CAWTHRON

REPORT NO. 3854

ASSESSMENT OF NEW ZEALAND FUR SEAL / KEKENO BYCATCH BY TRAWLERS IN THE COOK STRAIT HOKI FISHERY

ASSESSMENT OF NEW ZEALAND FUR SEAL / KEKENO BYCATCH BY TRAWLERS IN THE COOK STRAIT HOKI FISHERY

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ISSUE DATE: 20 June 2023

RECOMMENDED CITATION: Pavanato H, Schattschneider J, Childerhouse S, Briscoe D. 2023. Assessment of New Zealand fur seal / kekeno bycatch by trawlers in the Cook Strait hoki fishery. Prepared for Department of Conservation. Cawthron Report No. 3854. 32 p. plus appendices.

EXECUTIVE SUMMARY

The New Zealand fur seal / kekeno (hereafter fur seal) is the marine mammal most frequently caught in New Zealand commercial fisheries due to their large population size compared to other marine mammals, the spatial and temporal overlap between fur seal foraging areas and commercial fishing areas, and the likely attraction of fur seals to operating fishing vessels. This assessment focuses on bycatch from hoki trawling within the Cook Strait region, with the main following objectives: to identify fur seal breeding colonies and / or haul-outs within Cook Strait; to understand the interactions between fur seals and the hoki trawl fishery within this region; and to make recommendations that target knowledge gaps in order to help future mitigation actions that will reduce bycatch more effectively.

Boat-, land-based or helicopter surveys were carried out in the Cook Strait region, both in the North Island and South Island, in order to assess the status of seven breeding colonies / haul-outs, which included counts per age class. Bycatch data from hoki trawls were provided by the Ministry for Primary Industries for the calendar years 2012–2021, along with the database updated by government fisheries observers. For this period, we analysed the spatial and seasonal distribution of hoki trawls and Catch Per Unit Effort (CPUE). In addition, we estimated the probability of fur seal bycatch as a function of several factors, including fishing vessel (e.g. vessel length, tow speed), environmental (e.g. depth, distance from nearest colony / haul-out), and temporal characteristics (e.g. season, year), using a logistic regression framework. A test of proportions was used to infer whether a particular sex (female / male) and age class (juvenile / adult) was more likely to be caught by hoki trawls.

Only two breeding colonies around Cook Strait region were confirmed: Mātakitaki-a-Kupe / Cape Palliser and Ward Beach – Needles Point. A total of 2,016 hoki trawl tows were monitored by fisheries observers in Cook Strait in the period 2012–2021. From this, 112 tows had at least one fur seal caught, with a total of 157 individuals caught. Most hoki trawling with observers took place in autumn and winter, with a larger CPUE in winter and spring. Overall, the CPUE fluctuated annually, with a sharp increase noted in 2012–2013, 2015–2016 and 2020–2021. There is strong evidence for the probability of fur seal bycatch decreasing as vessel length increases, and increasing in winter and spring compared to autumn and summer. Regarding the demographic variables, most fur seals caught were adult males. The total estimate of the Cook Strait fur seal sub-population by direct count is approximately 1,800 individuals.

Overall, we recommend (i) increasing fisheries observer coverage in spring hoki trawl trips due to higher levels of bycatch, (ii) the establishment of a long-term monitoring programme to estimate abundance at the breeding colonies of Mātakitaki-a-Kupe / Cape Palliser and Needles Point, and (iii) the assessment of other sources of human-induced mortality other than hoki trawl bycatch to understand the viability of the Cook Strait sub-population. We also provide some suggestions for additional analyses that may be useful for assessing the interaction in more detail.

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1. INTRODUCTION

The Cawthron Institute (Cawthron) has been contracted by the Department of Conservation (DOC) to report on CSP project *POP2021-06 Fur seal population estimate and bycatch analysis, Cook Strait*. This is a collaborative project between Cawthron, DOC and the University of Otago. This report is the first of two reports to be developed as part of this contract – the second report will summarise the results of genetic analysis and will be developed in conjunction with the University of Otago.

1.1. Background

The New Zealand fur seal / kekeno (*Arctocephalus forsteri;* 'fur seals' hereafter) is the most frequently caught marine mammal in New Zealand's commercial fishing industry due to a large total population size compared to other marine mammals, the spatial and temporal overlap between fur seal foraging areas and commercial fishing areas, and the likely attraction of fur seals to operating fishing vessels (FNZ 2022). In contrast to an apparent increasing New Zealand population trend overall (Baker et al. 2019), fur seal bycatch continues at relatively high levels around New Zealand. This is particularly evident in the Cook Strait hoki trawl fishery, which may have unsustainable fur seal bycatch levels.

