Characterisation and mitigation of protected species interactions in the inshore trawl fishery

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Executive summary

Incidental capture of protected species in commercial fisheries is a global issue. Efforts to develop effective mitigation hinge on understanding the extent of protected species interactions and how they occur. In New Zealand, work to quantify protected species captures and understand potential drivers has been extensive in some fisheries and areas. However, there is uncertainty around the nature and extent of protected species interactions in inshore fisheries.

In this study we focus on the inshore trawl fleet and its protected species interactions. The inshore trawl sector is variable in terms of target fish species, vessel size, fishing practises, gear use and the protected species the vessels overlap with. To reduce risk to protected species it is important to understand the nature and extent of interactions in inshore trawl fisheries, and what factors influence capture events.

This study reviews operational practises and protected species interactions in inshore trawl fisheries, as documented by government fisheries observers in New Zealand. Information collected during 4,762 trawl events on 33 vessels across the inshore fleet from October 2013–December 2016 recorded a diverse range of protected species caught in nets, on warps (trawl cables) and as bird strike in observed inshore trawl operations. By their nature, observer data have several limitation. Observer placement is not random, with spatial and temporal data skews which limit representativeness; observer data are prone to quality and consistency issues; and observations only cover a small proportion of all fishing effort. As a result, only some data are robust enough for quantitative statistical analysis. This work therefore takes a two-pronged approach: quantitative statistical analyses where data are adequate, complemented by exploratory review of other existing observer data, aiming to identify patterns and trends that may be informative to explore further.

A total of 83 protected species interactions were recorded by observers, including individuals of 12 species of seabird, two species of dolphin, New Zealand fur seals, a white-pointer shark and a green turtle. Some of these protected species have a high conservation threat classification and rank highly in fisheries risk assessments. While 88% of all protected species captures were of a single individual per fishing event, up to five individuals were caught in a single fishing event. Net captures accounted for 67% of seabird captures on fishing gear, and warps caught 10% of seabird captures on gear. Seabirds were caught in fishing gear at a rate of 1.4 birds/100 observed trawls over the focal period. A further 21% of overall seabird interactions occurred as deck strike, or bird interaction with the deck or superstructure of vessels during fishing operations. Marine mammals, sharks and the turtle were all caught in the net, at a rate of 0.3 captures/100 trawls.

Statistical modelling found the key factors explaining captures were target fish species, fishery year and fishery area. However, observer coverage during the focal period was numerically skewed to fisheries in northern areas, so we have limited understanding of the effect of inshore trawling on protected species that are absent from or less abundant in northern parts of the country. Species more abundant in southern NZ that are frequently incidentally caught in offshore trawl fisheries include white-chinned petrels, white-capped albatross, sooty shearwaters, Salvin's albatross, Southern Buller's albatross, grey petrel, Cape petrel and NZ fur seal. It is not unreasonable to expect that inshore trawl fishing in the South Island may have more of such seabird and NZ fur seal interactions than recorded in the very small amount of observer effort here.

Seabird captures showed clear effects of using bycatch mitigation on capture rates. In observed trawl fishing, capture rates of seabirds on fishing gear were lowest when a bird baffler was used, and appeared

lower with net cleaning, illustrating the combination approach widely recommended for effective seabird mitigation. Discharging small fish or fish waste appeared linked to lower seabird capture rates than when no discharge was occuring, but this may result from relatively small numbers per category. Mammal (one bottle-nosed and seven common dolphins and five NZ fur seals), shark and turtle captures appeared influenced by discharge type, increasing with offal discharge. Capture risk may also be influenced by a number of other drivers, including varying spatial and seasonal abundance of protected species and target fish species, and uncertainty amplified by practises not being consistent within fleets or between trips of the same vessel.

Recommendations cover mitigation equipment and operational practices that could help reduce protected species bycatch, as well as research areas to progress for mitigating protected species captures in the inshore trawl fleet. Recommendations are also provided for enhancing data collection to improve understanding of the nature and extent of protected species captures in inshore trawl operations.

Contents

Introduction

Incidental mortality of protected species in commercial fisheries remains the most prominent and ongoing risk to many southern hemisphere species (e.g. Croxall et al. 2012; Phillips et al. 2016). The goals of National Plans of Action and Threat Management Plans are to reduce incidental captures of protected wildlife in New Zealand fisheries (e.g. MPI 2013). The use of devices that aim to reduce seabird strikes on trawl warps has been mandated on New Zealand trawlers ≥ 28m in overall length since April 2006 and sea lion excluder devices (SLEDs) have been used in some large-vessel trawl fisheries from 2007, but few large vessels target the inshore fish species that are the focus of this work (listed Appendix 1). Trawlers less than 28m overall length are not legally required to use specific mitigation equipment to prevent the incidental capture of protected species, and operational restrictions are limited to avoiding protected areas.

Due to insufficient observer coverage in inshore trawl fisheries (defined from here as trawl fisheries targeting inshore fish species, Appendix 1), the estimate of seabird mortality in inshore trawl fisheries is highly uncertain (Richard et al. 2017). Statistical modelling of annual potential fatalities is based on observed captures with estimates of vulnerability, overlap and undetected mortality (2017 Risk Assessment; Richard et al. 2017). In NZ fisheries, annual potential fatalities of seabirds are highest in inshore trawl fisheries, with a modelled fatality estimate of 4,800 (95% C.I. 3140–7080) seabirds killed annually (Richard et al. 2017). Seabird mortality in inshore fisheries is dominated by white-capped *Thalassarche cauta steadi* and Salvin's albatrosses *T. c. salvini* and is estimated to be sufficiently high to put these species into a 'high risk' category (Richard et al. 2017). The conservation status of these two species is Declining and Nationally Critical, respectively (Robertson et al. 2017). Fisheries observer data has also recorded captures of protected shark species and marine mammals in trawl fisheries (Abraham and Thompson 2015a; Francis 2017a, b).

Inshore trawl fisheries are widely varied in target species, gear used, fishing practices, environmental conditions encountered, and the protected species the vessels overlap with. Identifying the causes of protected species bycatch events is critical to inform effective mitigation against the incidental capture of protected species.

The scope of this work is to characterise the nature and extent of protected species interactions in observed New Zealand inshore trawl fisheries. This report:

- characterises and compares subsets of the inshore trawl sector;
- explores data available on protected species interactions during inshore trawl fishing; and,
- provides recommendations for future work to mitigate captures in New Zealand's inshore trawl fisheries.

To characterise the nature and extent of interactions, we focus on data collected by government fisheries observers. Unobserved sectors of the inshore trawl fisheries (those which have not had observer coverage) are not considered in detail in this report, except to note relevant observations from fisher interviews in those sectors.

Methods

Data sources

Fishing event and protected species bycatch data collected by fisheries observers were requested from the Ministry of Primary Industries (MPI). A complete extract of data tables related to protected species bycatch data was obtained (MPI Replogs 11402 and 11676), covering all fishing events and protected species bycatch data collected during the 2013–14 to 2016–17 fishing years. The tables include station information, environmental conditions, operational parameters, information on discharging, and data on mitigation devices used. Protected species capture information included trip number, capture date, species, life and injury status, mode and location of capture, and the comments field from the observer non-fish bycatch form.

Data tables were then refined to include only inshore trawl fishing events (defined using the Department of Conservation's Conservation Services Programme DOC CSP inshore trawl fisheries based on target fish species, excluding Cook Strait hoki; Appendix 1), and by year to include only the most recent three years of the data received. This subset of observer data was selected because it was the most recent available. A relevant dataset from 2007–2009 was not included as it would not reflect the past decade of fisheries management developments; further, the older dataset involved different coverage and differently skilled observers (K. Ramm pers. comm). The first observed fishing event in the refined dataset took place 14 October 2013 and the last observation on 31 December 2016.

This report also draws on relevant observer reports, grey literature, and discussions with a small cohort of 20 inshore trawl fishers from areas lacking data. Documentation from observed trips was provided by DOC CSP and MPI. Documentation was unavailable from 23 of the 110 observed inshore trawl trips in the 2013–14 to 2016–17 period. For other trips, documentation received was primarily edited trip reports, but also included excerpts of observer diaries, photographic logs, and information collected by observers to support the DOC CSP seabird liaison programme. Documentation included electronic scans, Microsoft Word and PDF documents. Information relevant to non-fish protected species captures was extracted from observer documentation and recorded separately.

Data grooming

Data were cleaned by removing any fishing event observations where discharging and mitigation data were missing (discharge-related fields "<null>" and mitigation_equipment "None" for entire trip, i.e. no indication that the fields were used), and if protected species bycatch was recorded as unknown (nonfish_bycatch code "U" unobserved). The two sources of protected species capture data were merged to provide a single consistent set of capture data. Where captures were recorded on both the fishing event form and the non-fish bycatch form, the non-fish bycatch data were accepted as authoritative. In other words, where no capture was recorded in the fishing event forms, non-fish bycatch data were used and were converted into the same information that was recorded on the fishing event forms.

The study's scope includes review of factors influencing all interactions including deck strikes, or interaction of birds with the deck or superstructure of vessels during fishing, because deck strikes necessarily occur only when fishing vessels are present. Deck strikes are recorded only during active fishing; that is, deck strikes occurring while a vessel is on anchor or steaming are not included. Deck strikes (capture_method code "I" and observer comments) were retained in overall bird interaction data, identified as 'overall'. The subset of seabirds caught in the net or on the warp are identified separately as gear captures, or 'gear', to distinguish gear captures from overall interactions. A single record of a pilot whale was discarded as it was already decomposed when retrieved from fishing gear.

The fishing event form allowed for multiple discharge types to be recorded, as well as discharge occuring at different stages. During data grooming, a single discharge type was determined for each fishing event observation. Discharge types were given the following order: no discharge, minced material, whole fish, and offal. This corresponds to increasing attractiveness of the material to animals attending a vessel (see e.g. Furness et al. 2007). The highest discharge type category recorded in an observed fishing event was then used to characterise the discharge type.

Similarly, discharge stage was given the following order: no discharges tow, haul, shot. Discharge during shooting were ranked higher than during hauling because animals captured on the warp during shooting are less likely to be retained and detected than animals captured during hauling (Parker et al. 2013). The highest stage category recorded in an observed fishing event was then used to characterise the discharge stage.

Mitigation device use was characterised as either none, bird baffler, tori line(s), warp scarer, bird baffler and tori line, or Other. Other typically occurred in COD tables without accompanying device description, but two observer reports mentioned makeshift baffler-type devices (one described as a rope between booms with soft rubber streamers instead of droppers). During modelling the baffler-and-tori and warp scarer categories were combined with the Other category.

A fishery was assigned to each fishing event based on the target species. Five fisheries were used: gurnard *Chelidonichthys kumu*, tarakihi *Nemadactylus macropterus*, snapper *Pagrus auratus*, trevally *Pseudocaranx georgianus*, John dory *Zeus faber* and Other target species. When trawls were towed across Fisheries Management Area FMA boundaries, start FMA was used to categorise fishing area. Four fishing areas were used: AKE (eastern North Island from North Cape to Bay of Plenty, or FMA 1), AKW (western North Island from North Cape to North Taranaki Bight, FMA 9), CEE (eastern North Island from south of Bay of Plenty to Wellington, FMA 2), and Other areas.

Reports of injured and uninjured live-captures were considered together following Pierre (2018), given the uncertainty of outcomes after release.

Analyses

Data were analysed in the R software package (R Core Team 2016). Capture data are tabulated in this report to summarise patterns and allow coverage to be assessed. Where data are adequate, we present the association between captures and the key covariates. For example, exploratory analysis included the area-based consideration, by method, of capture rates, and identification of frequently caught protected species in each area. Exploratory analysis also included the proportion of live captures amongst total captures, species composition of protected species live captures, and live captures in relation to target fish. Where data were not adequate, we provide qualitative assessements of factors that may influence protected species captures. Qualitative assessments are based on information in observer trip reports and observations by fishers.

Seabird interactions were analysed separately from captures of marine mammals, sharks and the turtle because animals approaching fishing gear from the air are expected to be affected by different factors than animals approaching from the water. After exploratory analysis, bird captures on fishing gear were separated from deck-strike interactions, but gear captures were not split by location since too few warp captures were recorded to usefully separate warp captures and net captures. Bird captures were not split further (e.g. into small birds and large birds, Abraham and Thompson 2009) because the dataset included very few large bird captures, being numerically skewed toward observed fishing in regions where few large-bird captures have been reported. Similarly, the two shark and turtle capture records were grouped together with marine mammal captures following exploratory analysis, because of their rarity.

Because of the range of related explanatory variables, correlations between captures and single variables may not provide a true picture of factors influencing protected species captures. To deal with this, the capture rate was modelled to estimate the average capture rate as a function of multiple explanatory variables. We fit negative binomial generalised linear models (GLM) of captures. Negative binomial models are suited to overdispersed count data like those available for this study, as illustrated by studies with similar capture data where negative binomial models give a good representation of the data (Abraham and Kennedy 2008; Abraham and Thompson 2009). GLM were fit using maximum likelihood routines from the MASS library (Venables and Ripley 2002). The model predicts the mean capture rate μ_i during a fishing event, i, as a linear function of a number of explanatory variables/covariates x_{ki}:

$$\log(\mu_i) = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \ldots + \beta_p x_{pi}$$

where x_{ki} is the value of the kth explanatory variable corresponding to the ith fishing event ($k = 1, ..., p$). The data are assumed to be drawn from a negative binomial distribution with mean, μ_i, and overdispersion, θ. The value of the intercept, β_0, the parameters, β_k, and the overdispersion are estimated by the model fitting. To calculate the multiplicative effect of a variable on the mean rate, we take the exponent of the corresponding parameter β.

Modelling used data at the fishing-event level, from the start of shooting to the end of hauling, rather than trip-level data or non-fish bycatch capture observations of individuals. The total number of captures were calculated for each observed fishing event.

We first fit a 'full' model including all explanatory variables of interest (those which exploratory analyses suggest are associated with captures), including the target species of the fishing event, the mitigation device used, the discharge type and discharge stage as defined for individual fishing event observations, the seabed depth, the FMA, and the fishing year. An automated step-wise routine, implemented via function *stepAIC* in the MASS library, then searches for the best model. The best model is the one where the explanatory variables are reduced to the subset which minimises the Akaike's Information Criterion (AIC).

Results

Data summary

The full data extract had a total of 135,638 records of observed fishing events. After refining to include only inshore trawl records from October 2013 to December 2016 (three and a half years), 5,266 observation records remained. A further 504 (9.6%) records were excluded from the analysis leaving 4,762 valid observations. Fishing event observations were excluded if discharging and mitigation data were missing (discharging fields all "<null>" and mitigation_equipment field "None" for entire trip, i.e. no indication that the fields were used; 398 records), if protected species bycatch was unknown (nonfish_bycatch code for not observed, "U", used; 105 records), and if a record was incorrectly assigned as a capture (retrieval of a long-dead pilot whale; 1 record). Some rejections are inevitable, for example when observers recorded that bycatch was unknown while off-shift. However, the rejection rate due to missing data (398 observed fishing events) could be reduced, and a rejection rate of less than 5% should be achievable.

Observations were retained from 334 different vessels, ranging in size from 13–59.5m. Seventy-seven observer trip reports were reviewed for relevant information (89% of reports available), and protected species interactions and mitigation options were discussed with 20 fishers from areas lacking observer data.

Importantly, this work focuses on observed inshore trawl fishing, using data solely from inshore trawl operations when a government fisheries observer was on board. Observed fishing events October 2013–December 2016 represented 3.03% of all inshore trawl fishing events (Abraham and Thompson 2015b). Observers are not placed at random over fisheries, and the proportion of inshore trawl fishing covered by observers varied by year in our focal period (Fig. 1). Observer coverage of inshore trawl fishing increased progressively from 2013/14 to 2015/16, increasing from 4.7% to 9.8% observer coverage in the fishery, coinciding with increasing trials of precision seafood harvest (PSH) equipment. In 2016/17 observer coverage dropped to 2.3% when effort shifted to other sectors.

