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

Graham C. Parker and Kalinka Rexer-Huber

DRAFT Report to Conservation Services Programme for project MIT 2017–03

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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, there has been extensive work to quantify protected species captures and understand potential drivers in some fisheries and areas. However, there is uncertainty around the nature and extent of protected species interactions in some 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 4763 trawl events on 34 vessels across the inshore fleet from October 2013–December 2016 recorded a diverse suite of protected species caught in nets, warp-cables and as deck strike in inshore trawl operations. A total of 84 protected species captures were recorded, including individuals of 12 species of seabirds, 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 57% of seabird captures, warps 9% and deck-strike 21%. Captures of marine mammals, sharks and turtles were all in the net.

Statistical modelling found the key factors explaining captures were target fish species, fishery year and fishery area. However, 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. Species more abundant in southern NZ that are commonly incidentally caught in offshore trawl fisheries include white-chinned petrels, 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 seabird and NZ fur seal interactions than recorded here.

Seabird captures showed clear effects of bycatch mitigation use on capture rates. In observed trawl fishing, seabird captures rates were lowest when a bird baffler was used, and appeared lower with net cleaning, illustrating the combination approach required for effective seabird mitigation. Discarding unwanted material did not explain all captures, with some seabirds caught when no discarding was occuring. Mammal (one bottle-nosed and seven common dolphins and five NZ fur seals), shark and turtle captures appeared influenced by discard type, increasing with offal discards. Practises were not consistent within fleets or between trips of the same vessel, so capture risks will necessarily also vary.

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

Interactions with commercial fisheries remains the most prominent and ongoing risk to many species of southern hemisphere seabirds (Croxall et al. 2012; Phillips et al. 2016). The goal of the National Plan of Action, Seabirds, is to reduce the incidental catch of seabirds in New Zealand fisheries (MPI 2013). The use of devices that aim to reduce seabird strikes on trawl warps has been required on New Zealand trawlers ≥ 28m in overall length since April 2006. Trawlers less than 28m overall length are not required to use specific mitigation equipment or operational techniques to prevent the incidental capture of protected species.

Due to a lack of observer coverage in inshore trawl fisheries, the estimate of seabird mortality in inshore trawl fisheries is highly uncertain (Richard et al. 2017). Statistical modelling suggests that annual potential mortalities of seabirds in New Zealand fisheries are highest in inshore trawl fisheries, with a mean of 4800 (95% c.i. 3140–7080) seabirds estimated killed annually (Richard et al. 2017). Seabird mortality in inshore fisheries is thought to be dominated by New Zealand 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 respective conservation status of these two species is Declining and Nationally Critical (Robertson et al. 2017). Fisheries observer data has also recorded captures of protected shark species and marine mammals in inshore trawl fisheries (Abraham and Thompson 2015a).

The inshore trawl fishery is 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 effectively mitigate 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 fisheries observers. Unobserved sectors of the inshore trawl fisheries (that is, 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 and commercial fishing data were requested from the Ministry for Primary Industries. 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 discarding, 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 Conservation Services Programme CSP inshore trawl fisheries, excluding Cook Strait hoki; Appendix 1), and by year to include only the most recent three years of the data received. 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 CSP and Ministry for Primary Industries (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 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 discarding and mitigation data were missing (discard-related fields "<null>" and mitigation_equipment "None" for entire trip, ie. 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 was converted into the same information that was recorded on the fishing event forms. Deck strikes were retained in bycatch data (capture_method code "I" and observer comments).

The fishing event form allowed for multiple discard types to be recorded, as well as discards occuring at different stages. During data grooming, a single discard type was determined for each fishing event observation. Discard types were given the following order: no discards, 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 discard type category recorded in an observed fishing event is then used to characterise the discard type.

Similarly, discard stage was given the following order: no discards, tow, haul, shot. This corresponds to increasing risk to animals attending a vessel. Discards during shooting are 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 is then used to characterise the discard 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 are not adequate, we provide qualitative assessements of factors that may influence protected species captures. Qualitative assessments are based on information in observer trip reports, observations by fishers.

Captures of seabirds, marine mammals, sharks and turtles were analysed separately, 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 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 numercally skewed toward observed fishing in regions where few large-bird captures occur. 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. Therefore, 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 are 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 discard type and discard 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 503 (9.6%) records were excluded from the analysis leaving 4,763 valid observations. Fishing event observations were excluded if discarding and mitigation data were missing (discarding fields all "<null>" and mitigation_equipment field "None" for entire trip, ie. no indication that the fields were used; 398 records), and if protected species bycatch was unknown (nonfish_bycatch code for not observed, "U", used; 105 records). Some rejections are inevitable, for example when observers record unknown bycatch during a period 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 34 different vessels, ranging in size from 13–82m. 77 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 exclusively on observed inshore trawl fishing, using data solely from inshore trawl fishing where there was a government fisheries observer on board. Observed fishing events in the October 2013–December 2016 period represented 3.03% of all inshore trawl fishing events (Abraham and Thompson 2015b). Observer coverage varied by year (Figure 1). The proportion of inshore trawl fishing observed increased progressively from 2013/14 to 2015/16, increasing from 4.7% to 9.8% observer coverage in the fishery. In 2016/17 observer coverage dropped to 2.3%. Inshore trawl fishing was observed to some extent in most fishing areas, although not evenly/equally, but there was no observer coverage in inshore trawl operations off the South coast of the South Island (fishing area SOU), and very little in East coast South Island operations.

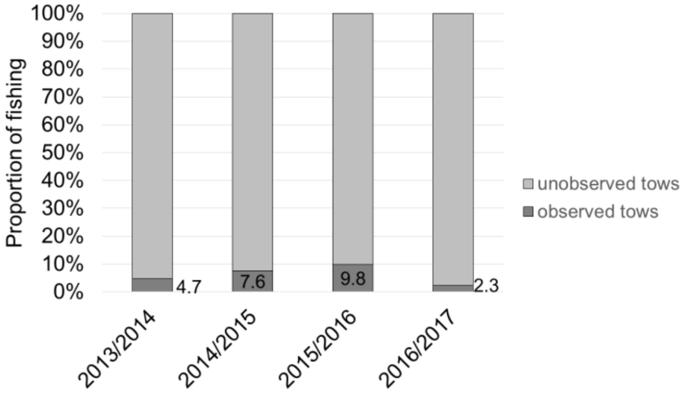

Figure 1. Observer coverage in inshore trawl fishing October 2013–December 2016 by year. Numbers above the horizontal axis give the proportion of observed fishing (% of the total number of fishing events). From data in Abraham and Thompson (2015b)

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	16	46
Total	1334	1733	1073	623	

