Capture of protected species in New Zealand recreational marine fisheries

Report prepared for Department of Conservation, Conservation Services Programme project BCBC2019-07a

Authors:
Edward Abraham

PO Box 27535, Wellington 6141
New Zealand
dragonfly.co.nz

Cover Notes

To be cited as:

Abraham, Edward (2021). Capture of protected species in New Zealand recreational marine fisheries, 39 pages. Report prepared for Department of Conservation.

CONTENTS

EXECUTIVE SUMMARY

Incidental captures of marine protected species in recreational fisheries occur throughout New Zealand, but there have been few systematic studies of this bycatch to date. Recent boat ramp surveys of recreational fishers and a national phone survey (National Panel Survey) included questions about protected species bycatch for the first time, providing data about capture incidents of seabirds in 2017–18.

This study used data from the 2017–18 surveys to derive estimates of seabird captures from boat-based line fishing in New Zealand. It provides capture estimates for different regions, corresponding with Fisheries Management Areas (FMAs), and distinguishing between line and longline fishing. Survey data were also used to calculate the overlap of recreational fisheries and seabird distributions for two species that are vulnerable to fishing impacts, black petrel and flesh-footed shearwater.

Seabird capture estimates varied across FMAs and by fishing method, with the highest number of estimated captures in line fishing. For line fishing, there was an estimated total of of 12 571 (95% c.i.: 10 944 to 14 356) captures in 2017–18. Of this total, there were 10 568 (95% c.i.: 9043 to 12 202) estimated captures in FMA 1, in northeastern North Island. This combination was the only FMA-method stratum with a mean estimate of over 1000 captures. The high estimate reflected both the high estimated fishing effort and the high estimated capture rate within this FMA. In comparison, there were a total of 86 (95% c.i.: 18 to 214) estimated captures for longline fishing across all FMAs. The total estimated captures, across all the estimated fishing was 12 656 (95% c.i.: 11 037 to 14 438).

In view of the scarcity of data available, the present study also reviewed the variety of data sources that collect information of protected species captures in recreational fisheries. Recommendations based on this review include the use of citizen-science platforms and crowd-sourced information to augment existing data collection efforts. Ensuring the consistent reporting of protected species captures is crucial for improving our understanding of the potential impacts of recreational fisheries on seabirds and marine mammals in New Zealand waters.

1. INTRODUCTION

Marine protected species are caught in a wide range of New Zealand commercial fisheries (e.g., see Abraham & Berkenbusch 2019). To reduce these captures, extensive measures are in place, including restrictions on fishing activity, mitigation measures, video monitoring, and collection of data using fisheries observers (Ministry for Primary Industries 2019).

In New Zealand, there is high participation in recreational fisheries: it was estimated from a recent national survey that there were 1 810 379 recreational fishing trips in this country during the 2017–18 fishing year (from October to September in the following year) (Wynne-Jones et al. 2019). Despite this high activity, little is known about the impacts of recreational fisheries on protected species. Without well-quantified information, it is difficult to assess and manage the potential impacts of recreational fishers on protected species, which include seabirds, marine mammals, reptiles, some sharks, some corals, and some other fish species.

Although there are many reports of the capture of seabirds and marine mammals in New Zealand recreational fisheries (see Abraham et al. 2010), there have been few studies of the recreational catch of these two groups of protected species. Two long-term studies of seabird captures in set nets were conducted in southeastern South Island (Otago), one on the capture of shags (Lalas 1991), and another on the mortality of yellow-eyed penguin (Darby & Dawson 2000). Both of these studies concluded that set netting had a high potential impact on the local populations. At Banks Peninsula, a study of Hector's dolphin estimated that between three and nine dolphins were caught annually in recreational set nets (Dawson 1991), before the introduction of the Banks Peninsula Marine Mammal Sanctuary in 1988.

Information about recreational fisheries, including bycatch of protected species, is available from a number of sources, consisting of ad-hoc records and systematic data collections. Efforts to systematically assess recreational fisheries in New Zealand include boat ramp surveys and the National Panel Survey (e.g., see Hartill et al. 2019, Wynne-Jones et al. 2019).

Boat ramp surveys have been routinely carried out by Fisheries New Zealand, to allow the assessment of recreational catch. The surveys are conducted through interviews of fishers as they return to boat ramps after a fishing trip.

The National Panel Survey (NPS) of recreational fisheries surveys people from throughout New Zealand over the course of a year (Wynne-Jones et al. 2019). It is a fishing-diary based method, that is balanced geographically and demographically. The NPS provides estimates of fishing effort for all fishing methods used by recreational fishers, by Fisheries Management Area (FMA).

Both types of surveys requested information about protected species (seabird) captures for the first time in 2017–18. For the 2017–18 boat ramp survey, the responses to questions relating to seabird captures can be directly linked to the fishers' reported fishing effort, allowing the determining of seabird capture rates (i.e., number of captures per effort). For the NPS, a question was asked about seabird captures as part of an exit survey at the end of the year in 2017–18.

This study provides an overview of sources of information about recreational fisheries and protected species captures in New Zealand waters. In addition, the 2017–18 data from both the boat ramp survey and the NPS were used here to obtain a national estimate of seabird captures from boat-based line fishing. Survey data were also used to estimate the overlap of recreational fisheries and seabird distributions for two species that are vulnerable to fishing impacts: black petrel and flesh-footed shearwater. In view of the general scarcity of recreational bycatch data, the current study also provides suggestions and recommendations for collecting information, including data that can be used to formally assess protected species bycatch in recreational fisheries.

2. METHODS

2.1 Protected species

Marine protected species in New Zealand include all marine mammals; all marine reptiles; all seabirds, other than black-backed gull (*Larus dominicanus*); several shark and ray species: oceanic whitetip shark (*Carcharhinus longimanus*), basking shark (*Cetorhinus maximus*), deepwater nurse shark (*Odontaspis ferox*), great white shark (*Carcharodon carcharias*), whale shark (*Rhincodon typus*), manta ray (*Manta birostris*), spinetail devil ray (*Mobula mobular*); several other fish species: spotted black grouper (*Epinephelus daemelii*), giant grouper (*Epinephelus lanceolatus*); and some corals: black corals (Antipatharia), gorgonian corals (Gorgonacea), stony corals (Scleractinia), hydrocorals (Stylasteridae) (New Zealand Government 1953, 1978, Miskelly 2014, 2016).

Although black-backed gull is not a protected species, it was included in this study. Often, records of seabird captures in recreational fisheries were not resolved at a species level, and so captures of all seabird species were considered here.

2.2 Overview of data sources

Information of marine recreational fisheries is available from a number of different data sources (Table 1). Systematic data collections of protected species captures in recreational fisheries provide records of seabird bycatch collected during surveys supporting fisheries research (Abraham et al. 2010, Hartill et al. 2019, Wynne-Jones et al. 2019). These surveys include boat ramp surveys conducted in 2007–08, supporting a fisheries research project and specifically collecting information about seabird captures (Holdsworth & Boyd 2008, Abraham et al. 2010).

The regular boat ramp surveys have been carried out consistently over a considerable period of time, and provide detailed information on the catch composition of recreational fishing; when combined with an estimate of total boat activity from aerial surveys, they provide an accurate estimate of the recreational take from boat-based fishing. In principle, the boat ramp and aerial surveys allow for detailed mapping of boat-based recreational fishing effort (but this information was not available from the most recent 2017–18 survey; see Hartill et al. 2019)

The NPS is carried out every five years, with the most recent survey in 2017–18 including questions about seabird captures (Wynne-Jones et al. 2019).

Data from the 2017–18 boat ramp survey and the NPS were used here to estimate seabird captures in recreational fisheries.

Ongoing data collections include ad-hoc reports to DOC of injured wildlife, captures of banded birds, and shark captures or strandings (Table 1). Some of these reports may be directly linked to recreational fishing or may include information that implicates these fisheries, such as the presence of specific gear. Similarly, DOC collects records of stranded marine mammals, which may contain relevant information, such as entanglement in fishing gear.

The ad-hoc records provide qualitative data about the occurrence and nature of protected species captures in marine recreational fisheries. For example, anecdotal reports to DOC document captures of protected sharks in recreational fisheries, when there is generally little information of recreational bycatch of this group of protected species. The latter includes recent captures of eight juvenile great white shark in recreational fishing, reported to DOC in the 12-month period from March 2019 to February 2020 (K. Middlemiss, DOC, pers. comm.). The captures were recorded across different regions, at Ninety Mile Beach, Kawhia Harbour, Tokerau Beach, Muriwai Beach, Waihi Beach, and Orewa Beach. Five captures were mortalities and three captures were released alive, with unknown post-release survival. The nature of the recreational fishing interactions included seven individuals caught on Kontiki beach longlining (both by being hooked and tangled in longline), and one capture in a recreational set net.

For seabirds, the presence of recreational (and other) fishing gear may be included with records of dead birds on New Zealand beaches, reported by members of the Ornithological Society for New Zealand through its beach patrol scheme.

Information of recreational fishing is also collected through other surveys and initiatives, including self-reporting by fishers, (Table 2). Some of these data collections include effort data.

Aerial overflight surveys provide for spatially-resolved records of recreational fishing from boats (Hartill et al. 2013, Hartill et al. 2019); these data are supplemented by web-camera monitoring of boat ramps to assess variations in fishing effort over time (e.g., Hartill et al. 2015).

Estimates of national fishing effort are available from the NPS, which is carried out at 5-yearly intervals (most recentlyin 2017–18; Wynne-Jones et al. 2019).

A logbook programme in the northern striped marlin fishery collects information on catch and effort in this recreational fishery. For recreational charter vessels, there is reporting of fishing effort and fish catch (of selected species) to Fisheries New Zealand; however, no information on any seabird or marine mammal captures that occur is reported.

2.3 Boat ramp surveys

Boat ramp surveys have been carried out consistently over a considerable period of time, and provide detailed information on the catch composition of recreational fishing; when combined with an estimate of total boat activity from aerial surveys, they provide an accurate estimate of the recreational take from boat-based fishing. In principle, the boat ramp and aerial surveys allow for detailed mapping of boat-based recreational fishing effort (but this information was not available from the most recent 2017–18 survey; see Hartill et al. 2019)

Table 1: Sources of data of the capture of protected species in marine recreational fisheries. For each source, the table indicates the data holder (DOC: Department of Conservation; OSNZ: Birds New Zealand). For capture information, the scope indicates the taxonomic group included in the data. Methods are: ad hoc, haphazard reporting; survey: independent survey with formal data collection procedures.

Source	Data holder	Scope	Method	Description
Boat ramp survey	Fisheries NZ	Seabirds	Survey	Survey of boat ramps, most recently during 2017–18. Fishers were asked if they had caught a seabird (43 669 interviews), and if so, what the outcome was (Hartill et al. 2019).
Diary survey	Fisheries NZ	Seabirds	Survey	National Panel Survey (NPS), carried out at 5-yearly intervals, most recently in 2017–18. At the final survey, fishers were asked whether a fisher had disrupted their fishing during the year (1203 responses), and if so, what the outcome was (Wynne-Jones et al. 2019).
Charter survey	Fisheries NZ	Seabirds	Survey	Independent observers on 57 charter vessels during 2007–08 recorded any seabird captures. Data were submitted to Fisheries NZ at project end (Abraham et al. 2010).
Boat ramp survey	Fisheries NZ	Seabirds	Survey	Survey of boat ramps during 2007–08. Fishers were asked if they had caught a seabird (763 interviews), and if so, what the outcome was (Abraham et al. 2010).
DOC hotline	DOC	All wildlife	Ad hoc	Primary contact point for reporting injured wildlife, which may include wildlife caught by fishing (Department of Conservation 2020b); ongoing.
Bird banding	DOC	Seabirds	Ad hoc	Records sightings of banded birds, including birds caught by fishing (Department of Conservation 2020c); ongoing.
Shark sightings	DOC	Sharks	Ad hoc	Public reports of sightings, captures, and strandings, which may include captures in recreational fishing (Department of Conservation 2020d); ongoing.
Strandings	DOC	Marine mammals	Ad hoc	Records of marine mammal strandings, includes records of animals that appear to have died as a result of fishing (Department of Conservation 2020a); ongoing.
Beach patrol	OSNZ	Seabirds	Ad hoc	Records of dead birds found on beaches, including birds caught by fishing (Birds New Zealand 2020); ongoing.