Inshore trawl fishing was observed to some extent in most fishing areas, although far from representatively (Fig. 2). Spatial coverage of the observer dataset across fisheries management areas shows the large majority of inshore trawl vessels were in AKE (25 vessels), with a smaller number in AKW and CEE (12 and 8 vessels respectively). Very little data were available from inshore trawl fisheries anywhere in the South Island for the focal period, with only six fishing events observed across CHA, SOU and SEC together over the period 2013–2016 (Fig. 2). No observations from inshore trawl fishing in CEW were available over this period. In these FMAs, species assemblages are expected to be different, so capture profiles and associated risk factors are also expected to be different. This assumption could be tested by prioritising observer coverage in unobserved fishery-areas. Breaking down fishing effort by year within areas, we see that the number of observed fishing events each year in AKE were roughly similar across years 2013–2016 (Fig. 2). In AKW, almost half of observed fishing took place in 2014, and most fishing in CEE occurred in 2016 (Fig. 2).

Observed inshore trawl fishing events are summarised by fishing year and target fishery in Table 1. The 2014 fishing year had the most observed fishing, mostly targeting snapper (36% of the year's observed fishing). Fishing years are referred to by start year in text, so 2014 means the 2014–2015 year. In all years, the snapper and tarakihi fisheries accounted for most of the observed fishing events.

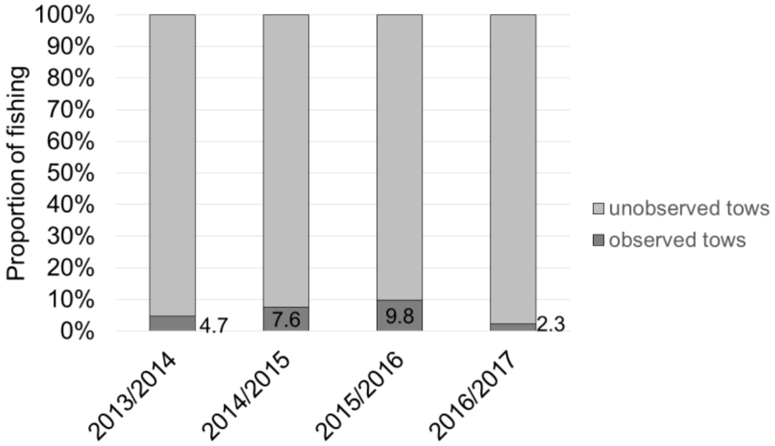

Figure 1. Observer coverage in inshore trawl fishing October 2013–December 2016 by year. Numbers above the horizontal axis give the proportion of observed fishing (% of the total number of fishing events). From data in Abraham and Thompson (2015b).

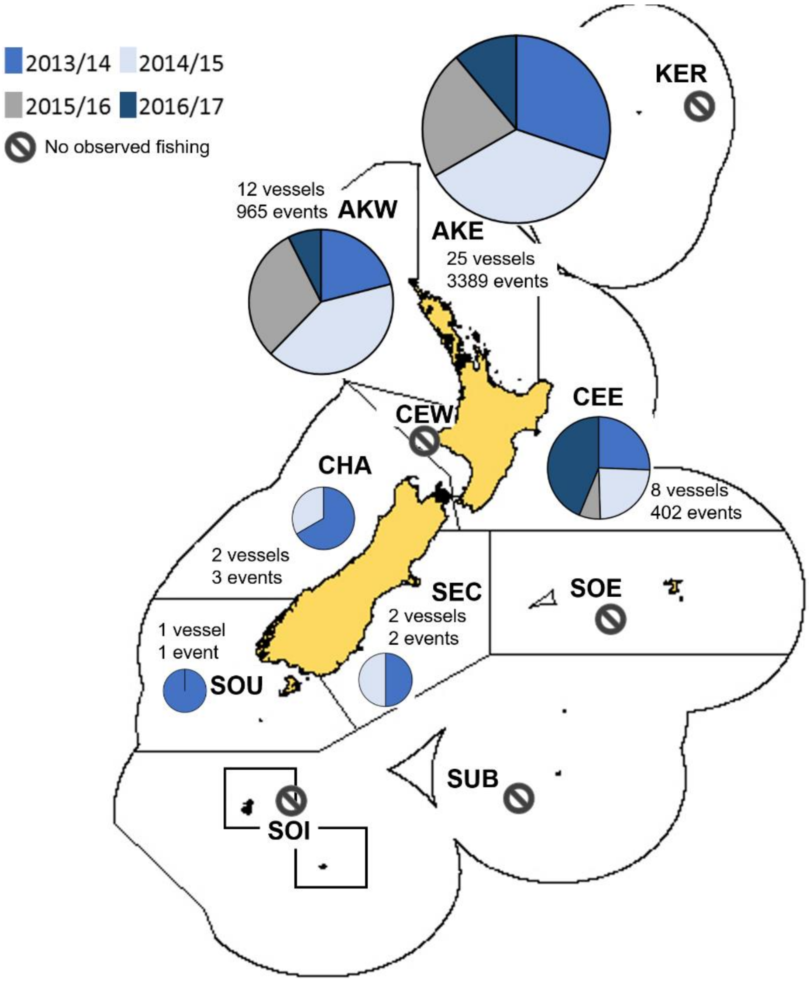

Figure 2. Observed inshore trawl fishing across fisheries management areas 2013–2016. Pies show fishing events in each FMA by fishing year, with the size of each pie indicating the total number of fishing events observed. Crossed circles indicate areas where no inshore trawl fishing effort was observed.

Table 1. Number of fishing events observed in inshore trawl fisheries, summarised by fishing year and target fishery.

	2013/14	2014/15	2015/16	2016/17	Total
Snapper SNA	456	617	477	263	1813
Tarakihi TAR	374	391	160	198	1123
Trevally TRE	241	381	245	91	958
John dory JDO	212	253	70	24	559
Gurnard GUR	40	89	104	31	264
Other	11	2	17	15	45
Total	1334	1733	1073	622	

Protected species captures

To produce a consistent dataset, information from the fishing event and non-fish bycatch forms was merged. Captures of one or multiple animals were recorded on 68 fishing events out of the 4,762 observed inshore trawl fishing events in our dataset. There were 25 tows where captures were recorded only on the non-fish bycatch form, so these were used to complete the fishing event records. Numbers of individuals captured and species captured in each tow were summarised from the non-fish bycatch form to complete the fishing event records.

Observer data received included 81 records of protected species individuals caught by vessels operating in inshore trawl fisheries, from 33 observed trips. This corresponds to a capture rate of 1.7 animals/100 observed fishing events in the focal period. Across all fishing events, 66 seabirds and 13 mammals (eight dolphins, five fur seals), one white pointer shark and one green turtle were captured in 68 fishing events (Table 2). Appendix 2 provides a full breakdown of protected species captures, including common and scientific names with species codes; here we use common names.

Shearwaters and black petrels were caught most frequently in all years, with captures of up to 1.21 black petrels/100 events observed in the 2015 fishing year (Table 2), reflecting the skew of observer coverage to northern waters (Fig. 2). Pterodroma petrels like the grey-faced petrel were also caught at a high rate in 2014. Dolphin (mostly common dolphins) and NZ fur seal captures were recorded at lower rates, but at rates consistently between 0.06 and 0.37 captures/100 events (Table 2). Albatross captures were only recorded by observers in 2015, at a rate of 0.28 white-capped albatrosses/100 events that fishing year. The rate of observed protected species captures increased annually from 1.27 captures/100 fishing events in 2013 to 2.89 captures/100 events in 2015 (Table 2). The overall capture rate in 2016 appears lower, likely because the data are for a part year, so species that are abundant in summer, autumn and winter will not have been represented.

The majority of observed protected species captures involved one individual caught in a single fishing event, or 88% of the 68 fishing events with captures (Table 3). All capture events involved five or fewer animals in a fishing event.

Table 2. Protected species bycatch recorded in observed inshore trawl fishing 2013–2016, giving the number of individuals caught (n) and the rate (average capture rate, in interactions per 100 fishing events for that fishing year).

	all years		2013/14		2014/15		2015/16		2016/17	
	n	rate	n	rate	n	rate	n	rate	n	rate
Flesh-footed and other shearwaters	23	0.48	8	0.60	11	0.63	4	0.37		
Black petrels and other Procellaria petrels	20	0.42	5	0.37	2	0.12	13	1.21		
Grey-faced and other Pterodroma petrels	10	0.21			6	0.35	3	0.28	1	0.16
Storm petrels	5	0.10					3	0.28	2	0.32
Common diving petrels	4	0.08	2	0.15	2	0.12				
White-capped albatross	3	0.06					3	0.28		
Unidentified seabird	1	0.02			1	0.06				
Total seabirds	66									
Dolphins	8	0.17	1	0.07	1	0.06	4	0.37	2	0.32
NZ fur seal	5	0.10	1	0.07	2	0.12			2	0.32
Green turtle	1	0.02			1	0.06				
White pointer shark	1	0.02					1	0.09		
Total	15									
Grand Total	81	1.70	17	1.27	26	1.50	31	2.89	7	1.12

Capture rate calculated based on the number of observed inshore trawl fishing events:
all years 4762; 2013/14 1334; 2014/15 1733; 2015/16 1072; 2016/17 623.

Table 3. Frequency of observed fishing events where 0–5 protected species captures occurred.

n individuals captured	n events
0	4694
1	60
2	5
3	0
4	2
5	1

Capture location and state

Animals caught were classified according to mode of capture and life status. Mode of capture was recorded by observers as recovered from net, warp, impact on vessel, other, or unknown. Life status was alive, considering live uninjured and live injured animals together, or dead.

The majority of seabirds were retrieved from the net, accounting for 67% of 58 seabird captures in fishing gear, while captures on the warp or doors were recorded more rarely (10% of gear captures) (Table 4). Deck strikes comprised 21% of seabird interactions overall. The capture mode 'other' was rarely clarified in data tables, but one corresponding observer report revealed that for that trip, other was also used for deck strikes.

Although warp captures were detected less frequently, birds caught on the warp or door were much less likely to survive (17%, 1 out of 6 captures was alive but in a poor condition) than if caught in the net (77% alive, or 30/39 captures) (Table 4), and potentially have a lower probability of being detected.

Up to five seabirds were recovered alive from the net in a single fishing event (Table 3), all black petrels with observers recording no visible injuries. The total rate of retrieval of dead seabirds was 0.31 birds/100 tows (15/4,762). A maximum of four birds were recovered dead from the net on any single fishing event, with multiple dead animals recovered from the net on two events. Warp mortalities were only observed singly on any given tow.

Marine mammals, sharks and turtles were all captured in the net, with much lower apparent survival than for seabird net captures: 27% were retrieved alive (cf. 77% of seabirds removed alive from the net) (Table 4). Across all species, multiple animals were retrieved alive from the net on five fishing events. Of the 57 live captures, 63% were reported with no visible injuries.

Further information on the recovered animals is available from the observer non-fish bycatch forms, including the sex, age, size (for some species), but the data are incomplete so were not analysed further.

Table 4. Mode of capture and life status of animals caught in observed inshore trawl fishing 2013 to 2016. Alive % is the percentage of live captures of all captures in a given capture mode.

SEABIRDS	Alive	Dead	All	Alive %
Net capture	30	9 [a]	39	77
Warp/door capture	1	5 [b]	6	17
Deck strike	14		14	100
other	4	1	5	80
unknown	4		4	100
all	53	15		
MAMMALS, SHARKS & TURTLES	**Alive**	**Dead**	**all**	**Alive %**
Net capture	4	11	15	27

A bird with 'unknown' life status included as dead because: [a] observer found bird unresponsive, unknown if alive or dead; and [b] bone and feathers were found in the warp splice.

Captures by fishery and area

Observers reported captures of protected species in areas AKE, AKW, CEE and SOU (Table 5). The largest number of observed captures occurred in AKE, with the majority of captures occurring in the tarakihi fishery (57% of captures in AKE). Captures were also recorded on trawls in AKW targeting tarakihi and trevally (Table 5). No fishing events were observed in CEW, SOE or SUB (Table 5), so no captures were reported. Given that observer coverage was not equal across FMAs (Fig. 2), captures in each FMA are best viewed proportionately. The highest rate of observed captures occurred in AKW, with 17 captures giving a capture rate of 1.8 animals/100 observed fishing events, compared to 1.7

captures/100 events in AKE. Observed captures in CEE resulted in a capture rate of 1.5 animals/100 events.

In AKE, flesh-footed shearwaters and black petrels were the most frequently caught species, while in AKW white-capped albatross were the species most frequently caught. Overall, most captures were of seabirds and most of those were small seabirds (shearwaters, black petrels and Pterodroma petrels), with the exception of three white-capped albatrosses reported caught in tows for gurnard, tarakihi and trevally in AKW (Table 5). Dolphins and NZ fur seals were the most common non-bird captures, caught in AKE, AKW and CEE on snapper, tarakihi and John dory trawls (Table 5).

The change in average capture rates by target fishery over time is shown in Table 6. Observed captures of marine mammals, sharks and turtles were higher in the tarakihi fishery than in other fisheries every year (Table 6B). Common dolphins and NZ fur seals were recorded caught in the tarakihi fishery, with a capture rate as high as 1.9 animals/100 tows in 2015. Capture rates were lower in the snapper fishery but increased progressively each year from no captures in 2013 to 0.8 captures/100 events in 2016 (Table 6B). Common and bottlenose dolphins, NZ fur seals and a white pointer shark were caught in the snapper fishery.

Each year, seabird capture rates were higher in the tarakihi fishery than in other fisheries, apart from 2014 when capture rates in John dory and tarakihi fisheries were the same (2 captures/100 tows) (Table 6A). Rates of seabird captures on fishing gear (gear) were similar or marginally lower than overall rates (o/a; all interactions including deck strike), with the direction of findings unchanged whether deck strikes were included or not. Seabird capture rates tended to be lowest in the snapper and trevally fisheries (Table 6A).

Table 5. Protected species captures reported from observed trips on inshore trawl vessels from 2013 to 2016, summarised by fishing area and fish target species. 'Overall' is the number of seabird interactions overall; 'gear' is the number of seabirds caught on the net or warp, excluding deck strike.

				seabirds				
FMA	FMA target	N all species	% of all captures in FMA	N overall	N gear	% all spp that were seabirds	% seabirds on gear	Species caught
AKE	JDO	11	19	9	8	82	89	XSH, XFS, XBS, XBP, CDD
	SNA	12	21	9	6	75	67	XSW,XSH,XGF,XFS,XDP,XBP,WPS,FUR,BDO
	TAR	33	57	30	28	91	93	XSW,XSH,XPC,XGF,XFS,XBP,XPC,FUR, CDD
	TRE	2	3	2	1	100	50	XDP,XBP
AKW	GUR	1	6	1	1	100	100	XWM
	SNA	2	12	2	0	100	0	XWF,XFS
	TAR	8	47	5	3	63	60	XWM,XST,XPT,XPM,FUR,CDD
	TRE	6	35	4	1	67	25	XWM,XWF,XKP,XGP,UNF,GNT
CEE	SNA	1	17	0	0			CDD
	TAR	5	83	3	3	60	100	XWF,XFS,FUR
SOU CHA SEC SOI	Other	2	100	2	2	100	100	XSH

BDO: bottlenose dolphin, *Tursiops truncatus*; CDD: common dolphin, *Delphinus delphis*; FUR: NZ fur seal, *Arctocephalus forsteri*; GNT: green turtle, *Chelonia mydas*; UNF: unidentified seabird; WPS: white pointer shark, *Carcharodon carcharias*; XBP: black petrel, *Procellaria parkinsoni*; XBS: bullers shearwater, *Puffinus bulleri*; XDP: common diving petrel, *Pelecanoides urinatrix*; XFS: flesh-footed shearwater, *Puffinus carneipes*; XGF: grey-faced petrel, *Pterodroma macroptera*; XGP: grey petrel, *Procellaria cinerea*; XKP: Cook's petrel, *Pterodroma cookii*; XPC: Procellaria petrels, *Procellaria* spp.; XPM: mid-sized petrels & shearwaters, *Pterodroma*, *Procellaria* & *Puffinus* spp.; XSH: sooty shearwater, *Puffinus griseus*; XST: storm petrel, Hydrobatidae; XSW: shearwaters, *Puffinus* spp.; XWF: white-faced storm petrel, *Pelagodroma marina*; XWM: white-capped albatross, *Thalassarche steadi*

Table 6. Protected species capture rates (captures per 100 fishing events) within each target fishery for seabirds (A) and mammals, sharks and turtles (B). For seabirds, n caught and rates are shown separately for the overall number of individuals recorded in all interactions including deck strike (o/a) and for the number caught on fishing gear (gear). Average capture rates are not calculated for year-fishery combinations where fewer than 100 fishing events were observed (indicated with an x). Protected species codes are defined Table 5.