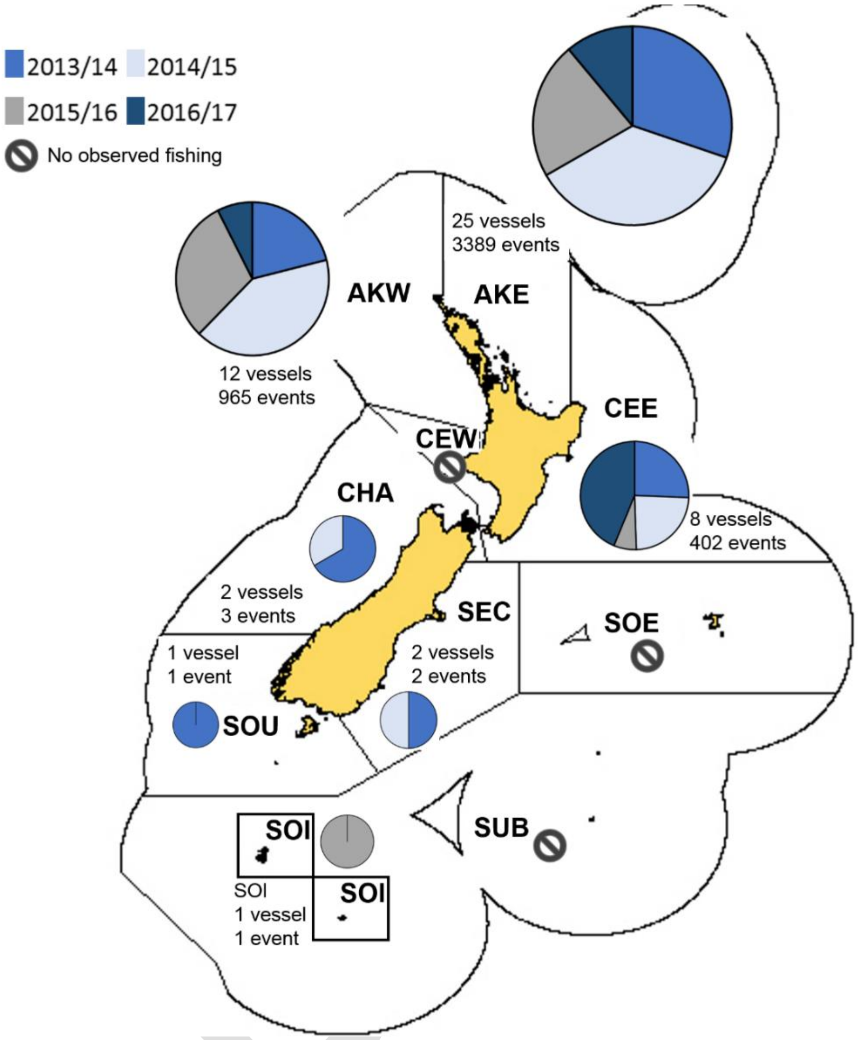

Figure 2. Observed inshore trawl fishing across fisheries management areas 2013–2016. Pies show the breakdown of fishing events in each FMA by fishing year, with the overall size indicating the total number of fishing events. Crossed circles indicate areas where no fishing effort was observed

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.

Spatial coverage of the dataset across fisheries management areas is shown in Figure 2. The large majority of inshore trawl vessels included in the observer dataset 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, 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. 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).

Protected species captures

To produce a consistent dataset, information from the fishing event and non-fishbycatch forms was merged. Captures were recorded on 69 fishing events. There were 25 tows where captures were recorded only on the non-fishbycatch 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-fishbycatch form to complete the fishing event records.

Observer data received included 84 records of protected species captures by vessels operating in inshore trawl fisheries, from 34 observed trips. The most recent capture included in the dataset received was reported on 31 December 2016. Across all fishing events, 68 seabirds and 16 mammals (eight dolphins, five fur seals, one pilot whale), one white pointer shark and one green turtle were captured in 69 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 1.04 black petrels/100 events in the 2015 fishing year (Table 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 occurred at lower rates, but at rates consistently between 0.06 and 0.32 captures/100 events (Table 2). Albatross captures were only recorded in 2015, but at relatively high rates: 0.24 white-capped albatrosses/100 events. The rate of protected species captures increased annually from 1.26 captures/100 fishing events in 2013 to 2.55 captures/100 events in 2015 (Table 2). The overall capture rate in 2016 appears lower, but this is 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 69 fishing events with captures (Table 3). All capture events involved five or fewer animals in a fishing event.

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

	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	0.437	8	0.595	11	0.617	4	0.318		
Black petrels and other *Procellaria* petrels	20	0.380	5	0.372	2	0.112	13	1.035		
Grey-faced and other *Pterodroma* petrels	10	0.190			6	0.337	3	0.239	1	0.113
Storm petrels	5	0.095					3	0.239	2	0.227
Common diving petrels	4	0.076	2	0.149	2	0.112				
White-capped albatross	3	0.057					3	0.239		
Unidentified seabird	1	0.019			1	0.056				
Dolphins	8	0.152	1	0.074	1	0.056	4	0.318	2	0.227
NZ fur seal	5	0.095	1	0.074	2	0.112			2	0.227
Green turtle	1	0.019			1	0.056				
Pilot whale	1	0.019					1	0.080		
White pointer shark	1	0.019					1	0.080		
Total	82	1.557	17	1.264	26	1.459	32	2.548	7	0.793

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

n individuals captured	n events
0	4694
1	61
2	5
3	0
4	2
5	1

Capture location and state

Animals caught were classified according to mode of capture (recovered from net, warp, impact on vessel, other, unknown mode of capture) and life status (alive, considering live uninjured and live injured animals together, or dead).

The majority of seabirds were retrieved from the net, accounting for 57% of seabird captures, while captures on the warp or doors were recorded more rarely (9% of captures) (Table 4). Deck strikes comprised a further 21% of seabird captures. 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 occurred 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%, 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 no visible injuries. The total rate of retrieval of dead seabirds was 0.57 birds/100 tows (27/4763). 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). 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 in a given 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	13		
MAMMALS, SHARKS & TURTLES		Alive	Dead	all	Alive %
	Net capture [c]	4	11	15	27

Birds 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.
[c] One animal dead prior to capture excluded from summary.

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. Tarakihi fishing activity accounted for most captures there. 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.

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).

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.

FMA	target	n captures	% of captures observed in FMA	% captures that were seabirds	Protected species caught
AKE	TAR	33	57	91	XSW,XSH,XPC,XGF,XFS,XBP,XPC,FUR,CDD
	SNA	12	21	75	XSW,XSH,XGF,XFS,XDP,XBP,WPS,FUR,BDO
	JDO	11	19	82	XSH,XFS,XBS,XBP,CDD
	TRE	2	3	100	XDP,XBP
AKW	TAR	8	47	63	XWM,XST,XPT,XPM,FUR,CDD
	TRE	6	35	67	XWM,XWF,XKP,XGP,UNF,GNT
	SNA	2	12	100	XWF,XFS
	GUR	1	6	100	XWM
CEE	TAR	6	86	50	XWF,XFS,PIW,FUR
	SNA	1	14	0	CDD
SOU	Other	2	100	100	XSH
CHA		0			
SEC		0			
SOI		0			

BDO: bottlenose dolphin, *Tursiops truncatus*; CDD: common dolphin, *Delphinus delphis*; FUR: NZ fur seal, *Arctocephalus forsteri*; GNT: green turtle, *Chelonia mydas*; PIW: pilot whale long–finned, *Globicephala melas*; 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. Average capture rates are not calculated for year-fishery combinations where fewer than 100 fishing events were observed (indicated with an x)