The most recent available data from the boat ramp surveys were from 2017–18 (Hartill et al. 2019). These data were based on an access point survey that was carried out during 2017–18, on boat ramps across New Zealand, for the purpose of estimating the recreational take of key fish species. The survey followed a long-established methodology (Hartill et al. 2007), and the data are held in the Fisheries New Zealand 'rec_data' database (Fisher & Dick 2007).

On survey days, interviewers were stationed at selected boat ramps for the entire day (from 07:30 or 08:00 h until half an hour after dusk), and they recorded all boats returning to the ramps. Fishers were interviewed, and were asked about their fishing effort (location, target species, fishing gear, start and end of fishing time, hours of fishing), and their catch. Where possible, fish were measured. During 2017–18, the protocol was expanded, with fishers being asked about interactions with seabirds. Specifically,

Table 2: Sources of data providing information about recreational fishing in New Zealand. For each source, the table indicates where the data are held (BWM: Bluewater Marine Limited; Fish4All: Fish4All Limited; Fishbrain: Fishbrain AB, Sweden). For fisheries effort, the scope indicates which component of the recreational fisheries is covered by the data. The method is either Ad hoc: haphazard reporting; Survey: independent survey with formal data collection procedures; Logbook: fisher self-reported; Statutory: reporting required by regulation; or Monitoring: passive monitoring methods.

Source	Held	Scope	Method	Description
Aerial & boat ramp survey	Fisheries NZ	Boat	Survey	Boat ramp and aerial survey used to estimated fishing effort and catch by recreational fishers using trailer boats. Most recent surveys in FMA 1 in 2017–18 (Hartill et al. 2013, Hartill et al. 2019).
Diary survey	Fisheries NZ	All	Survey	National Panel Survey (NPS), carried out at 5-yearly intervals, most recently in 2017–18. The most recent survey asked 6975 marine fishers and 2203 non-fishers about fishing catch and effort through 2017–18. All methods were recorded (Wynne-Jones et al. 2019).
Web camera	Fisheries NZ	Trailer-boat	Monitoring	Web-camera monitoring of boat ramps used to record recreational activity, in FMAs 1, 8, and 9 (Hartill et al. 2015).
Charter	Fisheries NZ	Boat	Statutory	All recreational charter vessels report fishing effort and catch of selected species to Fisheries NZ (Fisheries New Zealand 2020).
Billfish logbooks	BWM	Gamefish	Logbook	Logbook programme designed to collect catch and effort information from recreational vessels targeting marlin off northern New Zealand. (Holdsworth & Boyd 2017, Blue Water Marine 2020).
Fish4All	Fish4All	All	Logbook	Fish4All is a New Zealand organisation with a mobile app that allows fishers to record their catches, but not bycatch (https://www.fish4all.co.nz).
Fishbrain	Fishbrain	All	Logbook	Fishbrain is a Swedish company with a mobile app that allows fishers to record their catches, but not bycatch (https://fishbrain.com). It operates globally and is used by New Zealand fishers.

fishers were asked “Did you catch any birds with your fishing gear today?”. If the fisher answered “yes”, then they were shown a card with a description and photographs of seabirds, and asked to identify the seabird taxon as either: gull (A); gannet (B); shag (C); penguin (D); tern (E); albatross or mollymawk (F); petrel or shearwater (G); unidentified (U), where the letter in parentheses was the code recorded by the interviewer. If no bird was caught, the interviewer recorded “N”.

If the fisher had caught a bird, then a follow-up question was asked: “How did you catch the bird and what was the outcome?”, with the responses recorded in different categories (see Table 3).

The database records an identifier for the interview session (carried out by an interviewer at a boat ramp on a particular day), the boat, and the fisher. A record was made for each combination of fishing location, fishing method, and target species that was used by the fisher. The seabird bycatch questions were asked of each fisher. The response form allowed an interviewer to record a single seabird capture for each fisher, with the instructions to the interviewers stating ”if a fisher catches more than one bird, assign the next bird caught to another fisher’s number”.

Other information collected during the boat ramp surveys included:

- Session ramp: the boat ramp where the interview was held.
- Session date: the date of the session.
- Session conditions: typical sea conditions, rain, and wind during the interview session.
- Location: the area of the fishing, using the ‘fish_loc’ areas defined in the rec_data database (Fisher & Dick 2007).

Table 3: Details of seabird captures recorded during boat ramp interviews of recreational fishers. The responses were categorised based on the question asked when fishers had caught a bird: “How did you catch the bird and what was the outcome?”.

Capture method	Capture location	Outcome	Code
Tangled in line with no hook contact		Released alive	A
		Dead	B
Hooked but hook removed	Hooked in beak or gizzard	Released alive	C
		Dead	D
	Hooked externally	Released alive	E
		Dead	F
Hooked but hook not removed	Hooked in beak or gizzard	Released alive	G
		Dead	H
	Hooked externally	Released alive	I
		Dead	J
Caught in net		Released alive	K
		Dead	L

- Target species: the fish species that was primarily targeted (with the code 'GEN' recorded if no particular species was targeted).
- Fishing method: the method of the fishing, e.g., bait fishing, long line, trolling.
- Start time: the start time of the fishing (lines in the water), to the nearest quarter of an hour.
- End time: the end time of the fishing (lines out of the water), to the nearest quarter of an hour.
- Time spent on other activity: any time between the start and end of fishing that was not spent fishing (e.g., time spent for lunch, or other activities such as water skiing).

Data from the 2017–18 recreational boat-ramp survey were provided by Fisheries New Zealand, as an extract from the rec_data database. The data were summarised, including some data preparation:

- Fishing durations were defined from the difference between the start and end time of the fishing, less any non-fishing time (if any non-fishing time was recorded).
- Records were associated with a Fisheries Management Area (FMA), based first on the location of the fishing, and then on the location of the boat ramp where the fishing was carried out from (with the exception of any otherwise unlocated fishing from Mana, Wellington, which was in multiple FMAs).
- Boat-based fishing using a fishing rod, longline, or trolling was marked as methods to be included in the analysis; the fishing-rod methods were classed as either rod and bait, or rod and lure (to test whether birds may be caught more frequently if bait was used). In the estimation, the methods were grouped as either "line" or "longline".
- Target species were restricted to the most commonly targeted fish species (snapper, blue cod, kingfish, kahawai, gurnard, and tarakihi, hāpuku, and bluenose); all tuna and billfish were grouped as "gamefish"; all shellfish were grouped as "shellfish"; all other targets were grouped as "general".
- Records were marked as incomplete if either: the question about seabird captures was not answered, no FMA could be derived for the record; or no fishing duration could be defined.
- To assist with spatial modelling, an adjacency matrix was prepared, identifying the fishing locations that shared a common boundary (defined by being within two kilometres of each other). There were two disjointed locations in FMA 1: Asteron Reef (AST) and White Island (WHI). Fishing on Asteron Reef was merged with fishing in the close-by location Motiti Island (MII), while entries were added to the adjacency matrix to identify White Island as being adjacent to the Ōpōtiki (OPO) and the Matata (MAT) areas. In South Island, the Kaikōura area (KAI) was identifed as being adjacent to Port Underwood (POU) (there were no fishing locations between these two locations in the NPS).

The data preparation included summaries and the development of a statistical model to estimate capture rates in boat-fishing across all FMAs. In addition, a spatial model of seabird capture rates in FMA 1 was developed to represent variation in seabird capture rates throughout this northern region.

2.4 National Panel Survey

The 2017–18 National Panel Survey (NPS) was carried out between 1 October 2017 to 30 September 2018 by the National Research Bureau Ltd (NRB). A total of 6975 marine fishers were surveyed throughout the year about their fishing activity, and a further 2203 members of the public screened as "non-fishers" reported their fishing activity over the fishing year. The survey of fishers was carried out through a regular poll (weekly, fortnightly or monthly), which asked whether they had been fishing. They were able to reply with "yes" or "no"; fishers who replied "yes" were telephoned and asked follow-up questions about their fishing activity. The recruitment of people to the panel was balanced demographically and geographically, to allow for scaling from the survey to the New Zealand population. From the survey data, NRB were able to estimate fishing effort and catch by marine recreational fishers during the 2017–18 fishing year.

At the end of the year, the fishers were invited to participate in an exit survey, referred to as the "characterisation survey". During this survey, they were asked questions relating to seabird bycatch. Participants were first asked: "During the last fishing year, have seabirds disrupted your fishing activity?", and were able to respond "yes" or "no". They were then asked "How did seabirds disrupt your fishing? (select all that apply)", with the following possible responses:

- "By chasing and grabbing your baits (but not getting caught)".
- "By taking hooked or released fish (but not getting caught)".
- "By becoming entangled in your lines".
- "By taking a baited hook and needing to be unhooked".
- "Other (Please specify)".

They were asked: "How often did one of those events occur?", with the following possible responses:

- "Once or twice, occasionally".
- "Several times".
- "Most trips".

The final seabird-related question asked them to identify the birds as either:

- "large albatrosses";
- "smaller petrels or shearwaters, often darkly-coloured";

- “shags”;
- “terns”;
- “penguins”;
- “don’t know the name”;
- “other (please specify)”.

(Note that, because of the design of the survey, the answers to these questions cannot be related to one another if multiple responses are selected. For example, if someone selected multiple ways in which seabirds disrupted their fishing, and identified multiple seabirds, it is not possible to associate the seabird with the disruption method.)

The data from the characterisation survey were provided by Fisheries New Zealand. There was no direct link between the data in the characterisation survey and the main survey data that was available from the rec_data database. Fishers provided an estimate of their activity in the characterisation survey, but there was no available effort measure associated with the records of seabird captures.

2.5 Estimating seabird captures

To estimate seabird captures, two simple models were fitted to the data. The models were generalised linear models (GLMs) fitted using the Bayesian libraries BRMS (Bürkner 2017, 2018), which provides an interface to the Stan modelling software (Stan Development Team 2018). The first model was used to estimate the seabird capture rate in fishing using rod and longline methods, by method. Using the BRMS notation, the first model was specified as

```
capture  ~ offset(log(hours)) + method + fma,
```

where “capture” is the number of seabird captures; the number of captures was assumed to be proportional to the fishing duration (expressed in hundreds of hours), indicated by the “rate(hours)” notation. The linear predictor includes a fishing method fixed-effect (“longline”, relative to “line” fishing) and an FMA effect (FMAs relative to FMA 1).

The data were aggregated by method and FMA before modelling, so the input data set was small (with only 12 rows). The seabird captures were assumed to be drawn from a Poisson distribution. The prior for the model intercept was a normal distribution with a mean of -5, and a standard deviation of 2; the prior for the fixed effects was a normal distribution with a mean of 0 and a standard deviation of 1. The Markov chain Monte Carlo (MCMC) sampling was carried out for 1000 warm-up iterations, followed by 1000 further iterations, using four chains with no thinning, which resulted in the retention of 4000 samples of the posterior distribution of each parameter. The posterior distributions were summarised using the mean and the 95% credible interval, calculated from 2.5% and 97.5% quantiles of the posterior samples. In a Bayesian model, this credible interval can be interpreted as meaning that there is a 95% probability that the true value is within the credible interval, given the model, the data, and priors.

The estimated seabird captures in 2017–18 were assumed to be the product of a seabird capture rate (number of birds captures per 100 hours); the mean number of hours per trip; and the number of trips per FMA during 2017–18. For each of the seven FMAs and two methods, the seabird capture rate was estimated by taking 4000 samples of the estimated mean capture rate from the model; 4000 bootstrap samples of the mean number of hours of fishing per fisher-trip, from the boat ramp data; and 4000 samples from a lognormal distribution, paramaterised to give the number of trips reported by Wynne-Jones et al. 2019. The calculation was made for each of the 4000 sets of samples, allowing for uncertainty to be reported in the final estimate of the seabird captures.

For each FMA, Wynne-Jones et al. 2019 reported fishing effort as the number of trips made during the 2017–18 year, based on the gear used. An extract of the estimated number of trips was provided by FMA, fishing method, and platform. In particular, the number of trips was provided for "Rod or line (not long line)" and for "Long-line including set line, contiki or kite" fishing. These fishing methods were assumed to be equivalent to the "Line" and "Longline" method-groups derived from the boat ramp data. The fishing effort estimates were also provided by platform. Fishing from all vessel-based platforms, including "Trailer motor boat", "Larger motor boat or launch", "Trailer yacht", "Larger yacht or keeler", and "Kayak, canoe, or rowboat" was included in the estimate on the assumption that fishing from these platforms had the same characteristics, with respect to seabird bycatch, as boat-based fishing that was recorded during the boat ramp survey. Fishing that was "Off land, including beach, rocks or jetty" or from "Something else", was not included in the estimation.

