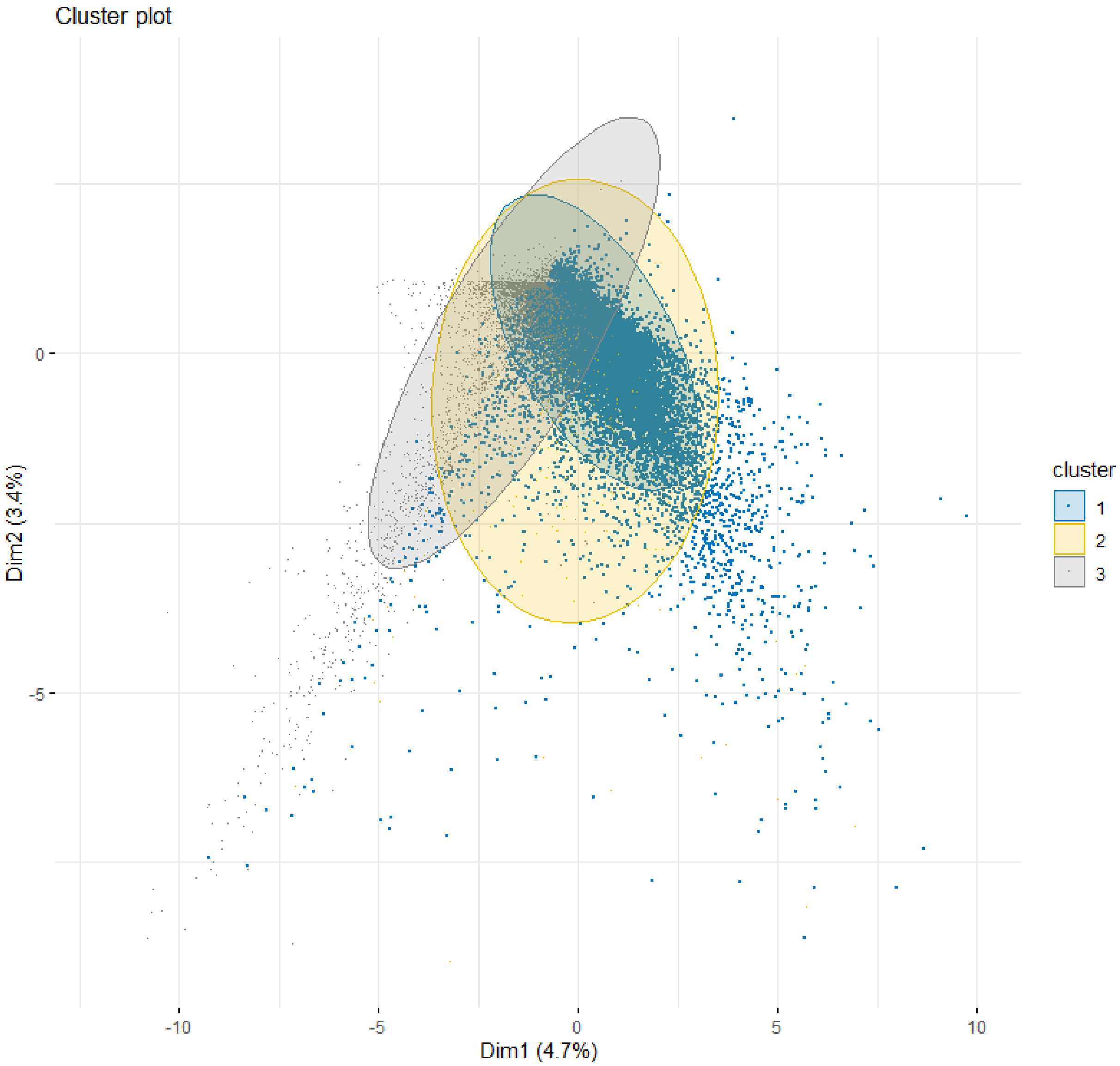

Figure 3-6: Principal components scatter plot with coloured ellipses indicating the location of clusters, plotted for the first two principal dimensions. PCA takes the data set with many variables (here n = 40 species) and reduces them to a smaller set of summary indices (principal components).

Table 3-14: Surface longline number of events by reported target species (2008–2023) and cluster, with mean reported fishing depth and SST (interquartile ranges in parentheses). Species only shown if there was more than one record. Darker shading of cells indicates higher values.

Target species	Cluster 1	Cluster 2	Cluster 3
Shortsnouted lancetfish (ABR)	1	13	0
Albacore tuna (ALB)	112	0	24
Bigeye tuna (BIG)	11 748	1 670	129
Bluenose (BNS)	4	0	0
Blue shark (BWS)	4	0	0
Kingfish (KIN)	3	0	0
Mako (MAK)	4	0	0
Northern bluefin tuna (NTU)	27	0	0
Striped marlin (STM)	2	1	0
Southern bluefin tuna (STN)	10 069	3 589	5 459
Swordfish (SWO)	3 574	663	52
Pacific bluefin tuna (TOR)	248	47	3
Yellowfin tuna (YFN)	16	3	0
Depth (m)	526 (250–718)	510 (185–730)	532 (106–788)
SST (°C)	18.7 (17.0–20.6)	17.1 (15.9–18.3)	15.4 (13.8–16.8)

Table 3-15: Surface longline total catch (2008–2023) and catch rate (t/event) by species (species code) and cluster. Species were included only where catches in at least one cluster were >5t. Darker shading of cells indicates higher values.

	Cluster 1		Cluster 2		Cluster 3	
Species code	Catch (t)	Catch rate (t/event)	Catch (t)	Catch rate (t/event)	Catch (t)	Catch rate (t/event)
Albacore tuna (ALB)	2 106.6	88.9	542.7	85.0	398.9	53.4
Blue marlin (BEM)	8.3	0.4	1.0	0.2	0.0	0.0
Bigeye tuna (BIG)	1 616.8	68.3	220.9	34.6	43.1	5.8
Bigscale pomfret (BSP)	2.9	0.1	6.5	1.0	12.0	1.6
Butterfly tuna (BTU)	62.3	2.6	35.3	5.5	30.8	4.1
Bronze whaler shark (BWH)	13.7	0.6	13.8	2.2	2.8	0.4
Blue shark (BWS)	3 207.9	135.4	6 910.2	1 081.9	1 253.8	167.8
Smoothskin dogfsh (CYO)	1.8	0.1	3.4	0.5	6.5	0.9
Pelagic stingray (DAS)	24.6	1.0	4.7	0.7	0.4	0.1
Dealfish (DEA)	7.3	0.3	18.0	2.8	44.8	6.0
Dolphinfish (DOF)	22.6	1.0	1.9	0.3	0.0	0.0
Lancetfish (LAT)	169.5	7.2	52.3	8.2	3.1	0.4
Escolar (LEP)	97.9	4.1	22.5	3.5	2.3	0.3
Mako (MAK)	703.6	29.7	490.2	76.7	113.6	15.2
Moonfish (MOO)	526.6	22.2	158.4	24.8	66.9	9.0
Oilfish (OFH)	52.2	2.2	21.7	3.4	9.0	1.2
Porae (POR)	13.6	0.6	20.7	3.2	5.7	0.8
Porbeagle (POS)	263.7	11.1	288.6	45.2	124.0	16.6
Rays (RAY)	29.2	1.2	6.6	1.0	0.3	0.0
Rays bream (RBM)	60.4	2.5	28.2	4.4	58.9	7.9
Rudderfish (RUD)	16.8	0.7	5.3	0.8	3.5	0.5
Skipjack tuna (SKJ)	5.9	0.2	1.4	0.2	0.4	0.1
Striped marlin (STM)	270.1	11.4	35.3	5.5	2.7	0.4
Southern bluefin tuna (STN)	2 273.4	96.0	1 099.8	172.2	7 203.1	964.2
Sunfish (SUN)	1 471.1	62.1	601.7	94.2	121.1	16.2
Swordfish (SWO)	5 142.4	217.1	1 099.6	172.2	418.3	56.0
Thresher shark (THR)	231.9	9.8	85.1	13.3	20.9	2.8
Pacific bluefin tuna (TOR)	258.5	10.9	42.0	6.6	68.9	9.2
Yellowfin tuna (YFN)	181.2	7.6	16.5	2.6	0.3	0.0

Table 3-16: Surface longline number of fishing events by month (2008–2023) and cluster. Darker shading of cells indicates higher values.

Month	Cluster 1	Cluster 2	Cluster 3
10	318	77	0
11	821	157	0
12	1 146	180	0
1	2 030	113	1
2	2 660	145	63
3	3 930	264	324
4	3 543	440	505
5	3 275	1 330	1 045
6	2 921	1 142	1 406
7	2 344	866	1 583
8	2 031	949	711
9	795	324	29

Table 3-17: Surface longline number of fishing events by fishing year (year ending) and cluster. Darker shading of cells indicates higher values.

Fishing year	Cluster 1	Cluster 2	Cluster 3
2008	1 509	310	139
2009	2 111	340	179
2010	2 226	422	190
2011	2 237	455	217
2012	1 856	653	272
2013	1 825	538	284
2014	1 397	545	380
2015	1 288	538	407
2016	1 733	568	401
2017	1 544	436	439
2018	1 551	579	476
2019	1 476	363	348
2020	1 633	125	436
2021	1 321	90	418
2022	936	10	478
2023	1 171	15	603

Table 3-18: Surface longline captures of marine reptiles (2008–2023) by species (or species group) and average leatherback (LBT) catch rate (2008–2023) by cluster. The code TLE is a turtle of unknown species. Darker shading of cells indicates higher values.

Species	Cluster 1	Cluster 2	Cluster 3
Banded sea krait (BSS)	0	0	0
Green turtle (GNT)	17	1	1
Hawksbill turtle (HBT)	4	2	1
Leatherback turtle (LBT)	212	22	1
Loggerhead turtle (LHT)	5	0	1
Olive ridley turtle (ORT)	0	0	1
Sea turtle (TLE)	13	3	0
LBT per 100 events	0.82	0.37	0.02
LBT per 100 000 hooks	0.90	0.34	0.01

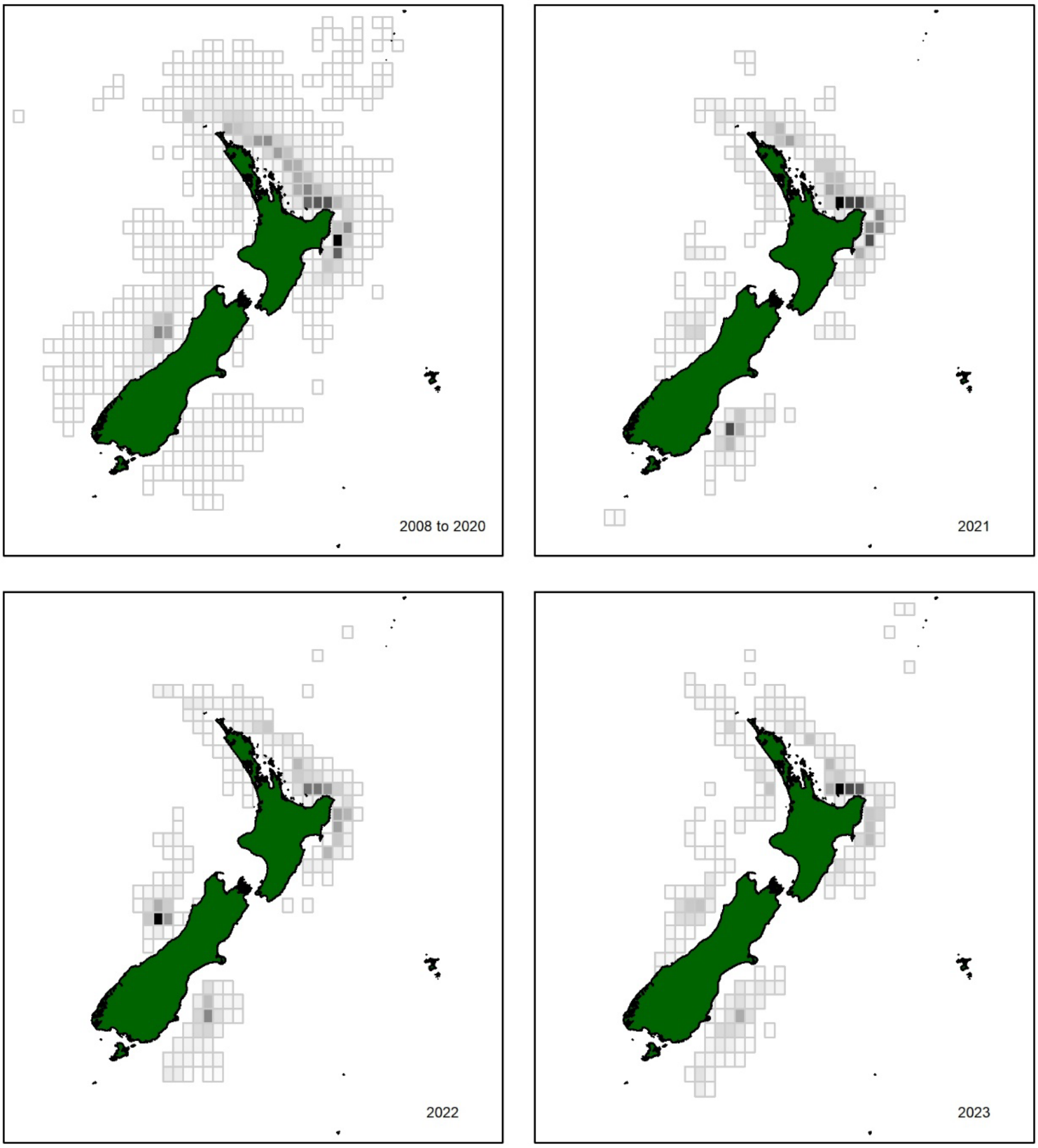

Figure 3-7: Cluster 1; spatial relative distribution of fishing events by 0.5° longitude and latitude cells, by fishing year (labelled year ending) for the last three fishing years (2023, 2022, 2021, and summarised for the years before that, 2008–2020). Darker shading indicates greater fishing effort.