	2013/14		2014/15		2015/16		2016/17		Protected species caught
	events	rate	events	rate	events	rate	events	rate	
SEABIRDS									
Snapper	456	0.66	617	0.81	477	0.63	263	0	XFS, XGF, XSW, XBP, XWF, XDP, XSH
Tarakihi	374	2.41	391	2.30	160	10.63	198	1.52	XBP, XFS, XSH, XSW, XBP, XPC, XWM, XPM, XST, XGF, XPT
John Dory	212	0.94	253	2.37	70	x	24	x	XFS, XSH, XBS, XBP
Trevally	241	0	381	0.52	245	1.63	91	x	XBP, XWM, XWF, XKP, XGF, XDP, UNF
Gurnard	40	x	89	x	104	0.96	31	x	XWM
Other	11	x	2	x	17	x	16	x	XSH
MAMMALS, SHARKS & TURTLES									
Snapper	456	0	617	0.16	477	0.21	263	0.76	FUR, WPS, BDO, CDD
Tarakihi	374	0.53	391	0.51	160	1.88	198	1.01	CDD, FUR, PIW
John Dory	212	0	253	0	70	x	24	x	CDD
Trevally	241	0	381	0.52	245	0	91	x	GNT
Gurnard	40	x	89	x	104	0	31	x	
Other	11	x	2	x	17	x	16	x	

The change in average capture rates by 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 6). Common dolphins, NZ fur seals and a pilot whale 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 0.76 captures/100 events in 2016 (Table 6). Common and bottlenose dolphins, NZ fur seals and a white pointer shark were caught in snapper fishing operations.

Each year, seabird capture rates were higher in the tarakihi fishery than in other fisheries, apart from 2014 when similar capture rates were seen in John Dory and tarakihi fisheries (2.3 and 2.4 captures/100 tows, respectively) (Table 6). Seabird capture rates tended to be lowest in the snapper fishery.

Bird captures were exceptionally high in the 2015 tarakihi fishery, with almost 11 captures per 100 tows. In that year, 65% of captures occurred on a single vessel (of the seven tarakihi vessels observed). 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 discarding any material 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 depth increases, the capture rate also increases to maximum captures at 150–209m fishing depth (Fig. 3), the depth range associated with tarakihi fishing (Table 7). Although the capture rate appears to drop for deeper fishing, there are few fishing events observed for trawls that start at deeper than 240m.

Capture rates are highest when gear is fished at 2.5–3kn (speed associated with John Dory and gurnard fishing, Table 7), and appear to decline at faster fishing speeds (Fig. 4). However, five captures occurred 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

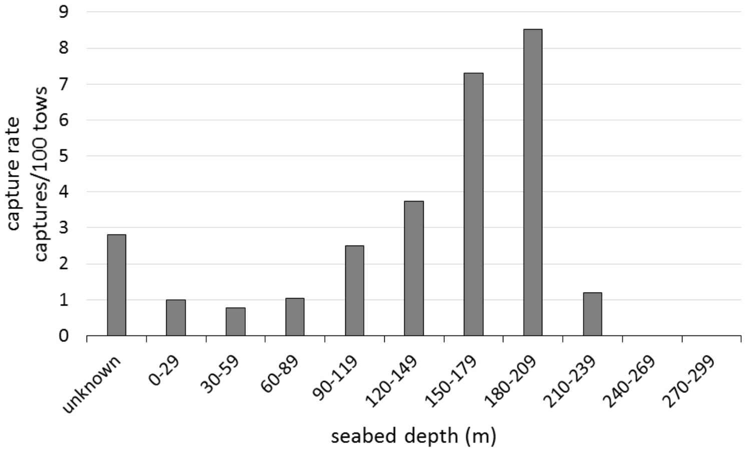

Figure 3. Fishing depth affects average capture rates (captures per 100 tows) of protected species in observed inshore trawl fisheries. Averages are only shown for depth groupings where more than 50 fishing events were observed.

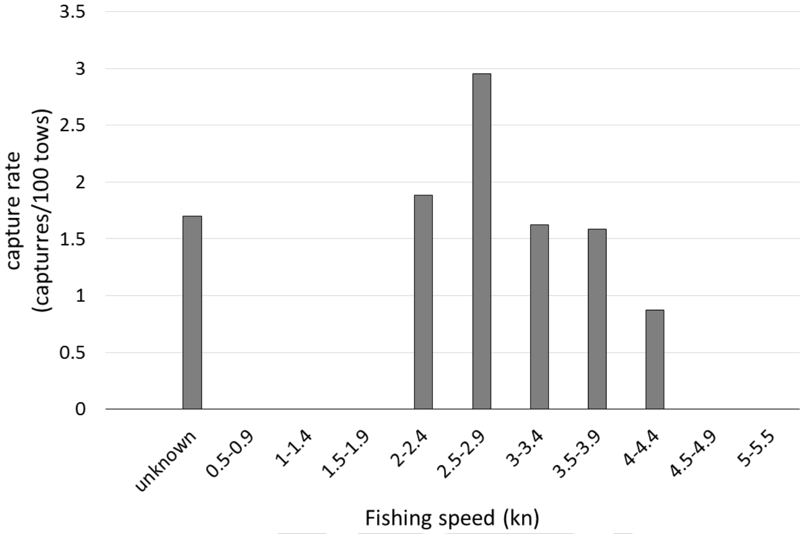

Figure 4. Fishing speed affects average capture rates (captures per 100 tows) of protected species in observed inshore trawl fisheries. Averages are only shown for speed groupings where more than 50 fishing events were observed

Mitigation use

The frequency of use of different bird mitigation devices during observed inshore trawl fishing is shown in Table 8. Bird bafflers were the most frequently used mitigation equipment, peaking in 2015 at 45% use and has since decreased. Tori lines decreased to negligible use from 2015. Between 45% and 58% of observed inshore trawl fishing used no mitigation device of any kind over the period 2013–2017.

The association between the use of mitigation and the capture rate in observed inshore trawl fishing is shown in Table 9. Bird captures occur at the highest rate when no mitigation device is used (2015 fishing year). The capture rate is generally lower when bird bafflers or tori lines are used than when there is no mitigation, but with some 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 a decrease in bird capture rate only in 2013. More recent tori line use has been too limited for comparison with bafflers so it is not clear whether tori lines or bafflers are more effective at reducing bird capture rates, but in a wider review of small-vessel trawlers, bafflers reduced seabird capture rates more effectively than did tori lines (Rexer-Huber and Parker 2018).

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, but sea state (as Beaufort categories) is available. Seabird capture rates increase progressively with increasing sea state, up to a maximum of 4.2 captures/100 tows at Beaufort 6 (Figure 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 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, c.f. 55 net captures).