Across "Line" and "Longline" fishing, 51.1% of trips were a trailer motor boat platform, 31.0% of trips were from shore fishing, 0.5% were from methods marked "Something else", and the remainder (17.4%) were from other vessels.

A second model was fitted to data restricted to FMA 1. The purpose of this model was to explore spatial variation in the seabird capture rate within the FMA 1 region. The model was a Conditional Autoregressive (CAR) model, which assumes that the mean capture rates in adjacent fishing locations are related to one another (Jin et al. 2005, Joseph 2016). In BRMS notation, this aspect is specified as:

```
capture  ~ offset(log(hours)) + method + car(adjacency, gr=location).
```

The adjacency matrix was calculated by identifying fishing location polygons that came within 2 km of each other. As with the national model, a Poisson distribution was assumed. The priors were the same as in the national model, and the standard deviation of the fishing location effects was a student-t distribution with mean 0, standard deviation of 2.5, and three degrees of freedom. The MCMC sampling was the same as in the previous model.

2.6 Seabird overlap with recreational fisheries

Fishing effort data were also used to analysis the overlap between the spatial distribution of recreational effort and seabirds. Analysing the overlap is part of the Spatially Explicit Risk Assessment (SEFRA; e.g., Sharp 2018), which provides a method for assessing the impacts of fishing on protected species populations. The method uses the overlap between the spatial distribution of fishing effort and species distributions, to allow extrapolating from observed fishing effort (where there is data on the captures) to all fishing effort. It is based on the assumption that the number of captures is proportional to both the fishing effort and the species density. The risk assessment then derives an estimated mortality (derived from the estimated captures using assumptions about the mortality rate of capture animals, and the number of animals that may be killed, but not recorded by observers). The mortality is then compared with an estimate of population productivity, to derive an estimated risk that the fishing is impacting the population. In the context of commercial fisheries, the SEFRA method has been applied to seabirds (Richard & Abraham 2020, e.g.,) and marine mammals (Abraham et al. 2017, Roberts et al. 2019) in New Zealand waters.

Here, the overlap was calculated for two seabirds species that breed in northern New Zealand and have been identified as vulnerable to fishing impacts: black petrel (*Procellaria parkinsoni*) and flesh-footed shearwater (*Puffinus carneipes*). Black petrel is the species with the highest risk of impact from commercial fishing, while flesh-footed shearwater is assessed to be at "high risk" (Richard & Abraham 2020).

For these two species, the overlap was analysed using their distributions and a relative intensity of fishing. The fishing intensity was calculated by Fisheries New Zealand based on counts of recreational fishing boats, from the 2011–12 aerial survey (Hartill et al. 2013). The distribution is of the annual density of fishing vessels per square kilometre, and integrates to 555 076 over the domain (which covers the North Island and Marlborough Sounds regions).

Black petrel and flesh-footed shearwater distributions were used from Fisheries New Zealand[1]. The seabird distributions were projected onto a 1-km grid (using the New Zealand Transverse Mercator 2000 projection), and normalised so that they integrated to one over the domain (this distribution does not account for the proportion of the population that is outside the New Zealand region). The overlap was calculated by mapping the fishing intensity onto the same grid, and multiplying the two together.

3. RESULTS

3.1 Boat ramp survey

The boat ramp survey was carried out between October 2017 and September 2018 (Hartill et al. 2019). A total of 51 295 fishers were interviewed. Of this total, 43 669 fishers were asked whether they had caught a seabird. Critical metadata (fishing duration, FMA) could not be derived from 23 interviews, and these interviews were not included in the present analysis. The dataset used for analysing seabird captures included data from 43 646 interviews that had been conducted of fishers from 17 627 fishing groups, during 2 170 distinct interview sessions at 77 boat ramps (Table 4).

The interview effort was primarily in FMA 1 (on the North Island east coast, see Figure 1 for FMA boundaries), and 76.8% of all interviews were carried out in this northern area (Table 4). This spatial bias reflected a goal of the survey during the 2017–18 fishing year, which was to provide estimates of recreational take of fish species in FMA 1, by carrying out boat ramp surveys in conjunction with aerial overflight surveys (used to count the number of boats fishing). Across all interviews, a total of 455 seabird captures were

[1] https://mpi.maps.arcgis.com

reported, with 92.3% of these captures reported from fishing in FMA 1. Within FMA 1, the seabird capture rate was 0.35 captures per 100 hours of fishing. Across all of the interviews, the average seabird capture rate was 0.29 captures per 100 hours of fishing.

Across all data, 76.8% of the fishers used a rod with baited hooks (this category also included fishers that used mixed methods, such as bait fishing and jigging, or a combination of bait fishing and use of plastic lures); 85.7% of the reported seabird captures were associated with this fishing method (Table 5). In comparison, 9% of fishers used a rod with a lure (such as fishing with plastic soft baits, jigging, and fly-fishing), and 9% of seabird captures were associated with this method. The seabird capture rates were the same (0.32 seabirds per 100 fishing hours) for both rod-fishing methods, irrespective of whether bait or lures were used. The other methods that reported seabird captures were trolling and longlining. Of the methods with no reported seabird captures, diving and the use of bottom gear (pots or dredges) had around 4000 hours of fishing effort reported, while the other methods had around 500 hours or less of fishing effort reported.

When restricted to boat-based rod, longline and trolling fishing methods, the seabird capture rates were highest within FMA 1, in the Hauraki Gulf area (Figure 1). In this area, the capture rates were over 1 seabird capture per 100 hours of fishing in some of the fishing locations. The FMA 1 area was also the region with the highest number of interviews. High seabird capture rates (over 0.5 seabirds per 100 hours of fishing) were also reported from fishing close to New Plymouth, in FMA 8, and at locations close to Dunedin, in FMA 3. Within FMA 7, fishing was surveyed in the Marlborough Sounds, Tasman Bay and Golden Bay regions, at the north of South Island. There were no interviews carried out on the South Island west coast. In FMA 5, all of the survey effort was of fishers using the boat ramp in Bluff, and there were no surveys of fishers in Fiordland, at the south of the South Island west coast.

The most frequently targeted species was snapper, which was targeted by 62.7% of all fishers (Table 6).The highest seabird capture rate was for recreational fishing targeting kahawai (0.87 captures per 100 fishing hours), while seabird capture rates for target

Table 4: Boat ramp interviews of recreational fishers carried out between October 2017 and September 2018, by Fisheries Management Area (FMA) (Hartill et al. 2019). Shown for each FMA are the number of fishers, the number of boats, the number of interview sessions, the number of distinct ramps surveyed, the total number of hours of fishing, the total number of reported seabird captures, and the seabird capture rate (captures per 100 hours of fishing). Interviews where the fisher was not asked about seabird captures, or that lacked information for deriving fishing duration or FMA were not included.

FMA	Fishers	Boats	Sessions	Ramps	Fishing hours	Captures	Capture rate
1	33 537	14 004	1 558	58	120 566	420	0.35
2	1 818	683	127	5	8 085	8	0.10
3	1 999	702	140	7	6 830	7	0.10
5	574	133	23	1	1 227	3	0.24
7	2 789	854	148	4	8 502	5	0.06
8	1 509	642	94	6	5 190	12	0.23
9	1 420	610	100	3	4 728	0	0.00
All	43 646	17 627	2 170	77	155 130	455	0.29

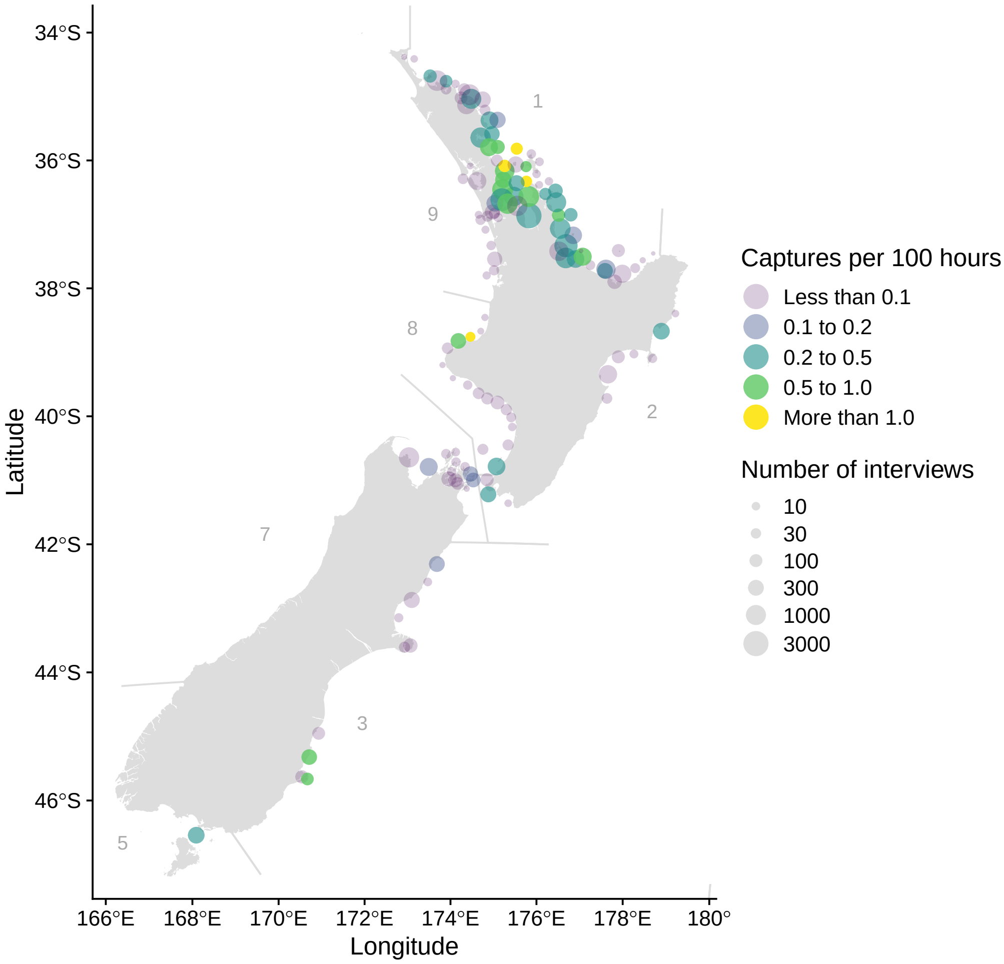

Figure 1: Seabird capture rate by recreational fishers by fishing location, based on boat ramp interviews (Hartill et al. 2019). For each reported fishing location, the colour of the circle indicates the capture rate (number of seabird captures per 100 hours of fishing), while the size of the circle indicates the number of fishers interviewed. Data were restricted to boat fishing by rod, longline or troll (the methods that had recorded captures). There were 106 interviews that reported a general fishing location, which are not shown on the map. Inshore boundaries of Fisheries Management Areas 1, 2, 3, 5, 7, 8, and 9 are indicated by grey lines.

Table 5: Seabird captures reported in boat ramp interviews of recreational fishers, by fishing method (Hartill et al. 2019). Shown for each method are the number of fishers interviewed, the number of boats that used it, the total number of hours of fishing, the total number of reported seabird captures, and the seabird capture rate (captures per 100 hours of fishing). The methods summarise the following methods reported by the interviewers: Rod and bait – baitfishing, baitfishing and plasic soft baits, baitfishing and jigging, live baiting (not balloon fishing); Rod and lure – jigging, plasic soft baits, poppers, fly casting, spinning; Longline – longlining, kite fishing (long-line); Diving – snorkel diving, scuba diving, spear fishing; Net – set net, drag netting; Bottom gear – dredging, potting (i.e., for crayfish); Trolling – trolling with lure, trolling (lure and bait), trolling with a bait; Bottom line – drop/dahn line, bottom longline; Gathering – hand gathering (eg pipi); Shore fishing – wharf (or jetty) fishing, surfcasting (off the rocks), surfcasting (rocks and sand); Mixed – 2+ expert methods.