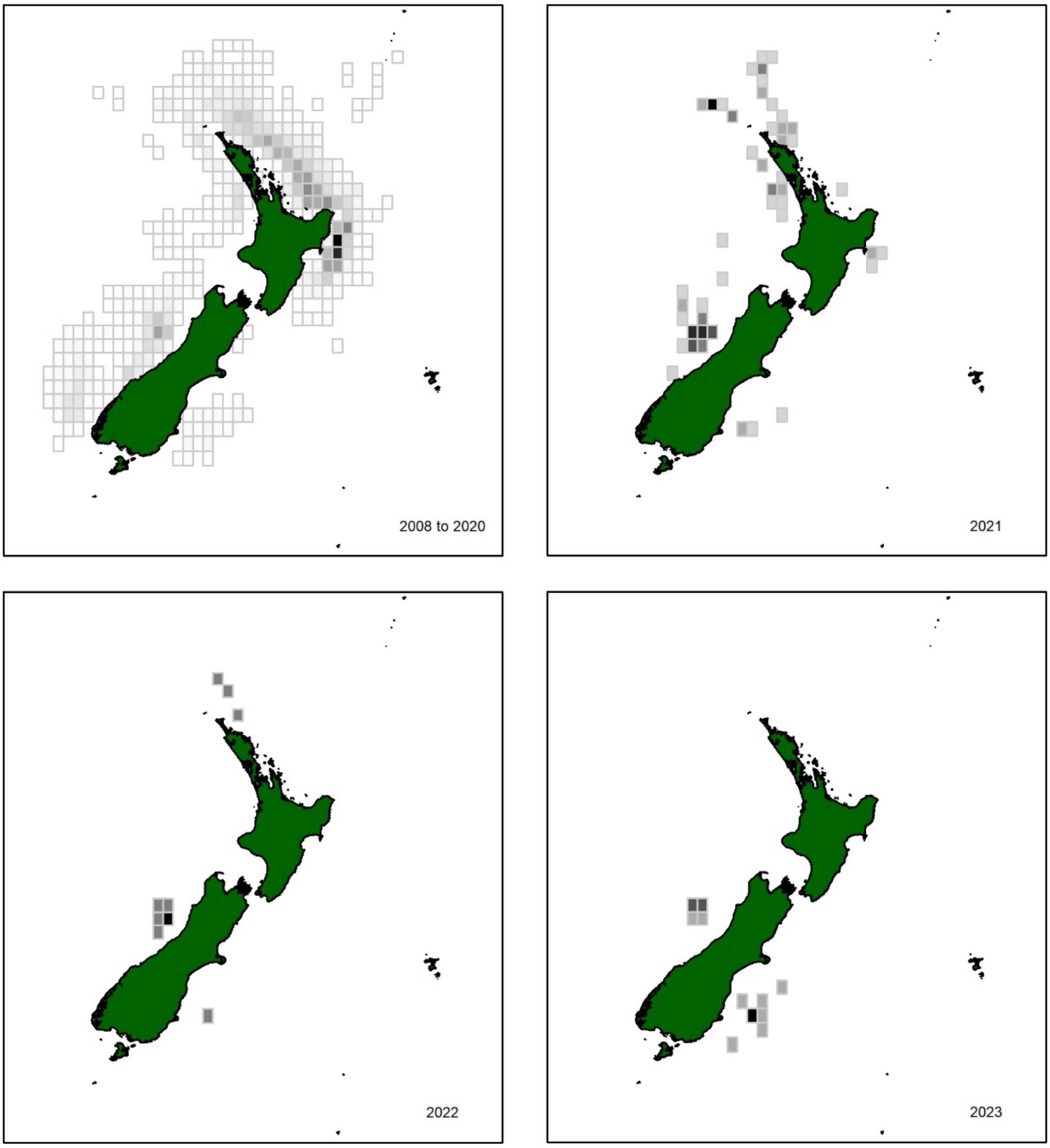

Figure 3-8: Cluster 2; spatial relative distribution of fishing events by 0.5° longitude and latitude cells, by fishing year (labelled year ending), for the last three fishing years (2023, 2022, 2021, and summarised for the years before that, 2008–2020). Darker shading indicates greater fishing effort.

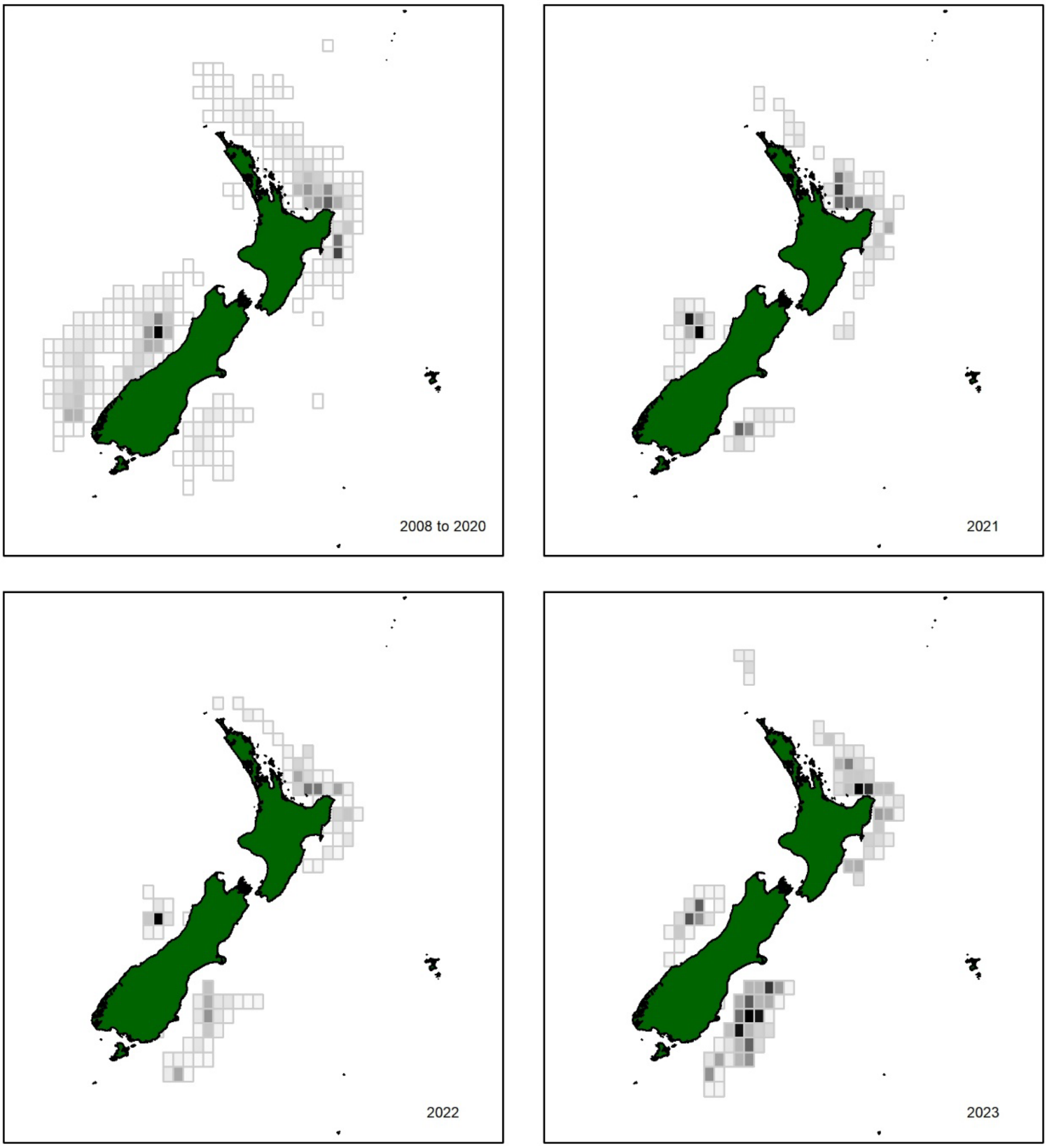

Figure 3-9: Cluster 3; spatial relative distribution of fishing events by 0.5° longitude and latitude cells, by fishing year (labelled year ending), for the last three fishing years (2023, 2022, 2021, and summarised for the years before that, 2008–2020). Darker shading indicates greater fishing effort.

3.2.2 Six clusters

Increasing the number of clusters from three to six provides greater resolution of the fisheries although still with high overlap (Figure 3-10). The higher resolution is mostly in the southern bluefin target fisheries (Table 3-19), although these fisheries captured relatively few leatherbacks (Table 3-20).

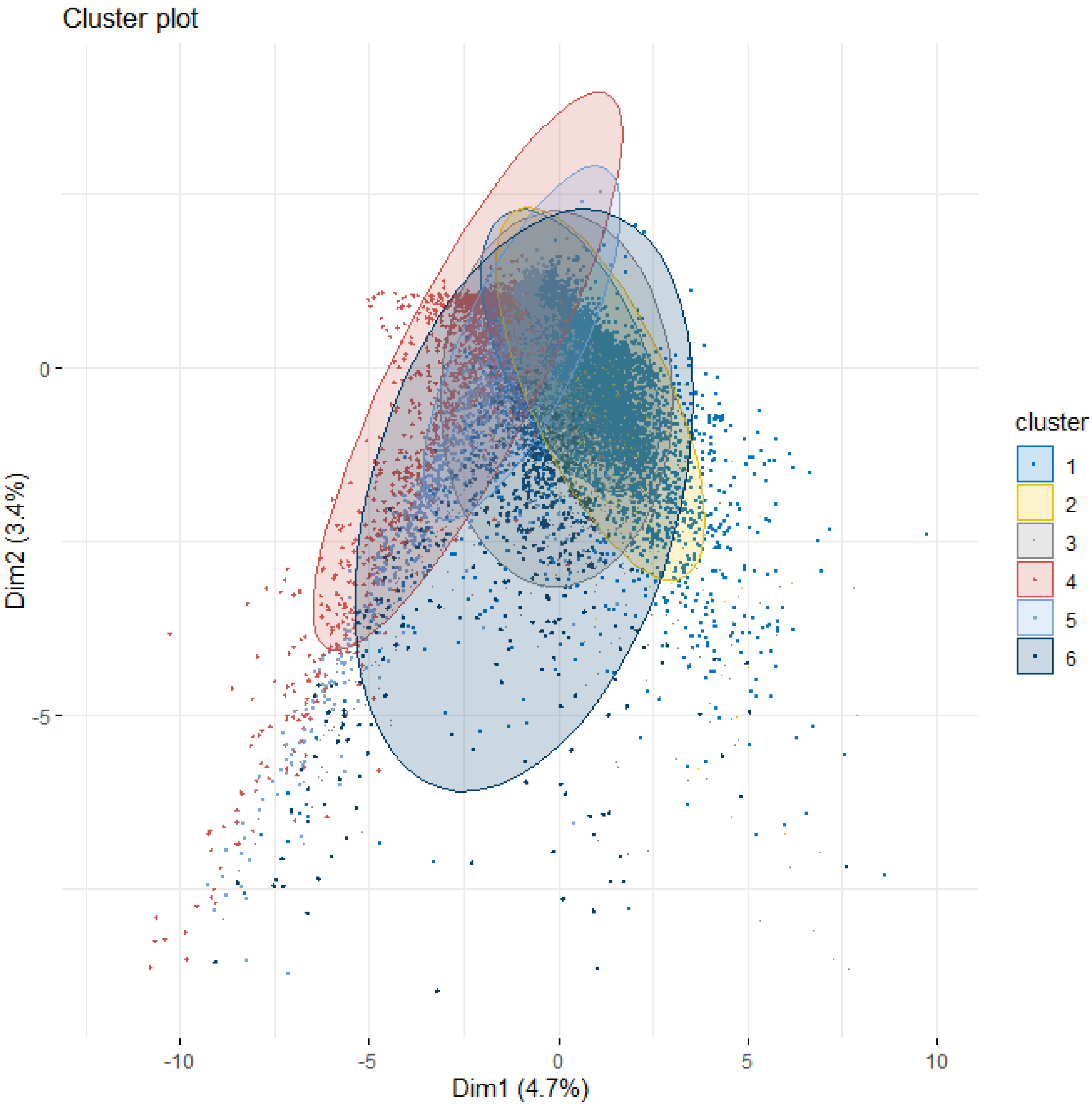

Figure 3-10: Principal components scatter plot with coloured ellipses indicating the location of clusters, plotted for the first two principal dimensions. The reported target species for Cluster 1 was most often bigeye tuna, followed by southern bluefin tuna (Table 3-19). Cluster 1 caught mainly blue shark, followed by swordfish, sunfish, and tunas (Table 3-20), with a relatively wide fishing season peaking between March and June (Table 3-21) and in relatively warm waters (mean SST of 18.6°C, Table 3-19). Effort had declined and been relatively low since 2021 (Table 3-23). Cluster 1 occurred primarily off the east coast North Island, often with high effort in the Bay of Plenty, and some fishing off the west coast South Island (Figure 3-11). Cluster 1 caught the greatest number of leatherbacks (n=138), with 0.76 leatherback per 100 events or 0.85 leatherbacks per 100 000 hooks (Table 3-23).

The reported target species for Cluster 2 was bigeye tuna, followed by swordfish (Table 3-19), but the highest catches, with especially high catch rates, were of swordfish, followed by blue shark, sunfish, and then bigeye tuna (Table 3-20). Cluster 2 fished in the warmest water (mean SST of 19.8 °C, Table 3-19) and peaked around March (Table 3-21). Effort in Cluster 2 was relatively low since 2019, although was higher in 2021 (Table 3-22). Cluster 2 was distributed predominantly off the east coast North Island, with a relative increase in effort around the Bay of Plenty and East Cape in 2021 (Figure 3-12). Cluster 2 had the highest catch rate of leatherbacks across both the three and six cluster analyses (1.35 leatherback per 100 events or 1.27 leatherbacks per 100 000 hooks) but caught fewer (n=76) overall than Cluster 1 (Table 3-23).

Clusters 3, 4, 5, and 6 all primarily targeted southern bluefin tuna, with Clusters 3 and 6 taking place earliest in the season peaking in May (Table 3-21) and catching mostly blue shark (Table 3-20). The main difference between Clusters 3 and 6 seemed to be a greater catch of albacore, bigeye tuna, swordfish, and sunfish in Cluster 3 (Table 3-20). Cluster 5 peaked later in June and July and caught less blue shark and more southern bluefin tuna, followed by Cluster 4 peaking latest in the year, in July, catching largely southern bluefin, with few blue shark (Table 3-20 and 3.2.8). Fishing effort in Clusters 3 and 6 declined over time and was absent in 2023, while effort in Cluster 5 remained relatively high since around 2015, and effort in Cluster 4 started to increase since 2014 (Table 3-22).

Cluster 3 largely occurred off the east coast North Island and the southwest corner of the South Island (Figure 3-13). Clusters 4 and 5 had similar distributions, primarily off the west coast South Island with some effort around the Bay of Plenty and East Cape, and east coast South Island particularly in 2023 (Figure 3-14 and Figure 3-15). The distribution of Cluster 6 was similar to Cluster 3 but had more fishing in the far south (Figure 3-16), and at colder water temperatures (mean SST of 16.3°C vs. 17.2°C) (Table 3-19). The mean depth of fishing across Clusters 1 to 5 was similar (512–536 m); Cluster 6 had the shallowest mean fishing depth of 487 m (Table 3-19).

Cluster 3 caught a relatively low number of leatherbacks (n=17), with 0.38 leatherback per 100 events or 0.38 leatherbacks per 100 000 hooks (Table 3-23). Clusters 4, 5, and 6 had very low numbers of reported leatherbacks, with Cluster 4 reporting no leatherbacks, Cluster 5 reporting three, and Cluster 6 reporting one. The catch rates of leatherbacks for Clusters 5 and 6 were 0.05 leatherback per 100 events or 0.04 leatherbacks per 100 000 hooks, and 0.13 leatherback per 100 events or 0.10 leatherbacks per 100 000 hooks, respectively (Table 3-23).

Further analysis within Clusters 1 and 2 (of six), or within Cluster 1 (of six), did not identify any additional useful fishery subunits; when the analysis was extended to include two further clusters withing Cluster 1 the fishing statistics and leatherback catch rates in each were very similar.

Of the vessels which did report a leatherback capture, those which caught the most leatherbacks had similar distribution of effort between clusters. This cluster included vessels that never reported leatherback bycatch, although they included some of the more active vessels (Table 3-24). The effort of all but one vessel reporting at least one leatherback was focused within Cluster 1.

Table 3-19: Surface longline number of events by reported target species (2008–2023) and cluster, with reported fishing depth and SST (interquartile ranges in parentheses). Species only shown if there was more than one record. Darker shading of cells indicates higher values.

Target species	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
Shortsnouted lancet (ABR)	1	19	0	0	0	0
Albacore tuna (ALB)	89	0	12	12	17	0
Bigeye tuna (BIG)	9 007	2 776	1 428	40	164	132
Bluenose (BNS)	3	1	1	0	0	0
Blue shark (BWS)	3	1	0	0	0	0
Kingfish (KIN)	3	0	0	0	0	0
Mako (MAK)	4	0	0	0	0	0
Northern bluefin (NTU)	18	9	0	0	0	0
Striped marlin (STM)	2	0	1	0	0	0
Southern bluefin (STN)	7 026	1 021	2 605	1 950	5 989	526
Swordfish (SWO)	1 711	2 044	375	9	67	83
Pacific bluefin tuna (TOR)	173	88	26	2	2	7
Yellowfin tuna (YFN)	15	1	3	0	0	0
Depth (m)	520 (190–729)	536 (370–684)	512 (190–750)	520 (90–795)	534 (110–778)	487 (113–724)
SST (°C)	18.6 (17.0–20.5)	19.8 (18.2–21.0)	17.2 (16.0–18.4)	15.0 (13.7–16.4)	15.7 (14.1–17.0)	16.3 (15.0–17.5)

Table 3-20: Surface longline total catch (2008–2023) and catch rate (t/event) by species (species code) for clusters. Species included only where catches in at least one cluster were >5t. Darker shading of cells indicates higher values. For species names see Table 3-14.