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	79	x			146	3
Total	1334		1733		1073		623		4763	

Table 9. Seabird capture rate when different bird mitigation devices were used during observed inshore trawl fishing. Capture rate is the number of captures per 100 tows. 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	capture rate	events	capture rate	events	capture rate	events	capture rate	events	capture rate
none	750	0.80	793	1.39	506	4.35	363	0.83	2412	1.74
baffler	314	2.23	651	0.77	487	0.62	259	0	1711	0.88
tori	267	0.37	225	2.67	1	x	1	x	494	1.42
other	3	x	64	x	79	x			146	2.05

Figure 5. Sea state and the influence on seabird capture rate in observed inshore trawl fishing. Capture rate is the number of seabird captures per 100 tows and sea state is recorded as Beaufort classes. Averages are not shown for sea states with fewer than 100 observed tows

Discarding

The discard management strategy during a given fishing event is characterised in two ways; by the type of material discarded, and by the fishing stage when discarding occurred. The frequency of different discard types during observed fishing events is shown in Table 10. In all years, the three main types of discards were no discards, fish, or offal. Discarding of minced material was rare, occurring on only three events (two different vessels), so was grouped with offal discards. Over the period 2013–2017, the proportion of observed fishing where offal (or offal and fish) was discarded rose annually, increasing from 8% to 25% in 2016. Discarding 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 discarded during any stage of fishing (zero discards) decreased from a high of 82% in 2013, and has since remained stable at around 68% of fishing with zero discards. When material was discarded, it was rare for material to be discarded during hauling (Table 10). Material was mostly discarded during the tow in 2013–2015, but from 2015 the majority of discarding occurred during shooting. Discarding while shooting increased annually from 7% to 20% in observed fishing events.

The capture rate of birds, grouped by discard type and mitigation use, in observed inshore trawl fisheries is show in Table 11. Captures were less frequent when bird bafflers or tori lines were used than when there was no mitigation, irrespective of discard type. When bird bafflers were used, there were no captures reported from tows with fish discarding. There is a surprising indication that fish and/or offal discarding is associated with lower bird capture rates than when there is no discarding, irrespective of mitigation use. This may be a result of the relatively small numbers of device-type combinations in observed fishing, but warrants further investigation.

Table 10. Percentage of the year's observed fishing events with different discard types and the fishing stage when discarding occurred.

	2013/14		2014/15		2015/16		2016/17	
	events	%	events	%	events	%	events	%
Discard type								
none	1098	82	1173	68	739	69	425	68
fish	128	10	250	14	121	11	42	7
offal	108	8	310	18	213	20	156	25
Discard stage								
not during fishing	1098	82	1173	68	739	69	425	68
tow	140	10	341	20	158	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 discard type and by the use of mitigation. The column and row headed 'all' show the average capture rate for all discard types and all mitigation types, respectively. Averages are not shown for device-type combinations with less than 100 observed tows (indicated by x)

	No discarding		Fish		Offal		All
	events	capture rate	events	capture rate	events	capture rate	
None	1679	2.03	202	0.99	531	1.13	1.38
Baffler	1281	1.09	281	0.00	149	0.67	0.59
Tori	390	1.03	46	x	58	x	1.03
Other	85	x	12	x	49	x	
All		1.38		0.50		0.90	

Captures are summarised by discard type and discard stage in Table 12. The capture rate of birds in observed inshore trawl fishing was highest when fish were discarded during shooting. Captures were more frequent when discarding happens during shooting than during tow, for both fish and offal discard types, and capture rates were lowest during tow when fish was discarded. However, there are surprising patterns: capture rates appeared to decrease as the material discarded shifted from none to fish to offal, across all discard stages, when rates are expected to increase. Bird capture rates were apparently high when there was no discarding of material, with the greatest variety of of species and number of individuals (e.g. all black petrels were caught during zero-discard fishing). This needs to be interpreted with some caution. High capture rates could simply be an artefact of data being highly skewed to fishing with zero discards (3435 events), or be a real pattern with relevance to seabird captures. Seabird capture rates relative to discarding and zero discards needs to be empirically tested.

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

Unexpected patterns of bird captures by discard type/stage may be the result of low numbers per group (223–396 fishing events for each discard stage-type grouping). Alternatively, they may indicate real differences in bird associations with discarding, 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 discard stage/type.

Table 12. Capture rate of protected species, grouped by tow-level discard type and by discard 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 discard types and all discard stages, respectively. Averages are not shown for device-type combinations with less than 100 observed tows (indicated by x)

	No material		Fish		Offal		All	Protected species
	events	capture rate	events	capture rate	events	capture rate		
Seabirds								
No discards during fishing	3435	1.57					1.57	XBP, XDP, XFS, XGF, XKP, XPC, XPM, XSH, XSW, XWF, XWM
tow			314	0.32	396	1.01	0.66	XBS, XST, XWF, XWM
haul			4	x	4	x		
shot			223	1.79	387	1.03	1.41	XFS, XGF, XPT, XSH, XST, XSW
All		1.57		1.06		1.02		
Mammals sharks and turtles								
No discards during fishing	3435	0.23					0.23	CDD, FUR
tow			314	0.32	396	0.51	0.41	CDD, FUR, WPS
haul			4	x	4	x		
shot			223	0.45	387	1.29	0.87	BDO, CDD, FUR, GNT, PIW, UNF
All		0.23		0.38		0.90		

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 vessels included here. On five vessels no captures were recorded over the course of 31 to 80 fishing events, while on other vessels capture rates of 0.4-4.3 captures/100 events were recorded. An exceptionally high capture rate was recorded on one vessel, where 15 individuals 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. There was no discarding recorded during fishing, but mitigation devices were not used by the vessel during observed fishing. Observer documentation does not highlight anything other than the lack of mitigation devices that could explain the high number of net captures on this vessel. Operational parameters for this vessel, including fishing depth, fishing speed and gear characteristics, appear average for vessels targeting tarakihi (2.9kn, 158m depth, sea state 3 – 4) except the vessel fished in slightly deeper water than the average for tarakihi fishing (Table 7). Two captures occurred when a PSH codend was in use (a black petrel and a shearwater), but the remaining 14 birds were caught while operating a standard bottom trawl codend. Time to haul gear also appeared typical of boats 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 boat's observed fishing (Table 13). Observer data show one vessel using 'other' mitigation equipment during 8% of its fishing events, but there with no further description or information in observer data or documentation. All but one vessel with capture rates of over 2 captures/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 occurred on vessels smaller than 28m (Table 13), even though vessels up to three times larger were included in the scope of this study. Among vessels with sufficient observed events, vessels with lower capture rates tend to be slightly longer (22m overall length, mean of vessels with 11 lowest capture rates, ranging 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 are highest in the vessel length class 17–20m, but also show a spike in vessels 25–27m length (Fig. 6). Warp captures are expected to occur at a higher rate on larger vessels, since larger vessels can continue fishing in poorer sea states, when the guillotine action of warps is most pronounced (G.P. pers. obs.). However, there were 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 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

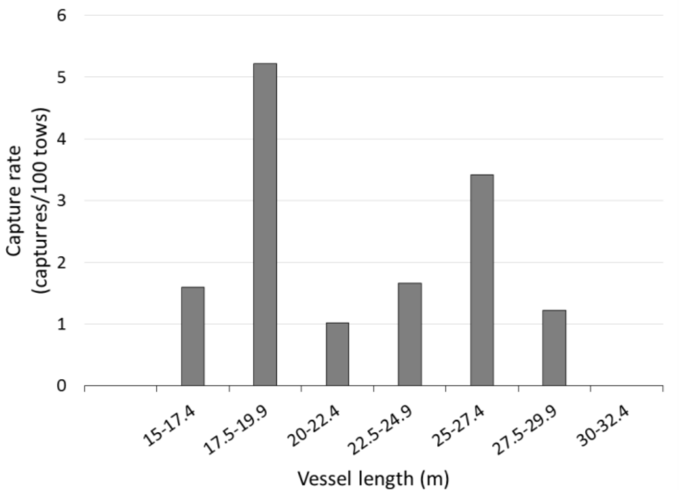

Figure 6. Protected species capture rates by overall vessel length. Capture rates (captures per 100 tows) for all protected species are summarised for vessels that had 100 or more fishing events observed.