Method	Fishers	Boats	Fishing hours	Captures	Capture rate
Rod and bait	33 536	14 122	122 041	390	0.32
Rod and lure	3 937	1 883	12 946	41	0.32
Trolling	2 121	991	9 340	23	0.25
Longline	802	394	2 000	1	0.05
Diving	2 225	1 017	4 156	0	0.00
Bottom gear	684	346	3 838	0	0.00
Net	186	99	524	0	0.00
Bottom line	29	16	124	0	0.00
Gathering	103	46	102	0	0.00
Mixed	10	3	36	0	0.00
Shore fishing	13	12	22	0	0.00
All	43 646	17 627	155 130	455	0.29

species with a more southern distribution (gurnard and blue cod) were low (0.03 and 0.15 captures per 100 fishing hours, respectively). Fishing targeting gamefish also had a low seabird capture rate (0.06 captures per 100 fishing hours). No captures were recorded from fishing targeting species that were fished using diving, bottom gear or hand gathering (rock lobster, shellfish, and kina), or from fishing targeting either hāpuku or bluenose.

Seabird captures were reported in all FMAs where interviews were carried out, excepting FMA 9 ((Table 7). The most frequently caught taxa were petrels and shearwaters, with 50.8% of all reported captures in this group. Captures were reported for all the taxa that were included in the form used by interviewers; however, 14.7% of captures were not identified. For all taxa, the highest number of captures was recorded in FMA 1, reflecting the higher interview effort (Table 4). The group with the highest proportion of captures outside of FMA 1 were albatrosses, which had over half of reported captures in other areas.

Birds were most frequently reported as tangled in the line, with no hook contact (Table 8): 58.7% of birds were reported to have been caught in this way; 18.9% of birds were reported as being hooked in the beak or gizzard, and 16.7% were reported as being hooked externally, or foul-hooked. The remaining captures were either caught in a net (these two net captures occurred during fishing with a rod and bait), or did not have the capture method recorded. Of the birds that were hooked, the hook was reported as being removed 90.7% of the time.

Table 6: Target species reported by recreational fishers during boat ramp interviews (Hartill et al. 2019). Shown for each target species are the number of fishers, the number of boats that targeted those species, the total number of hours of fishing, the total number of reported seabird captures, and the seabird capture rate (captures per 100 hours of fishing). The target "general" includes fishers that did not report a specific target species, and also species that were targeted for less than 1000 hours of fishing. The target "gamefish" included tuna, marlin and swordfish species.

Method	Fishers	Boats	Fishing hours	Captures	Capture rate
Snapper	27 380	11 606	97 891	328	0.34
General	5 440	2 315	18 861	47	0.25
Kingfish	2 042	932	7 716	33	0.43
Kahawai	905	421	2 183	19	0.87
Tarakihi	729	326	2 989	13	0.43
Blue cod	2 330	782	6 593	10	0.15
Gamefish	1 166	539	6 995	4	0.06
Gurnard	744	345	3 090	1	0.03
Rock lobster	1 026	536	4 492	0	0.00
Shellfish and kina	1 406	625	1 843	0	0.00
Hāpuku	303	125	1 444	0	0.00
Bluenose	175	75	1 032	0	0.00
All	43 646	17 627	155 130	455	0.29

Table 7: Seabird captures, by species group and area, reported by recreational fishers during boat ramp interviews (Hartill et al. 2019). Shown for each species group are the number of captures recorded in each Fisheries Management Area (FMA).

Taxon	FMA						
	1	2	3	5	7	8	All
Albatross	7		5	1		2	15
Gannet	32						32
Gull	31	1	2	1	1	6	42
Penguin	3						3
Petrel	225	4			2		231
Shag	38	2			2	3	45
Tern	19	1					20
Unidentified	65			1		1	67
All	420	8	7	3	5	12	455

The captured birds were reported as released alive in 98.4% of the records. Across all of the survey, there were only seven birds that were reported as dead. One bird was a gannet, caught during bait-fishing targeting snapper, that was hooked in the beak or gizzard. The other six records of dead birds were all from a single fishing group, also bait-fishing targeting snapper. The captures were all recorded as unidentified birds that had been tangled in the line.

These records illustrate a potential limitation of the data: all of the six fishers in the group that reported six dead captures had an identical seabird capture record reported for them. Across all the data, there were captures reported from interviews with fishers from 340 groups. Of these groups, 264 reported a single capture, while 76 reported more than one seabird capture (between two and six captures). Of the groups with multiple seabird captures, 46 reported the same number of captures as number of fishers in the group, with each capture being of the same seabird taxon, and with the same reported capture characteristics. Because of the structure of the form (allowing up to one seabird capture to be reported for each fisher), the number of reported captures could not be greater than the number of fishers in the group.

3.2 National Panel Survey (NPS)

There were 1847 responses to the NPS characterisation survey, and 1203 fishers answered the question relating to seabirds (“During the last fishing year have seabirds disrupted your fishing activity?”), with 295 (24.5%) fishers answering “yes”.

There were 52 respondents who reported that a bird took a baited hook and needed to be

Table 8: Seabird captures reported in boat ramp interviews of recreational fishers, by species group and outcome (Hartill et al. 2019). For each capture, the interviews recorded how the bird was caught (caught in a net, hooked externally, i.e., foul-hooked; hooked in the beak or gizzard; or tangled in the line without being hooked). For birds that were hooked, the interviewer recorded whether the hook was removed. For all captures, the outcome was recorded: whether the bird was dead, or was released alive.

Capture	Hook	Outcome	Albatross	Gannet	Gull	Penguin	Petrel	Shag	Tern	Unidentified	All
Caught in net		Alive	0	0	0	0	1	0	0	1	2
Hooked externally	Not removed	Alive	0	1	1	0	0	0	0	2	4
	Removed	Alive	3	7	4	1	39	7	4	7	72
Hooked in beak or gizzard	Not removed	Alive	1	0	0	0	2	2	0	6	11
	Removed	Alive	2	8	6	0	28	16	1	13	74
	Removed	Dead	0	1	0	0	0	0	0	0	1
Tangled		Alive	9	15	29	2	160	16	14	16	261
		Dead	0	0	0	0	0	0	0	6	6
Unknown			0	0	2	0	1	4	1	16	24
All			15	32	42	3	231	45	20	67	455

unhooked at some stage during the fishing year (Table 9). There were also 33 respondents who reported a bird becoming entangled in their lines. Respondents were able to select multiple responses, and some respondents reported both of these interactions. (Note that respondents were not able to report more than one interaction of the same kind.) There were 212 respondents who answered that the types of incidents disrupting their fishing (described in Table 9) occurred "once or twice, occasionally". In comparison, 62 respondents answered that that the incidents occurred "several times", and 20 answered that incidents occurred on "most trips". Respondents were not able to report how often entanglement or hooking occurred, compared with apparently more frequent incidents such as "…chasing and grabbing your baits (but not getting caught)".

3.3 Estimated seabird captures

The national model of seabird captures converged (all Gelman-Rubin $\hat{R}$ diagnostics were less than 1.00, and there were no divergent transitions), and traces of the MCMCs were stable and overlapping (Figure 2). Seabird capture rates were lower in "longline" than in

Table 9: Responses to the National Panel Survey question, "How did seabirds disrupt your fishing?". For each response, the number of people who selected it is shown; the two unique responses where from people who selected "other (please specify)". Respondents were able to select multiple responses, and so the number of responses is higher than the number of people who answered "yes" to the question "During the last fishing year have seabirds disrupted your fishing activity?".

Response	Number
By chasing and grabbing your baits (but not getting caught)	225
By taking hooked or released fish (but not getting caught)	92
By becoming entangled in your lines	33
By taking a baited hook and needing to be unhooked	52
Attacking fish on my float line while spearfishing	1
Kept trying to take our mussels	1
Total responses	404

Table 10: Responses to the National Panel Survey question, "What types of birds were involved?" (in captures). For each response, the number of people who selected it is shown. Two responses where "other" was selected and the bird group was described as "mollyhawks" were recoded as "large albatrosses". One response where the bird was described as "gannet grabbed a lewer on the surface" was recoded as "gannets".

Response	Number
Gulls	146
Shags	125
Smaller petrels or shearwaters, often darkly-coloured	74
Large albatrosses	32
Don't know the name	17
Terns	5
Gannets	2
Penguins	1

"line" fishing. Relative to FMA 1, mean capture rates were lower in all other FMAs. The FMAs with capture rates most similar to rates in FMA 1 were FMA 5 and FMA 8.

From the fitted model, the number of seabird captures was estimated by FMA and by method (Table 11). The highest number of trips was in FMA 1 (987 387; coefficient of variation, CV: 0.06), and the mean capture rate was also highest in this area (0.36 birds captures per 100 hours of fishing; CV: 0.05). These estimates used a mean number of hours of fishing per trip that was derived from the boat ramp survey data as 3.79 (CV: 0.008) for line fishing and 2.53 (CV: 0.01) for longline fishing.

The number of estimated seabird captures during 2017–18 was highest in FMA 1, in "line" fishing with a mean of 10 568 captures (95% c.i.: 9 043 to 12 202) (Table 11). This combination was the only FMA-method stratum with a mean estimate of over 1000 captures. The high estimate reflected both the high estimated fishing effort and the high estimated capture rate within FMA 1. The total estimated captures by line fishing, across all FMAs, had a mean of 12 571 (95% c.i.: 10 944 to 14 356) captures. Captures by "longline" fishing were considerably lower, with a total of 86 (95% c.i.: 18 to 214) captures across all FMAs. The total estimated captures, across all the estimated fishing were 12 656 (95% c.i.: 11 037 to 14 438). These estimates are based on capture rates from the boat ramp survey, which were applied to "Line" and "Longline" fishing effort from all boats.

The spatial model of seabird captures within FMA 1 converged (all Gelman-Rubin $\hat{R}$

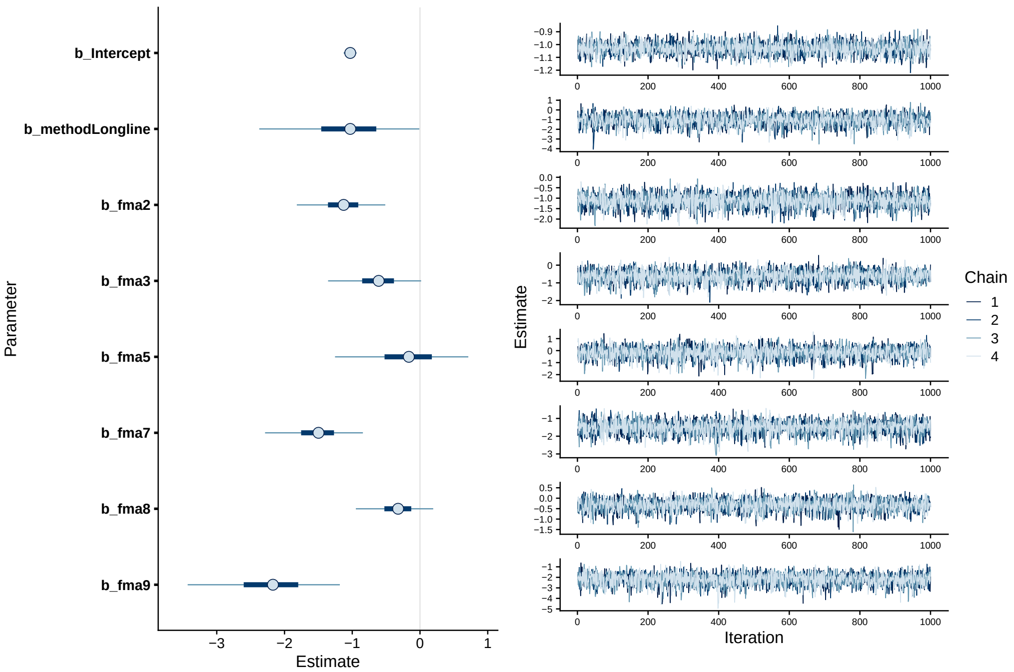

Figure 2: Credible intervals (left) and traces of the parameters (right) of the model of seabird capture rates by Fisheries Management Areas (FMA). Parameters are the model intercept, a method fixed effect (longline relative to a line effect), and FMA effects relative to FMA 1. Credible intervals shown are the 50% and 95% intervals (thick and thin lines), with the mean indicated by a point. Traces show the traces for each of the four chains, overlaid on one another.