	Cluster 1		Cluster 2		Cluster 3		Cluster 4		Cluster 5		Cluster 6	
Sp. code	**t**	**t/event**	**t**	**t/event**	**t**	**t/event**	**t**	**t/event**	**t**	**t/event**	**t**	**t/event**
ALB	1 425	87.6	663	117.8	342	75.5	127	42.0	429	60.5	62	62.2
BIG	1 161	71.3	442	78.5	180	39.8	12	4.1	63	8.9	22	22.4
BSP	2	0.1	<1	0.0	3	0.7	6	2.1	7	1.0	3	3.0
BTU	43	2.7	10	1.8	25	5.5	10	3.3	36	5.0	4	4.5
BWH	6	0.4	7	1.2	10	2.1	0	0.1	4	0.6	3	2.9
BWS	2 258	138.7	924	164.2	3 996	881.9	496	164.4	1 281	180.6	2 416	2 427.9
DAS	19	1.2	6	1.1	4	0.8	0	0.0	0	0.1	0	0.4
DEA	5	0.3	<1	0.1	10	2.2	25	8.4	26	3.7	4	4.0
DOF	15	0.9	8	1.4	2	0.3	0		0	0.0	0	0.0
LAT	133	8.2	38	6.8	45	9.8	1	0.2	5	0.8	3	3.2
LEP	74	4.6	25	4.4	18	3.9	0	0.2	4	0.5	2	2.3
MAK	451	27.7	27	48.5	288	63.5	36	11.9	139	19.6	121	121.6
MOO	397	24.4	108	19.1	124	27.3	22	7.2	84	11.9	17	17.5
OFH	36	2.2	14	2.4	15	3.3	3	1.0	11	1.5	4	4.4
POR	9	0.6	4	0.7	9	1.9	2	0.7	6	0.9	10	9.7
POS	185	11.4	57	10.1	165	36.4	50	16.5	131	18.4	89	89.7
RAY	15	0.9	17	2.9	4	0.9	0	0.0	0	0.1	0	0.2
RBM	38	2.4	14	2.5	19	4.2	32	10.6	38	5.3	7	6.6
RUD	12	0.7	4	0.7	4	0.9	2	0.5	3	0.4	1	0.6
STM	152	9.4	130	23.1	21	4.7	1	0.3	3	0.4	1	1.0
STN	1 010	62.1	312	55.4	608	134.1	3 962	1 313.6	4 456	628.3	229	229.7
SUN	1 117	68.6	526	93.4	316	69.7	32	10.5	152	21.5	51	51.5
SWO	1 629	100.1	3 808	676.3	563	124.2	135	44.8	415	58.5	110	110.7
THR	144	8.9	92	16.3	59	13.1	9	3.0	23	3.2	11	10.9
TOR	175	10.7	69	12.3	29	6.4	25	8.1	70	9.8	2	2.5
YFN	127	7.8	58	10.3	12	2.7	0	0.1	0	0.0	1	0.6

Table 3-21: Surface longline number of fishing events by month (2008–2023) and cluster. Darker shading of cells indicates higher values.

Month	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
10	292	17	81	0	1	4
11	792	28	151	0	1	6
12	1 027	113	178	0	0	8
1	1 519	528	91	0	3	3
2	1 726	913	119	11	98	1
3	2 315	1 541	189	80	383	10
4	2 273	1 090	316	142	631	36
5	2 170	883	925	376	1 081	215
6	2 019	422	800	498	1 567	163
7	1 673	204	614	665	1 509	128
8	1 551	167	713	240	885	135
9	698	55	274	1	81	39

Table 3-22: Surface longline number of fishing events by fishing year (year ending) and cluster. Darker shading of cells indicates higher values.

Fishing year	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
2008	1 199	272	258	60	133	36
2009	1 696	325	273	56	233	47
2010	1 673	480	374	74	203	34
2011	1 555	665	343	88	210	48
2012	1 198	569	446	83	361	124
2013	1 066	684	384	97	327	89
2014	935	426	365	154	340	102
2015	680	550	374	176	388	65
2016	1 072	545	439	128	485	33
2017	1 068	319	301	139	540	52
2018	1 087	335	435	158	530	61
2019	1 169	117	287	104	475	35
2020	1 284	152	106	123	523	6
2021	897	260	56	164	437	15
2022	674	85	5	176	483	1
2023	802	177	5	233	572	0

Table 3-23: Surface longline captures of marine reptiles (2008–2023) by species (or species group) and average leatherback catch rate (2008–2023) by cluster. Darker shading of cells indicates higher values.

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
Banded sea krait (BSS)	0	0	0	0	0	0
Green turtle (GNT)	9	6	2	1	1	0
Hawksbill turtle (HBT)	3	3	0	1	0	0
Leatherback turtle (LBT)	138	76	17	0	3	1
Loggerhead turtle (LHT)	5	0	0	0	1	0
Olive Ridleys turtle (ORT)	0	0	0	1	0	0
Sea turtle (TLE)	8	5	3	0	0	0
LBT per 100 events	0.76	1.35	0.38	0	0.05	0.13
LBT per 100 000 hooks	0.85	1.27	0.38	0	0.04	0.10

Table 3-24: Distribution of fishing effort (events) between clusters for vessels that reported at least one leatherback capture (total n = 235). Darker shading of cells indicates higher effort values. All effort recorded for each vessel is included (not just those which caught a turtle). The last row includes all vessels that never reported a leatherback (LBT) capture. Data in analyses cover the fishing years 2008–2023 inclusive.

Vessel	Cluster						No. leatherbacks (proportion)	Total events
	1	2	3	4	5	6		
a	879	324	206	64	213	37	72 (0.44)	1 723
b	335	120	58	47	117	2	44 (0.27)	679
c	1 582	304	391	60	226	29	32 (0.20)	2 592
d	617	316	162	7	57	16	28 (0.17)	1 175
e	1 052	301	290	66	201	34	17 (0.10)	1 944
f	135	253	124	15	44	11	13 (0.08)	582
g	568	187	199	64	285	27	5 (0.03)	1 330
h	485	202	140	74	156	27	4 (0.02)	1 084
i	1 268	375	41	33	205	6	3 (0.02)	1 928
j	84	71	49	1	20	3	3 (0.02)	228
k	271	88	70	3	42	7	2 (0.01)	481
l	404	143	131	22	116	15	2 (0.01)	831
m	258	149	108	36	156	4	2 (0.01)	711
n	271	83	47	69	197	4	2 (0.01)	671
o	187	46	30	1	6	0	1 (<0.01)	270
p	24	23	8	0	2	1	1 (<0.01)	58
q	210	168	4	17	70	0	1 (<0.01)	469
r	456	192	134	47	159	56	1 (<0.01)	1 044
s	274	48	50	28	114	6	1 (<0.01)	520
t	294	138	80	53	203	5	1 (<0.01)	773
No LBT	8 400	2 430	2 128	1306	3 651	458	235	18 373

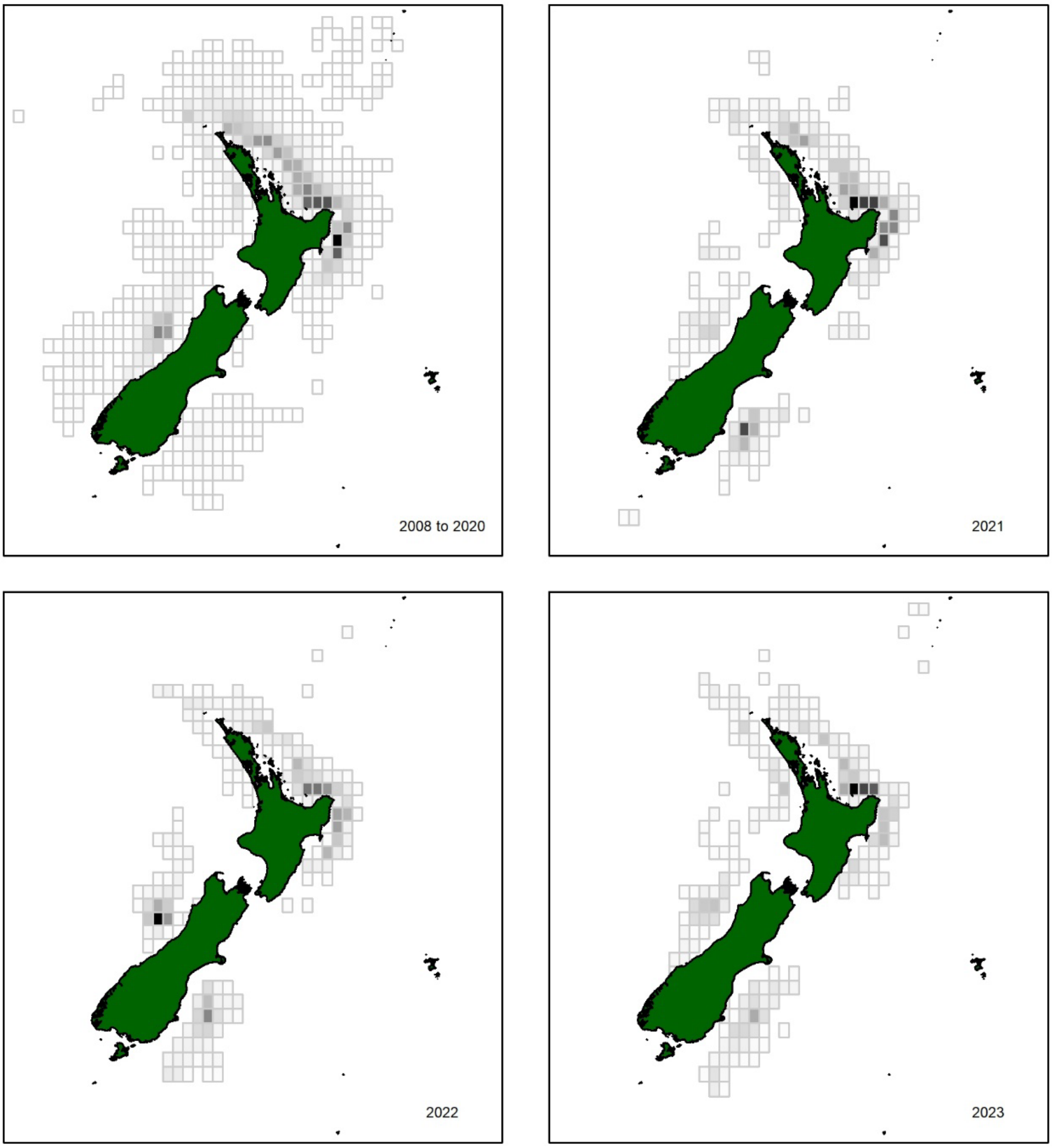

Figure 3-11: Cluster 1; spatial relative distribution of fishing events by 0.5° longitude and latitude cells, by fishing year (labelled year ending) for the last three fishing years (2023, 2022, 2021, and summarised for the years before that, 2008–2020). Darker shading indicates greater fishing effort.

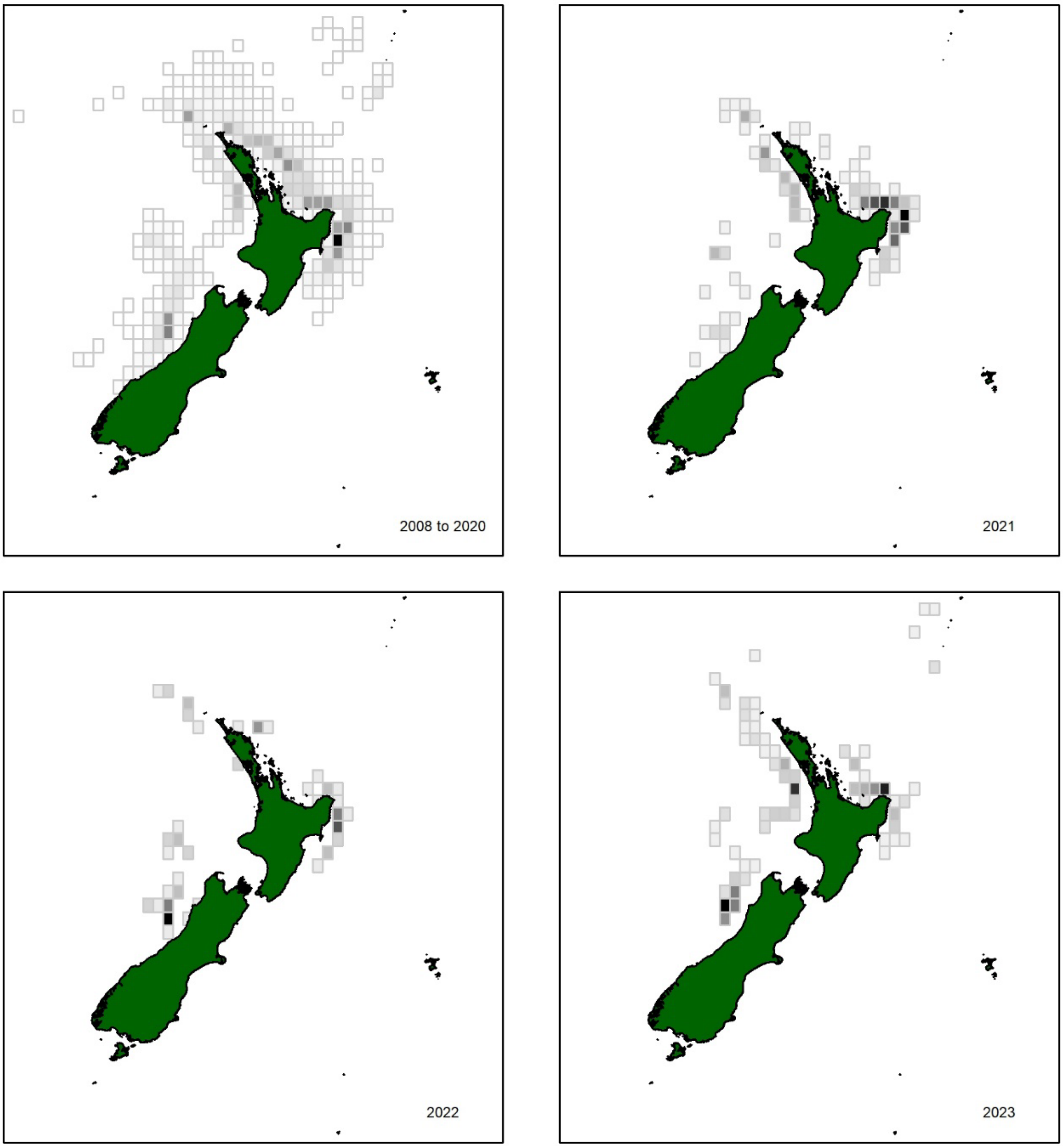

Figure 3-12: Cluster 2; spatial relative distribution of fishing events by 0.5° longitude and latitude cells, by fishing year (labelled year ending) for the last three fishing years (2023, 2022, 2021, and summarised for the years before that, 2008–2020). Darker shading indicates greater fishing effort.