A: Seabirds

	2013/14					2014/15					2015/16					2016/17					
		n caught		rate			n caught		rate			n caught		rate			n caught		rate		
	events	o/a	gear	o/a	gear	events	o/a	gear	o/a	gear	events	o/a	gear	o/a	gear	events	o/a	gear	o/a	gear	species
Snapper	456	3	1	0.7	0.2	617	5	3	0.8	0.5	477	3	2	0.6	0.4	263	0	0	0	0	XFS, XGF, XSW, XBP, XWF, XDP, XSH
Tarakihi	374	9	9	2.4	2.4	391	9	8	2.3	2.0	160	17	15	10.6	9.4	198	3	2	1.5	1.0	XBP,XFS,XSH,XSW,XPC, XWM,XPM,XST,XGF,XPT
John dory	212	2	2	0.9	0.9	253	6	5	2.4	2.0	70	1	1	x	x	24	0	0	x	x	XFS, XSH, XBS, XBP
Trevally	241	0	0	0	0	381	2	1	0.5	0.3	245	4	1	1.6	0.4	91	0	0	x	x	XBP, XWM, XWF, XKP, XGF, XDP, UNF
Gurnard	40	0	0	x	x	89	0	0	x	x	104	1	1	1.0	1.0	31	0	0	x	x	XWM
Other	11	2	2	x	x	2	0	0	x	x	17	0	0	x	x	16	0	0	x	x	XSH

B: Mammals sharks and turtles

	2013/14			2014/15			2015/16			2016/17			
	events	captures	capture rate	events	captures	capture rate	events	captures	capture rate	events	captures	capture rate	species
Snapper	456	0	0	617	1	0.2	477	1	0.2	263	2	0.8	FUR, WPS, BDO, CDD
Tarakihi	374	2	0.5	391	2	0.5	160	3	1.9	198	2	1.0	CDD, FUR
John dory	212	0	0	253	0	0	70	2	x	24	0	x	CDD
Trevally	241	0	0	381	2	0.5	245	0	0	91	0	x	GNT
Gurnard	40	0	x	89	0	x	104	0	0	31	0	x	
Other	11	0	x	2	0	x	17	0	x	16	0	x	

Observed seabird captures were exceptionally high in the 2015 tarakihi fishery, with gear captures at a rate of 9.4 captures per 100 tows (overall 10.6 interactions/100 tows) (Table 6A). In that year, 65% of captures in the observed tarakihi fleet (7 vessels) occurred on a single vessel. On this vessel, 13 black petrels/unspecified *Procellaria* were captured in the net in just eight tarakihi trawls fishing in AKE. The vessel was not recorded discharging any fish waste during fishing, but did not use any mitigation equipment and there was also no record of net cleaning (removal of stickers from the net before shooting it again). Observer documentation does not provide further insight into why such a high rate of captures occurred on this vessel: 'relatively low' bird numbers attended the vessel, always less than 100, and no gear problems were noted.

Operational characteristics of particular fisheries, like the fishing speed and seabed depth (Table 7), appear linked to the differences in capture rate among fisheries, as expected if particular fisheries correlate to capture rates. As depth increased, the capture rate also increased to maximum captures at 150–209m fishing depth (Fig. 3), the depth range associated with tarakihi fishing (Table 7). The majority of trawls took place at 30–90m depth (Fig. 3). Although the capture rate appears to drop for deeper fishing, there were few fishing events observed for trawls that start at deeper than 240m.

Capture rates were highest when gear was fished at 2.5–3kn (speed associated with John dory and gurnard fishing, Table 7), and appeared to decline at faster fishing speeds (Fig. 4). However, five captures were recorded in 294 fishing events where no operational parameters were documented ('unknown' in Fig. 4). The actual fishing speed for those capture events may substantially affect the pattern, but cannot be teased out further from the current data.

Table 7. Average fishing speed and seabed depth at start of fishing for each target fish species in observed inshore trawl fisheries. Averages are not shown for fisheries where fewer than 150 trawl events were observed (indicated with x).

	events	speed (kn)	seabed depth (m)
Gurnard	264	2.8	45
John dory	559	2.6	71
Snapper	1813	3.1	53
Tarakihi	1123	3.1	136
Trevally	958	3.2	50
Other	46	x	x

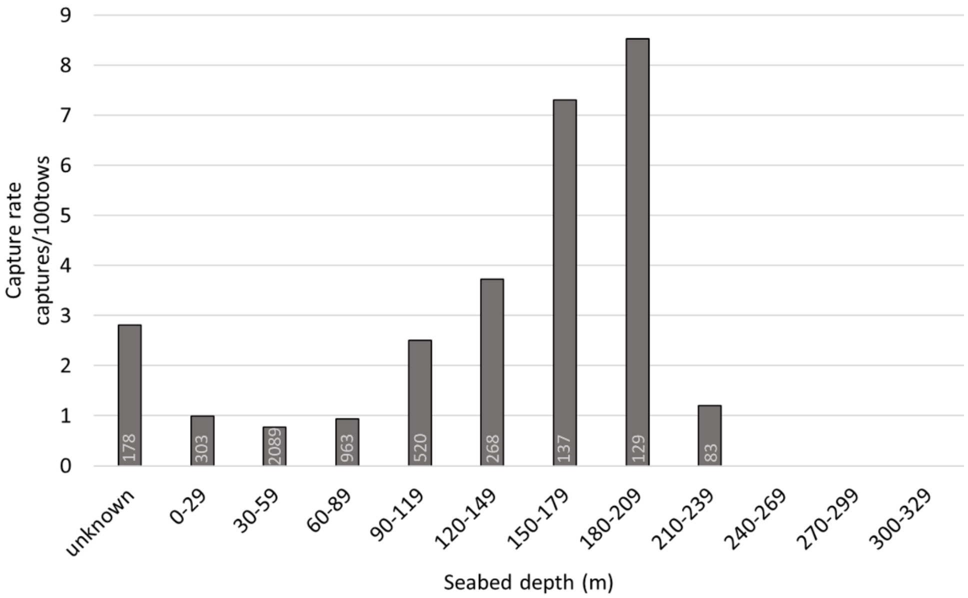

Figure 3. Fishing depth affects average capture rates (captures per 100 tows) of protected species in observed inshore trawl fisheries. Numbers in bars are the number of observed fishing events in each depth category. Averages are only shown for depth groupings where more than 50 fishing events were observed.

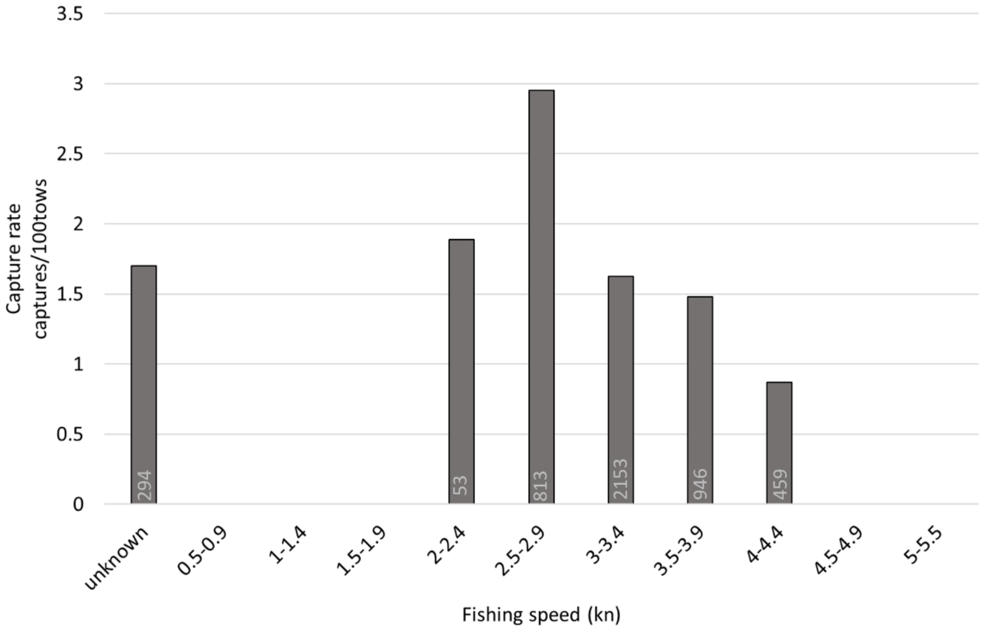

Figure 4. Fishing speed affects average capture rates (captures per 100 tows) of protected species in observed inshore trawl fisheries. The number of observed fishing events in each category is given in the bar. Averages are only shown for speed groupings where more than 50 fishing events were observed.

Gear type and configuration appears to affect protected species captures. Bottom trawl gear used for inshore target species had a higher capture rate when a standard codend was used (1.85 captures/100 events) than when gear included a PSH codend (1.25 captures/100 events). A PSH net replaces the conventional mesh lengthener and codend gear of a trawl with gear intended to reduce flow and turbulence in the net. PSH codends were used in 26% of observed fishing events (1,364 events) while 63% of observed fishing involved standard bottom trawl gear (3,294 events). About 20% of captures were recorded when PSH gear was in use.

Gear configuration links to captures were less clear. For example, capture rates appeared highest with a doorspread of 100–149m (0.91 captures/100 events), but by far the majority of fishing events had no doorspread value estimated (3,747 events, or 71% of fishing). Capture rates appear to have been highest at a headline height of 6–7m (2.15 captures/100 events) but the large majority of fishing involved a headline height of 4–5m (1.30 captures/100 events, 2,542 events or 48% of fishing) with relatively little fishing using other headline heights.

Net surface time showed a clearer association with capture rates. Capture rates increased as net surface time increased, with the capture rate more than four times greater when the net was at the surface for 11–15 mins compared to when net surface time was 1–5 mins (3.42 and 0.85 captures/100 events, respectively). Observers noted that PSH gear took longer to haul than standard gear, and trawl event data showed that bottom trawl gear with a standard codend was at the surface for on average 5 mins (ranging up to 164 mins), compared to gear with a PSH codend at the surface for on average 6 mins (up to 188 mins).

Mitigation use

The frequency of use of different bird mitigation devices during observed inshore trawl fishing is characterised in Table 8. Bird bafflers were the most frequently used mitigation equipment, peaking in 2015 at 45% use. Tori lines decreased to negligible use in observed fishing from 2015, while the proportion of observed inshore trawl fishing that used no mitigation device of any kind increased concurrently from 46% to 58% (Table 8). This does not necessarily mean that fishers stopped using tori lines, rather observer effort occurred on vessels that did not use (or have) tori lines.

The capture rates associated with mitigation use in observed inshore trawl fishing are shown in Table 9. Bird interactions were recorded at the highest rate when no mitigation device was used (2015 fishing year). When deck-strike interactions are removed, the pattern remains the same: the highest capture rate on fishing gear occurred with no mitigation device use (Table 9). The capture rate was generally lower when bird bafflers or tori lines were used than when there was no mitigation, but with some inter-annual variation that should be explored further. Bird captures were more frequent with use of bafflers than when no mitigation was used in one year (2013), and also more frequent during fishing that involved tori lines in another year (2014). Tori lines were linked to lower bird capture rates only in 2013 (Table 9). More recent tori line use on observed inshore vessels has been too limited for comparison with bafflers so it is not clear which is more effective at reducing bird warp capture rates, but in a wider review of small-vessel trawlers, bafflers reduced seabird interaction rates more effectively than did tori lines (Rexer-Huber and Parker 2019).

The efficacy of mitigation has been linked to environmental conditions, particularly wind speed and direction (Sullivan et al. 2006a; Snell et al. 2012). Little information on environmental conditions during fishing was available for this characterisation, so we used sea state (as Beaufort categories). Seabird capture rates increased progressively with increasing sea state, up to a maximum of 4.2 captures/100 tows at Beaufort 6 (Fig. 5). Beaufort 6 typically describes winds 22–27kn, and MetService state 'rough'. Data on fishing at higher wind speeds are rare. Increasing sea state is expected to increase warp captures but not necessarily net captures, as the warp moves over greater distances in larger seas creating a guillotine effect. However, too few warp captures were recorded to test if sea state affects the ratio of warp captures to net captures (6 warp captures cf. 55 net captures).

Deteriorating sea states were linked to increasing interactions whether deck strikes were included or excluded ('overall' and 'gear', respectively; Fig. 5). Deck strike interactions are believed to increase in poor weather conditions, but if we take increased sea state as a proxy for overall deterioration in conditions, the only spike in deck strike rate relative to gear capture rate occurred at Beaufort 4. This may partly be because deck strikes often occur in foggy or snowy, calm conditions not captured in the Beaufort scale, or when birds are attracted to vessel lighting (e.g. Black 2005). Foggy/snowy conditions and the extent of vessel light management were not represented in the data available for this report.

Table 8. Mitigation devices used in observed inshore trawl fishing. Usage % is the percentage of observed fishing events where a mitigation device was used. Averages are not shown for year-device combinations with fewer than 100 observed events (indicated with an x).

	2013/14		2014/15		2015/16		2016/17		all years	
	events	usage %	events	usage %	events	usage %	events	usage %	events	usage %
none	750	56	793	46	506	47	363	58	2412	51
baffler	314	24	651	38	487	45	259	42	1711	36
tori	267	20	225	13	1	x	1	x	494	10
other	3	x	64	x	78	x			145	3
Total	1334		1733		1072		623		4762	

Table 9. Seabird capture rate when different bird mitigation devices were used during observed inshore trawl fishing. Capture rate is the number of captures observed per 100 tows overall (o/a; interactions including deck strike) or caught on fishing gear (gear). Averages are not shown for year-device combinations with fewer than 100 observed tows (indicated with an x).

	2013/14			2014/15			2015/16			2016/17			All years		
	events	o/a	gear	events	o/a	gear	events	o/a	gear	events	o/a	gear	events	o/a	gear
none	750	0.80	0.53	793	1.39	1.13	506	4.35	3.75	363	0.83	0.55	2412	1.74	1.41
baffler	314	2.23	2.23	651	0.77	0.61	487	0.62	0	259	0	0	1711	0.88	0.64
tori	267	0.37	0.37	225	2.67	1.78	1	x	x	1	x	x	494	1.42	1.01
other	3	x	x	64	x	x	78	x	x				145	2.07	2.07

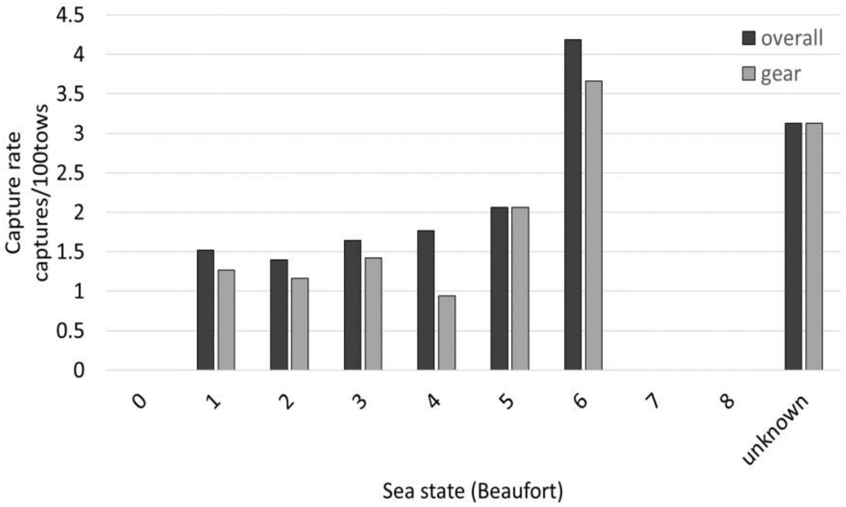

Figure 5. Sea state and the influence on seabird capture rate in observed inshore trawl fishing. Sea state is in Beaufort classes and capture rate is the number of seabird captures observed per 100 tows overall (dark grey; interactions including deck strike) or caught on fishing gear (light grey). Averages are not shown for sea states with fewer than 100 observed tows.