Table 11: Estimated captures of seabirds by recreational fishers using boat-based line and longline methods, during 2017–18. The number of trips is from the National Panel Survey from 2017–18, the capture rate (birds caught per 100 hours of fishing) is from statistical modelling of the boat ramp survey data, and the estimated seabird captures are derived by applying the estimated rate to the trip data. For the number of trips and the seabird capture rate, the mean and coefficient of variation (CV) is shown; for the estimated captures, the 2.5% and 95% quantiles of the posterior distribution are also given.

Method	FMA	Trips		Capture rate		Seabird captures			
		Mean	CV	Mean	CV	Mean	CV	2.5%	97.5%
Line	1	779 521	0.06	0.36	0.05	10 568	0.07	9 043	12 202
	2	71 838	0.12	0.12	0.32	327	0.34	149	583
	3	37 993	0.11	0.20	0.34	294	0.36	130	550
	5	21 222	0.15	0.33	0.49	269	0.53	77	631
	7	121 366	0.09	0.08	0.38	381	0.39	151	721
	8	56 164	0.12	0.27	0.28	571	0.31	285	960
	9	92 779	0.12	0.05	0.57	162	0.59	40	396
Longline	1	17 087	0.16	0.14	0.58	62	0.62	13	158
	2	2 829	0.36	0.05	0.69	3	0.97	0	12
	3	1 141	0.79	0.08	0.69	2	1.40	0	10
	5	587	0.71	0.13	0.83	2	1.44	0	9
	7	9 771	0.33	0.03	0.69	8	0.85	0	26
	8	2 911	0.30	0.11	0.67	8	0.83	1	25
	9	151	0.98	0.02	0.88	0	4.21	0	1
Line	All					12 571	0.07	10 944	14 356
Longline	All					86	0.60	18	214
Both	All					12 656	0.07	11 037	14 438

diagnostics were all equal to 1.00, and there were no divergent transitions). The traces of all chains overlapped (although there was high correlation in the intercept chain) (Figure 3). The CAR parameter was broadly distributed within the zero to one range (this parameter relates to the independence of adjacent zero, with a value of zero indicating independence of adjacent areas). The mean value of "longline" fishing was lower than "line" fishing, but the 95% credible interval overlapped zero.

From this model, seabird capture rates in FMA 1 were estimated, reflecting different rates throughout this northern region (Figure 4). Consistent with the use of a CAR model, the capture rate was smoothed, relative to the raw data (see Figure 1). There was high uncertainty in areas with low sampling effort and which were only adjacent to a single other area. The smoothing was apparent when compared with the seabird capture rate derived directly from the survey data (Figure 5). The highest values were reduced, although their credible intervals still included the original values (the credible intervals include the one-to-one line, which indicates equality between the observed and estimated rates). There was a high uncertainty associated with fishing locations that had no observed captures and few fishing hours of observation.

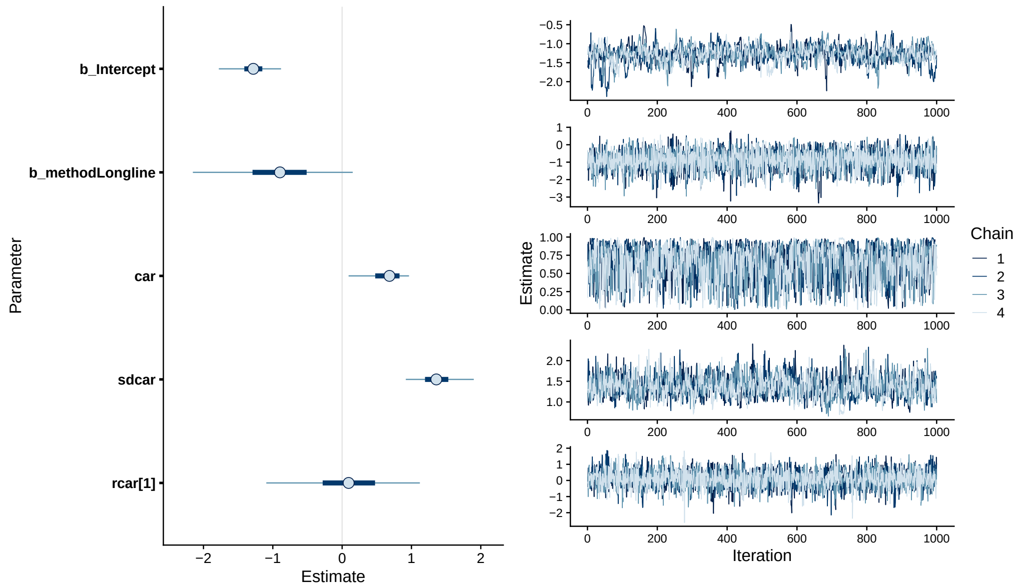

Figure 3: Credible intervals (left) and traces of the parameters (right) of the Conditional Autoregressive (CAR) model of seabird capture rates in Fisheries Management Areas (FMA) 1. Parameters are the model intercept, a method fixed effect (longline relative to a line effect), the CAR parameter, the standard deviation of the CAR random effects, and an example of one of the CAR random effects (there are 63 of these effects, one for each location with data in FMA 1). Credible intervals shown are the 50% and 95% intervals (thick and thin lines), with the mean indicated by a point. Traces show the traces for each of the four chains, overlaid on one another.

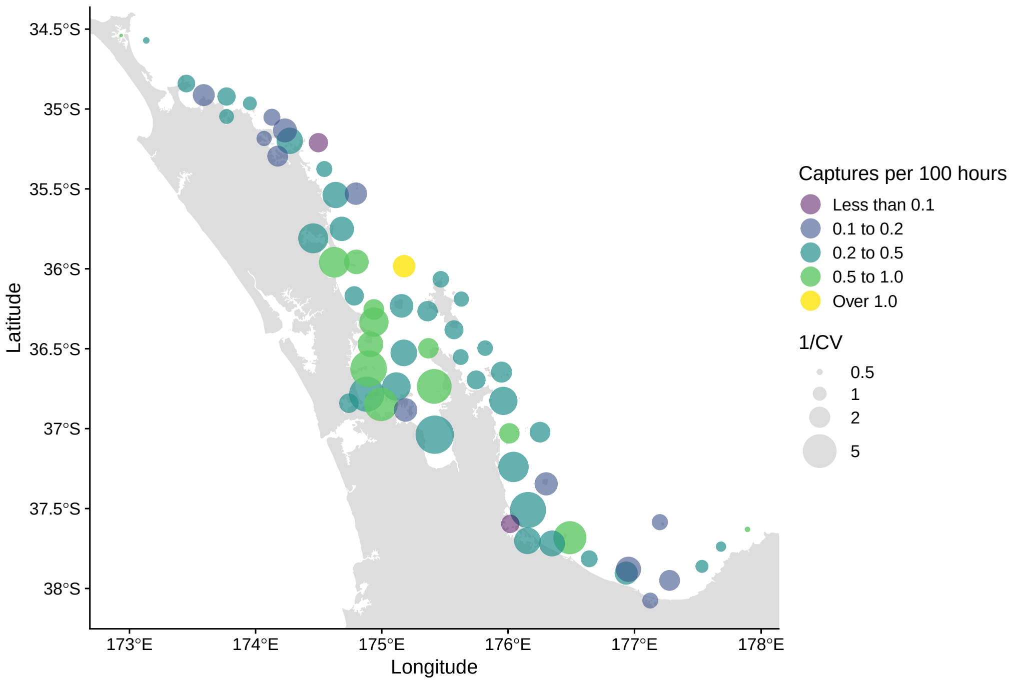

Figure 4: Estimated seabird capture rates in recreational fisheries within Fisheries Management Area 1. The capture rate (number of seabirds per 100 hours of fishing) was estimated for "line" fishing in the fishing locations. The colour indicates the mean of the posterior distribution, and the size of the circle is related to the inverse of the coefficient of variation (CV), with a larger circle reflecting a lower uncertainty.

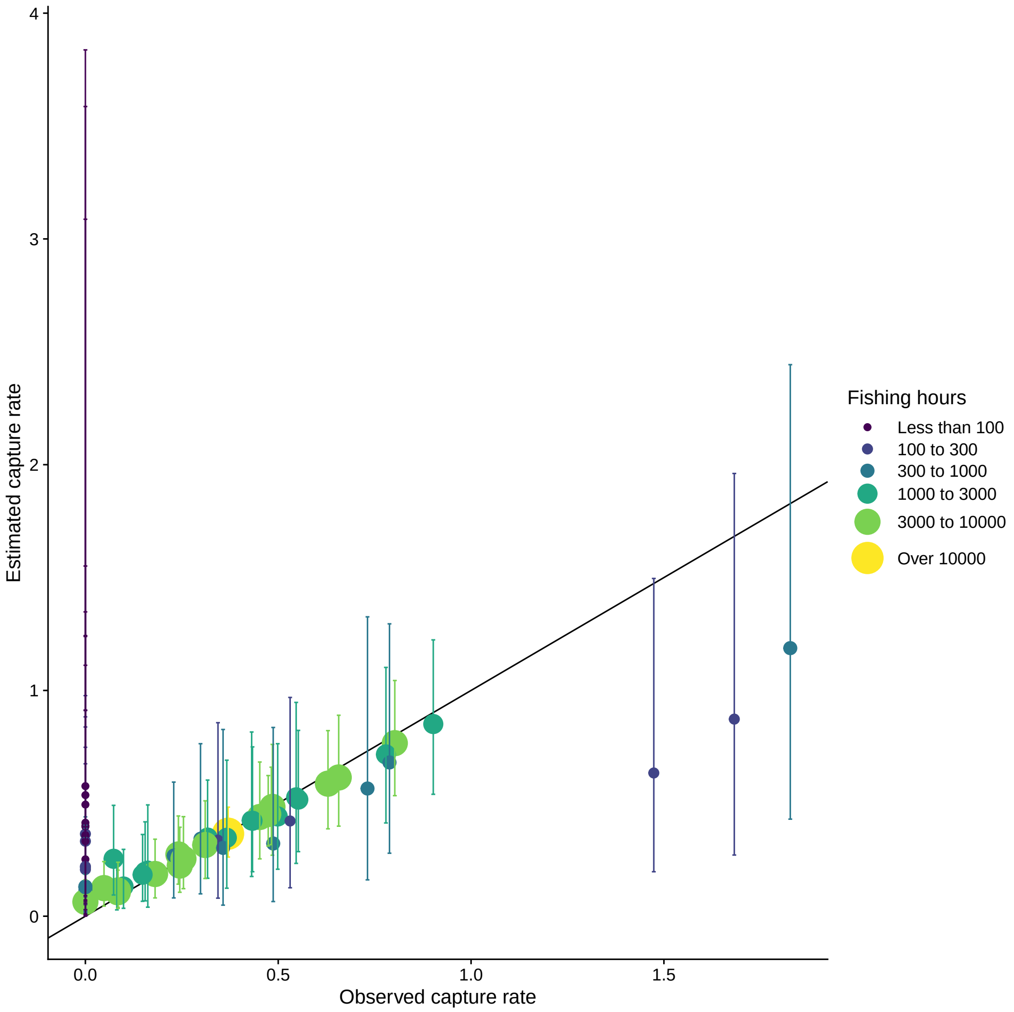

Figure 5: Estimated seabird capture rate (number of seabirds per 100 hours of fishing) in recreational fisheries within Fisheries Management Area 1 (FMA 1), compared with the observed capture rate directly from survey responses of fishers. Each circle corresponds to a fishing location within FMA 1, with the colour indicating the number of fishing hours in that area by fishers that were surveyed in the 2017–18 boat ramp survey (Hartill et al. 2019). On the y-axis, the circle indicates the mean value of the posterior distribution, and the line indicates the 95% credible interval.

3.4 Overlap and the risk assessment methodology

Effort data of recreational fishing in relation to seabird distributions were used to assess the overlap of black petrel and flesh-footed shearwater with recreational fisheries. The fishing effort used was fishing intensity, calculated by Fisheries New Zealand based on counts of recreational fishing boats, from the 2011–12 aerial survey (Hartill et al. 2013).

The distribution of black petrel was concentrated on the eastern side of Aotea/Great Barrier Island (where this species breeds), extending offshore and covering a relatively large area (Figure 6). Its overlap with fishing was highest along the eastern coastline of Aotea/Great Barrier Island and Coromandel Peninsula, and around Mercury Island.