Fur seals are captured predominantly in trawl fisheries, with 44% of total fur seal bycatch in hoki trawlers occurring between 2002 and 2020, and with 38% of this within the Cook Strait region (Fisheries New Zealand Protected Species Bycatch Database 2022[1]).

The hoki trawl fishery targets the Cook Strait region annually from late-June to mid-September, with effort peaking in July and August. A range of mitigation methods have been trialled (e.g. seal exclusion devices; Cleal et al. 2009) to reduce bycatch levels; however, none have been effective at significantly reducing or eliminating fur seal bycatch. To better inform mitigation options, it is important to gather and analyse information from both hoki trawl fisheries and bycaught animals.

Fisheries New Zealand (FNZ) has not provided any estimates of total fur seal bycatch in the Cook Strait hoki fishery since 2015 (FNZ 2022). The reason for this lack of estimates is unclear, but as a result, there have been no estimates for more than 6 years, despite this fishery having one of the highest catch rates in New Zealand. In the absence of any FNZ estimates, it is necessary to make some broad assumptions based on the available data. There are some data provided in the FNZ

[1] Available at https://protectedspeciescaptures.nz/PSCv6/released/new-zealand-fur-seal/trawl/all-vessels/cook-strait/2002-03-2019-20/

Protected Species Bycatch Database. For the Cook Strait trawl fishery targeting hoki over the 18-year period from 2002 to 2020,[2] these data include:

- 37,149 tows were undertaken in the fishery
- a mean capture rate of 8.6 (max = 29.2, min = 0.8) fur seals per 100 tows (based on data collected by observers)
- mean annual observed captures of 16.8 (total observed = 302, max = 32, min = 1) fur seals
- low mean observer coverage at only 10.7% (max = 21.2%, min = 3.3%)
- an overall rate of 84% (*n* = 253) of captured fur seals recorded as dead.

Based on these data (i.e. average bycatch rate multiplied by the total number of tows), approximately 3,195 fur seals have been caught in this fishery in the period 2002–2020. Given that 84% of these captures were reported as dead, then an estimated 2,684 fur seals have been killed in the hoki fishery over the last 18 years. This level of observed bycatch represents a significant proportion (approximately 17%) of all fur seals caught in all trawl fisheries across New Zealand over this period.

The exact New Zealand population size of fur seals is unknown; however, some estimates have been made. Wilson (1981) estimated the total abundance of the fur seal population at between 30,000 and 50,000 individuals. Two decades later in 2001, it was suggested that the total population could be as high as 100,000 (Harcourt 2005). However, this most recent estimate is now considerably out of date; moreover, it was based on limited data and the accuracy is difficult to assess in the absence of extensive and systematic surveys. There is no present reliable and robust estimate of the total population size for fur seals in New Zealand. In addition, there have only been a few systematic surveys of fur seals in the Cook Strait region over the last 30 years, leaving a large gap in our knowledge of this regional sub-population.

1.2. Scope

The broad objectives of this assessment are:

1. to identify New Zealand fur seal breeding colonies and / or haul-outs within the Cook Strait region that could overlap with fisheries.
2. to increase the understanding of interactions between New Zealand fur seals and the commercial hoki fishery within this region.
3. to recommend further data collection and analysis to aid in the monitoring of fur seals within Cook Strait.

[2] 2020/21 is the most recent year with data reported.

This report focuses specifically on answering the following questions, with the end goal of making recommendations for the most appropriate mitigation options:

1. What is the current distribution and status of fur seals in the Cook Strait region?
2. What is the bycatch risk of fur seals in the Cook Strait hoki trawl fishery?
3. Are there any temporal or spatial effects on bycatch rates?
4. Are there any fishery characteristics (e.g. vessel length, tow speed, depth) that increase the likelihood of bycatch?
5. Is there any pattern of caught fur seals in regard to sex and age class?
6. What is the current minimum estimate of the fur seal sub-population in the Cook Strait region?