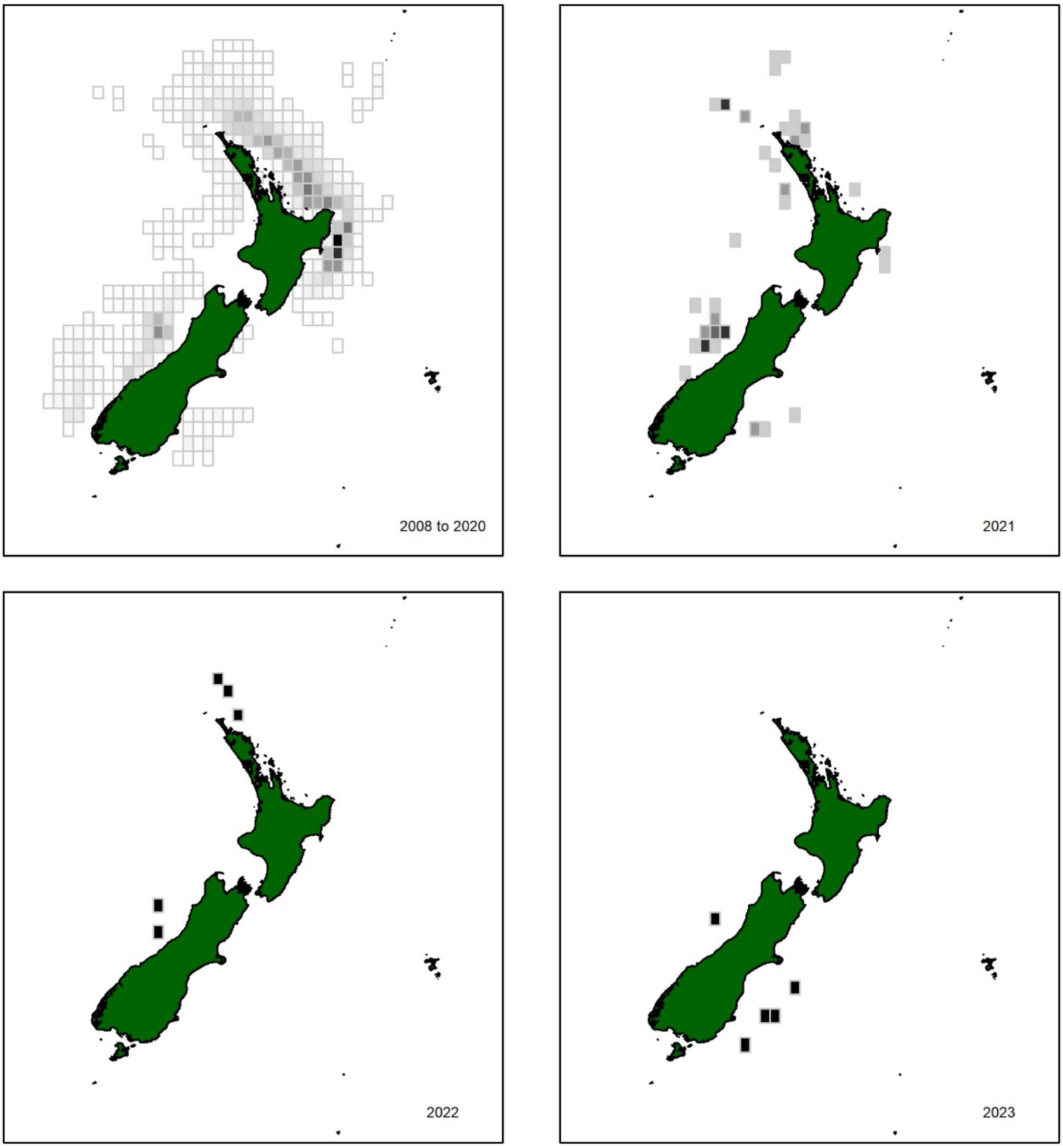

Figure 3-13: Cluster 3; spatial relative distribution of fishing events by 0.5° longitude and latitude cells, by fishing year (labelled year ending) for the last three fishing years (2023, 2022, 2021, and summarised for the years before that, 2008–2020). Darker shading indicates greater fishing effort.

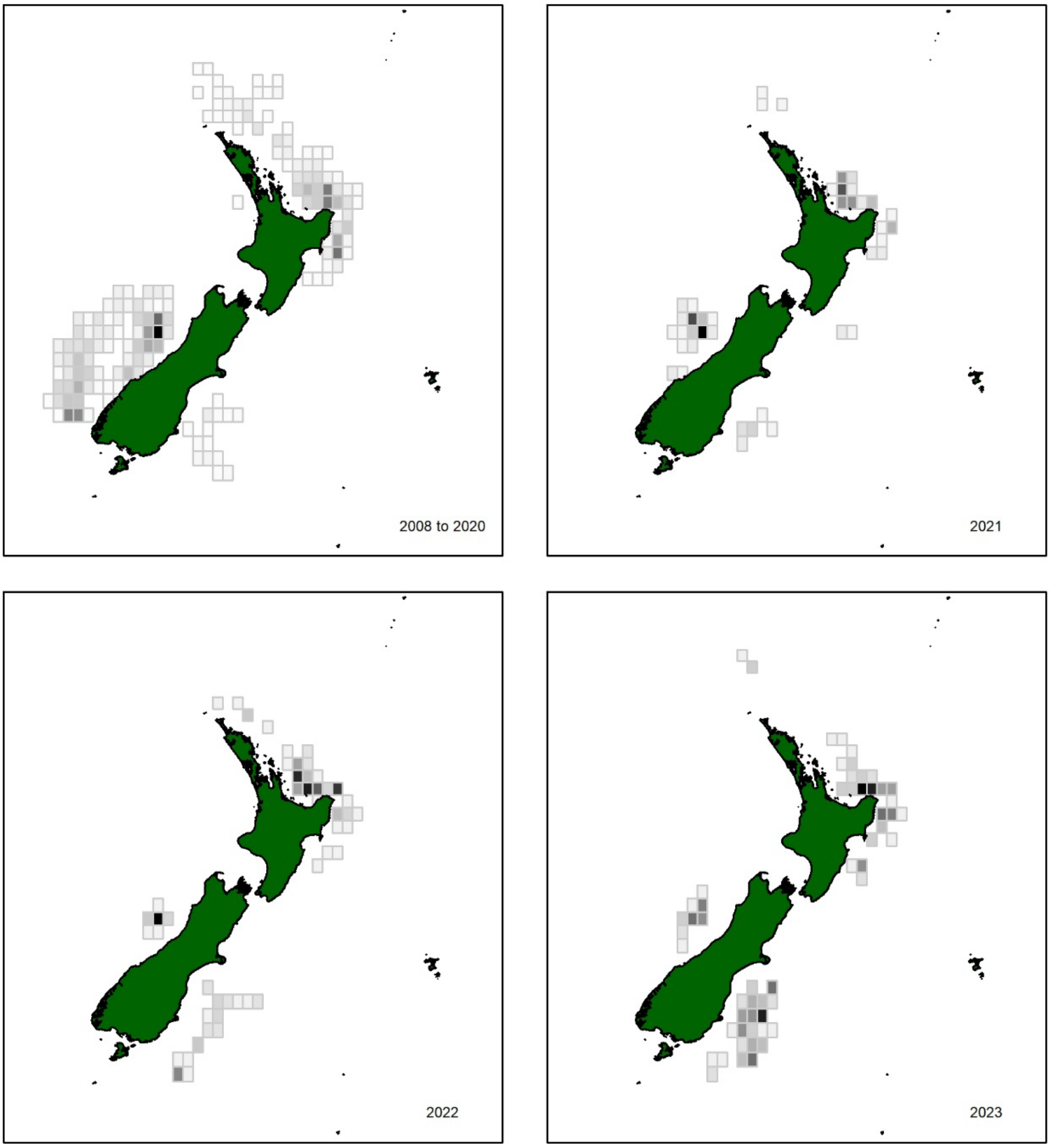

Figure 3-14: Cluster 4; spatial relative distribution of fishing events by 0.5° longitude and latitude cells, by fishing year (labelled year ending) for the last three fishing years (2023, 2022, 2021, and summarised for the years before that, 2008–2020). Darker shading indicates greater fishing effort.

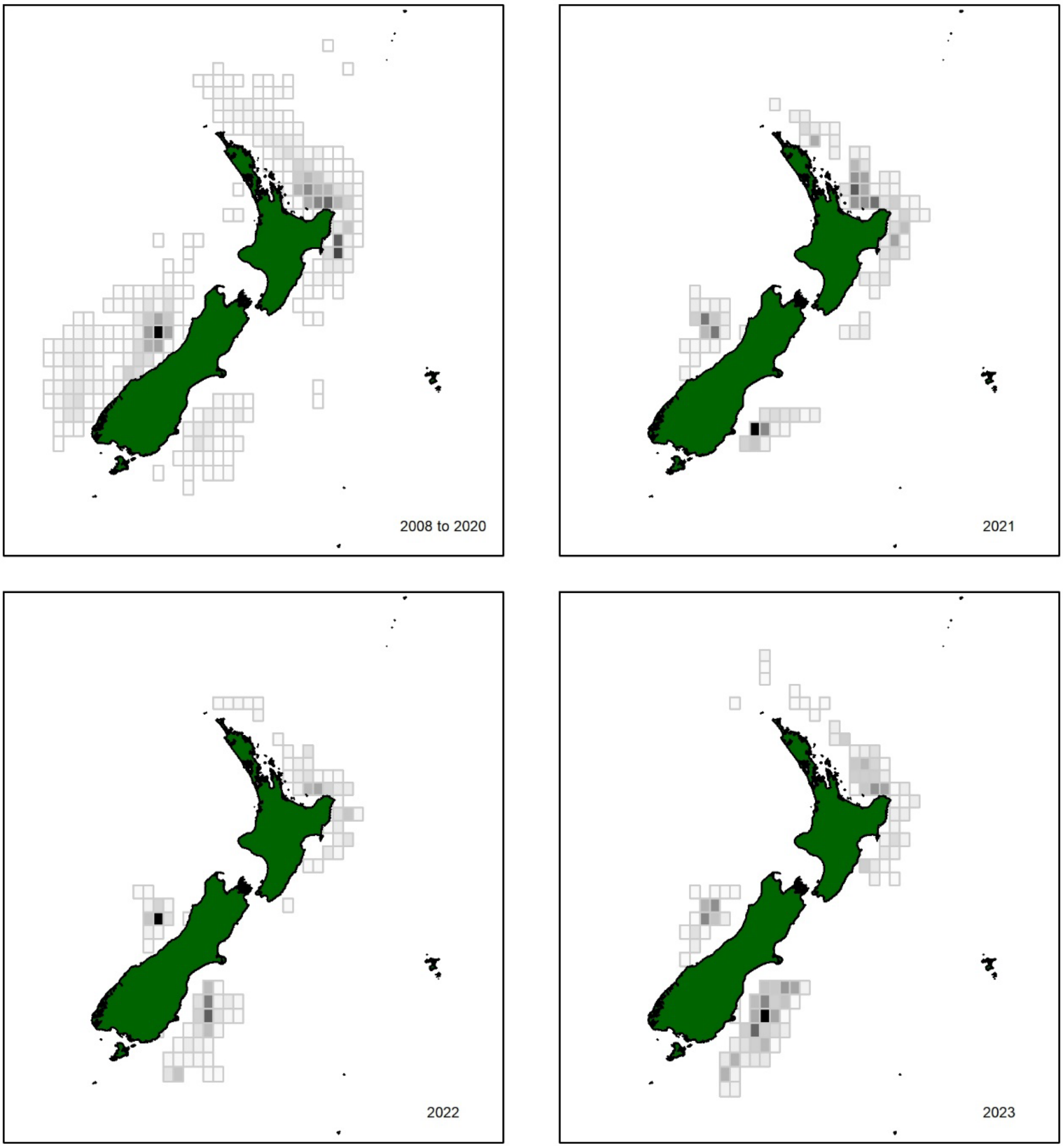

Figure 3-15: Cluster 5; spatial relative distribution of fishing events by 0.5° longitude and latitude cells, by fishing year (labelled year ending) for the last three fishing years (2023, 2022, 2021, and summarised for the years before that, 2008–2020). Darker shading indicates greater fishing effort.

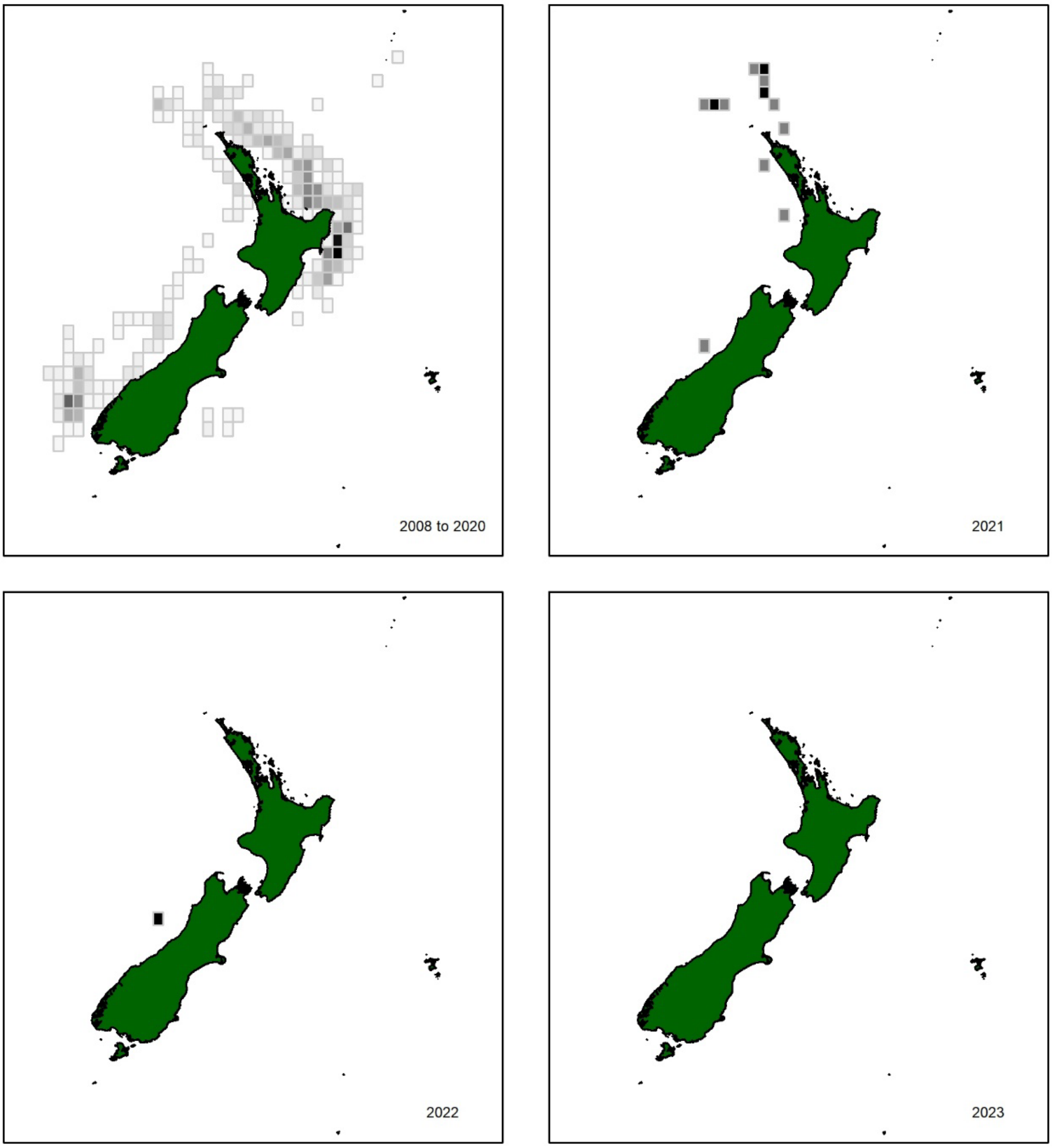

Figure 3-16: Cluster 6; spatial relative distribution of fishing events by 0.5° longitude and latitude cells, by fishing year (labelled year ending) for the last three fishing years (2023, 2022, 2021, and summarised for the years before that, 2008–2020). Darker shading indicates greater fishing effort.

3.3 Reapplying the 2021 GAM

The GAM described by Dunn et al. (2023) was refitted to the North Island data only (north of 40° S) from 2008–2021 as a binomial model with leatherback occurrence a function of the same four environmental predictors used previously. The predicted variable effects were similar to those described by Dunn et al. (2023), with an increase in catch rates in waters greater than about 18° C and with increasing chlorophyll, a decrease in catch rates with increasing EKE, and a peak in catch rates around 37–38° S (Figure 3-17).