Flesh-footed shearwater was distributed in the wider eastern North Island area, particularly in inshore waters (Figure 7). For this species, the overlap with recreational fisheries was high along the eastern North Island coastline, around Hauraki Gulf, Coromandel Peninsula and western Bay of Plenty.

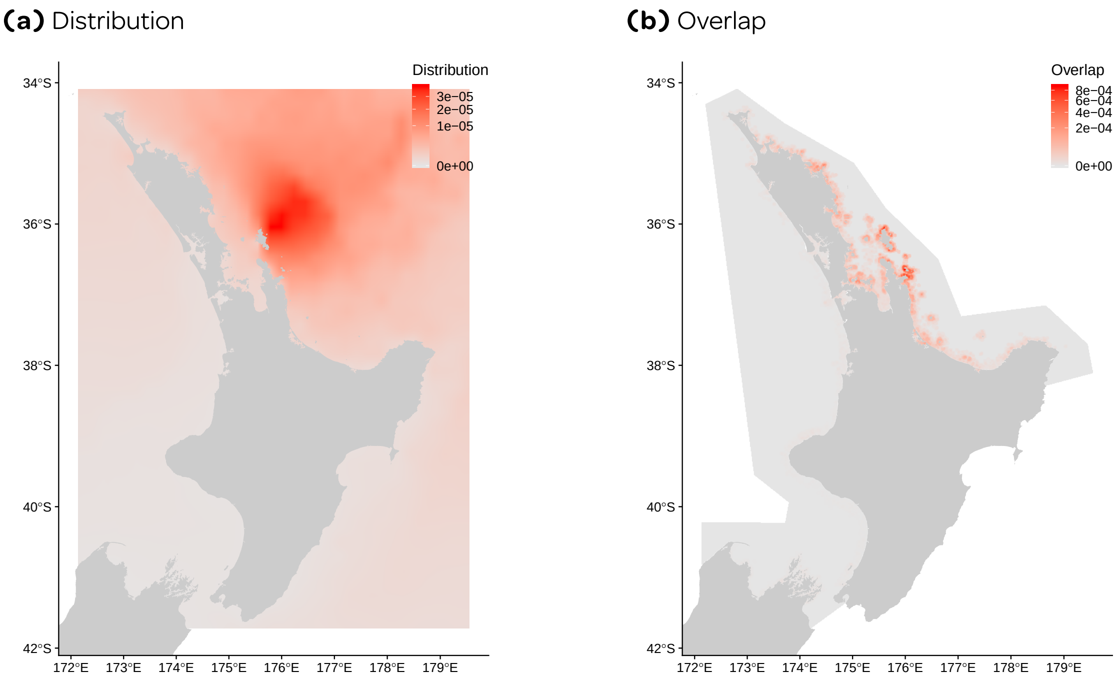

Figure 6: Black petrel (*Procellaria parkinsoni*) distribution (a) and overlap with recreational fisheries (b) in northern New Zealand.

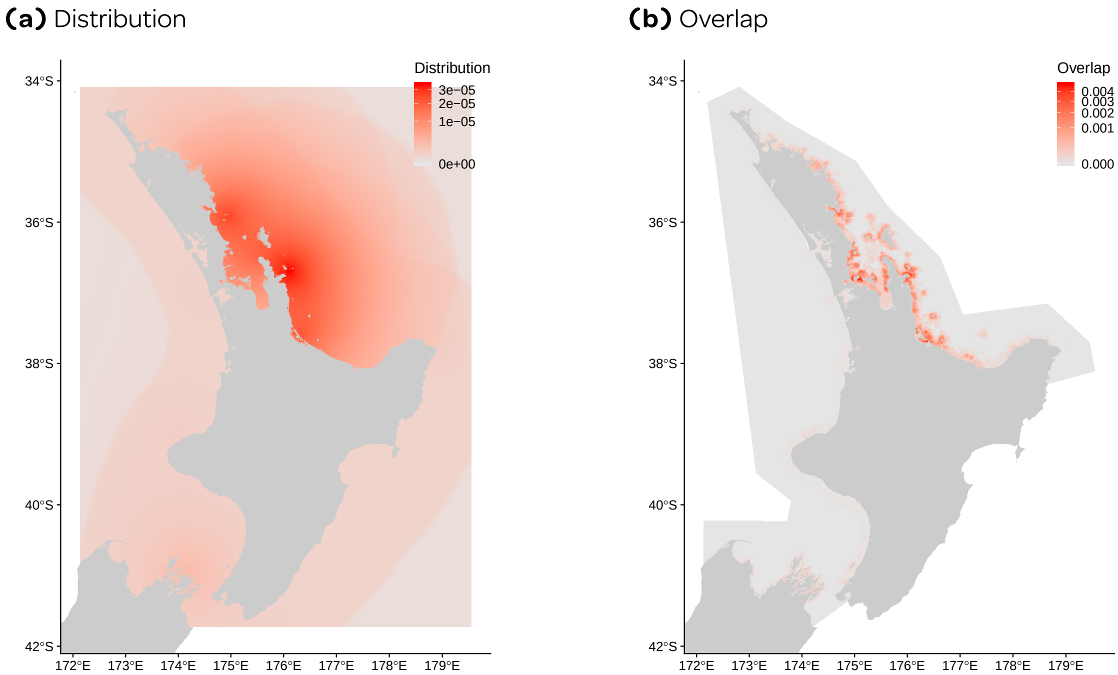

Figure 7: Flesh-footed shearwater (*Puffinus carneipes*) distribution (a) and overlap with recreational fisheries (b) in northern New Zealand.

4. DISCUSSION

4.1 Seabird captures in recreational fisheries

Both the boat ramp survey and the NPS included questions about seabird captures for the first time in 2017–18. Data from the responses, combined with effort data, allowed the estimation of seabird captures in recreational fisheries in New Zealand. The data were limited to boat-based line and longline fishing, with an overall estimate of 12 656 (95% c.i.: 11 037 to 14 438) seabird captures across the two fishing methods. The majority of captures were by longline, with an estimated mean of 12 571 (95% c.i.: 10 944 to 14 356) captures, compared with 86 (95% c.i.: 18 to 214) estimated captures in line fishing.

Within the limitations of the study, the highest captures estimates for each of these two boat-based fishing were in FMA 1, with 10 568 (95% c.i.: 9043 to 12 202) estimated seabird captures in line fishing and 62 (95% c.i.: 13 to 158) estimated captures in longline in northern North Island. The highest capture rates were in Hauraki Gulf.

Estimated seabird capture rates (number of seabird caught per 100 hours of fishing) varied between line and longline fishing and also depended on the FMA. For line fishing, the mean estimated capture rate ranged from 0.05 (CV: 0.57) seabirds in FMA 9 to 0.36 (0.05) seabirds in FMA 1. For longline fishing, it was 0.02 (CV: 0.88) seabirds in FMA 9 compared with 0.14 (CV: 0.58) seabirds in FMA 1.

These estimates are comparable to an earlier study in 2007–08 that used boat ramp surveys to interviews fishers about seabird captures (Abraham et al. 2010). Estimates from this earlier research indicated an annual total of 11 500 (95% c.i.: 6600 to 17 200) seabird captures in small-boat recreational fisheries (i.e., fishing using trailer boats) in north-eastern New Zealand. The seabird capture rate was estimated at 0.22 (95% c.i.: 0.13 to 0.34) seabirds per 100 hours of fishing, and the national estimate was up to 40 000 seabird captures per year. The similar estimates in the current study highlight that the bycatch of seabirds in recreational fisheries in New Zealand is consistent and ongoing.

Limitations of this study include the use of the NPS data for the scaling of effort: the estimate of total captures was derived here by scaling effort across all platforms, because the data extract did not allow linking to the effort data. Preferably the scaling would be applied across effort with similar characteristics as the effort surveyed in the boat ramp surveys. This limitation could be easily addressed, so that the capture rates from the NPS and the boat ramp survey can be compared.

4.2 Seabird mortalities

Understanding the mortality that results from capture in recreational fisheries remains a key uncertainty. For example, flesh-footed shearwater found on northeastern New Zealand (Bay of Plenty) beaches following the MV Rena oil spill in 2011 showed signs of having been killed following capture in recreational fisheries (Miskelly et al. 2012).

Neither the current nor the earlier bycatch study provide estimates of seabird mortalities. The direct response to the boat ramp survey suggest that the mortality rate was low (1.5% of captures were recorded as dead). The dead birds were from only two groups of fishers. This mortality rate does not include any birds that were released alive and that died subsequently. Furthermore, there may be reluctance by fishers to report mortalities to boat ramp interviewers. It is possible that the use of self-reporting tools, such as mobile applications, may alleviate this potential reluctance.

Gaining a better understanding of post-release survival would require additional information about capture incidents, such as the nature and severity of injuries. In commercial fisheries, one of the proposed options for assessing seabird captures includes an assessment tool that ranks the likelihood of post-capture survival by the severity of the injury sustained (Bell 2020). This ranking system was developed to guide decisions about the selection of captured birds for tagging studies focused on post-release survival. This assessment tool could potentially be amended to collect information about the post-release survival of seabirds in recreational fisheries also.

4.3 Potential for a risk assessment approach

Calculating the overlap between recreational fisheries and black petrel and flesh-footed shearwater highlights the potential for applying a risk assessment framework to recreational fishing. This approach has been used for seabird captures in commercial fisheries, allowing the assessment of potential fishing impacts on seabird populations (Richard & Abraham 2020). A similar approach could be used for recreational fisheries by combing seabird capture estimates with assumptions about mortality rates.

A critical aspect for applying the risk assessment is the development of spatial distributions of recreational fishing effort, using data from the boat ramp and aerial surveys and from the NPS. Although the NPS survey was not designed for this purpose, it may be possible to use the data to derive effort distributions for recreational fishing methods with limited data (i.e., set net). For example, the 2019 assessment of threats to Māui and Hector's dolphin included recreational set-net fishing (Roberts et al. 2019). For this assessment, a distribution of recreational set-net fishing was developed by Fisheries New Zealand. It may be possible to apply a similar approach to seabirds.

Even without capture rate information, an overlap analysis of species distributions and recreational fishing effort could be used to guide management interventions (such as focusing attention on areas where the provision of educational material to recreational fishers would be beneficial). Species-specific estimates of seabird bycatch, such as for black petrel or flesh-footed shearwater, could then be made by making assumptions about the relative vulnerability of particular species to capture.

4.4 Collection of formal data on recreational fishing

Current records of protected species captures are available from a variety of sources, largely consisting of opportunistic sightings and observations. This kind of anecdotal information is important for documenting incidental captures in recreational fisheries and for guiding information needs. Nevertheless, the ad-hoc nature and lack of fishing effort information usually preclude a formal assessment of these data.

The boat ramp surveys are the most reliable source of available information on seabird bycatch in recreational fisheries. Data from the boat ramp survey allowed for the current analysis, directly relating the captures to a measure of fishing effort, and providing a spatial estimate of seabird capture rates. These data could be used to estimate captures within a risk assessment framework.

Nevertheless, there are a number of limitations of these data:

- The survey only collects information from boat-based fishing, so that there is no systematically-recorded data for other methods such as set netting and shore-based fishing activities.
- The collection of information on the current form is limited in how the data are reported, and this aspect has affected the utility of the data. On the current form, a fisher can only report a single capture. This shortcoming may lead to the under-reporting of captures and an underestimate of capture rates. It is recommended that each fisher is asked whether or not they caught a seabird, and that a separate form is used when the answer is positive. The second form could ask for more detail on the capture. Because of the low number of positive responses, this additional form is not expected to markedly increase the survey effort.
- The prompt question differs between the NPS and the boat ramp survey. The collection of capture information should be standardised across all reporting methods to ensure that consistent information is collected (including the prompt question, the prompt and recording of taxon, the recording of how the capture occurred, and of the outcome).
- The analysis of the boat ramp survey data is focused on estimating the total catch of fish species. It is recommended that spatial maps of recreational fishing effort are developed from these data.

Other recommendations from this study include future research efforts that increase the understanding of seabird captures in recreational fisheries. For example, small-scale studies that focus on seabird attendance and interactions with recreational fisheries could help to clarify the relative likelihood of large shearwater species (e.g., flesh-footed and sooty shearwaters) and small shearwaters (e.g., Buller's shearwater) of getting caught in recreational fisheries.