Discharge of fish waste

The discharge management strategy during a given fishing event is characterised in two ways: by the type of material discharged, and by the fishing stage when discharging occurred. The frequency of different discharge types during observed fishing events is shown in Table 10. In all years, the three main types of discharge were no discharge, fish, or offal. Discharging of minced material was rare, occurring on only three events (two different vessels), so was grouped with offal discharge. Over the period 2013–2017, the proportion of observed fishing where offal (or offal and fish) was discharged rose annually, increasing from 8% to 25% in 2016. Discharging of fish alone decreased over the same period, to a low of 7% in 2016 (Table 10).

The proportion of observed fishing where no material of any type was discharged during any stage of fishing (zero discharge) decreased from a high of 82% in 2013, and has since remained stable at around 68% of fishing with zero discharge. When material was discharged, it was rarely discharged during hauling (Table 10). Material was mostly discharged during the tow in 2013–2015, but from 2015 the majority of discharging occurred during shooting. Discharging while shooting increased annually from 7% to 20% in observed fishing events.

The rate of bird interactions, grouped by discharge type and mitigation use, in observed inshore trawl fisheries is shown in Table 11. Interactions were less frequent when bird bafflers or tori lines were used than when there was no mitigation, irrespective of discharge type (overall in Table 11). This remained the case when considering just captures on fishing gear (gear, Table 11). When bird bafflers were used, there were no captures reported from tows with fish discharging. A surprising indication that fish and/or offal discharging was associated with lower bird capture rates than when there was no discharging, irrespective of mitigation use, is likely an artefact of the relatively small numbers of device-type combinations in observed fishing.

Table 10. Percentage of annual observed fishing events with different discharge types and the fishing stage when discharging occurred.

	2013/14		2014/15		2015/16		2016/17	
	events	%	events	%	events	%	events	%
Discharge type								
none	1098	82	1173	68	739	69	425	68
fish	128	10	250	14	121	11	42	7
offal	108	8	310	18	212	20	156	25
Discharge stage								
not during fishing	1098	82	1173	68	739	69	425	68
tow	140	10	341	20	157	15	71	11
haul	3	<1	1	<1	4	<1		
shot	93	7	218	13	172	16	127	20

Table 11. Bird captures per 100 tows for all observed fishing events, grouped by tow-level discharge type and by the use of mitigation. Capture rates are calculated overall (all captures and interactions including deck strike) or just for captures on fishing gear (gear). Averages are not shown for device-type combinations with less than 100 observed tows (indicated by x).

	No discarding			Fish			Offal		
	events	overall	gear	events	overall	gear	events	overall	gear
None	1679	2.03	1.79	202	0.99	0.50	531	1.13	0.56
Baffler	1281	1.09	0.86	281	0	0	149	0.67	0
Tori	390	1.03	0.51	46	x	x	58	x	x
Other	85	x	x	12	x	x	48	x	x

Observed captures are summarised by discharge type and discharge stage in Table 12. The capture rate of birds in observed inshore trawl fishing was highest when fish were discharged during shooting. Interactions were recorded more frequently when discharging happened during shooting than during tow, for both fish and offal discharge types, with the highest seabird interaction rate when fish was discarded during shooting (Table 12). Capture rates were lowest during tow when fish was discharged. These patterns hold when all interactions are considered (including deck strike) as well as when captures on fishing gear are considered alone. However, there were surprising patterns: capture rates appeared to decrease as the material discharged shifted from none to fish to offal, across all discharge stages, when rates are expected to increase (e.g. Furness et al. 2007). Bird capture rates appeared high when there was no discharging of material (second-highest capture rate, after captures when fish discharged during shot), with the greatest variety of species and number of individuals (e.g. all black petrels were caught during zero-discharge fishing). This needs to be interpreted with caution. Relatively high capture rates could simply be an artefact of data being highly skewed to fishing with zero discharge (3,435 events) (Table 12). Alternatively, high capture rates with zero discharging could be a real pattern relevant to seabird captures. In deepwater fisheries, observers noted that net captures appeared to increase when fish waste was withheld (R. Wells pers. comm.). Seabird capture rates relative to discharging and zero discharge needs to be empirically tested.

Capture rate patterns for marine mammals, sharks and turtles better fit the assumption that discharged material will increase capture rates. Captures were least frequent with no discharge and most frequent when discharging offal during shooting, with captures of a greater range of species. The capture rate was higher when offal was discharged than when fish was discharged, both during tow and shoot. Similarly, capture rates were higher when discharging during shooting (and involved more species) than during tow, irrespective of the material discharged.

Unexpected patterns of bird captures by discharge type/stage may be the result of low numbers per group (223–396 fishing events for each discharge stage-type grouping). Alternatively, they may indicate real differences in bird associations with discharging, so should be explored further. Further exploration of a larger fishing event dataset would also help confirm capture rate patterns for marine mammals, sharks and turtles relative to discharge type/stage.

Table 12. Capture rate of protected species, grouped by tow-level discharge type and by discharge stage. Capture rate is the number of animals caught per 100 tows, shown separately for seabirds and for mammals, sharks and turtles. The column and row headed 'All' show the average capture rate for all discharge types and all discharge stages, respectively. Seabird rates are for overall interactions (overall, including deck strikes) and for captures occurring on fishing gear (gear). Averages are not shown for device-type combinations with less than 100 observed tows (indicated by x).

Seabirds	No material			Fish			Offal			All		Protected species [a]
	events	overall rate	gear rate	events	overall rate	gear rate	events	overall rate	gear rate	overall rate	gear rate	
No disc during fishing	3435	1.57	1.31							1.57	1.31	XBP,XDP,XFS,XGF,XKP,XPC, XPM,XSH,XSW,XWF,XWM
tow				314	0.32	0	395	1.01	0.76	0.71	1.01	XBS,XST,XWF,XWM
haul				4	x	x	4	x	x			
shot				223	1.79	1.79	387	1.03	0.26	1.31	1.03	XFS,XGF,XPT,XSH,XST,XSW
All		1.57	1.31	541	0.92	0.74	786	1.02	0.51			

Mammals sharks and turtles	No material		Fish		Offal		All	Protected species [a]
	events	rate	events	rate	events	rate		
No disc during fishing	3435	0.23					0.23	CDD,FUR
tow			314	0.32	395	0.51	0.44	CDD,FUR,WPS
haul			4	x	4	x		
shot			223	0.45	387	1.03	0.84	BDO,CDD,FUR,GNT
All		0.23	541	0.37	786	0.76		

[a] Protected species codes are defined in Table 5

Captures by vessel

Capture rates in observed fishing events are summarised by vessel in Table 13, presented in decreasing order of total capture rate (all protected species combined). Only the 22 vessels where 30 or more fishing events were observed are included.

There is considerable variation in the average capture rate between observed vessels here. On five vessels no captures were recorded over the course of 31 to 80 fishing events, while on other vessels capture rates of betwee 0.4 and 4.3 captures/100 events were recorded. An exceptionally high capture rate was recorded on one vessel, where 15 animals were caught in the net over the course of 30 observed fishing events during a single trip in AKE. On that vessel, up to four individuals were caught in a single trawl, mostly black petrels but also two shearwaters. That vessel was not observed discharging during fishing, but mitigation devices were not used by the vessel. Observer documentation did not highlight anything else that could explain the high number of captures on this vessel. Operational parameters for this vessel, including fishing depth, fishing speed and gear characteristics, appeared average for vessels targeting tarakihi (2.9kn, 158m depth) except the vessel fished in slightly deeper water than the average for tarakihi fishing (Table 7). The vessel with exceptional captures had two captures when a PSH codend was in use (a black petrel and a shearwater), but the remaining 14 birds were caught while operating a standard codend. Time to haul gear also appeared typical of vessels fishing similar targets, although this assumes that the time to haul from depth to doors-up reflects the time when the net is available to birds while hauling from surface to deck. Environmental conditions recorded (sea state 3–4) were also within the typical operating range (Fig. 5).

Mitigation devices were used on eight of the 22 vessels, mostly bird bafflers deployed throughout a trawler's observed fishing (Table 13). Observer data showed one vessel using 'other' mitigation equipment during 8% of its fishing events, but with no further description or information in observer data or documentation. All but one vessel with capture rates of greater than 2 animals/100 tows did not use mitigation devices. There is no clear pattern of capture rates according to a vessel's primary target species.

All captures were recorded on trawlers smaller than 28m (Table 13), even though vessels up to twice as large were included in this study (scope included any vessel targeting inshore trawl fish species). Among vessels with sufficient observed events, vessels with lower capture rates tended to be slightly longer (22m overall length, mean of vessels with 11 lowest capture rates, range 15–30m) than vessels with higher capture rates (19m, mean of vessels with 11 highest capture rates, range 15–25m) (Table 13). Finer vessel length groupings confirm that capture rates were highest in the vessel length class 17–20m, but also show a spike in vessels 25–27m length (Fig. 6), which could simply result from some vessel sizes being more common in particular fisheries. Warp captures are expected to occur at a higher rate on larger vessels, since larger vessels trawl faster and can continue fishing in poorer sea states, when the guillotine action of warps is most pronounced (G.P. pers. obs.). However, there were too few warp captures recorded to assess changes in the warp- to net-capture ratio with vessel size.

Table 13. Capture rates by vessel. Capture rates (number of captures recorded per 100 fishing events) for all protected species are summarised for vessels that had 30 or more fishing events observed. Vessels are ordered by decreasing total capture rate. Vessel length is overall vessel length to nearest 5m; Fishery is the target species for most observed tows; Mitigation is the mitigation device used most frequently (B, baffler; T, tori line(s); O, other; or N, no mitigation device used); %mit is the percentage of events where mitigation device(s) were used.

	Vessel length	Fishery	events	Mitigation	%mit	Capture rate
1	15	TAR	30	N	0	50.0
2	15	JDO	117	N	0	4.27
3	25	TAR	146	N	0	3.42
4	20	TRE	160	B	100	3.13
5	15	JDO	98	N	0	3.06
6	15	SNA	190	N	0	2.63
7	15	TAR	152	N	0	2.63
8	20	TAR	258	T	100	1.94
9	20	SNA	53	O	8	1.89
10	25	SNA	502	T	99	1.59
11	20	JDO	529	B	100	1.32
12	20	TAR	98	N	0	1.02
13	25	TAR	596	N	0	1.01
14	20	TAR	328	N	0	0.91
15	15	SNA	124	N	0	0.81
16	20	SNA	792	B	100	0.63
17	15	SNA	235	N	0	0.43
18	15	TAR	80	N	0	0
19	30	TRE	62	B	100	0
20	30	SNA	40	B	100	0
21	20	TAR	39	N	0	0
22	20	GUR	31	N	0	0

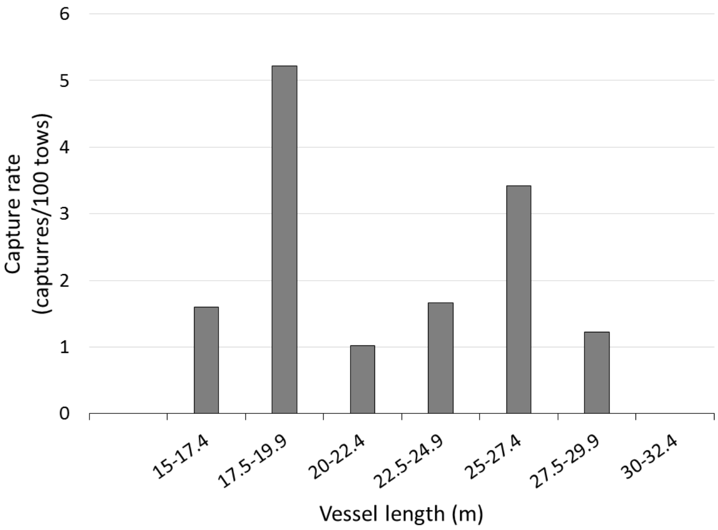

Figure 6. Protected species interactions by overall vessel length. Capture rates (captures per 100 tows) for all protected species are summarised for vessels that had 100 or more fishing events observed.

Modelled captures

The best fitted model of seabird captures is summarised in Tables 14 and 15. Seabird capture rates were related to the target fishery, year, and fishing area. To assess the multiplicative effect of each explantory variable on the mean capture rate, μ, we calculate the exponent of the estimate of the linear predictor, β. In the tarakihi fishery, the number of birds captured increased to $exp(2.00) = 7.39$ times the number caught during snapper target trawls, and the number captured was 2.99 times higher in the John dory fishery than when snapper was the target. There is a year factor which remains after other explanatory variables have been accounted for, with capture rates in 2015 being a factor of 2.97 higher than during 2013. In this model none of the area terms were significant, but CEE was still associated with lower capture rates than AKE, assuming the other covariates remain the same.

Analysis of variance results (Table 15) show the reduction in deviance as terms were sequentially added to the model. Terms are included in order of decreasing explanatory power. Fishery target explained the most deviance, followed by the year and fishing area.

Table 14. Coefficients of terms in capture model for seabirds. Coefficients are estimated for terms in the linear predictor, relative to the snapper fishery, the 2013–14 year, and fisheries management area AKE.

		Estimate	Std. Error	Significance
Intercept		-5.53	0.43	***
Target	tarakihi	2.00	0.40	***
	trevally	-0.01	0.55	
	John dory	1.09	0.50	*
	gurnard	-0.61	1.11	
	Other	-1.27	3.03	
Fishing year	2014–15	0.31	0.39	
	2015–16	1.09	0.41	**
	2016–17	-0.51	0.72	
Area (FMA)	AKW	-0.08	0.39	
	CEE	-1.17	0.68	.
	Other	5.49	3.03	.

Significance: *** p<0.001, ** p<0.01, * p<0.05, **.** p<0.1

Table 15. Deviance of capture model for seabirds. ANOVA table of deviance explained (% explained) as terms are sequentially added to the model.

	Degrees of freedom	Deviance	Residual deviance	% explained	Significance
Initial			322		
Target	5	34	387	10.66	***
Fishing year	3	14	273	3.71	**
Area	3	8	265	2.95	*

Significance: *** p<0.001, ** p<0.01, * p<0.05, **.** p<0.1

These models are for seabird captures only, excluding the small number of marine mammal, shark and turtle captures. To check the effect of excluding non-bird captures, we also modelled captures of all protected species together (dolphin, fur seal, shark, turtle, seabird). As for captures of seabirds alone, the best model shows protected species capture rates related to fishery, year and area, but with less deviance explained by each term than in the bird capture model. Since non-bird captures did not affect the terms included in the capture model but reduced the explanatory power of terms, we retained the model where terms have the best explanatory power (seabird capture model).