2. METHODS

2.1. Distribution and status of fur seal colonies in the Cook Strait region

Surveys to determine the breeding status of fur seal colonies (breeding colonies and haul-outs) and to enable direct counts of animals were carried out in the Cook Strait region, both in the North Island and South Island. In terms of survey areas, the Cook Strait region was defined as the immediate coastline around the area of the observed bycatch, specifically within approximately 40–50 km of the centre of the bycatch and being limited by Queen Charlotte Sound / Tōtaranui to the west and Ward Beach to the east in the South Island, and Tongue Point to the west and Mātakitaki-a-Kupe / Cape Palliser Lighthouse in the North Island. The following sites were visited (Figure 1):

- Turakirae Head and surrounding area
- Mātakitaki-a-Kupe / Cape Palliser and surrounding area
- Ōwhiro Bay to Tongue Point
- Te Whanganui / Port Underwood to Kura Te Au / Tory Channel
- Te Parinui o Whiti / White Bluffs in Clifford Bay
- Te Karaka / Cape Campbell
- Ward Beach – Needles Point.

A range of different survey methodologies was used depending on the characteristics of each site, including:

- boat-based surveys – visual inspection of the coastline from a vessel using both naked eye and binoculars to determine if any fur seals were present.
- land-based surveys – visual surveys were undertaken both by vehicle and foot, using naked eye and binoculars, to determine if any fur seals were present. Closer approaches were made at some sites to confirm numbers.
- helicopter survey – at one site (Te Parinui o Whiti / White Bluffs). A visual survey was undertaken using a helicopter, using both naked eye and binoculars to survey the area for fur seal presence.

Various information on the fur seals found during the surveys were collected, including:

- approximate numbers (e.g. live and dead)
- location
- age class (e.g. pup, juvenile, adult) and sex
- general behaviour.

Dates and timing of the survey work varied considerably between sites, as the work was based on available resources. Between two and four people were involved in each survey. Given the limited resources available for the survey work, the main aim was to identify locations where fur seals were present rather than obtain highly accurate colony and sub-population estimates. However, direct counts were undertaken, particularly for areas where pups were found. It is recognised that the three different survey methodologies have different strengths and weaknesses, and are, therefore, not directly comparable. The surveys do, however, provide useful assessments of the broad-scale distribution and approximate abundance of fur seals in the Cook Strait region. Future work may be planned to undertake more detailed survey work at the identified breeding colonies.