Similarly, a targeted programme that collects a small amount of data from fishing methods other than methods represented in the boat ramp survey could help with the development of a risk assessment. Other methods include shore-based kontiki or longline fishing, and also set netting. A small amount of information on relative capture rates between species in groups (such as "petrels and shearwaters") would also help support a risk assessment. This information could be provided without requiring fishing effort information.

4.5 Options for collecting bycatch data

There are a number of options for expanding the collection of data on protected species captures, such as the systematic use of mobile applications and other crowd-sourced information. For mobile applications, the government's digital strategy recommends that government develops open standards and APIs (application programming interfaces)(New Zealand Government 2021). In the context of information on recreational fishing, this goal is broadly aligned with the recommendations by Hartill and Thompson (2016); their review of self-reporting tools for recreational fishers recommended that the government develops an interface that allows the collection of information on recreational fisheries in a consistent way. A consistent, overarching approach would allow for existing applications to contribute data, while supporting a range of data collection mechanisms without fragmenting the data.

Bycatch data are most valuable when associated effort (such as hours of fishing) is recorded. For this reason, the recording of protected species captures could be combined with fishing diary applications that are recording fishing trips and effort. If a broad-scale data collection is a goal, then working with a provider of a fishing diary application may be the most effective approach to collect the data of protected species captures. An important aspect of this digital approach is ensuring that consistent information is collected, regardless of how it is reported. An example is Fish4All[2], a New Zealand mobile application that allows fishers to record their catch. The developers of Fish4All have indicated that they have draft designs for recording protected species bycatch within their application.

One of the key challenges for the design of any data collection is ensuring the consistent recording of zero captures; i.e., fishing trips with no protected species captures. Reporting that does not include zero captures (i.e., incident reporting) is of less value, but may help determine the relative catch rates of different species. The reporting of this information could be combined with the reporting of sighting information, such as on citizen-science platforms like eBird (https://ebird.org) and iNaturalist (https://www.inaturalist.org).

Another challenge is the accurate identification of species, which is missing from the

[2] https://www.fish4all.co.nz/

data collection to date. For this reason, any application should encourage the taking of photographs.

To keep fishers engaged with a reporting platform, it may be necessary to provide an incentive for them to report information. For example, fishing diary applications could also maintain information about the fishing history.

People may discuss protected species captures in the online communities, such as Facebook and Twitter, where they are active. As an example, in February 2021, a seagull was reported on the Paekākāriki Facebook page (Paekākāriki Tauhokohoko). This page is by a private group, restricted to residents of the community, with around 1000 members. The bird was caught in a towel, and taken to the Wellington Bird Rehabilitation Trust[3]. According to the Facebook discussion, the bird was likely to be euthanased, with the Trust commenting that at the time they were getting "on average a bird a day with fish hooks attached". There is valuable information in this incident, allowing insight into what people do when they find an entangled bird. Having a designated group, or a staff member active on these platforms would allow direct engagement across a wide audience. This engagement would allow for rich data collection on the incidents.

When birds are caught, they may be taken to wildlife rehabilitation centres. These centres are a national network of organisations that rescue and rehabilitate birds (and often also other wildlife). There is potential for obtaining valuable information on the nature of these capture incidents from these organisations; in particular the impact of the capture on birds is evident from these reports. As an example, between July 2020 and March 2021, The Nest Te Kōhanga at Wellington Zoo had nine birds brought to them, including pied shags and red-billed gulls[4].Of these, seven birds needed to be euthanased. Ideally, these organisations would contribute data on captures to the Department of Conservation in a format that would allow their integration with data from other sources.

4.5.1 An example platform: iNaturalist

Anecdotal information is also available from the citizen-science platform iNaturalist, which allows the collection of observations from a broad audience, including non-fishers. Any iNaturalist observer can upload a record with a photographs to this platform; metadata, such as the time and location of each record, is also recorded, allowing observations to be mapped. There is a large and active iNaturalist community in New Zealand, reporting nature observations through this platform (https://inaturalist.nz): in 2021, over 19,000 people reported around 1,000,000 observations of about 16,000 species. Data from iNaturalist may be made available through an open license.

This platform allows the set up of specific projects, such as the "New Zealand Fishing Gear Bycatch" project (https://inaturalist.nz/projects/new-zealand-fishing-gear-bycatch). Observers who have been part of this project have collated observations of protected species bycatch and fishing gear entanglements, with 38 observations to date (May 2021), spread across 19 species (see examples in Figure 8). Observations include 11 records of pied shag hooked or tangled in fishing gear; a New Zealand fur seal hooked in the mouth with the trace attached; an eagle ray hooked in the mouth with the trace attached; and a manta ray with trailing hook and line. The iNaturalist platform also allows DOC staff to

[3]https://www.wbrt.org.nz/

[4]https://www.tvnz.co.nz/one-news/new-zealand/plea-fishers-take-used-gear-home-bird-injuries-skyrocket-over-summer

interact with observers, for species to be identified from uploaded photographs, and the mapping of capture incidents.

The iNaturalist platform may be used for monitoring purposes. An example of its use for the monitoring of biodiversity in New Zealand is the myrtle rust project (https://inaturalist.nz/projects/myrtle-rust-reporter). Myrtle rust is a fungal disease that infects plants of the Myrtaceae family, which includes native species such as pōhutukawa and mānuka. The key website for disseminating information about myrtle rust is maintained by a collaboration between Biosecurity New Zealand and DOC (https://www.myrtlerust.org.nz/).

Visitors to the website are directed to an iNaturalist project page to report observations of myrtle rust on New Zealand plants. By early 2021, over 1700 potential records of myrtle rust had been reported by over 400 different observers. The project homepage on iNaturalist allows communication with iNaturalist observers through a summary of observations to date, the provision of information and instructions, and through blog posts. By choosing to use the iNaturalist platform for the myrtle rust reporting, Biosecurity New Zealand and DOC were able to take advantage of the thousands of active iNaturalist observers who are already used to reporting observations, while taking advantage of all the features offered by the platform.

With participation from DOC, the existing iNaturalist project could be expanded, and used for the dedicated reporting of incidental captures in recreational fisheries. The advantages of using the platform include the ability to directly engage with iNaturalist observers, and to have a systematic approach for recording observations, such as the inclusion of photographs, and location and time data. Department of Conservation staff would be able to directly engage with the users to improve the data quality. For example, observations on iNaturalist of black stingray (*Bathytoshia lata*) that were potentially killed and discarded in set-net fishing were commented on by DOC staff (C. Duffy), including updating the species identification and follow-up communication[5].

4.6 The Department of Conservation's own application

The Department of Conservation has developed its own mobile application for reporting protected species bycatch. This application was trialled in Marlborough Sounds during 2020, and its use has since been expanded nationally. Data that have been reported via this application are publicly available for viewing (Figure 9). By July 2021, there were captures of six pied shag, three great white shark, two black-billed gull, two New Zealand fur seal, one green turtle, one gannet, and one black spotted grouper reported through this platform.

With suitable promotion, this application may become a valuable source of information on protected species bycatch. Some of the captures that are reported in the interface were entered by Department of Conservation staff, following reports from other sources. The database may grow to be the central collection point of records from other sources (such as iNaturalist, Facebook, media reports, and from wildlife rehabilitation centres). To facilitate this broader use, it is recommended that the database be reviewed to ensure that it supports a full range of data (such as the fate information available from the wildlife centres), that provenance information is clearly recorded (to avoid any duplication), and

[5] https://inaturalist.nz/observations/66754542

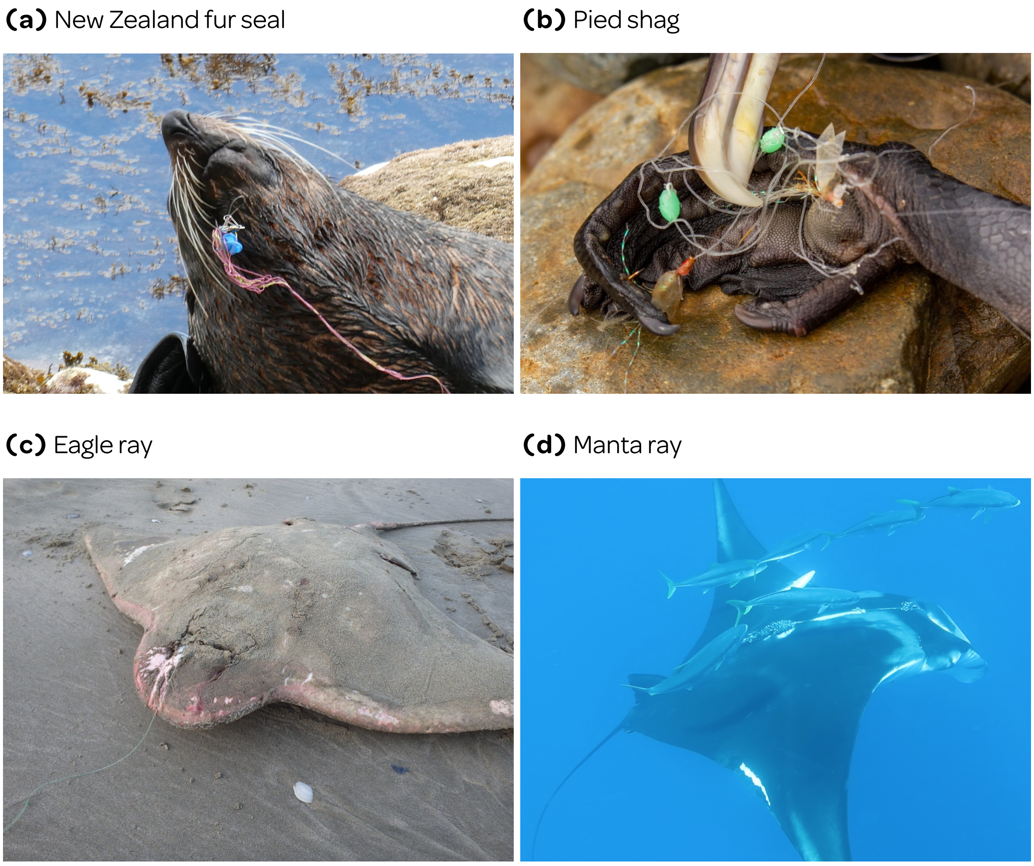

Figure 8: Example observations from the iNaturalist project “New Zealand Fishing Gear Bycatch”: (a) New Zealand fur seal, Mauao, September 2019, observation by “robyn_b”; (b) Pied shag, Kāpiti Island, May 2020, observation by Ben Knight; (c) Eagle ray, Ninety-mile beach, February 2019, observation by “ellalis”; (d) Manta ray, Poor Knights Islands, January 2018, observation by Kate Malcolm, Dive Tutukaka.

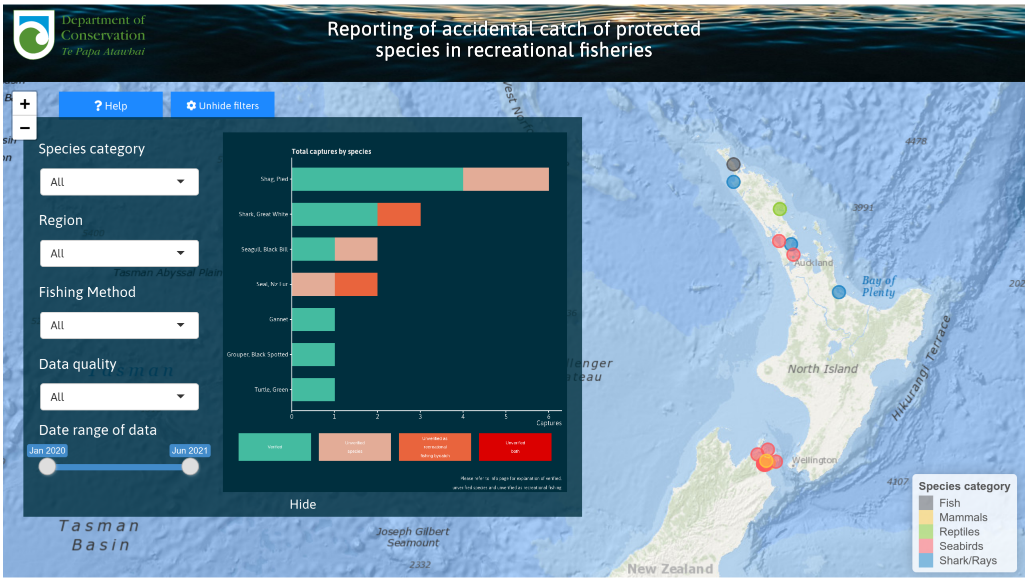

Figure 9: A screenshot from the Department of Conservation website, showing protected species captures reported via their mobile application (the screenshot was taken on 9 July 2021, from https://docnewzealand.shinyapps.io/protectedspeciescatch/.

that a full range of data entry methods is developed. The latter could include an API (so that third-party applications like Fish4All could report data), a web interface (for people who did not want to install a phone application for a single capture), and an interface for key Department of Conservation contact points (such as the DOC hotline). Wildlife rehabilitation centres may also be able to directly enter data into the database, or the API could potentially be used to be integrated with their own data collection systems (depending on the sophistication of these systems). Currently, this application has been under development. As its use continues, care needs to be taken to ensure that there is a consistent pathway for reporting these incidents, so that it is clear to people what actions they should take when they capture a protected species, or when they find an animal that someone else has caught.