Discussion

This work characterises the nature and extent of protected species interactions in observed New Zealand inshore trawl fisheries and shows where we might have problems in terms of protected species bycatch rates, information gaps, and inadequate management actions. Our focus on observed fishing means that the data are shaped by observer placement. Spatial and temporal biases are unavoidable, meaning that observer data are not representative of all fishing areas and target species year-round. However, observers provide our best source of independent data for inshore trawl fishing at this stage, so the information warrrants exploratory review to identify patterns and trends that may be informative to explore further. Exploratory review showed that only some data were robust enough for quantitative statistical analysis. Therefore this work took a dual approach: quantitative statistical analyses where data were adequate, complemented by summary review of other observer data to identify patterns and trends for further investigation.

Inshore trawl operations are highly varied, targeting a wide range of fish species (39 target species) throughout New Zealand. Vessels therefore use a range of fishing gear and fishing practices, encountering different environmental conditions across the inshore trawl fleet and overlapping with different protected species across New Zealand's Fisheries Management Areas.

Protected species captures

A diverse range of protected species were recorded caught in nets, warp-cables and as deck strike in inshore trawl operations. This included individuals of 12 species of seabirds, two dolphin species, New Zealand fur seals, a white-pointer shark and a green turtle recorded caught by fisheries observers. Some of these protected species have a high conservation threat classification and rank highly in estimates of fisheries risk. For example, white-pointer sharks are Threatened - Nationally Endangered, and black petrels and flesh-footed shearwaters are classified as Threatened - Nationally Vulnerable, with 'very high' and 'high' fisheries risk respectively (Richard et al. 2017; Robertson et al. 2017; Duffy et al. 2018).

Shearwaters and black petrels were the most frequently caught protected species in all years. While 88% of all protected species captures were of a single individual per fishing event, five black petrels were caught in a single fishing event. A different vessel caught 13 black petrels over the course of eight trawls targeting tarakihi, four petrels being caught in three consecutive trawls. The vessel was not using mitigation against warp strike, but all 13 captures were entangled in the net so warp mitigation devices would not have prevented the captures. The vessel was not recorded discharging fish waste during fishing, suggesting the fish in the net were the attractant to the black petrels (particularly during hauling, since most petrels were still alive when retrieved). Black petrels and common northern NZ shearwater species (Buller's shearwater, flesh-footed shearwater) feed in small groups, and flesh-footed shearwaters for example forage mostly near breeding colonies (Bell 2013; Heather and Robertson 2015). Feeding in groups likely makes these species vulnerable to multiple captures in a single fishing event, as documented by the five black petrels caught in the net during a single event.

Seven interactions with grey-faced petrels were recorded, most having landed in the pound before it was filled but some also arriving as deck strike. Grey-faced petrels were recorded as bycatch only three times in observed trawl fisheries 2002–2016 (Abraham and Thompson 2015c), although those records exclude deck-strike interactions. Grey-faced petrels are not known as a vessel-following species (Marchant and Higgins 1990) but can be attracted to lights (G.P. pers. obs). Because grey-faced petrels breed on numerous islands and some mainland sites in north-eastern and north-western NZ (Heather and Robertson 2015), they are more likely to overlap with fishing vessels there than in other parts of NZ and encounters may increase if populations are growing due to conservation management.

Five NZ fur seals were recorded as protected species captures in this report. Observers recorded 1,532 fur seal captures in all NZ trawl fisheries 2002–2016, mostly from southern fisheries management areas but also in high numbers in the Cook Strait (Abraham and Thompson 2015a) and mostly by large deepwater trawlers. Areas where fur seal captures occur frequently could not be included in this work when there was no observer coverage on inshore vessels in an area (most of southern NZ), or because a fishery was outside the study's scope (Cook Strait hoki). The rate of fur seal captures recorded in observed inshore trawl fisheries here cannot be sensibly extended to other regions where no observer data was available.

Dolphin captures are recorded much less often than fur seal captures in NZ trawl operations overall (Abraham and Thompson 2015a), but this was not true for observed inshore trawl operations. Seven common dolphin captures and one bottle-nosed dolphin capture were documented by observers on inshore trawl vessels here. Considering that 209 common dolphins were reported caught in all observed large- and small-vessel trawl fisheries from 2002 to 2016 (Abraham and Thompson 2015a), inshore trawl operations contributed substantially to common dolphin captures in the three years 2013–16. The bottle-nosed dolphin capture observed in this study, recorded on a Northland John dory trawler, is the only capture of a bottle-nosed dolphin recorded by a fisheries observer in any NZ trawl fishery since 2002 (Abraham and Thompson 2015a).

A single white-pointer shark was recorded in observed inshore trawl fishing during the focal period of this report, caught alive while fishing for snapper in north-eastern NZ. The only fish waste discharge during that trawl was whole fish discharged during the tow. Twenty-seven white-pointer shark captures have been reported across observed NZ fisheries in the period 2002–2016, 21 of which were in trawl fisheries (inshore and deep-water trawl fisheries grouped) (Francis 2017a). Captures of protected shark species, which comprise six species including white-pointer sharks, have been reported by observers from throughout central and southern NZ, including the subantarctic islands (e.g. Francis and Lyon 2014; Francis 2017a, b).

Management actions aimed at mitigating protected shark captures are voluntary, with the only legal requirement being that captures be reported (as for all protected species). Operational procedures for trawlers >28m LOA focusing on shark captures (Deepwater Group 2017) have been in place since

October 2013. In 2016 it was not yet clear if the actions had had an effect on shark captures (Francis 2017b). Net height reductions and limits on fishing in the favoured areas during key times of year for given shark species would likely reduce shark captures, but due to other factors captures likely cannot be eliminated (Francis 2017a, b).

Spatial coverage

The data used to estimate protected species interactions in the inshore trawl fishery in this report comes from just 3% of fishing activity during 2013–2016 (observed fishing range 2.3%–9.8% per annum), and includes very little or no observed fishing from many NZ commercial fishing management areas. In the areas that were observed to any extent, the temporal spread of the data was uneven over the 3.5-year focal period apart from in Auckland East (AKE), where effort was more evenly distributed over time. The lack of spatial and temporal coverage of observer effort in the inshore trawl fleet 2013–2016 prevents a quantitative characterisation and comparison of protected species interactions across all sectors of the NZ inshore trawl fishery. Observer coverage is numerically skewed to fisheries in northern areas, so we have limited understanding of the effect of inshore trawling on protected species that are absent from or less abundant in northern parts of the country.

Trawls targeting tarakihi in this report recorded the highest rate of seabird bycatch. Tarakihi is found throughout New Zealand (Annala 1987) and is targeted by inshore trawl fisheries in the South Island (Langley 2018). Because only six inshore trawl fishing events in the South Island were observed in the three-year focal period, only qualitative insight into protected species interactions with the inshore trawl fishery in South Island areas is possible.

Many of the species consistently caught in offshore trawl fisheries are less abundant in northern NZ than in southern NZ, such as white-chinned petrels, sooty shearwaters, white capped albatross, Salvin's albatross, southern Buller's albatross, grey petrel and Cape petrel (Marchant and Higgins 1990; Abraham and Thompson 2015c; Heather and Robertson 2015). Black petrels are closely related to white-chinned petrels and are similar in behaviour, as are sooty shearwaters relative to flesh-footed shearwaters. White-chinned petrels and sooty shearwaters were the first- and second most commonly bycaught protected species in observed NZ trawl fisheries overall for the period 2002–2016, with most observed effort on large offshore trawlers. These seabird species overlap in time and space with inshore fisheries operating in areas where very little observer data exist, but interactions are reported anecdotally. Inshore trawl fishers from Bluff describe sooty shearwater deck strike as a regular occurrence at certain times of year (pers. comm. to G.P.). It is therefore notable that during the single observed fishing event in SOU, two sooty shearwaters were recorded entangled in the net. This may have been coincidence, but warrants further attention as sooty shearwaters are abundant in southern South Island during the birds' breeding season (Sagar 2013) and therefore overlap with inshore trawling there.

White-capped albatrosses were recorded as captures in the three years of data used in this report. Other *Thalassarche* albatross species like Salvin's albatross and Buller's albatross (Southern and Northern/Pacific) are also common scavengers behind most forms of fishing vessels, and are vulnerable to both warp-strike and net capture (Abraham and Kennedy 2008; Baird 2008). Salvin's and Buller's albatrosses were the fourth- and fifth most commonly caught seabird species in observed NZ trawl fisheries 2002–2016 (Abraham and Thompson 2015c). White-capped albatrosses have been collected dead from Otago beaches with broken wingbones consistent with warp strike (humeri broken; G.P. unpubl. data). The majority of observed trawl mortalities of *Thalassarche* albatross species 2002–2016 were in southern NZ (Abraham and Thompson 2015c), so it is not unreasonable to expect that inshore trawl operating in southern waters may have had more albatross interactions than recorded in the very limited data available in our focal period for those areas.

In New Zealand, and internationally, the vast majority of warp captures of seabirds in trawl fisheries is of large birds, particularly of albatrosses and giant petrels (*Thalassarche* and *Macronectes* species) (Sullivan et al. 2006b; González-Zevallos et al. 2007; Watkins et al. 2008; Abraham 2010; Favero et al. 2011; Koopman et al. 2018). The three albatross captures observed in this study were on the warp and the door. Warp captures are prone to undetected or cryptic mortality (heavy contacts, loss of corpse over the course of fishing) (Sullivan et al. 2006b; Watkins et al. 2008; Richard et al. 2017; Koopman et al. 2018), as illustrated by observer notes in this study. An albatross was "observed being run down by warp and not surfacing during tow, on hauling nothing found", and another was also not recovered after it "dropped off as door contacted vessel". A further warp interaction was indicated solely by bone shards and feathers in the warp splice, further illustrating the potential for warp interactions to go unrecorded, leading to underestimates of seabird mortality rates. Capture rates are based on birds brought onto deck, so bycatch estimates have to account for cryptic/undetected mortality. Current efforts to account for cryptic mortality include a scalar on seabird warp captures in modelled estimates of annual potential fatalities (Richard et al. 2017), although there has been no specific imperical testing to inform the magnitude of the scalar (currently a 10x scalar used). The position of the observer during the haul was not recorded in the information available for this study, yet the ability for an observer to detect a seabird corpse on a warp or trawl door is affected by observer location. Health and safety requirements in some sectors of NZ trawl fisheries do not allow observers on deck during hauling, so hauls are observed from the bridge. This places the observer tens of meters from the stern and on the other side of the gantry, greatly reducing the observer's view of fishing gear.

Fur seal captures do not appear common in inshore trawl operations (five captures, this study), relative to captures across the whole trawl fleet (1,532 captures across all observed NZ trawling 2002–2016) (Abraham and Thompson 2015a). However, this should be interpreted cautiously: seals are comparatively more abundant in southern NZ than northern areas, and most fur seal captures in other trawl fisheries were in southern FMAs (Abraham and Thompson 2015a), but observer records were available for just six fishing events across all southern FMAs together, or 0.001% of inshore trawl fishing effort. As noted earlier, the extent of fur seal captures in southern inshore trawl fishing could not be estimated with any certainty here.

Some southern inshore trawl vessels have different operational characteristics to those in northern inshore trawl fisheries. Clement and Associates (2008) summarised the inshore trawl fleet at that time, classing vessels <28m as inshore. Average trawl speed was slightly lower in small vessels in southern NZ than in the north (2.3–2.8 knots vs. 3.0–3.2kn) (Clement and Associates 2008). In practise, the difference between 2.3 and 3.0kn is approximately 30cm per second so is not a dramatic difference and we would think is not very influential on warp-strike rates. We cannot assume protected species captures in the south will follow the same patterns as those recorded by observers in the north, but since the highest capture rates reported here were for the slower end of the trawling speed, and targets in southern regions involve slower fishing speeds, inshore trawl interactions between seabirds and warp cables in the south of NZ merit further investigation.

Average vessel length has been reported as slightly longer in northern NZ inshore trawl (19m compared to 16m in southern NZ) (Clement and Associates 2008). The small difference in vessel length is unlikely to produce a difference in conditions the vessels can fish in, which would be relevant because larger vessels can fish poorer sea states which produce a greater guillotine effect of the warp, increasing the risk of seabird warp captures (Sullivan et al. 2006b; Melvin et al. 2011; Koopman et al. 2018). Worse average sea states are more common in the South Island than North Island, though, so this may impact on protected species interactions with trawl fisheries in the south. Inshore trawl vessels included in this report did not appear to fish in winds over 27kn. This is similar to the limits of what smaller (<20m) inshore trawl vessels fish in, in southern New Zealand (G.P. pers. obs.). However, the vessel size difference may be enough to influence discharging practises if fishers feel there is not enough space to retain discharge, if catch rates are higher, or if fishers have stability concerns. Some sole operators of small inshore trawl fishing vessels in the South Island have concerns about their ability to use mitigation, discussed further below in the mitigation section of the discussion.

Target species

Seabird captures were lowest in trawls targeting snapper and trevally and consistently higher for trawls targeting tarakihi. The snapper fishery was the most observed fishery in all three years by effort, and the most consistently observed inshore trawl fishery over time. For other fisheries, the pattern of seabird captures was less obvious. For example, John dory fishing more than doubled its seabird capture rates in one year, bringing capture rates to the highest of all fisheries, but too little John dory fishing was observed in other years for comparison.

The cause of the comparatively high seabird capture rate in tarakihi trawls, particularly in 2015/16, is unclear from observer data and reports. A single vessel was responsible for 65% of reported seabird bycatch in the 2015 fishing year, but the observer report gives no clarity to why this vessel had a comparatively high capture rate. Vessel effects are not uncommon in protected species bycatch analyses, but the cause of the effect cannot always be determined (e.g. Parker 2012, 2013). This study could not quantitatively assess vessel effects, but there were indications of a vessel size effect in inshore trawl fisheries, where all protected species captures occurred on vessels <28m. Vessel gear configurations vary (e.g. winch speed, warp-block height, position of discharge scuppers, how discharge interacts with propellor wash and where discharge becomes available to scavenging protected species, stern gantry height etc), with some aspects directly affected by vessel size. Smaller vessels may also have different constraints on mitigation device deployment and design, as well as on other practises that can affect capture rates like discharge management (Rexer-Huber and Parker 2019). The duration of shoot or haul, therefore the period of time that the net is on the surface, varies by vessel as well. Net surface time affected capture rates, with greater capture rates increasing with longer net surface time. Net surface time appeared slightly longer for PSH gear than standard gear (this study), and net surface time is also thought to be influenced by deck practises, winch speed and how well winches are maintained (ACAP 2017).

Captures of marine mammals were highest in the observed tarakihi fishery each year, as for seabirds, mostly catching fur seals and dolphins. A greater range of species was caught in snapper trawls—dolphins, fur seals and a white pointer shark—but mammals were caught at lower rates each year in the snapper fishery than in the tarakihi fishery. John dory and gurnard fishing had low rates of observed marine mammal, shark and turtle bycatch in the study period.

As a fishing method, bottom trawling has limited ability to target specific fish species but a single target species code must be assigned to each fishing event, confounding our ability to link target species to particular protected species interactions. Another consideration is that inshore trawlers often target several fish species on different tows of the same fishing trip (i.e. snapper, tarakihi and trevally). There could plausibly be follow-on effects of, for example, tarakihi fishing on subsequent sets for a different target.

Location of capture

Net captures

As expected, all mammal, shark and turtle captures occurred in the net. Only four individuals were removed alive, or 27% of captures. When details were given, observers mostly recorded that animals were caught in the codend (four instances) with only one record of the animal retrieved from the lengthener.

Offal and fish was discharged during both shooting and towing in about half of the events where a mammal, shark or turtle was caught.

The majority of seabird captures were in the net (67%, or 39 of the 58 birds caught on gear), and most of those were alive when retrieved. If we take life status as a proxy for when birds were caught (alive indicating captures during hauling, dead being captured during shoot or tow, following Pierre 2018), 77% of seabird net captures would have occurred during the haul, not the shoot or tow. It was rare for vessels to discharge material of any sort during hauling, discounting discharge as the attractant leading to seabird captures in the net during the haul.