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.

These models are for seabird captures only, excluding the small number of marine mammal, shark and turtle captures. To check the effect of excluding these non-bird captures, we also modelled captures of all protected species together (dolphin, fur seal, pilot whale, 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).

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

Discussion

This work characterises the nature and extent of protected species interactions in 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.

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 suite 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 species of dolphin, New Zealand fur seals, a long-finned pilot whale, a white-pointer shark and a green turtle recorded as captures by fisheries observers. Some of these protected species are of a high conservation threat classification and rank highly in fisheries risk assessments (e.g. Level Two Risk Assessment) (Richard et al. 2017). For example, black petrels and flesh-footed shearwaters are Threatened - Nationally Vulnerable, and white-pointer sharks are Threatened - Nationally Endangered (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 eight trawls targeting tarakihi, four of which were caught in three consecutive trawls. The vessel was not using mitigation against warp strike, but all 13 captures were net captures so warp mitigation devices would not have prevented the captures. The vessel was not recorded discarding 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 New Zealand shearwater species (Buller's, flesh-footed) feed in small groups, flesh-footed 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 fishing event.

Seven captures of grey-faced petrels were recorded, most having landed in the pound prior to it being filled but some also arriving as deck strike. Grey-faced petrels were not recorded as bycatch in observed trawl fisheries (excluding deck-strike) 2002 – 2013 (Abraham and Thompson 2015c). Grey-faced petrels are not known as a vessel following species (Marchant and Higgins 1990) but can be attracted to lights (G. Parker pers.obs). Because grey-faced petrels breed on numerous islands and some mainland sites in north-eastern and north-western New Zealand (Heather and Robertson 2015), they are more likely to overlap with fishing boats there than in other parts of New Zealand, and encounters may increase if populations are growing due to conservation management.

Five New Zealand fur seals were recorded as protected species captures in this report. Observers recorded 1532 fur seal captures in New Zealand trawl fisheries 2002 – 2016, mostly from southern fisheries management areas but also in high numbers in the Cook Strait (Abraham and Thompson 2015a). Areas where fur seal captures occur frequently were not included in this work if 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 reported much less often than fur seal captures in NZ trawl operations overall (Abraham and Thompson 2015a), but this was not true for 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 trawl fisheries 2002 – 2016 (Abraham and Thompson 2015a), observed inshore trawl operations contributed substantially to common dolphin captures in the three years 2013–16. In addition to inshore trawl operations, most common dolphin captures occurred in larger-vessel (> 43m LOA) operations targeting Jack mackerel (Abraham and Thompson 2015a). The bottle-nosed dolphin capture observed in this study, recorded on a Northland John Dory trawler, is the only recorded capture of a bottle-nosed dolphin in any NZ trawl fishery since 2002 (Abraham and Thompson 2015a).

A single long-finned pilot whale was reported captured in a trawl net, but was already decomposed to the extent that the observer noted "Decomposed body in net-head only came on board" so clearly was not caught alive by that vessel. Thirteen individual pilot whale captures in trawl fisheries were reported from observed trawl fisheries 2002–2016 (Abraham and Thompson 2015a). All but one of the thirteen captures were of multiple individuals (6, 2, and 4 whales) and all whales were caught dead. The cause of death of the pilot whale recorded here is unknown, but it can not have been a re-capture of a previous pilot whale capture as it was encountered in CEE, and all exisiting capture records are from the opposite coast in CEW (in the Taranaki Jack-mackerel fishery on vessels > 43m LOA) (Abraham and Thompson 2015a).

A single white-pointer shark was recorded as protected species bycatch in this report, caught alive while snapper fishing in north-eastern NZ. The only material discarded during that trawl was whole fish discarded during the tow. Eight white-pointer shark captures have been reported from observed New Zealand fisheries 2002 – 2016, six of which were in set-net fisheries (Abraham and Thompson 2015a). The individual recorded here is one of only two recorded captures in trawl fisheries since 2002. The other white-pointer shark capture occurred in the Auckland Islands, on a much larger trawler (> 43m, cf. <20m) targeting arrow squid (Abraham and Thompson 2015a). Captures of protected shark species (six species including white-pointer sharks) are rarely reported from observed fisheries (e.g. Francis and Lyon 2014; Francis 2017), and are skewed toward captures in subantarctic waters (e.g. basking sharks, Francis 2017).

There are no management actions aimed at mitigating basking shark captures, although, captures are required to be reported (as with all protected species), and sharks returned to the sea. The Deepwater Group has operated an active mitigation programme to reduce shark captures since October 2013 but in 2016 it was not yet clear if the mitigation had an effect on shark captures (Francis 2017). It has been suggested that headline heights of less than 4m, and a reduction of fishing in the favoured depth range of sharks, would likely reduce basking shark captures, but due to other factors captures likely can't be eliminated (Francis 2017).

Spatial coverage

The data used to estimate protected species interactions in the inshore trawl fishery in this report comes from just 3% of observed fishing activity during 2013–2016 (range 2.3 % – 9.8 % per annum), and includes very little or no observed fishing from many of New Zealand's commercial fishing management areas. In the areas that were observed to any extent, the temporal spread of the data is uneven over the 3.5 year period apart from in Auckland East (AKE), where effort was more evenly distributed over the study period. 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 New Zealand 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 years of data used in this report, only a qualitative insight into protected species interactions with the inshore trawl fishery in South Island areas is possible.

Species commonly incidentally caught in offshore trawl fisheries such as white-chinned petrels, sooty shearwaters, Salvin's albatross, Southern Buller's albatross, grey petrel and Cape petrel (Abraham and Thompson 2015c) are less abundant in northern than in southern New Zealand (Marchant and Higgins 1990; 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 New Zealand trawl fisheries 2002 – 2016. These 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 interesting to note that on the single observed fishing event in SOU, two sooty shearwaters captures were recorded entangled in the net. This may just have been coincidence, but warrants further attention as sooty shearwaters are abundant in southern South Island during the birds breeding season and therefore overlap with inshore trawling (Sagar 2013).

White-capped albatrosses were recorded as captures in the three years of data used in this report. Other *Thalassarche* albatross species (Salvin's and Buller's albatrosses) are also common scavengers behind all forms of fishing vessels, are vulnerable to warp-strike and net capture (Abraham and Kennedy 2008; Baird 2008), and were the fourth and fifth most commonly caught seabird species in observed New

Zealand 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. Parker 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 for those areas here.