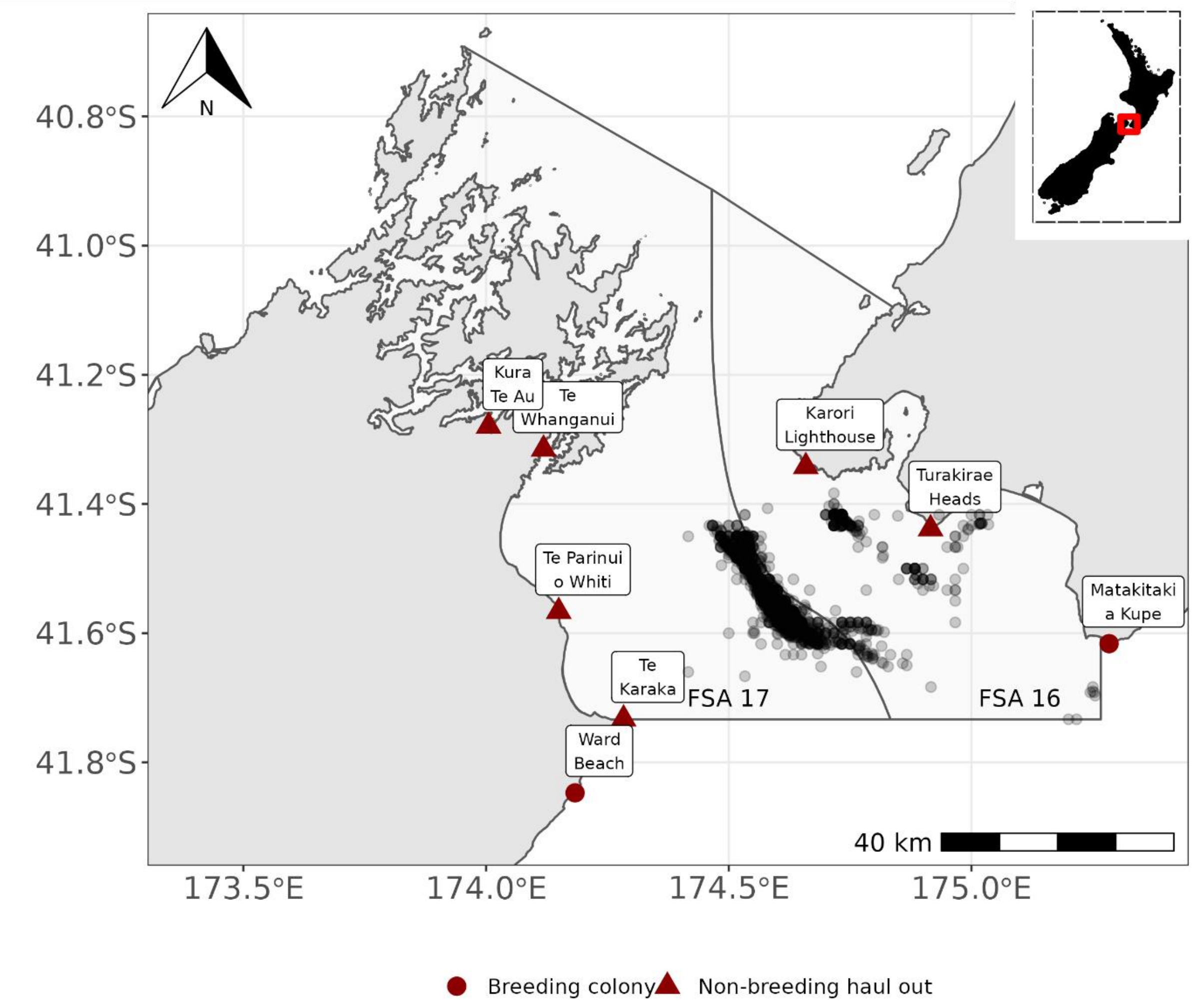

Figure 1. Map of the Cook Strait region showing the limits of Fisheries Statistical Areas (FSA) 16 and 17, and fur seal colonies (red circles) and haul-outs (red triangles) considered in this study. Points in black represent the starting point of all hoki trawling events for the period 2012–2021.The data were sourced from the Centralised Observer Database (Sanders & Fisher 2020).

2.2. Acquisition of bycatch data

The New Zealand fur seal bycatch data used in this study were sourced from the Centralised Observer Database (COD; Sanders & Fisher 2020). This database contains independent information collected by fisheries observers on catch and fishing effort for commercial fishing vessels. The dataset used in this report was collected by fisheries observers in the period 2012–2021 (calendar years) from trawls targeting hoki in the Cook Strait region, specifically FNZ Fisheries Statistical Areas (FSA) 16 and 17. The attributes in this dataset are related to the number and type (e.g. sex and age) of fur seals caught (if any), as well as date, time, geographic location, number of turns per tow and type of fishing gear used in each tow.

In addition to the COD database, information from the Enterprise Data Warehouse (EDW; Percy 2021) database was also used. The dataset sourced from EDW included the location of all hoki trawl tows (regardless of whether they had observers on board) from 2012 to 2021 in the Cook Strait region.

The two data sources (COD and EDW datasets) used in this study were requested from and provided by the Ministry for Primary Industries (MPI).

2.3. Spatio-temporal distribution of hoki tows and Catch Per Unit Effort

To examine the spatio-temporal distribution of hoki tows in the Cook Strait region, we calculated the Catch Per Unit Effort (CPUE) using the number of tows conducted per season as the effort unit. We classified fishing locations by assigning the starting point of each tow to a spatial grid with a resolution of 0.05 degrees, which is approximately half the average distance covered by a tow. Next, we calculated CPUE per grid cell and season by counting the number of animals caught in each grid and dividing this number by the number of tows.

2.4. Inferential analysis

The purpose of the data analysis was twofold. First, we aimed to estimate the probability or risk of fur seal bycatch as a function of spatio-temporal (space and time) and fisheries-related covariates. Second, we aimed to understand how the magnitude of fur seal bycatch varied as a function of demographic variables, such as age class and sex. For both objectives, only data from the COD database were used.

2.4.1. Risk of bycatch

In order to estimate the risk of bycatch of fur seals in hoki trawls in the Cook Strait region, we fitted generalised linear models (GLM) assuming a Bernoulli distribution for the data. This type of model is also known as logistic regression. GLMs allow the variable of interest to be described as a linear function of covariates, or explanatory variables, via a link function. The advantage of GLMs over linear models is that the response variable can have any arbitrary distribution rather than the normal distribution (Dobson & Barnett 2008).