Warp captures

Seabirds were caught on the warp or doors less frequently than in the net (10% of seabird captures in fishing gear). Offal and fish was mostly discharged during the tow. Continuous discharge availability during trawl towing has been shown to increase seabird attendance at vessels and lead to increased contacts with the warp cables, and subsequent incidental mortality rates (e.g. Abraham and Thompson 2009; Pierre et al. 2012). One of the six recorded warp captures was technically alive, but the observer recorded that it was "disorientated unlikely to survive" having been submerged for 5–10 min. A small study in the South Atlantic demonstrated that a high proportion of seabird warp interactions go undetected by an observer based on the stern of a vessel (Parker et al. 2013).

Cryptic, or non-detected, mortality of seabirds killed by trawl warp strike is a significant but difficult to quantify occurrence in trawl fisheries (Parker et al. 2013; Richard et al. 2017; Koopman et al. 2018). Fisheries observers did not record the type and condition of the warp cables used on inshore vessels in the data available for this work, but warp type and condition have an influence on protected species captures and the retention of corpses. The presence and condition of splices in steel warp cables, and whether the splices are wrapped or not, has an effect on the probability that a seabird struck and entangled in the warp will remain on the warp until hauling and be detected by an observer. An unknown proportion of inshore trawl fishing vessels use Dyneema®, which unlike steel warps do not have warp splices. No studies of seabird interactions or retention with Dyneema warps have been conducted, but Dyneema warps may have benefits for seabird mitigation that should be explored. Fishers described that birds "bounce off" Dyneema warps, and that brighter Dyneema warp colours may be more conspicuous hence better avoided by seabirds (R. Burch pers. comm.).

Mitigation devices provide another indication that warp strike—and undetected mortality—may be a more important contributor to seabird bycatch than this study can show. That is, the seabird capture rate on fishing gear (with deck strikes removed) was higher when no warp mitigation was used during fishing—the majority of fishing events—than when tori lines or bafflers were used. Mitigation devices are discussed further below.

Another factor that could influence trawl warp strike is fishing depth. Since increasing fishing depth typically increases the warp angle so that the warp-water interface is closer to the vessel, we would expect less risk of warp captures with increased fishing depth as less warp is available to seabirds. This study included too few warp captures to test how the ratio of warp captures to net captures changes with depth, but this could warrant further investigation.

Deck strikes

This project's scope includes birds subject to deck strike. Bird strike on vessels comprised 17% of protected species interactions characterised in this report. Deck strike most often occurs when seabirds are attracted to vessel lighting, become disoriented when near to the lighting source, and crash into the vessel (Ryan 1991; Black 2005; Montevecchi 2006; Depledge et al. 2010). Daytime deck strike also occurs, sometimes because birds are clipped by a line or rigging when circling a vessel, or when densely foggy conditions occur.

The post-release survival of birds that have ended up on deck and required assistance to leave is not known and is difficult to test. Bird strikes on Southern Ocean vessels happen commonly, but resulting mortality is thought to be generally low (Black 2005). However, deck strike can injure birds not just physically as a result of impact on the vessel, but also by oily and dirty gear and decks soiling birds' feathers and reducing the insulative and aerodynamic qualities of birds' plumage (G.P. pers. obs.). As for other live captures of seabirds in fishing gear, fisheries observers cannot be expected to provide expert assessment of the condition of the seabird upon release, making any insight into the probability of post-release survival of deck-strike birds difficult.

Unidentified storm petrels were recorded as deck-strike captures on two occasions, and unidentified diving/storm petrel on 10 occasions. Unidentified is of concern here because the storm petrel and diving petrel groups each include a species with high conservation threat status and only one breeding site. The endemic NZ storm petrel *Fregetta maoriana* breeds on a single island, Hauturu/Little Barrier, and is classified as Nationally Vulnerable (Robertson et al. 2017). Until 2003, the NZ storm petrel was thought extinct but at-sea photographs lead to its rediscovery. The first thorough inspection of a NZ storm petrel resulted from a bird flying onto a fishing vessel near Little Barrier at night (Gaskin 2017), likely attracted by the vessel's lights. At the southern end of the country, South Georgian diving petrels *Pelecanoides georgicus* breed only on Whenua Hou/Codfish Island, and are classified as Nationally Critical (Robertson et al. 2017). South Georgian and common diving petrels are both prone to deck strike on vessels due to attraction to lights (Black 2005). Because NZ storm petrel and South Georgian diving petrel populations are small, even minor levels of mortality from deck strike may negatively impact upon the populations so should be mitigated against where possible. Given the extent of unknown species identifications for storm petrels and diving petrels, the vulnerability of some species and the subtleties of species identification, careful photographs should be a particular priority when dealing with diving and storm petrels on vessels.

It is likely vessel lighting is a major driver of deck strikes in NZ fishing operations, given the extent of evidence from other regions (Ryan 1991; Black 2005; Montevecchi 2006). Observers did not record lighting being managed (reduced, shielded, or usage limited) specifically to reduce the risk of deck strikes by seabirds. This does not mean that vessels were not managing their lighting, just that observers were not tasked with recording if lighting practises considered effects on seabirds. We could not assess the nature and extent of lighting and light spill in inshore trawl fisheries, or explore effects on deck strike rates, but the potential for reduced light spill and reduced but safe light levels should be explored as a potential way to mitigate deck strikes.

Mitigation

All captures of protected species were on inshore trawl vessels less than 28m in length overall (LOA), despite vessels up to 59.5m observed targeting inshore trawl fish species. Vessels smaller than 28m are not required by New Zealand law to use specialised equipment or to modify fishing techniques to mitigate the incidental mortality of protected species (NZ Government 2010), apart from staying outside prohibited areas. About a third of observed inshore trawl operators voluntarily used mitigation equipment and six of the 17 vessels that captured protected species were using mitigation equipment. A mitigation device was used in just under half of observed fishing events in this study. More widely, another study showed around 36% of NZ smaller-vessel trawl fishing operations (vessels <28m LOA) voluntarily use equipment and/or manage their discharge in some way to mitigate against the incidental capture of protected species (Rexer-Huber and Parker 2019).

Seabird capture rates were generally higher in observed fishing when no mitigation device was used, as were overall bird interaction rates, and the highest bird capture rates occured when no mitigation was used (2015 fishing year). It is not apparent why warp mitigation should reduce captures that mostly occurred in the net, but could simply be an index of intentions; that is, fishers who voluntarily use bird mitigation devices (which are recorded in observer data) may also have taken other actions to limit seabird interactions (potentially not recorded). The use of mitigation across the observed inshore trawl fleet changed considerably during the three-year focal period of this study. Baffler use steadily increased to peak at 45% and then slightly decreased to 42%. Tori line usage became insignificant on observed vessels from 2015 while vessels using no mitigation equipment increased. This may simply reflect a shift in observer placement to vessels that lacked mitigation equipment, not a wider trend in the fleet. Low tori line usage rates mean the relative effectiveness of tori lines and bird bafflers cannot be compared, but capture rates when bafflers were in use progressively decreased each year of this study.

Baffler use appeared to decrease seabird capture rates both in inshore trawl operations (this study) and on small-vessel trawlers more widely (Rexer-Huber and Parker 2019). However, the nature of information used for these studies mean that the varying contributions of vessel effects, weather, season etc. on baffler effectiveness cannot be properly accounted for. Trials testing the efficacy of mitigation devices in trawl fisheries—which explicitly control for vessel effects, weather, season and area—remain to be conducted in NZ smaller-vessel fisheries. Internationally, limited testing of mitigation equipment has been conducted on small trawl vessels <28m LOA (González-Zevallos et al. 2007; Pierre et al. 2014; Koopman et al. 2018).

Net mitigation

The majority of captures of protected species were in the net, both overall and when specifically considering seabirds. Few mitigation techniques to prevent incidental captures of seabirds in trawl nets have been tested, and fewer methods are in use in fisheries (Parker 2017).

Net binding prevents the net webbing from opening at the surface during shooting, potentially reducing the risk of animals tangling while the net is near the surface and drowning. Guidelines for net binding to reduce incidental seabird bycatch exist for at least one fisheries association in NZ (Deepwater Group), but there were no records of this method in use in inshore trawl operations. First trialled in the South Georgia icefish trawl fishery (Sullivan et al. 2004), three types of net binding have had limited testing on two classes of NZ trawl vessels; a factory-freezer trawler 106m LOA (seven tows trialled) and a fresh fish trawler 42m LOA (five tows trialled) (Cleal et al. 2009). Net binding does not mitigate captures during hauling, and no information indicates net binding may mitigate incidental fur seal or dolphin mortality in trawl fisheries.

A second method, net cleaning to remove entangled fish and fish scraps (known in NZ as 'stickers') that may attract animals to a net during shooting, shows some association with lower capture rates in the NZ smaller-vessel trawl fleet (Rexer-Huber and Parker 2019). Net cleaning efficacy has not been quantified (ACAP 2017) and is supported by observation only (Hooper et al. 2003). Sticker removal is included in seabird risk-management plans (vessel-specific voluntary plans) being implemented in NZ trawl fisheries, so empirical testing of efficacy is overdue.

Similarly, discharging material in the period when the net is near the surface could also attract animals. Inshore trawlers rarely discharge during hauling for that reason (3% or less of observed fishing each year in the NZ inshore trawl fleet), but discharging during shooting is relatively common (up to 20% of annual observed effort) (this study). Holding discharge during shooting, until the gear is at depth, is likely to help reduce net captures, especially if the net was cleared of stickers or other potential attractants to scavengers prior to shooting. Avoiding discharging for a period before shooting the net could also reduce bird abundance at shooting.

Mitigation equipment to prevent fur seal or dolphin captures in trawl nets is not established in NZ inshore fisheries. Seal exclusion devices (SEDs), based on the sea lion exclusion devices (SLEDs) used in offshore trawl fisheries in southern New Zealand, were trialled ten years ago but SEDs did not work as well as SLEDs and have not become standard in the trawl fisheries that capture fur seals in NZ (Cleal et al. 2009). Other approaches trialled to reduce seal captures include acoustic deterrents of various sorts and sensory deterrents (Baird 2004). Dolphin captures can be mitigated with a range of approaches including acoustic devices and gear modifications (Leaper and Calderan 2018), but are not in use in most NZ inshore trawl operations.

Operational actions by fishers to reduce net captures have been documented by observers, including turning the vessel during the tow to close up the mouth of the trawl and reduce the chance of seal or dolphin capture. Such reactive mitigation actions—animals seen therefore steps taken—require more work to understand the extent of use in the fleet.

Seabird warp mitigation

Bird bafflers are a widely-used approach to mitigate warp-strike of seabirds in trawl fishing. In inshore trawl operations, 36% of fishing events involved bafflers. Bafflers were the most commonly used device, comprising 73% of fishing where a device was used. Variations of bafflers have been tested to a limited degree on large factory freezer trawlers in NZ, Falkland Islands and USA (Melvin et al. 2011; Cleal and Pierre 2016; Kuepfer 2017). Bafflers have not been tested on trawlers <28m LOA in NZ, but a recent Australian study reported that a baffler trialled on a 29m vessel significantly reduced rates of heavy warp interactions compared to the control (84% less than a pinkie buoy clipped to the warp at each shot; Koopman et al. 2018).

Tori lines, also known as bird streamers, bird-scaring lines and bird-scaring streamers, were deployed on 10% of inshore trawl fishing events, comprising 21% of mitigation device use. Tori lines have been tested extensively in commercial longline and deepwater trawl fisheries in New Zealand and overseas, and are repeatedly shown to reduce seabirds taking hooks in the longline fisheries and succumbing to warp-strike in trawl fisheries (Sullivan et al. 2006a; Løkkeborg 2011; Melvin et al. 2011; Cleal et al. 2012). In trawl operations, tori line testing has focused on larger vessels. For example, testing took place on 66m (Sullivan et al. 2006a), 84.1m and 102.4m trawlers (Melvin et al. 2011), a 105m trawler (Cleal et al. 2012) and 75.4m and 67.8m trawlers (Snell et al. 2012). However, tori lines have not been tested on smaller commercial trawl fishing vessels <28m LOA in NZ nor to any extensive degree overseas.

Important design considerations affect tori line function, including streamer placement and material, and aerial extent of the lines overall (NZ Government 2010; ACAP 2017). A wide range of materials are used for streamers but not all to the same effect. Poor design can increase the risk of tori lines tangling with fishing gear, which can have safety consequences. Safety issues are most pronounced for solo-operator small vessels, since warp blocks are almost always outboard of the vessel's side rail (Tuck et al. 2013). Some streamer material can also increase risk to birds, particularly very soft, flexible tubing because it wraps around wings, increasing the chance of dragging and injuring or drowning. Streamer positioning is crucial to effective tori lines: if streamers are too close to the warp the tori line will entangle and be pulled down when hauling, but if streamers are too far from the transom birds can enter between the first streamer and transom and be positioned in the high-risk warp-water interface zone. The probability of streamers catching birds also increases if the tori is in the air over too short a distance, leaving streamers dragging in the water where seabirds can become entangled. Seabirds can also become caught on the drag object if the backbone of the tori line is on the water's surface. Streamers or backbone on the surface also increase the risk that the tori line will tangle with fishing gear. Aerial extent is affected by the height of the attachment point and the effectiveness of the drag object. Vessels operating at slower speeds may need to add to the drag object. Similarly, vessels reporting problems getting enough aerial extent in calm conditions could add to the drag object when deploying tori lines in calm weather, or try increasing the height of the tori-line attachment point to the vessel, as worked on small longline vessels (Pierre and Goad 2016).

Internationally, a number of other devices to mitigate against seabird interactions with warp cables have been trialled. Testing of road cones deployed on warp cables to try and reduce bird strike at the warp-water interface was conducted in Argentina, but was very limited. Ten hauls without and 12 hauls with a warp road cone were trialed on a 26m trawler (González-Zevallos et al. 2007). In trawls with the cone the number of contacts was reduced by 89% and the average distance between seabirds and cables was increased from 0.9m to 2.9m (González-Zevallos et al. 2007). This test was conducted in January and February, when albatrosses (mainly black-browed albatrosses) were potentially at lower abundance in the area due to attending distant breeding colonies. Black-browed albatrosses are part of the same *Thalassarche* grouip as NZ's white-capped, Buller's and Salvin's albatrosses, and are considered similar in behaviour and vulnerability to trawl risk.

Other mitigation devices trialled include a water-sprayer and pinkie buoys to reduce albatross interactions with warp cables. A water sprayer trialled on a 20m LOA vessel significantly reduced rates of heavy warp interactions (58.9% less than the control; Koopman et al. 2018). Trials with a pinkie buoy clipped to the warp found the pinkie buoy reduced heavy seabird interactions with the warp by 75% (Pierre et al. 2014). Safety concerns have been raised with the use of pinkie buoys, particularly for solo operators whose warp blocks are outboard of the bulwarks, requiring the operator to reach out to attach the clip (Tuck et al. 2013).

Discharging fish waste

Managing discharge is a widely-recognised approach to mitigating protected species captures in fisheries (Pierre et al. 2012; Maree et al. 2014; Kuepfer et al. 2016; Kuepfer and Pompert 2017). Vessels reviewed here mostly avoided discharging during the haul, which follows best practice to reduce the risk of net captures (ACAP 2017). More concerning is that discharging during shooting became more common, increasing from 7% to 20% of observed trawls over the three-year period of this study. Discharging during the shoot can attract animals to the net and therefore increase the chance of captures, and is also associated with higher risk of warp captures (e.g. Maree et al. 2014). Animals caught in the net or on the warp during shooting have no chance of survival through duration of the tow so the impacts are greater than when captured during the haul, when they may survive. Further, the risk of losing animals caught at shooting is greater than at later fishing stages, so discharging during shooting could increase the problem of undetected mortalities.