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 in this study occurred on the warp and the door. Warp captures are prone to undetected 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. Of the three albatrosses caught, one 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 capture was indicated solely by bone shards and feathers in the warp splice, further illustrating the potential for unrecorded warp captures leading to underestimates of seabird capture rates. The position of the observer during the haul is 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, may be affected by where the observer is located. Health and safety requirements on large offshore trawlers in New Zealand do not allow observers to be on deck during hauling so hauls are observed from the bridge. This places the observer a minimum of thirty metres from the stern, and on the other side of the gantry, therefore greatly reducing the observers perspective.

Fur seal captures don't appear common in inshore trawl operations (5 captures, this study), relative to captures across the whole trawl fleet (1532 captures across all NZ trawling 2002–2016) (Abraham and Thompson 2015a). However, this should be interpreted with caution due to lack of spatial coverage in the data used here: seals are also comparatively more abundant in southern New Zealand than northern areas, and most fur seal captures in other trawl fisheries were in southern fisheries management areas (Abraham and Thompson 2015a). In this study, observer records were available for just seven fishing events across all southern FMAs together, or 0.001% of inshore trawl fishing effort, so 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 northern inshore trawl fisheries. Clement et al. (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 New Zealand than in the north (2.3 – 2.8 vs. 3.0 – 3.2 knots) (Clement and Associates 2008). In practise, the difference between 2.3 and 3.0 knots is approximately 30 cm per second so is not a dramatic difference and we would think is not very consequential in regards to warp-strike rates. We cannot assume protected species captures in the south will follow 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 New Zealand merit further investigation.

Average vessel length has been reported as slightly longer in northern New Zealand inshore trawl (19m compared to 16m in southern New Zealand) (Clement and Associates 2008). The small difference in LOA is unlikely to produce a difference in conditions the vessels can fish in, which is relevant because larger vessels can fish poorer sea states which produce a guillotine effect of the warp, increasing the risk of seabird warp captures (Sullivan et al. 2006b; Melvin et al. 2011; Koopman et al. 2018). Poorer 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 27 knots. This is similar to the limits of what smaller (< 20m) inshore trawl vessels fish at in southern New Zealand (G. Parker pers. obs.). However, the vessel size difference may be enough to influence discarding practises if fishers feel there is not enough space to retain discards, or 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 consistently high 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. 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 2015/16, and 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. Trawl vessel gear configurations vary (e.g. winch speed, warp-block height, position of discard scuppers, how discards interact with propellor wash and where discards become available to scavenging protected species, stern gantry height etc), some 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 discard management (Rexer-Huber and Parker 2018). 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 could not be characterised for the inshore trawl fishery here as the time was rarely documented, but is 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 tarakihi fishery each year, mostly of fur seals and dolphins. This follows tarakihi featuring the most numerous seabird captures also. A greater range of species was caught in snapper trawls—dolphins, fur seals and a white pointer shark—but at lower rates each year 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 is limited in the 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 specific species interactions. Another consideration is that inshore trawlers often target several species on different tows of the same fishing trip (ie. snapper, tarakihi and trevally). There could plausibly be follow-on effects of, for example, tarakihi fishing on subsequent sets of a different species.

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 (excluding a pilot whale that was dead well prior to capture). When details were given, observers mostly recorded that animals were caught in the codend (4 instances) with only one record of the animal being caught in the lengthener. Offal and fish was discarded during both shooting and towing in about half of the events where a mammal, shark or turtle capture was recorded.

The majority of seabird captures were in the net (57%), 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)], this indicates that 77% of seabird net captures occurred during the haul, not the shoot or tow. It was rare for vessels to discard material of any sort during hauling, discounting discards 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 (7% of seabird captures). Offal and fish was mostly discarded during the tow. Continuous discard 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 captures may 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® rather than steel warps, which do not have warp splices. No studies of seabird interactions 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 bright warp colours are available, and due to greater conspicuousness may be better avoided by seabirds (R. Birch pers. comm.).

Another indication that warp strike—and undetected mortality—may be a more important contributor to seabird bycatch than this study can show comes from mitigation devices. That is, the seabird capture rate was higher when no warp mitigation was used during fishing (the majority of fishing events) than when tori lines or bafflers were used (mitigation 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. Seabirds subject to deck-strike comprised 17% of protected species interactions characterised in this report. Deck strike most often occurs because some seabird species are attracted to lighting, become disoriented when near to the lighting source, and end up crashing into the vessel (Ryan 1991; Black 2005; Montevecchi 2006; Depledge et al. 2010).

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. Black (2005) suggested that bird strikes on Southern Ocean vessels happen commonly, but resulting mortality is generally low. 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. Parker pers. obs.). As for other live captures of seabirds in fishing gear, we cannot expect fisheries observers to provide an accurate 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 storm petrels and diving petrels each have a species with high conservation threat status and only one breeding site. The endemic New Zealand 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 New Zealand storm petrel resulted from a bird flying onto a fishing boat near Little Barrier Island at night (Gaskin 2017), likely attracted by the vessel's lights.At the southern end of the country, South Georgian diving petrels *Pelacanoides 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 associated with 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 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 seabird effects. 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 levels and light spill 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 vessel sizes in this study ranging up to 82m. Vessels less 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 (e.g. Furness et al. 2007). About a third of 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 discards in some way to mitigate against the incidental capture of protected species (Rexer-Huber and Parker 2018).

Seabird capture rates were generally higher when no mitigation device was used, and the highest bird capture rates occured when no mitigation was used (2015 fishing year). The use of mitigation across the inshore trawl fleet changed considerably during the three year period that this report focused on. Baffler use steadily increased to peak at 45% and then slightly decreased to 42%. Tori-line usage became insignificant from 2015 so 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 appears to decrease seabird capture rates both in inshore trawl operations (this study) and on small-vessel trawlers more widely (Rexer-Huber and Parker 2018). However, the nature of information used for these studies mean that the varying contributions of vessel effects, weather, season etc cannot be properly accounted for. Trials testing the efficacy of mitigation devices in trawl fisheries—which explicitly control for vessel effects, weather, season etc—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 have been tested to prevent the incidental captures of seabirds in trawl nets, 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 and drowning while the net is near the surface. Guidelines for net binding to reduce incidental seabird bycatch exist for at least one fishing company group in New Zealand (Deepwater), 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 (7 tows trialled) and a fresh fish trawler 42m LOA (5 tows trialled) (Cleal et al. 2009). No information was available suggesting 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 that may attract animals to a net during shooting, has not been quantified (ACAP 2017) and is supported by observation only (Hooper et al. 2003), but shows some association with lower capture rates in the NZ smaller-vessel trawl fleet (Rexer-Huber and Parker 2018). This requires further testing.

Similarly, discarding material in the period when the net is near the surface could also attract animals. In NZ trawlers do not discard during hauling for that reason, but discarding during shooting is relatively common (Rexer-Huber and Parker 2018). Holding discards 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 discarding for a period before shooting the net could also reduce bird abundance at shooting.