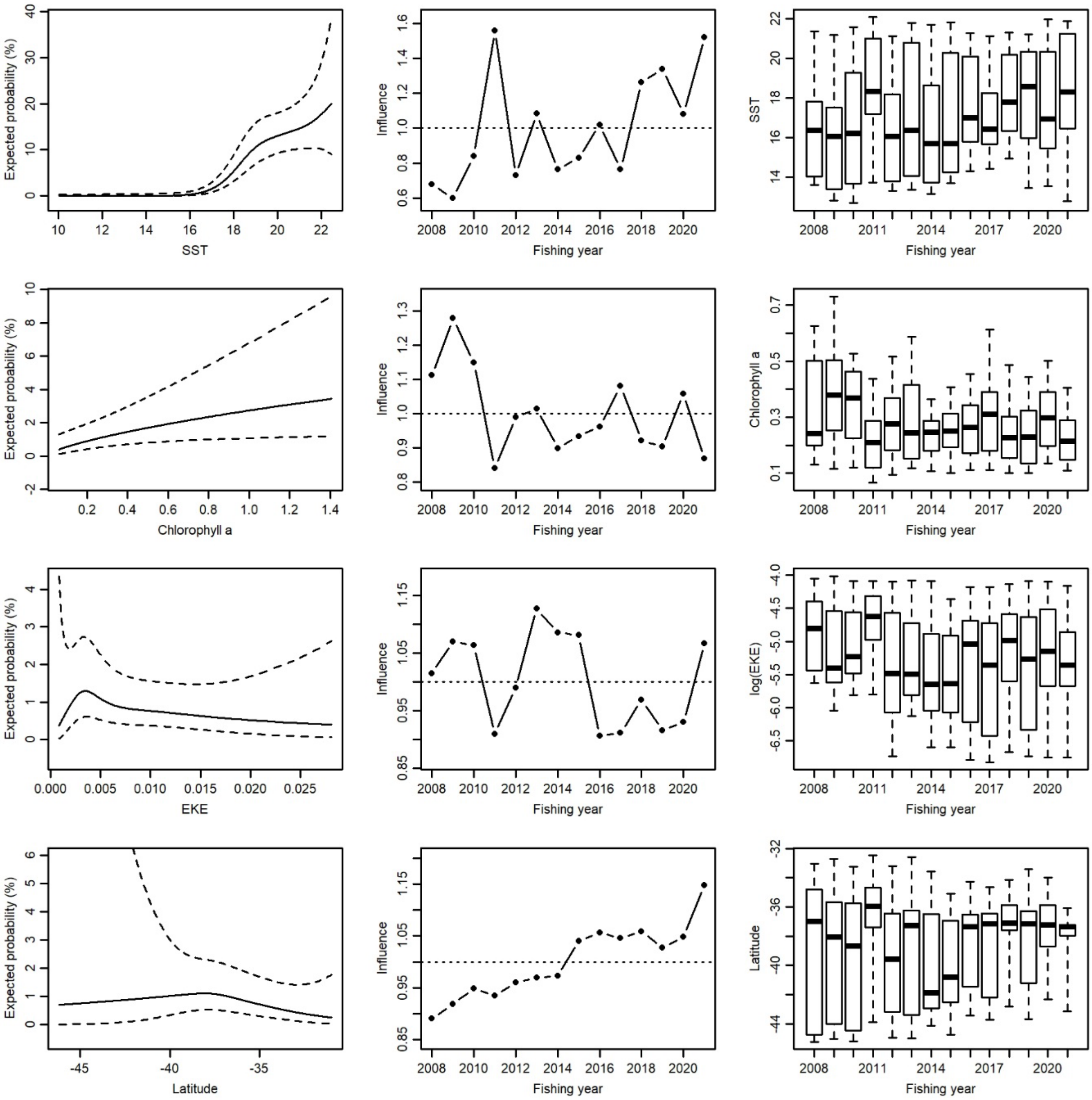

Figure 3-17: Leatherback turtle predicted probability of capture from the generalised additive model (GAM) predictors: Left panels, the predicted coefficient effect (with 95% confidence interval) estimated with other coefficients fixed at their median values; Middle panels, the influence of each term on the estimate by fishing year; Right panels, the distribution of each variable by fishing year (box plot showing median as the solid bar, interquartile range as the box, with whiskers extending to the 5% and 95% intervals).

The GAM using data to 2021 predicted captures in 2022 and 2023 that were very close to the observed captures (Figure 3-18).

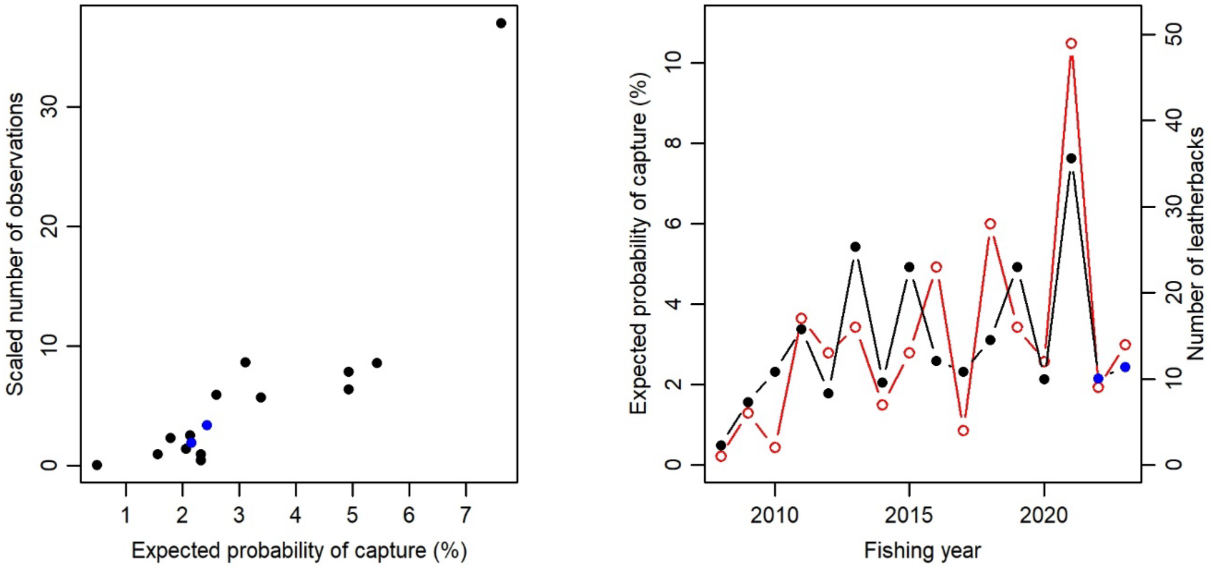

Figure 3-18: Left panel, the observed number of leatherback turtle reported captures versus the generalised additive model (GAM) predicted probability of leatherback turtle capture by fishing year using data to 2021; Right panel, the GAM expected median probability of capture (black line and points) and the observed reported number of captures (red line and points) by fishing year (scaled to have the same mean). Projected years 2022 and 2023 are shown as blue points.

3.4 Influence of environmental conditions

3.4.1 Leatherback turtles

The base model (2024 model) had five variables and explained 19.0% of the deviance:

> Leatherback occurrence ~ sqrt(mld0p125_MO) + log(MaggradOISST) + Ugeo_mean + bathymetry + log(HooksBetweenFloats) + LightsticksBetweenFloats + Emoonphase

Individually, LightsticksBetweenFloats explained the most deviance (9.4%), followed by mld0p125_MO (6.3%), bathymetry and HooksBetweenFloats (both 4.4%), Ugeo_mean (2.3%), EMoonPhase (1.0%), and MaggradOISST (0.8%). The inclusion of SST, primary productivity (chlorophyll), or EKE variables into this base model increased the deviance explained by no more than 0.3%.

Mixed layer depth (mld0p125_MO) and SST were correlated ($R^2 = 0.83$) and described a seasonal effect, with shallowest mixed layer depth occurring with highest SST during December to February (summer), and the reverse occurring in winter (peaking in August). Both mixed layer depth and SST explained more deviance than a day-of-year variable. The mean surface zonal current (Ugeo_mean; a positive value means stronger easterly currents) encompassed a spatial effect, being generally >0 at latitudes 32–38° S, highest at around 37° S, and <0 at latitudes south of 38° S. When Ugeo_mean was replaced with latitude the GAM explained 1.1% less deviance; a longitude predictor was not significant. The total hook number variable was significant and explained 0.6% additional deviance, but the predicted effect was not an expected monotonic increase, but multimodal, and so was likely aliasing for other aspects of fishing. Total hook number varied significantly (t-tests $p<0.05$) between vessels, with five vessels fishing primarily around the Bay of Plenty area and three further north, and three vessels starting fishing about a month later in the year. There was also a year trend in the total number of hooks used, from around 1000 per set at the start of the time series (2007–08) steadily declining to around 800 at the end (2022–23), but with a peak of around 1000 in 2020–21.

An alternative model (2021 model) including the four model variables identified by Dunn et al. (2023) explained 10.2% of the deviance:

> Leatherback occurrence ~ ST4-climatology + log(chl-a) + log(EKE) + latitude

The 2024 model predicted a slow increase in probability of leatherback capture from 2008 to 2014, followed by a low in 2016, an increase to a peak in 2021, then returning to average levels (Figure 3-19). This was broadly similar to the observed trend, except the observed trend included peaks in 2016 and 2018.

The 2024 model predicted more captures in shallower depths, where the SST gradient (MaggradOISST) was low (<1), the mixed-layer depth (mld0p125_MO) was shallow (<150 m), easterly currents (Ugeo_mean) were stronger (>0.15), when the moon was fuller, when the number of hooks between floats was lower (<10), and the number of light stocks between floats was higher (Figure 3-20).

The 2021 model predicted the 2021 peak in leatherback bycatch occurred when fishing was in relatively warm water SST, and in areas where eddy kinetic energy (EKE) was low and latitude was consistent with the Bay of Plenty (Dunn et al. 2023). The 2024 model predicted the 2021 peak to be caused by fishing further from strong SST gradients (fronts) and when fishing occurred in shallower waters and closer to the surface (fewer hooks between floats).

When plotted, the 2024 and 2021 models show two different predicted distributions of leatherback captures in FMAs 1 and 2, and their ability to reproduce the distribution of observed captures is different (Figure 3-21). The 2021 model arguably has a more comparable distribution to the leatherback captures (Figure 3-22). The 2024 model had a more coastal and restricted predicted distribution around East Cape and extended south towards off the Mahia Peninsula, consistent with leatherback captures. The 2024 model provided a more restricted predicted distribution of leatherback captures in the eastern Bay of Plenty, but unlike the 2021 model, it predicted a lower occurrence of leatherback captures in the western Bay of Plenty and off Coromandel. The 2024 GAM highlighted an area of higher predicted distribution east of Great Barrier Island, consistent with observed captures; this area is perhaps not as pronounced in the 2021 model (Figure 3-21).

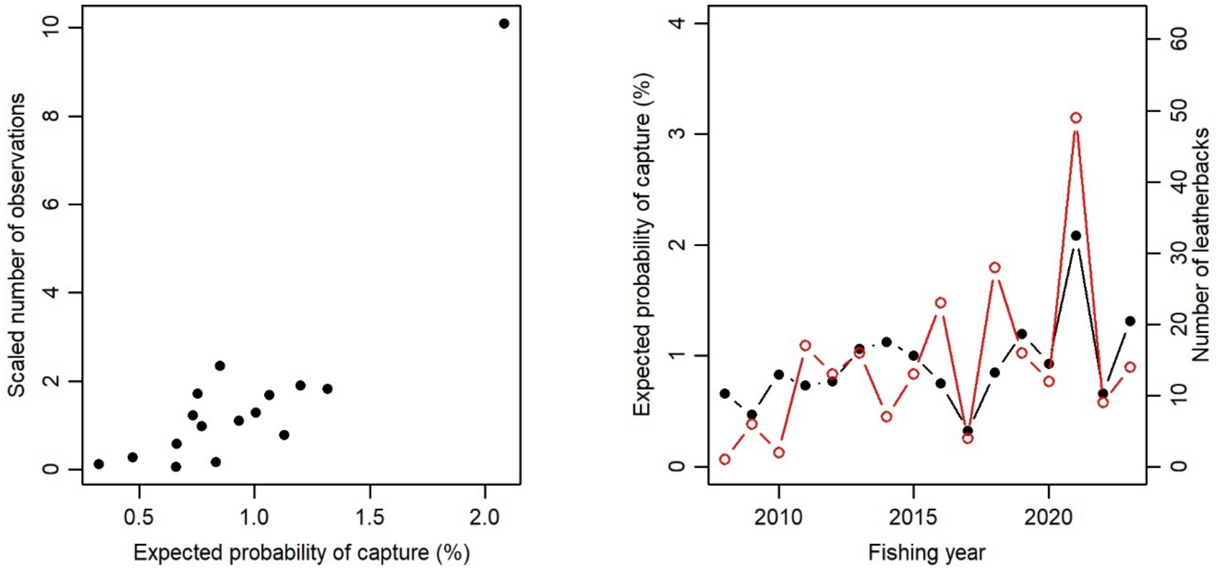

Figure 3-19: Left panel, observed number of leatherback turtle reported captures in FMA 1 and 2 vs the GAM predicted probability of leatherback turtle capture by fishing year; and right panel, GAM expected median probability of capture (black line) and the observed reported number of captures (red line) by fishing year (scaled to have the same mean).

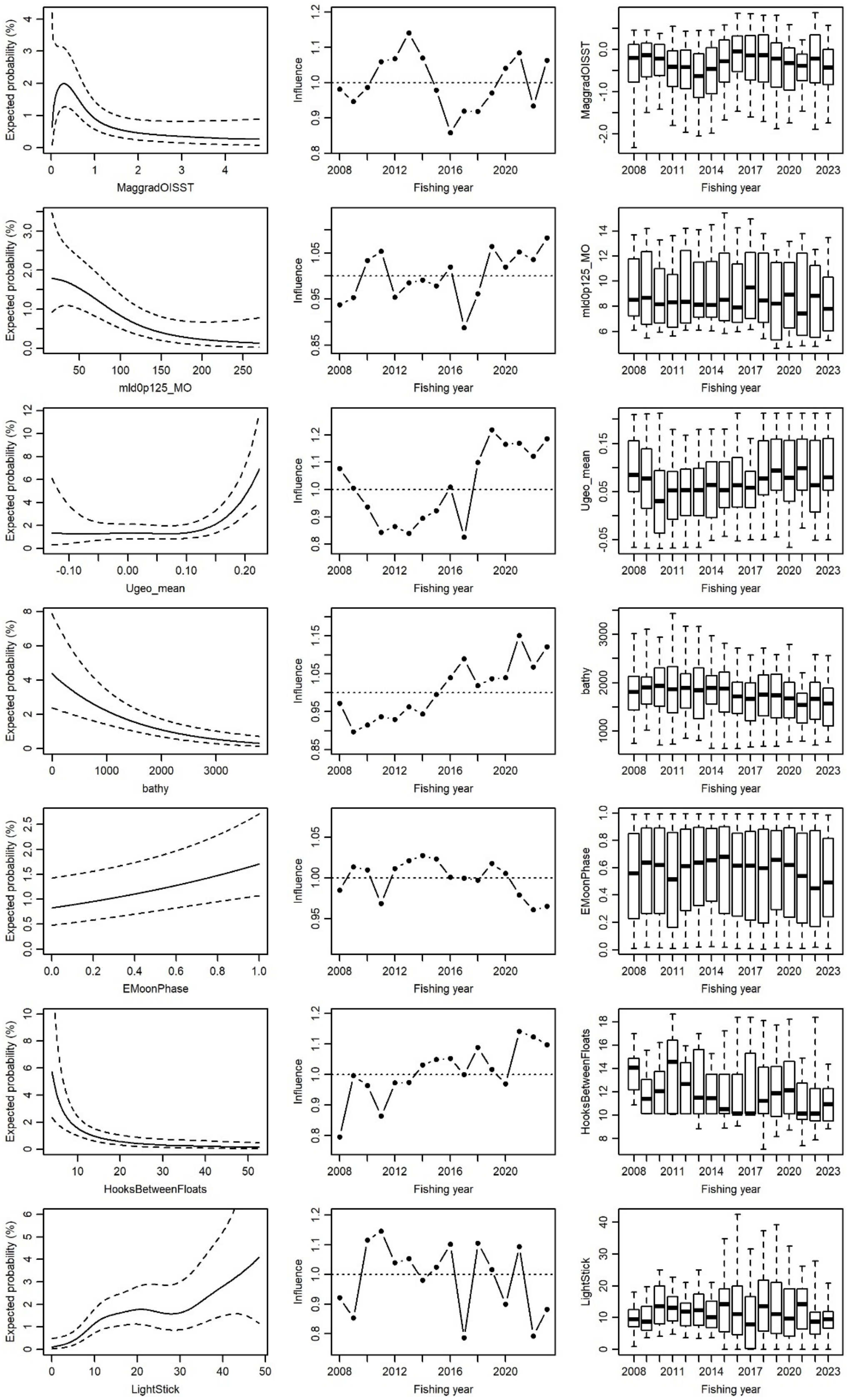

Figure 3-20: Leatherback turtle predicted probability of capture in FMA 1 and 2 from the GAM predictors: left panels, the predicted coefficient effect (with 95% confidence interval) estimated with other coefficients fixed at their median values; centre panels, the influence of each term on the estimate by fishing year; right panels, the distribution of each variable by fishing year (box plot showing median as the solid bar, interquartile range as the box, with whiskers extending to the 5% and 95% intervals).