No discharging occurred while fishing (zero discharge) for 68–82% of inshore trawling reviewed here. However, the second-highest seabird capture rate was recorded for fishing with zero discharge, following the capture rate with discharging at shot. For example, black petrels were only recorded caught during fishing with zero discharge. This could simply be an artefact of zero discharge being by far the most frequent discharge 'management' approach (3,435 events out of 4,762 total in this study), or could be the result of zero discharge being considered adequate mitigationby fishers so other mitigation was not used. However, most captures occurred in the net, so warp-protecting mitigation devices are unlikely to have helped. In contrast to seabird captures, mammal captures were low during fishing with zero discharge, as expected. Taken together, we suggest zero discharging alone is not adequate for preventing net or warp captures of seabirds, and should be used together with a mitigation device.

Bird captures were slightly higher when fish was discharged than with offal discharge in observed inshore trawl fishing, contrasting with work in other regions where offal appeared to be more attractive (e.g. Furness et al. 2007). There was some indication that fishing stage could have an influence, with higher bird capture rates if shoot discharging involved fish and if tow discharging involved offal, but numbers were small so this would need further work to have any confidence in the pattern. On the other hand, marine mammal net captures were higher when offal was discharged than fish, and capture rates were lowest when nothing was discharged. For both groups (seabirds and mammals, sharks and turtles), numbers relative to discharging practises were too few for much confidence in these findings, but the pattern is of sufficient interest to explore further.

Risk exacerbators

To reduce or eliminate protected species captures requires a thorough understanding of factors that exacerbate the risk of captures. This work did not reveal novel factors that increase the risk of protected species interactions; rather, we provide more evidence that a combination of actions are required (e.g. ACAP 2017). Here we discuss in turn each potential contributor to the risk of captures, and possible ways to reduce or eliminate the risk.

Lack of mitigation against warp strike

Warp mitigation via a baffler or tori lines reduced seabird capture rates overall, with the highest capture rates recorded when no mitigation device was used, but the majority of fishing did not use a mitigation device to protect the warps (this study). Since device use is associated with reduced capture rates, mitigation devices should be used more widely. Warp mitigation should not in theory have been able to reduce captures, since recorded captures were mostly in the net. However, warp mitigation use may simply reflect broader fisher intent, with fishers who voluntarily use bird mitigation devices potentially also taking other (unrecorded) actions to limit seabird interactions. Warp mitigation is particularly important if vessels do not manage discharge (i.e. discharging is continuous during shooting or towing) because under those conditions any vulnerable seabird species in attendance are likely to constantly be at the warp-water interface and prone to warp strike.

Condition of warps and warp splices

Because loose sprags at the splices of steel warps can ensnare seabirds, some FMOs recommend that warp splices are bound. We suggest that the risk of splices to seabirds is low: most seabirds subject to warp-strike are poor divers, so the splice must be within meters of the surface (a very low probability event, given the length of warps) to ensnare seabirds. Wrapping splices may in fact have a negative effect on seabird mortality estimates, if wrapping reduces the probability that seabird corpses are retained on the warps to be detected at hauling. Observers do not report on the condition of warp cable splices, but occasionally record feathers or bone found in the warp. Without information on warp splices and warp condition, it is not possible to distinguish whether splices retain birds already caught, or directly cause mortality/injury to seabirds.

Greasy warp cables have been implicated in the capture of seabirds, with seabirds becoming stuck on warp-cables in NZ deepwater fisheries (R. Wells pers. comm.) and elsewhere (Madden et al. 2014). In this study we found no mention by observers of grease on warp cables in observer data or reports, so it is not possible to explore whether warp captures are similarly affected by warp grease in NZ inshore fisheries.

Discharging fish waste

There is a clear relationship between discharged material and protected species attending fishing vessels generally. In this study, vessels mostly avoided discharging during the haul per domestic and international guidelines (e.g. ACAP 2017). Discharging during shooting was associated with the highest seabird capture rates, and shoot discharging became more common over the three years 2013–2016 (this study). Ideally discharge would be retained on board throughout shooting and for a period before the net is shot to avoid attracting animals to the area where they can then get entangled in the net. If discharging during shooting is unavoidable, discharging should only occur once nets are below the surface. However, this is still less than ideal in the case of seabirds since outgoing warps mean that a bird entangled at the warp-water interface will be immediately dragged under.

It was common for inshore trawl vessels to discharge nothing during any stage of fishing (zero discharge). However, zero discharge was associated with the second-highest seabird capture rate (following the capture rate with discharging at shot), and the lowest capture rate of mammals, sharks and turtles. A zero-discharge strategy may prove an important way to reduce captures of animals like dolphins and seals, but should not be used without concurrent seabird mitigation (i.e. combine zero discharge with warp mitigation).

Net stickers

Net cleaning to remove entangled fish waste (sstickers) shows some association with lower capture rates in the NZ smaller-vessel trawl fleet (Rexer-Huber and Parker 2019). It is plausible that stickers should affect net captures in inshore trawl as well, but the majority of net captures reported here appear to have been caught at the haul (34 out of 54 net captures were alive) rather than during shooting (20 caught dead) as would be expected if stickers in the net attracted ting animals leading to captures during shooting. However, seabird life status is not a perfect proxy for inferring seabird capture stage (Pierre 2018), with the implication that since some of the dead animals could also have been killed during haul, the proportion caught at haul could have been higher. The level of cryptic or non-detected net mortality is unknown but modelling of annual potential fatalities attempts to account for this by considering 50% of live captures as dead (Richard et al. 2017). The true extent of net captures during shooting remains uncertain, so the potential for net stickers to influence captures also remains unclear. Given the number of animals caught dead, perhaps during shooting, sticker removal warrants further exploration. Testing sticker removal efficacy is also important since sticker removal is included in vessel-specific seabird risk-management plans.

Vessel effects

There was a suggestion in the data of fewer captures on slightly longer vessels (mean 22m versus 19m). The range of vessel lengths overall, and the rare occurence of protected species captures, mean this should be interpreted with caution. However, we expect vessel effects relating to size (e.g. discharge management or mitigation device capability) could affect seabird captures and should be explored further.

Recommendations

Mitigating captures

Our analyses have highlighted several options for reducing the risk of interaction with protected species which should be incorporated into vessel practices. Some mitigation actions have been implemented since the study period, with other actions planned (MPI, CSP). We focus on proven methods or devices (e.g. ACAP 2017) and identify where an approach shows promise but needs testing.

1. **Warp mitigation --** Seabird capture rates were lower in observed fishing when a mitigation device (baffler/tori) was used than with no mitigation device, including when there was no discharge during fishing. Although warp mitigation should not affect net captures or deck interactions, warp mitigation reduced seabird capture rates despite retaining deck strikes and including net captures (this study).
2. **Retaining all discharge** throughout fishing (zero-discharge) **--**
    a. Mammals: lower mammal capture rates were found with zero discharge than when anything discharged, at any stage.
    b. Seabirds: zero discharge has been shown to reduce the risk of interaction in some fisheries (e.g. Maree et al. 2014), but zero discharge was not enough to mitigate seabird captures on its own (this study); should be used together with warp mitigation.

3. **Discharge type and stage --** If discharging fish or offal during fishing is unavoidable the following should be considered:
    a. Mammals: offal discharge was linked to higher capture rates than discharged fish.
    b. Seabirds: continue with no-discharge during hauling, discharging instead during tow together with warp mitigation. Discharge during shooting appears to be a risk exacerbator and should be avoided. If discharging absolutely must occur during shooting, material should be held until the gear is at depth since this could help reduce net captures. Avoiding discharge for a period before shoot may also reduce bird abundance around the vessel at shooting.
4. **Net cleaning --** Removing stickers from nets may reduce interactions during shooting by reducing the presence of attractants. Testing of efficacy needed.
5. **Net surface time –** Reducing the time the net is available at the surface during shooting and hauling should reduce captures. This study showed that capture rates increase with longer net surface time.

Future work

Here we pull together areas identified throughout this report where further work is required, recommending steps for progressing work to mitigate protected species captures in inshore trawl fisheries.

Unexpected patterns of seabird captures by discharge type/stage could be due to sample size imbalance (highly skewed to fishing with zero discharge, and relatively few events for each type-stage category), or may indicate real differences in bird associations with discharging. Uncovering the real relevance of discharging practises to seabird captures requires empirical testing.

Since capture events are numerically rare, a lot of fishing effort data are required for a sufficiently large sample for quantitative analysis of captures. A larger fishing event dataset would be beneficial throughout, but particularly to confirm capture rate patterns for marine mammals, sharks and turtles relative to discharge stage/type.

The lack of observer data from southern inshore trawl fisheries limits our understanding of protected species interactions in the greater South Island. Information on the nature and extent of interactions between inshore trawl fisheries and species that are more abundant in the south should therefore be a priority.

Warp mortalities are likely underestimated, as bird capture rates were highest when no warp mitigation was used.

- Ways to retain animals that impacted the warp should be explored. For example, warp type and condition could affect seabird retention until hauling. Trial warps with sprags cf. bound splice cf. no splice (e.g. Dyneema® warps). Trials could include an experimental device (e.g. Parker et al. 2013).
- Vessel size: warp interactions are expected to occur at higher rates on larger vessels which can fish in poorer sea states when the guillotine action of warps is most pronounced. This study included too few warp captures to assess changes in the warp- to net-capture ratio with vessel size.
- Fishing depth: Since warp angle increases with increasing fishing depth, we expect less risk of warp interactions with increased fishing depth as less warp is available to seabirds. More warp capture data required to test how the ratio of warp captures to net captures changes with depth.

Warp testing: Potential for Dyneema® warps to provide additional seabird mitigation should be tested. Fishers describe that birds 'bounce off' Dyneema warps, and that the bright warp colours are seen and avoided by birds (R. Burch pers. comm.). Trial Dyneema cf. steel warps, considering fate of bird after bounce.

Storm and diving petrel ID: Storm petrels and diving petrels are prone to deck strike but are rarely identified to species (mostly generic code used) (this study). Because NZ storm petrel and South Georgian diving petrel populations are small, deck strike can easily impact the populations so should be mitigated for. Given the extent of 'unknown' species identifications, the vulnerability of NZ storm petrels and South Georgian diving petrels, and the subtleties of species ID, careful photographs should be a particular priority when dealing with diving- and storm petrels on vessels.

Lighting management: Vessel lighting is expected to be a driver of deck strikes in NZ fishing operations, given evidence from other regions (Ryan 1991; Black 2005). Too little data on lighting and light spill in inshore trawl fisheries were available for this study to explore effects on deck strike rates. Poorer weather conditions (indicated by sea state) did not appear to increase deck strike rates, but the data available did not enable testing for foggy, still conditions sometimes associated with deck strike events. Lighting should be explored as a potential way to mitigate deck strikes, particularly around high-risk areas (titi islands, Hauturu, Codfish), assessing levels (deck lights, stern lights, both?) and light spill (deck cover, light shields?).

Sticker removal: A substantial proportion of captures reported in this study were dead on capture, suggesting capture at some stage during shooting or towing. Stickers in the net are expected to increase the attractiveness of the net at shooting, which could contribute to captures at that fishing stage. Given the number of animals caught dead, sticker removal in inshore operations warrants further exploration as a shot mitigation approach. Efficacy testing is important as sticker removal is rolled out in vessel Seabird Risk-Management Plans.

Net availability: The majority of protected species captures in inshore trawl operations were caught in the net, and the highly variable gear and operational practises across the fleet is expected to affect net surface time. Data on the duration of net availability at the surface during shooting and hauling need to be explored further to assess potential effects of gear type (e.g. PSH linked to longer surface time than standard codend). Operational practises that could reduce net surface time in inshore trawl operations should also be explored.

Gear characteristics (headline height, doorspread, etc.) may influence protected species captures, potentially by affecting net availability, but data in this report were skewed or had few events per category. As noted above for better quantifying captures of marine mammals, sharks etc, a larger trawl gear-fishing event dataset would help draw out gear-related parameters that influence protected species captures.

Refining capture data collection

This section primarily deals with the observer information used in this study, identifying data gaps and making suggestions to improve the accessibility of relevant information.

Data coverage

The characterisation of protected species captures presented in this report is based on observer records, as a proxy for captures occurring in unobserved areas, fisheries and vessels. Very little observer data were available for this work from any part of the South Island (CHA, SEC and SOU), and no data for the focal period were available from the west coast of the North Island (CEW). In these areas, protected species assemblages are expected to be different, so capture profiles and associated risk factors are also expected to be different. This assumption could be tested by prioritising observer coverage in unobserved fishery-areas, or via e-monitoring as progressed in other countries.

Data completeness

In observed areas, government fisheries observers already collect a broad range of information from at-sea observations of longline fishing activity (e.g. Sanders and Fisher 2015). Ensuring that observer records are as complete as possible will help maximise the value of this dataset (Goad 2017; Pierre 2018). Efforts to characterise what is going on in a fishery, for example, hinge on observers reporting when something is *not* happening as well as when it is. For example, a "<null>" entry in the database for the fields mitigation_equipment or mitigation_event is much less useful than "None" (or its code), and <null> for offal or fish discharge fields is similarly less useful than "N" or none. In this study, 9.6% of records had to be excluded because of missing information, mostly nulls.

Information accessibility

In many cases, information relevant to this study appeared to be restricted to mention in observer documentation (reports and diaries) mainly because relevant data fields or codes were not available. For example, some information on discharge in bottom longline set and haul logs collected by observers does not appear to be entered into COD, as discussed in Pierre et al. (2013), so data collected were unavailable for this work. Some observers entered such information as notes in COD (e.g. comment_catch_weight field). Notes in data fields were more useful than no information at all, but are likely laborious to enter and interpretation of notes can be subjective for users.

To make best use of information recorded by observers, we suggest a number of ways that existing observer data collection could be developed. In particular, the following information types could benefit from codes or a tick-box field to routinely and systematically record observations:

Seabird captures

- When a seabird capture was observed to occur: during shooting (i.e. actually observed taking place during shot, not when observer detected it), during tow, during haul, other, or unknown
- Deck strikes: location codes variably used for deckstrike, mostly called I (impact or deck strike), but sometimes O (other). Information on when event occurred (night/day, fishing stage) would help
- Losses: Indicators of animal captured but lost during fishing (e.g. feathers in the warp or warp splice, or at the door)
- Warp view: Could observer view the warps during hauling or not?
- Some way to indicate interactions occurring outside of fishing (e.g. while steaming, while on anchor); these interactions should be documented as they are part of a vessel's fishing operations in an area.

Mitigation

- Stage mitigation used: Category needed to record when mitigation device utilised (e.g. shot only, entire fishing operation?)
- Net cleaning: Sticker removal from net needs category in COD, including some indication of frequency (before all shots, before some shots) and extent (all stickers, some stickers).
- Discharge codes: H (discharge held) code seems used variably, sometimes used interchangeably with N (no discharge)
- Batch discharging: Structure required for batch discharging (if occurring, and how). Is batch discharging occurring; if so, what fishing stage, amount in batch, interval between batches or storage period, where relative to fishing operations (between warps, port/starboard, other), some indication of how swift the discharge mechanism is (i.e. time taken for batch to go overboard)
- Deckloss: If fish and offal losses are included as part of general discharge categories, users cannot assess the effect of irregular pulses or batches of material off the deck. Suggest a separate category (what fishing stage, where relative to fishing operations).