Mitigation equipment to prevent fur seal and/or dolphin captures in trawl nets is not established in New Zealand, and was not recorded for any inshore trawl fishing. Seal exclusion devices (SEDs), based on 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 trawl fisheries that capture fur seals in New Zealand (Cleal et al. 2009). Other approaches to reducing seal captures trialled include accoustic 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 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.

Net weighting on or near the codend may help reduce seabird net captures. Net weighting has been shown to increase the angle of net ascent during hauling operations, thereby reducing the amount of time the net is on the water's surface (Hooper et al. 2003; ACAP 2017). To date only very limited trials have been conducted, in CCAMLR trawl fisheries (Sullivan et al. 2004).

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 deployed bafflers. Bafflers were the most commonly used device, comprising 72% of fishing where a device was used. Variations of bafflers have been tested to a limited degree on large factory freezer trawlers in New Zealand, Falkland Islands and USA (Melvin et al. 2011; Cleal and Pierre 2016; Kuepfer 2017). Bafflers have not been tested on trawlers < 28m LOA in New Zealand, but a recent Australian study reported that a baffler trialled on a 29m LOA vessel significantly reduced rates of heavy warp interactions compared to the control (83.7% less then 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 trawl fisheries in New Zealand and overseas, and 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). For trawl fisheries, tori line testing has focused on larger vessels. For example, testing took place on a 66m trawler (Sullivan et al. 2006a), an 84.1m and 102.4m trawler (Melvin et al. 2011), a 105m trawler (Cleal et al. 2012) and a 75.4m and 67.8m trawlers (Snell et al. 2012). However, on smaller commercial trawl fishing vessels < 28m LOA, tori lines have not been tested in New Zealand, or to an extensive degree overseas.

There are important design considerations that 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 (most pronounced for solo-operator small vessels, since warp blocks are often outboard of the rail (Tuck et al. 2013). Some streamer material can increase risk to birds, particularly very soft, flexible tubing because it wraps around birds' wings, increasing the risk of dragging and injuring or drowning. If streamers are too far from the transom birds will drift 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. Very limited teesting of using road-cones deployed on warp-cables to try and prevent of reduce bird strike at the warp-water interface was conducted in Argentina. Ten hauls without and 12 hauls with a roadcone attached to the warp were trialed on a 26.4m (± 2.4m) trawler (González-Zevallos et al. 2007). In trawls with the mitigation device the number of contacts was reduced by 89% and the average distance between seabirds and cables was reduced from 0.9m to 2.9m (González-Zevallos et al. 2007).

This test was conducted in January and February, when (black-browed) albatrosses were potentially at lower abundance in the area due to attending distant breeding colonies.

As well as trialling a baffler, Koopman et al. (2018) trialled a water-sprayer to reduce albatross interactions with warp cables. The water sprayer was trialled on a 20m LOA vessel and significantly reduced rates of heavy warp interactions (58.9% less than the control, a pinkie buoy clipped to the warp at each shot) (Koopman et al. 2018). In trials Pierre et al. (2014) found the pinkie buoy reduced heavy seabird interactions with the warp by 75%. Safety concerns have been raised with the use of pinkie buoys, particularly for solo operators whose warp-blocks outboard of the gunnels, requiring the operator to reach out to attach the clip (Tuck et al. 2013).

Discarding

Managing discards is a widely-recognised approach to mitigating protected species captures in fisheries (Pierre et al. 2012; Kuepfer et al. 2016; Kuepfer and Pompert 2017). Vessels reviewed here mostly avoided discarding during the haul, which follows best practice to reduce the risk of net captures (ACAP 2017). More concerning is that discarding during shooting became more common over the three year period of this study. Discarding during the shoot can attract animals to the net and therefore increase the chance of captures. Animals caught in the net during shooting have no chance of survival so the impacts are greater than when captured during the haul, when they may survive. Further, the risk of losing animals caught at shot is greater than at later fishing stages, so discarding during shooting could increase the problem of undetected mortalities.

No discarding occurred at any stage of fishing (zero discards) for 68-82% of inshore trawling reviewed here. However, the second-highest seabird capture rate was recorded for fishing with zero discards, following the capture rate with discarding at shot. For example, black petrels were only recorded caught during fishing with zero discards. This could simply be an artefact of zero discards being by far the most frequent discard 'management' approach (3435 events out of 4736 total in this study), or could be the result of zero discards being considered adequate so other mitigation not used. This study provides some support for the latter argument: most fishing with zero discards did not use a mitigation device, producing in the highest capture rate of any device-discard combination (2 animals/100 fishing events). In addition, mammal captures were low during fishing with zero discards, as expected. Taken together, we suggest zero discarding of any material is not an adequate seabird mitigation approach alone, and should be used together with a mitigation device.

Bird captures were similar when fish was discarded and when offal was discarded, contrasting with work in other fisheries 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 shot discarding involved fish and if tow discarding 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 is discarded than fish, and capture rates were lowest when nothing was discarded. For both groups (seabirds and mammals, sharks and turtles), numbers relative to discarding practises were too few to put 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 each potential contributor to the risk of captures in turn, 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. The majority of fishing did not use a mitigation device to protect the warps. Since devices reduce capture rates, they should be used more widely. Warp mitigation is particularly important if vessels do not manage discards, i.e. discarding is continuous during shooting or towing, because under those conditions seabirds are constantly in the warp-water interface area 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: because most seabirds subject to warp-strike are poor divers, so the splice must be within metres 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 seabirds mortality estimates, if wrapping reduces the probability seabird corpses are retained on the warps and detected at hauling. Observers do not report on the condition of warp cable splices, but occasionally record that 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 (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.

Discarding

There is a clear relationship between discarded material and protected species attending fishing vessels generally. In this study, vessels mostly avoided discarding during the haul per domestic and international guidelines (e.g. (ACAP 2017). Discarding during shooting was associated with the highest seabird capture rates in this study, and shot discarding became more common over the three year period 2013–2016. Ideally discards would be retained on board throughout shooting, and for a period before the net is shot as well to avoid attracting to the area where they can then get entangled in the net during shot. If discarding during the shooting period is unavoidable, discarding should only occur once nets are away from 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 discard nothing during any stage of fishing (zero discards). However, zero discards were associated with the second-highest seabird capture rate (following the capture rate with discarding at shot), and the lowest capture rate of mammals, sharks and turtles. Zero discarding may prove an important way to reduce captures of animals like dolphins and seals, but should not be used without concurrent seabird mitigation (ie. combine zero discards with warp mitigation).

Net stickers

The majority of net captures reported here appear to have been caught at the haul (34 out of 55 net captures were alive) rather than during shooting (21 of 55 caught dead) as would be expected if stickers in the net are attracting seabirds leading to captures at that fishing stage. However, the level of cryptic or non-detected net mortality is unknown, and life status is not a perfect proxy for inferring capture stage (Pierre 2018). The true extent of net captures during shooting remains hazy, so the potential for net stickers to influence captures cannot be completely discounted. Given the number of birds caught dead, perhaps during shooting, sticker removal warrants further exploration.

Vessel effects

There is 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. discard management or mitigation device capability) could affect seabird captures and should be explored further.