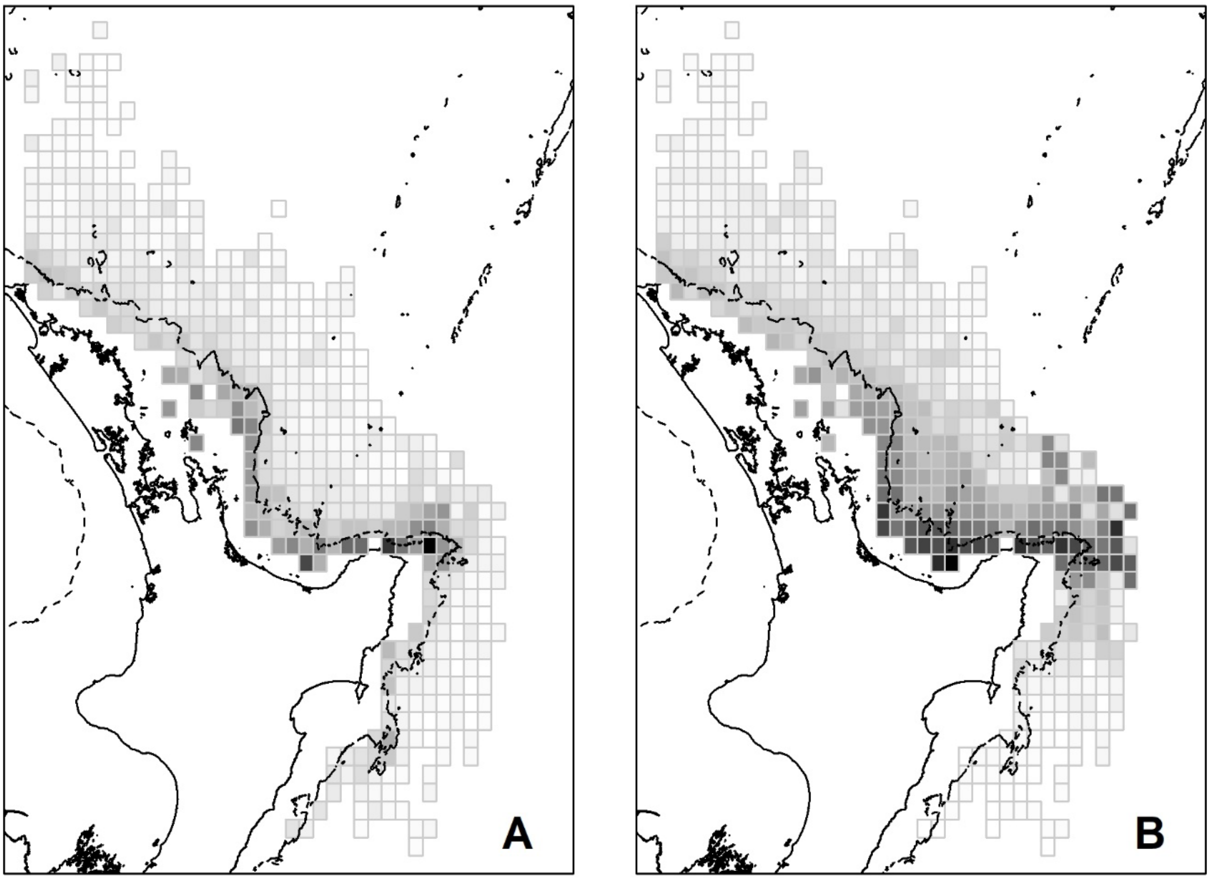

Figure 3-21: Probability of leatherback capture in surface longlines for commercial fishing records 2008 to 2023 in FMAs 1 and 2, using A, the GAM developed in 2024 (Section 3.4.1), and B, the GAM developed in 2021 (Section 3.3). Darker shading indicates greater probability. Broken line indicates the 1000 m isobath.

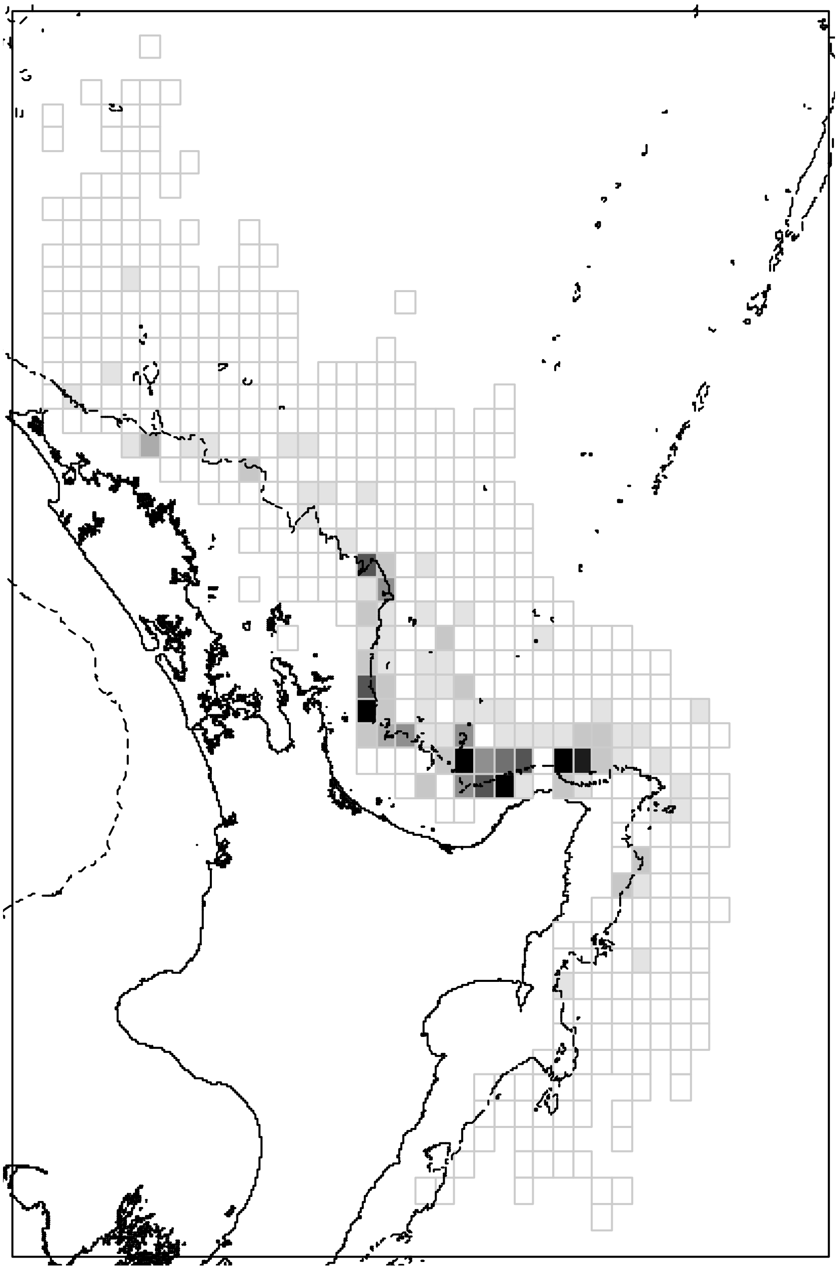

Figure 3-22: Distribution of fisher and observer-reported leatherback turtle captures from 2008 to 2021 in FMA 1 and FMA 2 (n=183). Broken line indicates the 1000 m isobath. Darker shading indicates greater probability.

3.4.2 Overlap with catch rates of swordfish, bigeye tuna, southern bluefin tuna, albacore, sunfish, porbeagle, mako, and blue shark

The leatherback 2024 model variables from Section 3.4.1 were almost all significant for the other species. For albacore, all variables were significant ($p<0.001$) except MaggradOISST in the binomial and hooks between floats in the lognormal, explaining 9.3% in the binomial GAM and 16.7% in the lognormal GAM. For bigeye all variables were significant ($p<0.01$) except MaggradOISST and hooks between floats in the binomial and MaggradOISST in the lognormal, explaining 15.6% in the binomial GAM and 7.0% in the lognormal GAM. For southern bluefin tuna all variables were significant ($p<0.05$) except hooks and light sticks between floats in the binomial and MaggradOISST and EmoonPhase in the lognormal, explaining 13.2% in the binomial GAM and 7.2% in the lognormal GAM.

For moonfish all variables were significant (*p*<0.05) except MaggradOISST in the binomial and EmoonPhase in the lognormal, explaining 7.7% in the binomial GAM and 9.4% in the lognormal GAM. For sunfish all variables were significant (*p*<0.01) except EMoonPhase in the binomial and MaggradOISST and EmoonPhase in the lognormal, explaining 4.9% in the binomial GAM and 10.5% in the lognormal GAM. For swordfish all variables were significant (*p*<0.05) except hooks between floats in the binomial and lognormal, explaining 17.2% in the binomial GAM and 16.5% in the lognormal GAM.

For blue shark all variables were significant (*p*<0.05) except EMoonPhase in the binomial and MaggradOISST in the lognormal, explaining 15.6% in the binomial GAM and 15.0% in the lognormal GAM. For mako all variables were highly significant (*p*<0.01) except bathymetry in the binomial and MaggradOISST in the lognormal, explaining 6.3% in the binomial GAM and 15.3% in the lognormal GAM. For porbeagle all variables were significant (*p*<0.001) except MaggradOISST in the binomial and MaggradOISST, bathymetry, and EmoonPhase in the lognormal, explaining 16.9% in the binomial GAM and 11.1% in the lognormal GAM.

Overall, the species with variable effects most similar to leatherbacks was swordfish, being similar in five of the seven variables (Figure 3-23). Southern bluefin tuna and mako were similar in four of the seven variables. The species least similar to leatherbacks were porbeagle (0/7), blue shark (1/7), and albacore and moonfish (2/7).

Leatherbacks and swordfish had higher bycatch and catch rates when the SST gradient (MaggradOISST) was lower, when the mixed layer depth was shallower, in shallower water, towards the full moon, and when more light sticks were used (Figure 3-23). Whilst bigeye tuna catch rates were also relatively high when the mixed layer depth was shallower, towards the full moon, when the mean zonal current was stronger, and with fewer hooks between floats, they were conversely relatively high further offshore and when fewer light sticks were used. Sunfish were similar to leatherbacks in having higher probability of bycatch when the mean zonal current was stronger, in shallower water, and when more light sticks were used, but in contrast the leatherbacks catch rates were higher closer to high SST gradients (fronts), over a wider range of mixed layer depths, and when more hooks between floats were used. The number of light sticks between floats was not strongly correlated with any other variable but tended to be higher for sets starting in the evening than those starting in the early morning, and was lower when targeting southern bluefin tuna. Hooks between floats, a proxy for depth of fishing relative to the sea surface, varied little (e.g., with target species) and was not correlated with any other variable. There was little difference by reported target species in line length and total hook counts, hooks between floats, or light sticks between floats except for southern bluefin tuna (Table 3-25).

Table 3-25: Fishing statistics (median, with 95% CI in parentheses) for line length (km), total hook count, hooks between floats, and light sticks between floats, by reported target species, for surface longline fishing in FMA 1 and FMA 2 and fishing years 2008–2023.

Reported target species	Line length	Total hook count	Hooks between floats	Light sticks between floats
Albacore	40 (36–57)	1060 (787–1300)	10 (7–17)	13 (2–30)
Bigeye tuna	41 (31–56)	950 (700–1200)	11 (8–18)	12 (0–32)
Southern bluefin tuna	39 (26–56)	920 (600–1300)	12 (9–18)	6 (0–23)
Swordfish	44 (31–58)	900 (650–1200)	11 (7–16)	22 (8–44)
Pacific bluefin tuna	46 (37–56)	1000 (791–1150)	12 (9–17)	19 (6–39)

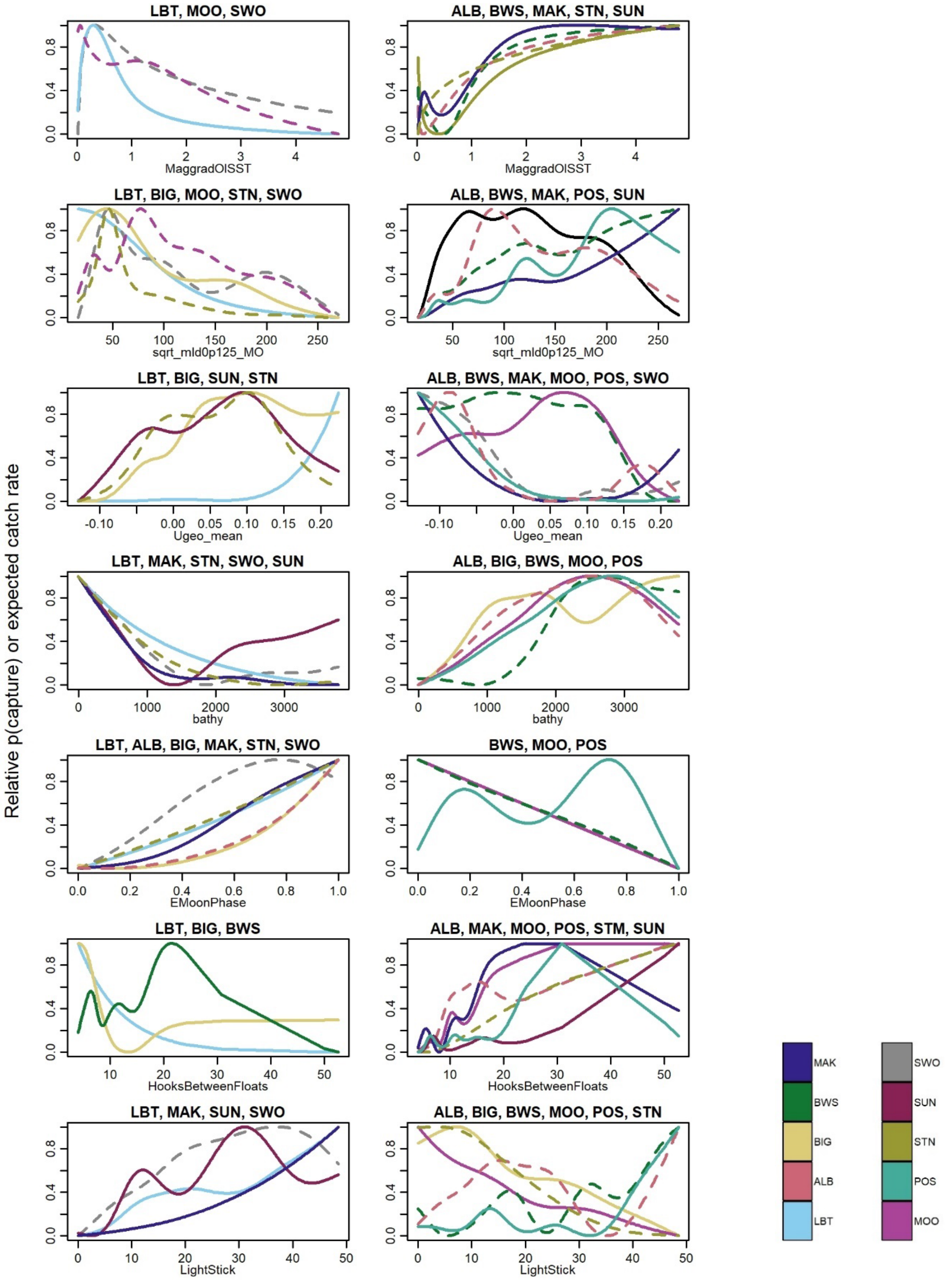

Figure 3-23: Leatherback turtle (LBT), mako (MAK), swordfish (SWO), bigeye tuna (BIG), sunfish (SUN), southern bluefin tuna (STN), albacore (ALB), porbeagle (POS), moonfish (MOO), and blue shark (BWS) predicted probability of capture (leatherbacks) or catch rates (fishes) in FMA 1 and 2 from a binomial GAM for leatherbacks, and delta-lognormal GAM for fishes, for the same variables as selected for the leatherback GAM. Effects are not plotted when both the binomial and lognormal were insignificant (p<0.05). The predicted effect is estimated with other coefficients fixed at their median values.