4.7 Entanglements from discarded gear

The focus of the data analysis in this report was on active fishing. There is anecdotal evidence that many shorebirds are caught in discarded fishing gear. For example, in 2017, an oystercatcher had its foot amputated after being tangled in line left at Omaha Beach[6]. Discarded gear also poses a risk in subtidal environments, with the potential to impact a broader range of protected species than shorebirds. The interventions needed to reduce the impact of discarded gear will be different from the interventions needed to reduce the impact of direct captures. For this reason, it may be important to distinguish between captures that result from active fishing compared with captures from discarded gear.

There are organisations in New Zealand that are actively reducing marine litter

[6]https://www.tvnz.co.nz/one-news/new-zealand/oystercatchers-leg-amputated-after-getting-tangled-in-line-left-careless-fish

subtidally (Ghost Diving New Zealand[7]) and on coastlines (Sustainable Coastlines[8]). Sustainable Coastlines has a formal data collection programme, with the data being made openly available [9]. During beach cleanups, they record each type of marine litter, including discarded fishing gear. This information could form a basis for understanding entanglement risks to shore species from discarded gear.

4.8 Recommendations

The following recommendations are aimed at improving the data collection on seabird bycatch in recreational fisheries:

1. Engagement with people in the online platforms where they are active.
2. Support and build on existing initiatives so that people are able to capture useful data.
3. Ensure consistent collection of information across the different initiatives, so that an integrated analysis can be undertaken.
4. Collaboration with bird rehabilitation organisations nationally to ensure that they are able to contribute data.
5. Develop consistent messaging for the Department of Conservation, so that people know how to report injured or tangled animals, in a way that captures the data.
6. Develop the protected species reporting application to be a central database, holding capture information that has initially been reported on a range of platforms.
7. Develop spatial maps of fishing activity to understand the potential impacts on wildlife.

5. ACKNOWLEDGMENTS

Thanks to the many people who have provided advice and assistance with this project, including Bruce Hartill (NIWA) for help with the boatrap survey data, and more general advice on recreational fisheries; Martin Cryer and Tyler Northern (MPI) for help with accessing resources on recreational fishing; and Alisdair Gray and Andy Heinemann (NRB) for help with the National Panel Survey data.

This work was funded by the Department of Conservation (through project BCBC2019-07a). I am grateful to Dr Karen Middlemiss (DOC Marine Science Advisor) for advice, contract management, and review of earlier drafts

[7]https://ghostdivingnz.org
[8]https://sustainablecoastlines.org
[9]https://litterintelligence.org/

6. REFERENCES

Abraham, E. R. & Berkenbusch, K. (2019). Preparation of data for protected species capture estimation, updated to 2017–18. *New Zealand Aquatic Environment and Biodiversity Report No. 234*. 49 p. Retrieved from https://fs.fish.govt.nz/Page.aspx?pk=113&dk=24767

Abraham, E. R.; Berkenbusch, K. N., & Richard, Y. (2010). The capture of seabirds and marine mammals in New Zealand non-commercial fisheries. *New Zealand Aquatic Environment and Biodiversity Report No. 64*. 52 p.

Abraham, E. R.; Neubauer, P.; Berkenbusch, K., & Richard, Y. (2017). Assessment of the risk to New Zealand marine mammals from commercial fisheries. *New Zealand Aquatic Environment and Biodiversity Report No. 189*. 123 p. Retrieved from http://fs.fish.govt.nz/Page.aspx?pk=113&dk=24554

Bell, M. (2020). *Investigate options for assessing the post-release survival of seabirds that interact with commercial fisheries in New Zealand*. Unpublished Technical Report to the Department of Conservation. Retrieved from https://www.doc.govt.nz/globalassets/documents/conservation/marine-and-coastal/marine-conservation-services/reports/draft-reports/int2019-06-post-release-survival-of-seabirds-draft-report.pdf

Birds New Zealand (2020). *Birds New Zealand beach patrol*. Retrieved from https://beach-patrol.dragonfly.co.nz/

Blue Water Marine (2020). Bilfish logbooks. Retrieved from https://bluewatermarine.co.nz/project/billfish-logbooks/

Bürkner, P.-C. (2017). brms: An R package for Bayesian multilevel models using Stan. *Journal of Statistical Software*, *80*, 1–28. doi:10.18637/jss.v080.i01

Bürkner, P.-C. (2018). Advanced Bayesian multilevel modeling with the r package brms. *The R Journal*, *10*(1), 395–411. doi:10.32614/RJ-2018-017

Darby, J. T. & Dawson, S. M. (2000). Bycatch of yellow-eyed penguin (*Megadyptes antipodes*) in gillnets in New Zealand waters 1979–1997. *Biological Conservation*, *93*, 327–332.

Dawson, S. M. (1991). Incidental catch of Hector's dolphin in inshore gillnets. *Marine Mammal Science*, *7*, 283–295.

Department of Conservation (2020a). *New Zealand whale and dolphin stranding database, Wellington, New Zealand*. Retrieved from https://www.doc.govt.nz/nature/native-animals/marine-mammals/marine-mammal-sightings/marine-mammal-sighting-form/

Department of Conservation (2020b). *Report sick, injured or dead wildlife*. Retrieved from https://www.doc.govt.nz/nature/native-animals/sick-injured-and-dead-wildlife/

Department of Conservation (2020c). *What to do if you find a banded bird*. Retrieved from https://www.doc.govt.nz/our-work/bird-banding/finding-a-banded-bird/

Department of Conservation (2020d). *You can help sharks/mangō*. Retrieved from https://www.doc.govt.nz/nature/native-animals/marine-fish-and-reptiles/sharks-mango/you-can-help/

Fisher, D. O. & Dick, C. (2007). Database documentation: rec_data. *NIWA Fisheries Data Management Database Documentation Series*. Retrieved from https://www.fisheries.govt.nz/dmsdocument/15583-database-documentation-rec-data

Fisheries New Zealand (2020). Charter fishing vessel operators. Retrieved from https://www.mpi.govt.nz/travel-and-recreation/fishing/charter-fishing-vessel-operators/

Hartill, B.; Bian, R.; Rush, N., & Armiger, H. (2013). Aerial-access recreational harvest estimates fornsnapper, kahawai, red gurnard, tarakihi and trevally in FMA 1 in 2011–12. *New Zealand Fisheries Assessment Report 2013/70*. 44 p.

Hartill, B.; Rush, N.; Armiger, H., & Bian, R. (2019). Aerial-access recreational harvest estimates for snapper, kahawai, red gurnard, tarakihi and trevally in FMA 1 in 2017–18. *New Zealand Fisheries Assessment Report 2019/23*. 39 p.

Hartill, B.; Rush, N.; Bian, R.; Millar, A.; Payne, G., & Armiger, H. (2015). Web camera and creel survey monitoring of recreational fisheries in FMAs 1, 8, and 9. *New Zealand Fisheries Assessment Report 2015/52*. 32 p.

Hartill, B. & Thompson, F. (2016). Review of self-reporting tools for recreational fishers. *New Zealand Fisheries Assessment Report 2016/06*. 35 p. Retrieved from http://fs.fish.govt.nz/Page.aspx?pk=113&dk=23998

Hartill, B.; Watson, T.; Cryer, M., & Armiger, H. (2007). Recreational marine harvest estimates of snapper and kahawai in the hauraki gulf in 2003–04. *New Zealand Fisheries Assessment Report 2007/25*. 55 p.

Holdsworth, J. C. & Boyd, R. O. (2008). Size, condition, and estimated release mortality of snapper (*Pagrus auratus*) caught in the SNA 1 recreational fishery, 2006–07. *New Zealand Fisheries Assessment Report 2008/53*. 37 p.

Holdsworth, J. C. & Boyd, R. O. (2017). Striped marlin catch and CPUE in the New Zealand sport fishery 2013–14 to 2015–16. *New Zealand Fisheries Assessment Report 2017/18*. 27 p.

Jin, X.; Carlin, B. P., & Banerjee, S. (2005). Generalized hierarchical multivariate CAR models for areal data. *Biometrics*, *61*(4), 950–961.

Joseph, M. (2016). *Exact sparse CAR models in Stan*. Retrieved from http://mc-stan.org/documentation/case-studies/mbjoseph-CARStan.html

Lalas, C. (1991). *Assessment of bird kills in set nets in otago harbour over a period of eight years (1977–1985)*. Unpublished report held by Department of Conservation, Dunedin.

Ministry for Primary Industries (2019). *Aquatic Environment and Biodiversity Annual Review 2018*. Wellington, New Zealand: Compiled by the Fisheries Science Team, Ministry for Primary Industries. 704 p.

Miskelly, C. M. (2014). Legal protection of new zealand's indigenous terrestrial fauna–an historical review. *Tuhinga*, *25*, 25–101.

Miskelly, C. M. (2016). Legal protection of new zealand's indigenous aquatic fauna–an historical review. *Tuhinga*, 81.

Miskelly, C.; Baylis, S.; Tennyson, A.; Waugh, S.; Bartle, S.; Hunter, S.; Gartrell, B., & Morgan, K. (2012). *Impacts of the Rena oil spill on New Zealand seabirds*. Unpublished poster held by Te Papa, Wellington. Retrieved from http://collections.tepapa.govt.nz/publication/3818

New Zealand Government (1953). Wildlife Act 1953. Parliamentary Counsel Office, New Zealand Legislation. Retrieved from %7Bhttp://www.legislation.govt.nz/act/public/1953/0031/latest/DLM276814.html%7D

New Zealand Government (1978). Marine Mammals Protection Act 1953. Parliamentary Counsel Office, New Zealand Legislation. Retrieved from %7Bhttp://www.legislation.govt.nz/act/public/1978/0080/latest/DLM25111.html%7D

Richard, Y. & Abraham, E. R. (2020). Assessment of the risk of commercial fisheries to New Zealand seabirds, 2006–07 to 2016–17. *New Zealand Aquatic Environment and Biodiversity Report No. 237*. 61 p. Retrieved from https://mpi.govt.nz/dmsdocument/39407

Roberts, J.; Webber, D.; Roe, W.; Edwards, C., & Doonan, I. (2019). Spatial risk assessment of threats to Hector's and Māui dolphins (*Cephalorhynchus hectori)*. *New Zealand Aquatic Environment and Biodiversity Report No. 214*. 168 p. Retrieved from https://www.mpi.govt.nz/dmsdocument/35007/direct

Sharp, B. R. (2018). Spatially Explicit Fisheries Risk Assessment (SEFRA): A framework for quantifying and managing incidental commercial fisheries impacts on non-target species and habitats. Chapter 3. In *Aquatic Environment and Biodiversity Annual Review 2018*. 38 p. Wellington, New Zealand: Compiled by the Fisheries Management Science Team, Ministry for Primary Industries.

Stan Development Team (2018). RStan: the R interface to Stan. R package version 2.17.3. Retrieved from http://mc-stan.org/

Wynne-Jones, J.; Gray, A.; Heinemann, A.; Hill, L., & Walton, L. (2019). National panel survey of marine recreational fishers 2017–18. *New Zealand Fisheries Assessment Report*, *2019/24*. 104 p.