Recommendations

Mitigating captures

Our analyses have identified several options for reducing the risk of interaction with protected species which should be incorperated into vessel practices:

1. This study indicates that warp mitigation is important, seabird capture rates are lower when a mitigation device (baffler/tori) is used than when no mitigation device is present (including when there are no discards during fishing).
2. Retaining all discards througout fishing (zero-discards):
    a. **Mammals:** lower mammal capture rates were found with zero discards than when anything discarded, at any stage.
    b. **Seabirds**: zero discards (ie. discards retained throughout fishing) has been shown to reduce the risk of interaction however is not enough to mitigate seabird captures on its own; should be used together with warp mitigation.
3. If discarding fish or offal during fishing is unavoidable the following should be considered:
    a. **Mammals:** offal discards are linked to higher capture rates than discarded fish.
    b. **Seabirds:** continue with no-discards during hauling and discard during tow (together with warp mitigation). Discard during shooting appears to be a risk exaserbator and should be avoided. If discarding must absolutely occur during shooting, it should be held until the gear is at depth (as this could aid in the reduction of net captures). Avoiding discard for a period before shot may also reduce bird abundance around the vessel at shooting.
4. Sticker cleaning may also reduce interactions during shooting by reducing the presence of attractants.

Future work

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

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

Further exploration of a larger fishing event dataset would also help confirm capture rate patterns for marine mammals, sharks and turtles relative to discard 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 species that are more abundant in the south and inshore trawl fisheries should therefore be a priority.

Warp captures may be underestimated, as bird capture rates were highest when no warp mitigation was used.

- Ways to retain warp captures should be explored. For example, warp type and condition could affect seabird retention until hauling. Trial warps with sprags relative to bound splice relative to no splice (Dyneema® warps) or experimental device (e.g. Parker et al. 2013).
- Vessel size: warp captures are expected to occur at a higher rate on larger vessels which can fish in poorer sea states when the guillotine action of warps is most pronounced. However, there were few warp captures recorded 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 captures 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

Potential for seabird warp mitigation using Dyneema® warps should be tested, with fishers describing that birds 'bounce off' Dyneema warps, and that the bright warp colours are seen and avoided by birds (R. Birch pers. comm.). Dyneema vs steel warps.

Storm petrels and diving petrels are prone to deck strike but are rarely identified to species (generally generic code used). Because NZ storm petrel and South Georgian diving petrel populations are small, deck-strike may easily negatively impact upon the populations so should be mitigated for. Given the extent of 'unknown' species identifications for storm petrels and diving petrels, the vulnerability of some species (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.

Vessel lighting is expected to be a driver of deck strikes in NZ fishing operations, given the extent of evidence from other regions (Ryan 1991; Black 2005). Too little data on the nature and extent of lighting and light spill in inshore trawl fisheries were available for this study to explore effects on deck strike rates. Lighting should be explored as a potential way to mitigate deck strikes, particularly around high-risk areas (titi islands, Hauturu, Codfish). Levels (deck lights, stern lights, both?), light spill (deck cover, light shields?)

Sticker removal: A substantial proportion of captures reported in this study were dead on capture, suggesting capture occurred 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 birds caught dead, sticker removal warrants further exploration as a shot mitigation approach.

Net availability: The majority of protected species captures in inshore trawl operations are caught in the net, and the fleet is highly variable in is gear and operational practises which is expected to reflect on net surface time. Data are needed to assess the time a net is available at the surface during shooting and hauling (time net at surface, from doors up to net on deck, was recorded much less often by observers than time from depth to doors up), and practises that could reduce net surface time should be explored.

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 was available from the west coast of the North Island (CEW). In these FMAs, 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" for none. In this study, 8% of records had to be excluded because of missing information, mostly nulls.

Information accessibility

In many cases, information relevant for 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 discards in bottom longline set and haul logs collected by observers (as discussed in Pierre et al. 2013) does not appear to be entered into COD, 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 a user.

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 the 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
- Indicators of animal captured but lost during fishing (e.g. feathers in the warp or warp splice, or at the door)
- Could observer view the warps during hauling or not?
- Some way to indicate captures occurring outside of fishing (e.g. while steaming, while on anchor); these interactions should be documented as they are part of fishing operations in an area.

Mitigation

- Category needed to record when mitigation device utilised (shot only? entire fishing operation?)
- Period when net at surface (time doors up to net on deck) rarely reported, but of more relevance to understanding seabird captures than time from fishing depth to doors-up (mostly what is reported). Need category for time in mins from doors up to net on deck.

- 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).
- Discard codes: H (discards held) code seems used variably, sometimes used interchangeably with N (no discards)
- Batch discarding: Structure required for batch discarding (if occurring, and how). Needs categories; is it happening; if so, what fishing stage, amount in batch, interval between batches or storage period, where relative to fishing operations (between warps, port/stbd, other), some indication of how swift the discharge mechanism is (i.e. how long it takes for batch to go overboard)
- Deckloss: if fish and offal losses included as part of general discard categories cannot assess effect of irregular pulses/batches of material off the deck. Separate category (what fishing stage, where relative to fishing operations).

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Appendices

Appendix 1

List of CSP inshore trawl fishery target species included in inshore trawl fishing data for this work, 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, ie. 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. (King tarakihi)
TRE	Trevally	*Pseudocaranx georgianus*
TUR	Turbot	*Colistium nudipinnis*
YBF	Yellowbelly flounder	*Rhombosolea leporina*

Appendix 2

Protected species captures 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**	**1.028**
black petrel	*Procellaria parkinsoni*	XBP	14	0.267
flesh-footed shearwater	*Puffinus carneipes*	XFS	14	0.267
grey-faced petrel	*Pterodroma macroptera*	XGF	7	0.133
Procellaria petrels		XPC	6	0.114
sooty shearwater	*Puffinus griseus*	XSH	6	0.114
shearwater spp.		XSW	3	0.057
bullers shearwater	*Puffinus bulleri*	XBS	1	0.019
Cook's petrel	*Pterodroma cookii*	XKP	1	0.019
mid-sized petrels/shearwaters	*Pterodroma, Procellaria* & *Puffinus* spp.	XPM	1	0.019
Pterodroma petrels		XPT	1	0.019
Diving petrels, storm petrels			**10**	**0.190**
Common diving petrel	*Pelecanoides urinatrix*	XDP	5	0.095
white-faced storm petrel	*Pelagodroma marina*	XWF	3	0.057
storm petrel spp.		XST	2	0.038
white-capped albatross	*Thalassarche steadi*	XWM	**3**	**0.057**
unidentified seabird		UNF	**1**	**0.019**
Common dolphins and other marine mammals			**14**	**0.267**
common dolphin	*Delphinus delphis*	CDD	7	0.133
NZ fur seal	*Arctocephalus forsteri*	FUR	5	0.095
bottlenose dolphin	*Tursiops truncatus*	BDO	1	0.019
pilot whale long finned	*Globicephala melas*	PIW	1	0.019
green turtle	*Chelonia mydas*		**1**	**0.019**
white pointer shark	*Carcharodon carcharias*		**1**	**0.019**