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References

Abraham ER (2010) Warp strike in New Zealand trawl fisheries, 2004–05 to 2008–09. New Zealand Aquatic Environment and Biodiversity Report No. 60. Ministry of Fisheries, Wellington

Abraham ER, Kennedy A (2008) Seabird warp strike in the southern squid trawl fishery, 2004–05. New Zealand Aquatic Environment and Biodiversity Report, No. 16. Ministry of Fisheries

Abraham ER, Thompson FN (2015a) Protected species bycatch in New Zealand. Prepared by Dragonfly Data Science from data held by the Ministry for Primary Industries. https://psc.dragonfly.co.nz/2017v1/

Abraham ER, Thompson FN (2015b) Data for the analysis of protected species captures. Prepared by Dragonfly Data Science from data held by the Ministry for Primary Industries. https://psc.dragonfly.co.nz/2017v1/

Abraham ER, Thompson FN (2015c) Captures of all birds in trawl fisheries, in the New Zealand Exclusive Economic Zone, from 2002–03 to 2015–16. https://psc.dragonfly.co.nz/2017v1/

Abraham ER, Thompson FN (2009) Warp strike in New Zealand trawl fisheries, 2004–05 to 2006–07. New Zealand Aquatic Environment and Biodiversity Report No. 33. Ministry of Fisheries, Wellington

ACAP (2017) ACAP review and best practice advice for reducing the impact of pelagic and demersal trawl fisheries on seabirds. Reviewed at AC10. Agreement on the Conservation of Albatrosses and Petrels, Hobart

Annala JA (1987) The biology and fishery of tarakihi, *Nemadactylus macropterus*, in New Zealand waters. Fisheries Research Division Occasional Publication No. 51. Ministry of Agriculture and Fisheries, Wellington

Baird SJ (2008) Net captures of seabirds during trawl fishing operations in New Zealand waters. NIWA Client Report WLG2008–22, prepared for Clement and Associates. NIWA, Wellington

Baird SJ (2004) Discussion on possible approaches for mitigating the bycatch of fur seals in the hoki fishery. Paper for the Hoki Fishery Management Company Environmental Steering Group. NIWA, Wellington

Bell EA (2013) Black petrel. In: New Zealand Birds Online. www.nzbirdsonline.org.nz

Black A (2005) Light induced seabird mortality on vessels operating in the Southern Ocean: incidents and mitigation measures. Antarct Sci 17:67–68

Cleal J, Clement G, Wells R (2009) Mitigating incidental captures of fur seals in trawl fisheries. A report commissioned by Department of Conservation. Clement and Associates, Auckland

Cleal J, Pierre JP (2016) Development of bird baffler designs for offshore trawl vessels. Conservation Services Programme Project MIT2013/05 Final Report. Report from Clement and JPEC. Department of Conservation, Wellington

Cleal J, Pierre JP, Clement G (2012) Warp strike mitigation devices in use on trawlers >28m in length operating in New Zealand fisheries: at sea trials and analysis. Conservation Services Programme project MIT2011/07. Clement and Associates

Clement and Associates (2008) New Zealand inshore trawl gear and operations survey. A report commissioned by Seafoood Innovations and the Seafood Industry Council. Clement and Associates, Nelson

Croxall JP, Butchart SHM, Lascelles B, et al (2012) Seabird conservation status, threats and priority actions: a global assessment. Bird Conserv Int 22:1–34. doi: 10.1017/S0959270912000020

Deepwater Group (2017) Sharks Operational Procedures 2017-18. From http://deepwatergroup.org/wp-content/uploads/2017/06/Sharks-2017.pdf

Depledge MH, Godard-Codding CAJ, Bowen RE (2010) Light pollution in the sea. Mar Pollut Bull 60:1383–1385

Duffy C, Francis M, Dunn M, et al. (2018) Conservation status of New Zealand condrichthyans (chimaeras, sharks and rays), 2016. New Zealand Threat Classification Series 23. Department of Conservation, Wellington

Favero M, Blanco G, García G, et al. (2011) Seabird mortality associated with ice trawlers in the Patagonian shelf: effect of discards on the occurrence of interactions with fishing gear. Anim Conserv 14:131–139. doi: 10.1111/j.1469–1795.2010.00405.x

Francis M (2017a) Bycatch of white sharks in commercial set nets. Prepared for Department of Conservation. NIWA, Wellington

Francis M (2017b) Review of commercial fishery interactions and population information for New Zealand basking shark. Prepared for Department of Conservation. NIWA, Wellington

Francis MP, Lyon WS (2014) Review of commercial fishery interactions and population information for the oceanic whitetip shark, a protected New Zealand species. Report WLG2014–40 prepared for Department of Conservation. NIWA, Wellington

Furness R, Edwards A, Oro D (2007) Influence of management practices and of scavenging seabirds on availability of fisheries discards to benthic scavengers. Mar Ecol Prog Ser 350:235–244. doi: 10.3354/meps07191

Gaskin CP (2017) New Zealand storm petrel. In: Miskelly CM (ed) New Zealand Birds Online. www.nzbirdsonline.org.nz

González-Zevallos D, Yorio P, Caille G (2007) Seabird mortality at trawler warp cables and a proposed mitigation measure: a case of study in Golfo San Jorge, Patagonia, Argentina. Biol Conserv 136:108–116

Heather B, Robertson HR (2015) The Field Guide to the Birds of New Zealand. Penguin, Auckland

Hooper J, Agnew D, Everson I (2003) Incidental mortality of birds on trawl vessels fishing for icefish in Subarea 48.3. WG-FSA-03/79, SC-CAMLR XXII. CCAMLR, Hobart

Koopman M, Boag S, Tuck GN, et al. (2018) Industry-based development of effective new seabird mitigation devices in the southern Australian trawl fisheries. Endanger Species Res 36:197–211

Kuepfer A (2017) The warp deflector (pinkie system): practical implications of a physical seabird bycatch mitigation device trialled in the Falkland Islands trawl fishery. SBWG8 Inf 17. Agreement on the Conservation of Albatrosses and Petrels, Hobart

Kuepfer A, Gras M, Pompert J (2016) Discard management as a seabird by-catch mitigation tool: The effect of batch-discarding on seabird interactions in the Falkland Islands trawl fishery. SBWG7 Inf 25. Agreement on the Conservation of Albatrosses and Petrels, Hobart

Kuepfer A, Pompert J (2017) Discard management as a seabird bycatch mitigation tool: Results from further batch-discard trials in the Falkland Islands trawl fishery. SBWG8 Inf 16. Agreement on the Conservation of Albatrosses and Petrels, Hobart

Langley AD (2018) Stock assessment of tarakihi off the east coast of mainland New Zealand. New Zealand Fisheries Assessment Report 2018/05. Ministry for Primary Industries, Wellington

Leaper R, Calderan S (2018) Review of methods used to reduce risks of cetacean bycatch and entanglements. CMS Technical Series No. 38. UNEP/CMS Secretariat, Bonn

Løkkeborg S (2011) Best practices to mitigate seabird bycatch in longline, trawl and gillnet fisheries - efficiency and practical applicability. Mar Ecol Prog Ser 435:285–303

Madden C, Mansfield L, Maree B, Wanless RM (2014) Fouling and mortality of seabirds from heavily greased trawl warps. S6_ 4_73 ICAWA Conference, Senegal

Marchant S, Higgins PJ (eds) (1990) Handbook of Australian, New Zealand and Antarctic birds. Volume 1, ratites to ducks. Oxford University Press, Melbourne

Maree BA, Wanless RM, Fairweather TP, et al. (2014) Significant reductions in mortality of threatened seabirds in a South African trawl fishery. Anim Cons 17:520-529

Melvin EF, Dietrich KS, Fitzgerald S (2011) Reducing seabird strikes with trawl cables in the pollock catcher-processor fleet in the eastern Bering Searichar. Polar Biol 34:215–226

Montevecchi WA (2006) Influences of artificial light on marine birds. In: Rich C, Longcore T (eds) Ecological consequences of artificial night lighting. Island Press, Washington, pp 99–113

MPI (2013) National Plan of Action to reduce the incidental catch of seabirds in New Zealand fisheries. Ministry for Primary Industries, Wellington

NZ Government (2010) Seabird Scaring Devices Circular 2010 (No. F517). New Zealand Gazette No. 29

Parker G, Crofts S, Pompert J, et al. (2013) In the wake of a factory trawler: Research into undetected seabird mortality. Report to Agreement on the Conservation of Albatrosses and Petrels SBWG5. Falkland Islands Fisheries Department, Stanley

Parker GC (2012) An assessment of seabird bycatch in Falkland Island trawl fisheries: July 2010 to June 2011. Falkland Islands Government, Stanley

Parker GC (2013) An assessment of seabird bycatch in Falkland Island trawl fisheries: July 2011 to June 2012. Falkland Islands Government, Stanley

Parker GC (2017) Stocktake of measures for mitigating the incidental capture of seabirds in New Zealand commercial fisheries. Report to Southern Seabird Solutions Trust. Parker Conservation, Dunedin

Phillips RA, Gales R, Baker GB, et al. (2016) The conservation status and priorities for albatrosses and large petrels. Biol Conserv 201:169–183

Pierre JP (2018) Mitigating seabird captures during hauling on smaller longline vessels. Conservation Services Programme Project MIT2015–02. JPEC Ltd

Pierre JP, Abraham ER, Richard Y, et al. (2012) Controlling trawler waste discharge to reduce seabird mortality. Fish Res 131–133:30–38. doi: 10.1016/j.fishres.2012.07.005

Pierre JP, Gerner M, Penrose L (2014) Assessing the effectiveness of seabird mitigation devices in the trawl sectors of the Southern and Eastern Scalefish and Shark fishery in Australia. JPEC Ltd, Wellington

Pierre JP, Goad DW (2016) Improving tori line performance in small-vessel longline fisheries. Report prepared by JPEC Ltd and Vita Maris. Department of Conservation, Wellington

R Core Team (2016) R: a language and environment for statistical computing

Rexer–Huber K, Parker GC (2019) Characterising of discharge management in small-vessel trawl and longline fisheries. Report to Conservation Services Programme. Parker Conservation, Dunedin

Richard Y, Abraham ER, Berkenbusch K (2017) Assessment of the risk of commercial fisheries to New Zealand seabirds, 2006–07 to 2014–15. New Zealand Aquatic Environment and Biodiversity Report 191. Ministry for Primary Industries, Wellington

Robertson HA, Baird K, Dowding JE, et al. (2017) Conservation status of New Zealand birds, 2016. New Zealand Threat Classification Series 19. Department of Conservation, Wellington

Ryan PG (1991) The Impact of the Commercial Lobster Fishery on Seabirds at the Tristan da Cunha Islands, South Atlantic Ocean. Biol Conserv 57:339–350

Sagar PM (2013) Sooty shearwater. In: New Zealand Birds Online. www.nzbirdsonline.org.nz

Snell KRS, Brickle P, Wolfaardt AC (2012) Refining Tori lines to further reduce seabird mortality associated with demersal trawlers in the South Atlantic. Polar Biol 35:677–687. doi: 10.1007/s00300–011–1113–z

Sullivan BJ, Brickle P, Reid TA, et al. (2006a) Mitigation of seabird mortality on factory trawlers: trials of three devices to reduce warp cable strikes. Polar Biol 29:745–753. doi: 10.1007/s00300-006-0111-z

Sullivan BJ, Liddle GM, Munro GM (2004) Mitigation trials to reduce seabird mortality in pelagic trawl fisheries (Subarea 48.3). WG–FSA–04/80. CCAMLR, Hobart

Sullivan BJ, Reid TA, Bugoni L (2006b) Seabird mortality on factory trawlers in the Falkland Islands and beyond. Biol Conserv 131:495–504

Tuck GN, Knuckey I, Klaer NL (2013) Informing the review of the Commonwealth Policy on Fisheries Bycatch through assessing trends in bycatch of key Commonwealth fisheries. Final Report 2012/046. Fisheries Research and Development Corporation, Canberra

Venables WN, Ripley BD (2002) Modern Applied Statistics with S. Fourth Edition. Springer, New York. ISBN 0–387–95457–0, Fourth. Springer, New York

Watkins BP, Petersen SL, Ryan PG (2008) Interactions between seabirds and deep-water hake trawl gear: an assessment of impacts in South African waters. Anim Conserv 11:247–254

Appendices

Appendix 1

List of CSP inshore trawl fishery target species included in inshore trawl fishing data for this study, from CSP definition inshore trawl.

Species code	Name	Species
BCO	Blue cod	*Parapercis colias*
BNS	Bluenose	*Hyperoglyphe antarctica*
BRI	Brill	*Colistium guntheri*
CAR	Carpet shark	*Cephaloscyllium isabellum*
ELE	Elephant fish	*Callorhinchus milii*
ESO	N.Z. sole	*Peltorhamphus novaezeelandiae*
FLA	Flats mixed, i.e. flounders, soles, brill, turbott (YBF, SFL, BFL, GFL, LSO, ESO, BRI, TUR)	
FLO	Flounder unspecified (BFL,DAB,SFL,GFL,YBF)	
GFL	Greenback flounder	*Rhombosolea tapirina*
GSH	Ghost shark	*Hydrolagus novaezealandiae*
GUR	Gurnard	*Chelidonichthys kumu*
HAP	Hapuku	*Polyprion oxygeneios*
HPB	Hapuku & bass	*Polyprion oxygeneios* & *P. americanus*
JDO	John dory	*Zeus faber*
JGU	Spotted gurnard	*Pterygotrigla picta*
KAH	Kahawai	*Arripis trutta, A. xylabion*
KIN	Kingfish	*Seriola lalandi*
LDO	Lookdown dory	*Cyttus traversi*
LEA	Leatherjacket	*Meuschenia scaber*
LSO	Lemon sole	*Pelotretis flavilatus*
MDO	Mirror dory	*Zenopsis nebulosa*
MOK	Moki	*Latridopsis ciliaris*
PIP	Pipefish	*Syngnathidae*
RCO	Red cod	*Pseudophycis bachus*
RSK	Rough skate	*Zearaja nasuta*
SCH	School shark	*Galeorhinus galeus*
SDO	Silver dory	*Cyttus novaezealandiae*
SFI	Starfish	*Asteroidea* & *Ophiuroidea*
SFL	Sand flounder	*Rhombosolea plebeia*
SKI	Gemfish	*Rexea* spp.
SNA	Snapper	*Pagrus auratus*
SPD	Spiny dogfish	*Squalus acanthias*
SPE	Sea perch	*Helicolenus* spp.
SPO	Rig	*Mustelus lenticulatus*
STA	Giant stargazer	*Kathetostoma* spp.
TAR	Tarakihi	*Nemadactylus macropterus* & *N.* sp.
TRE	Trevally	*Pseudocaranx georgianus*
TUR	Turbot	*Colistium nudipinnis*
YBF	Yellowbelly flounder	*Rhombosolea leporina*

Appendix 2

Protected species captures recorded in observed inshore trawl fishing operations 2013–2016, where capture rate is the number of individuals caught per 100 fishing events.

		code	n caught	capture rate
Mid-sized petrels and shearwaters			**54**	**1.134**
black petrel	*Procellaria parkinsoni*	XBP	14	0.294
flesh-footed shearwater	*Puffinus carneipes*	XFS	14	0.294
grey-faced petrel	*Pterodroma macroptera*	XGF	7	0.147
Procellaria petrels		XPC	6	0.126
sooty shearwater	*Puffinus griseus*	XSH	6	0.126
shearwater spp.		XSW	3	0.063
bullers shearwater	*Puffinus bulleri*	XBS	1	0.021
Cook's petrel	*Pterodroma cookii*	XKP	1	0.021
mid-sized petrels/shearwaters	*Pterodroma, Procellaria* & *Puffinus* spp.	XPM	1	0.021
Pterodroma petrels		XPT	1	0.021
Diving petrels, storm petrels			**10**	**0.210**
Common diving petrel	*Pelecanoides urinatrix*	XDP	5	0.105
white-faced storm petrel	*Pelagodroma marina*	XWF	3	0.063
storm petrel spp.		XST	2	0.042
white-capped albatross	*Thalassarche steadi*	XWM	**3**	**0.063**
unidentified seabird		UNF	**1**	**0.021**
Common dolphins and other marine mammals			**14**	**0.273**
common dolphin	*Delphinus delphis*	CDD	7	0.147
NZ fur seal	*Arctocephalus forsteri*	FUR	5	0.105
bottlenose dolphin	*Tursiops truncatus*	BDO	1	0.021
green turtle	*Chelonia mydas*		**1**	**0.021**
white pointer shark	*Carcharodon carcharias*		**1**	**0.021**