3.5 Differences between vessels with reported leatherback captures and those without

Five surface longline vessels reported at least 10 leatherback captures each between 2008 and 2023 and accounted for 91% (n=192/211) of the total leatherback records. Of the 20 vessels recording surface longline effort in 2023, 10 had never reported a leatherback bycatch.

There was relatively little difference between vessels that reported leatherback and those with no reported bycatch for most variables, the exception being latitude (and to a lesser extent longitude). Vessels that did report leatherback bycatch had a focus of fishing effort around 37° S, a location that includes the Bay of Plenty (Figure 3-24), and relatively more fishing effort over summer, and in warmer waters, with fishing effort decreasing slightly after about 2017. Fishing effort for vessels with no reported leatherback bycatch declined substantially from 2008 to 2023.

The absence of leatherback captures on Chatham Rise is consistent with a lack of SLL fishing effort in that region (Figure 3-25).

When compared within the fishery cluster that reported most leatherback captures (Cluster 1 of the 3-cluster analysis in Section 3.2.1) the difference between vessels that did and did not have reported leatherback bycatch was reduced (Figure 3-26). The difference was still apparent in latitude and longitude (the peak being roughly just north of East Cape), with vessels reporting leatherbacks also fishing in areas with slightly higher SST and less frequently targeting southern bluefin tuna (STN). The observer coverage was lowest in Cluster 1 (7.1%), higher in Cluster 2 (14.7%), and highest in Cluster 3 (21.7%).

Only two vessels completed both observed and unobserved trips within the leatherback bycatch hotspot area and season. The first vessel completed 40 observed fishing events and 159 unobserved events, with no leatherbacks encountered in the observed events, and 12 in the unobserved events (0.075 leatherbacks per event). The second vessel completed 55 observed fishing events and 173 unobserved events, with four leatherbacks encountered in the observed events (0.073 leatherbacks per event) and 13 in the unobserved events (0.075 leatherbacks per event).

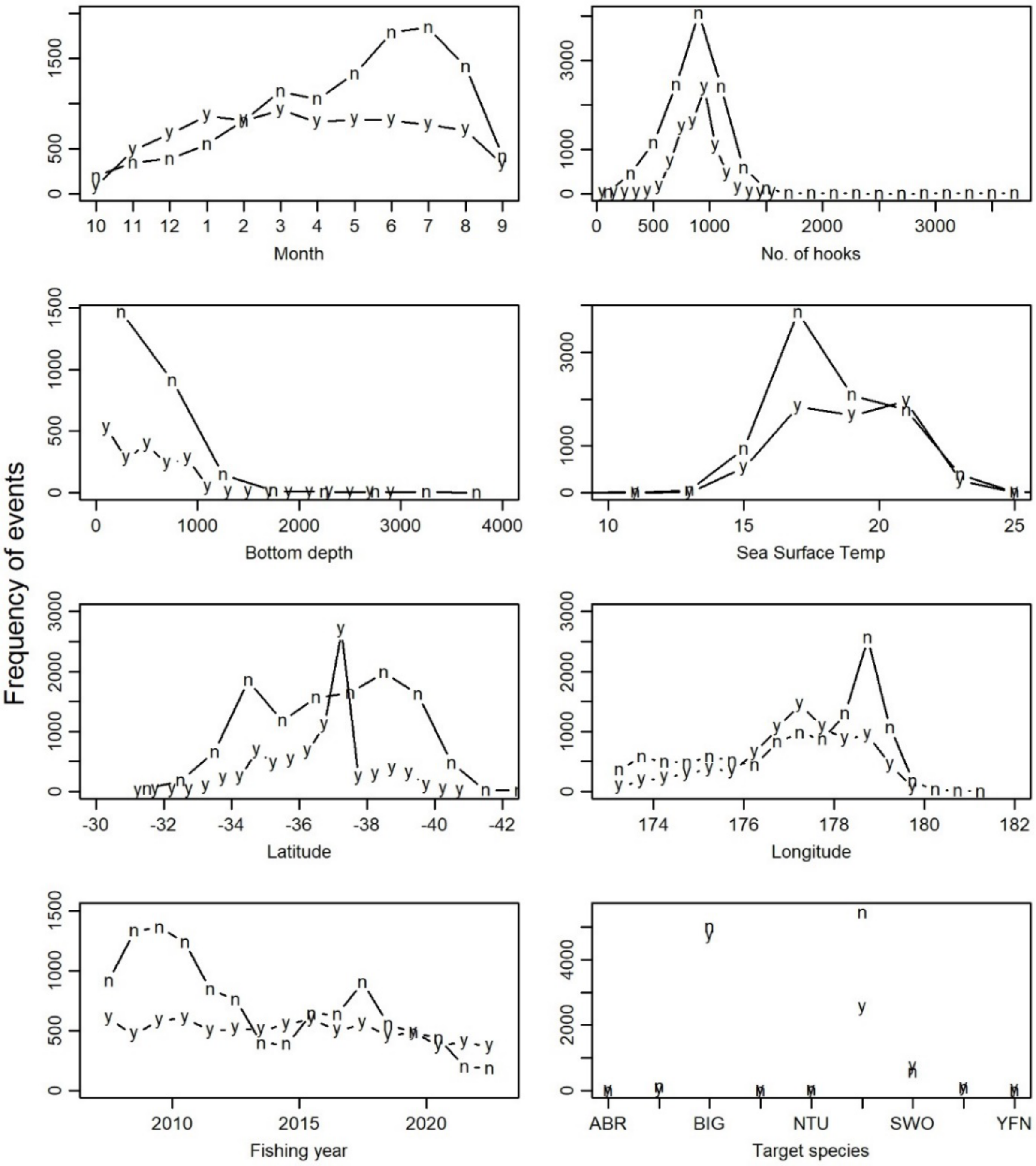

Figure 3-24: Frequency of surface longline fishing events in FMAs 1 and 2 by reported fishing effort variables for all years combined (2008–2023). y, reported at least 10 leatherback captures; n, never reported a leatherback capture.

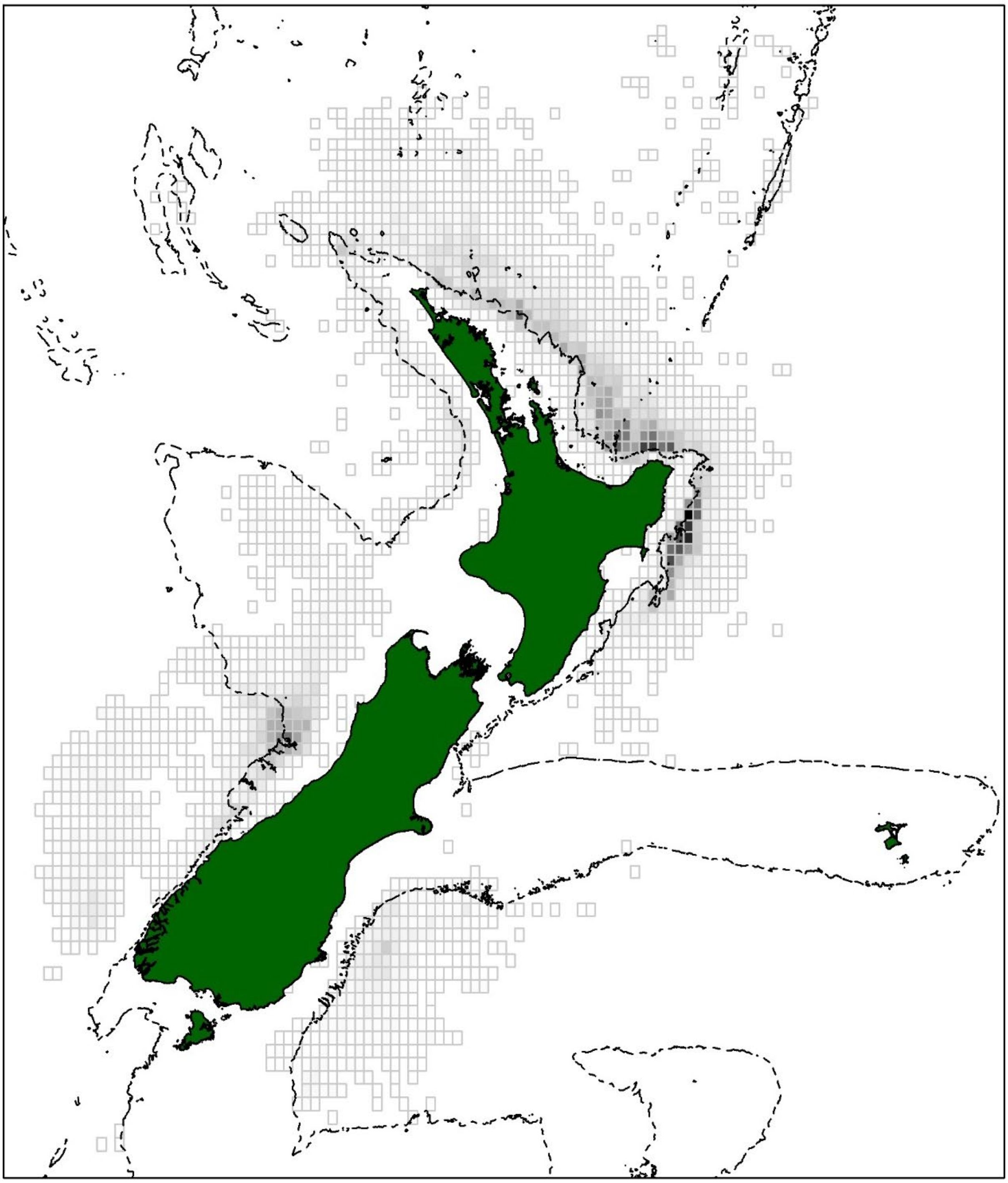

Figure 3-25: Distribution of surface longline fishing effort (events) for all years combined (2008–2023), by 0.2° latitude and longitude cells. Darker cells indicate more effort. The broken line indicates the 1000 m isobath.

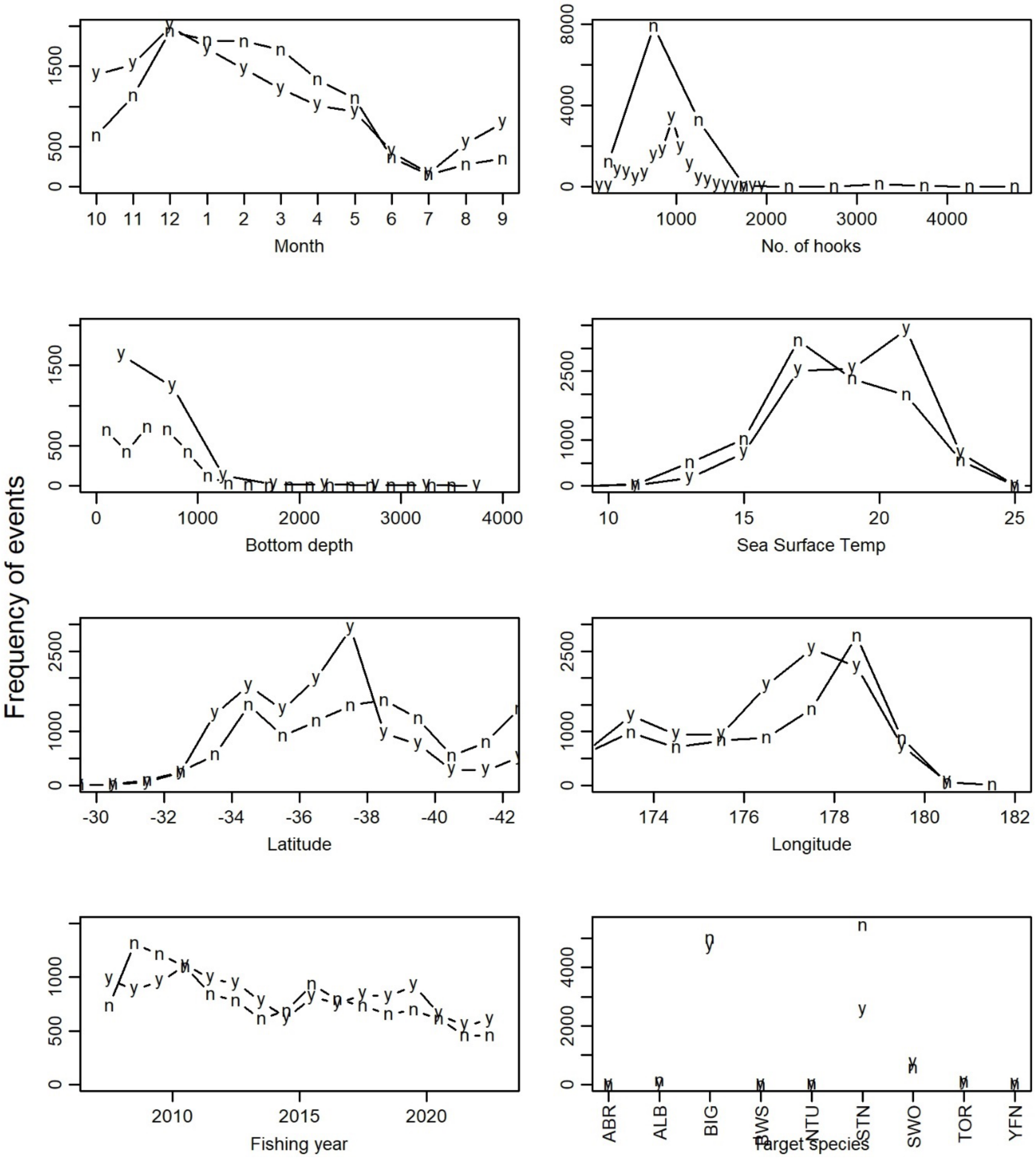

Figure 3-26: Frequency of surface longline fishing events in FMAs 1 and 2 for Cluster 1 (see Section 3.2.1) by reported fishing effort variables for all years combined (2008–2023). y, reported at least 10 leatherback captures; n, never reported a leatherback capture.

4 Discussion

4.1 Fishery characterisation

The fisheries characterisation indicated leatherback bycatch was greatest in the fishery reported as targeting bigeye tuna. However, the analyses based on clustering of catch compositions into different units (métiers) produced a different result, with the strongest association between leatherbacks and vessels fishing for swordfish. This difference was because the reported target species did not necessarily reflect the species most frequently caught. The cluster analyses did not isolate the Bay of Plenty region where leatherbacks were most frequently reported, but most leatherbacks were taken in the cluster where SST was highest. If there was a characteristic in the fishing pattern that resulted in more leatherback captures, this attribute was at a finer level of detail than the catch classification analyses or resulted from factors other than those included in the analyses here (i.e., target species, month, latitude, catch composition, vessel).

While all New Zealand longline fishers are required to nominate a target species for each set, the target species is often recorded as a preferred species, while the gear setup is generalised to land a range of target species (Brouwer & Griggs 2009). Internationally, swordfish target fisheries have been associated with relatively high leatherback capture rates attributed to a relatively shallow (50–100 m) fishing depth, whereas the targeting of tuna is usually deeper, at 100–300 m depth (Donoso & Dutton 2010, Santon et al. 2024). Swordfish are reported to conduct vertical migrations coming to the surface waters at night and use deeper water during the full moon (Sepulveda et al. 2018. Tracey et al. 2023). Although Brouwer & Griggs (2009) reported vessels targeting bigeye tuna usually fish deeper (reported as more hooks per basket), we found no substantive difference. An alternative to modifying target species by changing the fishing gear may be changing the location and timing of fishing. In 2021, the year when most leatherback turtle captures were reported, there was relatively more fishing in shallower waters where the mixed layer depth was shallower (summer) and the zonal current was stronger and using fewer hooks between floats (fishing closer to the surface). Fishing in areas with stronger zonal current and shallower mixed layer depth with more light sticks as predicted by the GAM analyses to increase catch rates of bigeye tuna, the primary reported target species, but fishing with less light sticks (shallower) would reduce catch rates of bigeye tuna. This would be consistent with skippers focusing on timing and location of fishing as a method to target species, rather than changing the setup of the fishing gear.

The leatherback bycatch hotspot, as defined by latitude and month, included overall 24.4% of the bigeye tuna catch, 17.9% of swordfish catch, and 0.1% of the southern bluefin tuna catch. The overlap between species and leatherback catch was calculated into broad spatial and temporal regions (i.e., by month and latitude bin) and would overestimate the impact of closing the region of highest leatherback captures (the ‘hotspot’ north of East Cape); these estimates are a worst-case scenario. However, only a small number of vessels (around five) dominated the fishery in the Bay of Plenty region, so any restrictions to fishing would have a disproportionately large impact on these vessels. The analyses of catches in the leatherback hotspot were not refined in the final analysis as the objective for this work was to characterise the fisheries and improve our understanding of leatherback interactions, not to suggest or evaluate an actual closed area at this time.

4.2 Leatherback distribution in relation to environmental variables

The updated (2024) GAM for FMA 1 and 2 only selected the SST gradient and not a direct SST variable as reported previously (Dunn et al. 2023). This difference may be a consequence of a more spatially restricted dataset where absolute temperature was less important. The 2024 GAM outperformed the 2021 GAM in terms of deviance explained but did include additional variables, so this comparison is not fair. The 2024 GAM also predicted a spatial distribution that was similar but not obviously better than the 2021 GAM in reproducing the observed pattern of leatherback bycatch. When developing a Spatial Distribution Model (SDM), the best approach may be to use data from all areas rather than restrict data to FMA 1 and 2; this would provide the SDM with as much information as possible, including observations towards the edges of the species range (i.e., FMA 7).

The 2021 GAM was not used as a predictive model, only to investigate hypotheses for increasing leatherback bycatch. The 2021 GAM did correctly predict the general increase during 2008–2011, the zigzag pattern from 2011–15, and the high point in 2020–21. Although the 2021 GAM did predict the low probability of capture in 2020, it did not predict the higher catches either side of 2020. The closeness of projections to observations in 2022 and 2023 suggests the 2021 GAM could be useful, however the observed captures for 2022 and 2023 were close to the time-series average for 2008 to 2021 (median = 13), so a projection simply assuming average captures for 2022 and 2023 would have performed similarly well.

Anecdotal information from fishers was that the leatherback bycatch rate was relatively high in 2023, but overall bycatch was reduced because fishing effort was lower. Skippers also reported that leatherback bycatch was not predictable but was associated with warmer waters in summer (late-summer especially), and ocean currents were more important than target species. The zonal ocean current was a predictor of leatherback bycatch in the 2024 GAM (this study) but not the 2021 GAM (Dunn et al., 2023). Because the GAMs used different predictors the reason for the peak in bycatch in 2021 remains equivocal. The 2021 model predicted the 2021 peak in leatherback captures when fishing occurred in relatively warm water SST, and in areas where EKE was low and latitude was consistent with the Bay of Plenty (Dunn et al. 2023). The 2024 model predicted the 2021 peak to be caused by fishing further from strong SST gradients (fronts) and when fishing occurred in shallower waters and closer to the surface (fewer hooks between floats). The modelling approach used was the same in both studies, so the different conclusions are caused by differences in the data set (2024 used only FMA 1 and FMA 2), combined with using a procedure to select the “best” model, accepting that there are others with different variable selections that perform very nearly as well.

The leatherback predicted environmental variable effects were closest to those for swordfish. Although sunfish have been associated with leatherbacks elsewhere (Mosnier et al. 2019), in New Zealand, their environmental effect was similar only for zonal currents, depth, and light stick use (3 of 7 variables). Leatherbacks are thought to be associated with areas where gelatinous zooplankton abundance is relatively high, which is speculated to include frontal zones (e.g., Benson et al. 2011), but this response was not obtained in the GAM analyses. It may be that leatherbacks off the east coast of the North Island are more abundant in coastal retention areas that aggregate prey (Benson et al. 2011) and are located away from the offshore frontal zones.

Surface longline fishing effort was generally greatest deeper than the 1000 isobath (Figure 3-25). The GAM predicted leatherback occurrence was greater shallower than the 1000 m isobath, through most of the range (Figure 3-21). Reported bycatch of leatherbacks was generally close to the 1000 m isobath, although shallower in places (e.g., off Coromandel), and deeper in others (e.g., north of East Cape) (Figure 3-22). Depth may have a role in the relative intersection of the leatherback and fishery distributions, and it partially explained the 2021 peak in bycatch, so may be a notable factor in determining leatherback bycatches off northeast New Zealand.

The GAM analyses also found light levels were influential, as the density of light sticks being used and as moon phase. Fewer light sticks on the lines, and less moonlight (or weaker tidal currents), was associated with less bycatch. Turtles have been shown to orientate towards light sticks on longlines (Wang et al., 2007) and show rhythms associated with moon phase (Kot et al., 2010), so this result may warrant further investigation. The East Auckland current and East Cape current have zonal flows that are almost always positive (easterly flow) (Fernandez et al., 2018). It is possible that relatively high easterly flow brings leatherbacks into the eastern Bay of Plenty and East Cape fished areas more frequently, and away from shallower coastal regions on the east coast North Island that are less fished.

Although large-scale oceanic conditions have been suggested to impact leatherback distribution, there is no clear pattern of this influence in New Zealand. Whilst 2021 notably had a La Niña winter and spring and a peak in leatherback captures, those ocean conditions previously occurred in 2010 and 2011 when leatherback captures were around the time series average. Peak capture of leatherbacks around Australia were also in different years, in 2008 and 2018 (Hazel et al. 2024).

4.3 Vessels with reported leatherback bycatch and those without

The comparison of vessels which did and did not report leatherback captures also suggested that the primary influence on leatherback capture was location. The limited data from the observer programme did not suggest the presence or absence of an observer affected reporting of leatherback captures. There have been no observers on surface longline vessels off the east North Island for the last two years. Electronic Monitoring (EM, i.e., cameras on vessels) was introduced to the fleet from 16 January 2024. It has been shown overseas that the introduction of EM influences estimates of bycatch and protected species captures (Emery et al. 2019). EM may influence not only the vessels that report bycatch, but also how often bycatch is reported on vessels that usually report (Brown et al. 2021). Any influence by EM in leatherback bycatch reporting should be reviewed in future years.

4.4 Other issues

The objective of this project was not to design or recommend a spatial-temporal closure to reduce leatherback bycatch, but to further understand the fishery and patterns of leatherback capture reporting. If a closed area was required, an analysis approach using clustering might be considered as it naturally defines boundaries through binary splits of the data.

Siders et al. (2024) were able to predict with good accuracy hotspots of leatherback occurrence using a similar (less constrained) data set to the analyses conducted here, however those hotspots were often relatively small, spread out, and ephemeral (at the scale of between weeks). Siders et al. (2024) suggested the idea of move-on rules to come with this ephemeral nature of hotspots. Such a rule would need to be tested, as Siders et al. (2024) found a ‘hotspot’ area in the following week may have a probability of leatherback capture no different to other areas, therefore a move-on rule might accomplish little in terms of reducing leatherback bycatch. It might be more practical to consider broader areas and times for fishing restrictions, if this was a chosen mitigation method, for example based upon depth and general location (e.g., east of Coromandel, central Bay of Plenty to north of East Cape). Our analyses here suggested such restrictions might influence only a small number of vessels, and might not actually impact their catches substantially, however actually quantifying that impact would require an agreed ‘closed area’ to be evaluated (which was not done here).

Internationally, the preferred approach for bycatch mitigation is to develop spatial distribution models (SDMs) for spatial risk assessments (e.g., DiMatteo et al. 2024, Lopez et al. 2024). For New Zealand, there are now three versions of an SDM; this study, Dunn et al. (2023), and Siders et al. (2024), all of which are slightly different. A reliable risk assessment requires a credible and accepted SDM, which ideally needs to be tested with fishery independent data (e.g., telemetry, aerial surveys), especially given the New Zealand fishery dependent data are limited (n = 239 leatherbacks in n = 37 636 fishing records). Such an approach could also be extended into a more holistic and integrated multispecies approach (e.g., EcoCast, https://coastwatch.pfeg.noaa.gov/ecocast/map_product.html).

Six records of leatherback captures were found south of 42° S, which may be amongst the most southern known records for leatherbacks globally. These records were all off the west coast South Island, with the furthest south occurring in March 2013 at 43.5° S and at a vessel-reported sea surface temperature (SST) of 17.8° C. Off Chile, the most southern record of a free-swimming leatherback was reported at 38° 39’ S, and possibly to 42° S (Donoso & Dutton, 2010). Hazel et al. (2024) reported leatherback captures around the south coast of Tasmania at similar latitudes and close to 44° S.

Satellite tagging data suggests that leatherbacks using different nesting beaches may have different migration routes leading to different probabilities of encountering New Zealand fisheries (Figure 4-1). For example, Indonesian leatherbacks may enter New Zealand waters via Australia and the Tasman Front, travel across the top of the North Island and down through the Bay of Plenty (Benson et al. 2011). However, leatherbacks from the Solomon Islands may enter New Zealand waters from a more oceanic direction, and encounter less fishing effort enroute to Chatham Rise (Peter Waldie, unpublished data). Currently it is not known whether the Bay of Plenty is actually a key foraging site for leatherbacks, or whether the surface long line fishery effort concentrated in the area is capturing migrating turtles. The aerial leatherback habitat survey scheduled for austral summer 2025 should help to provide more information on the habitat in the Bay of Plenty region. Regardless of the stock composition, all subpopulations in the Pacific and Indian Oceans are at high risk of extinction (National Marine Fisheries Service & U.S. Fish and Wildlife Service 2020).

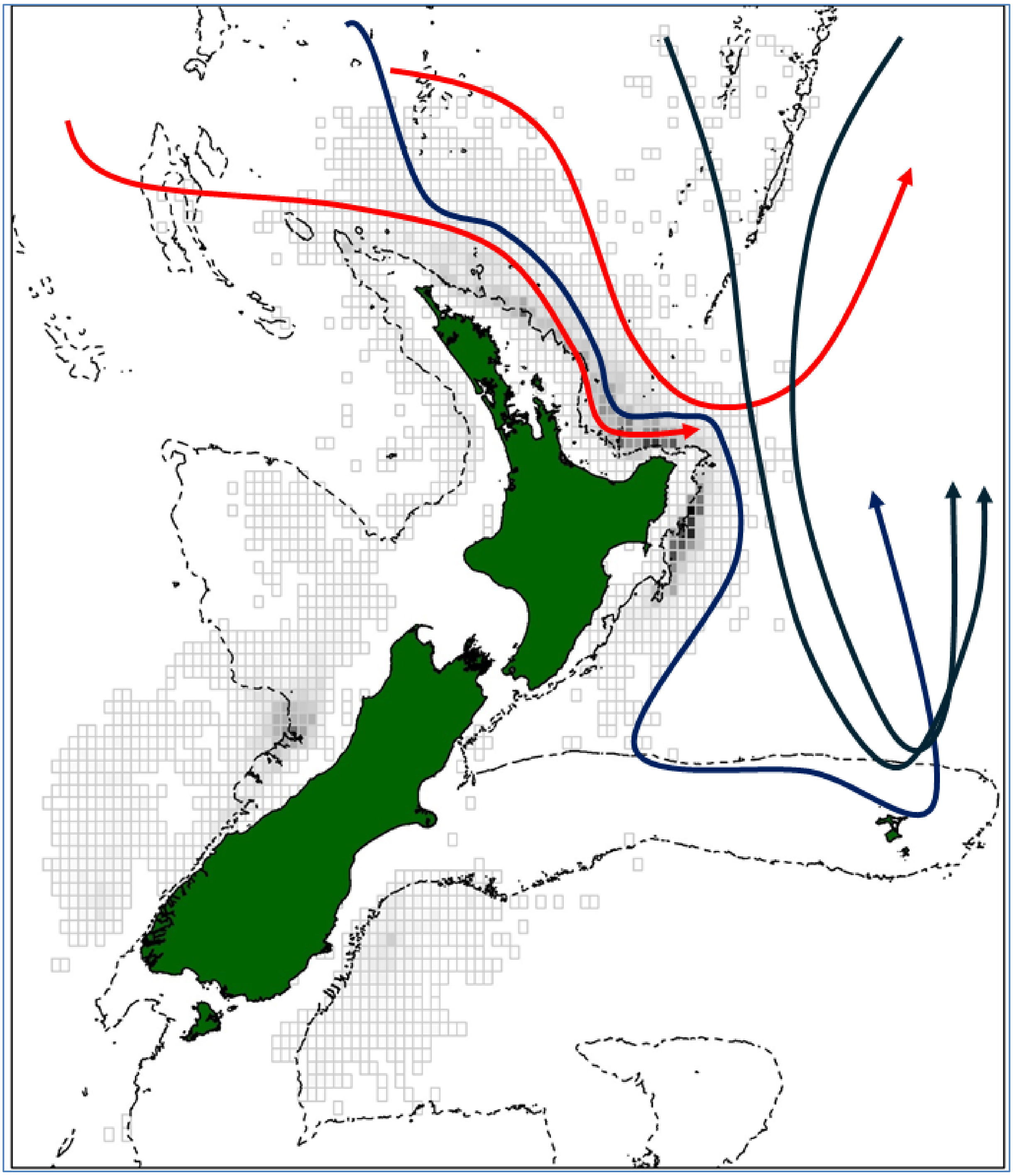

Figure 4-1: Distribution of surface longline fishing effort (events) for all years combined (2008–2023), by 0.2° latitude and longitude cells. Darker cells indicate more effort. The broken line indicates the 1000 m isobath. The red arrows are (hand drawn) indicative of the satellite (telemetry) tracks for Indonesian nesting leatherbacks (Benson et al. 2011), and dark blue arrows indicative of the satellite tracks of Solomon Islands nesting leatherbacks (P. Waldie, tags released 2022–23, unpublished data).

5 Recommendations

We recommend the following:

- Leatherback size should be recorded wherever possible. There may be important differences in foraging behaviour between adults, which make regular migrations to nesting beaches, and juveniles, which do not.
- Further consideration of spatio-temporal closures to protect leatherbacks should be deferred until after the aerial survey has been completed in 2025.
- If a SDM is required for risk assessment and/or informing potential aerial closures, then research needs to be completed to identify the most robust SDM approach and data set, and variables should be included in SDMs only when they have plausible predicted effects.
- Variables describing distance from land or particular isobaths might be tested as additional potential predictor variables (DiMatteo et al. 2024) and potentially as criteria for fished-area restrictions.
- A tool to show areas outside leatherback bycatch hotspots where target catch could be maintained for swordfish and tuna could be developed, similar to the US West Coast fisheries EcoCast product.

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