The risk of bycatch is defined as the probability of a particular fur seal being caught by a tow event during hoki trawling. The response variable was defined as a Bernoulli trial with '1' representing a fur seal bycatch event, and '0' otherwise.

Competing models were fit with all the possible combinations of the covariates described in Table 1. These covariates were previously tested for collinearity.

Table 1. Description of covariates used in the logistic regression model to estimate the risk of fur seal bycatch in hoki trawls in Cook Strait, including each covariates' description, source and type (categorical or numerical).

Covariate	Description	Data source	Type
Vessel size	Small: < 28 m Large: ≥ 28 m Used as a proxy for other vessel characteristics (e.g. length, headline length, wing spread, sweep length, gross tonnes), as all of these variables had a large degree of collinearity.	COD database	Categorical
Fisheries Statistical Area	16 or 17	COD database	Categorical
Season	Summer: December to February Autumn: March to May Winter: June to August Spring: September to November	COD database	Categorical
Tow turn	Yes: tow with one or more turns No: tow without turns	COD database	Categorical
Year	2012 to 2021, calendar years	COD database	Numerical, integer
Tow speed	Trawling speed in knots	COD database	Numerical, continuous
Depth	Seabed depth in metres	COD database	Numerical, continuous
Distance from nearest colony	Calculated as the distance between each fur seal bycatch location (starting point of the tow) and the closest identified breeding or haul-out colony	Fur seal colony surveys and COD database	Numerical, continuous

With the selected covariates, the objective was to test whether there was evidence for different bycatch risk in regard to:

- large and small vessels as an indication for large and small trawling gear (e.g. headline height, sweeps, wings)
- Fisheries Statistical Areas 16 and 17
- season (i.e. did bycatch risk change across seasons?)
- tow speed (i.e. did bycatch risk change between slow and fast towing?)
- annual trend (i.e. did bycatch risk change over time?)
- depth (i.e. did bycatch risk change with water depth?)
- distance from nearest colony (i.e. was bycatch risk increased by distance to nearest breeding colony?).

Model selection was carried out using a full model averaging procedure on the basis of Akaike Information Criteria with small sample size correction. This is the standard approach available in the package *MuMIn* available in *R* (Bartoń 2022). The benefit of using model averaging is that we do not assume that there is a single best model but instead consider several models that differ in fit slightly. The procedure calculates a weighted average of model parameter estimates, such that little weight is given to the parameter estimates from models that provide only a limited explanation of the variance in the response variable (Symonds & Moussali 2011).

2.4.2. Bycatch variability per the demographic variables

For this part of the analysis, information on fur seal caught reported by observers was used. For each bycaught individual, we summarised the following demographic variables: sex (female / male, n = 99) and age class (juvenile / adult, no pups were recorded, n = 95).

In order to obtain age class of each individual, we used the recorded total length, assuming that female adults were greater than 115 cm, male adults greater than 145 cm, and male juveniles between 118 cm (shortest male recorded) and 145 cm (McKenzie et al. 2007).

One-sample tests of proportions were used to test the null hypothesis that bycatch proportions between male / female and juvenile / adult were the same.

3. RESULTS

3.1. Distribution and status of fur seal breeding and haul-out colonies in the Cook Strait region

The surveys confirmed there were only breeding colonies with pups in the central and eastern regions of Cook Strait. These were at Mātakitaki-a-Kupe / Cape Palliser, with an estimated 335 pups observed in February 2022, and Ward Beach – Needles Point, with a further 36 pups observed in September 2022 (Table 2). The surveys' GPS tracks indicating the sampling effort are provided in Appendix 1. The completed survey routes and trackpoints can be provided on request.

Table 2 Fur seal haul-out and breeding colony assessment in the Cook Strait region from 2021 to 2022. The geographical location of each haul-out / colony corresponds to the centroid of the area over which seals were seen. Full details of exact observed locations are provided in Appendix 1.

Colony	Status	Geographic location	Survey date	Individuals responsible for survey	Number of adults and sub-adults	Number of pups
Turakirae Head and surroundings	Haul-out	41°26'18"S, 174°54'56"E	9 February 2022	L. Boren	10	0
Mātakitaki-a-Kupe / Cape Palliser and surroundings	Breeding	41°36'42"S, 175°16'28"E	29 March 2022	L. Boren and S. Childerhouse	405	335
Karori Lighthouse / Tongue Point	Haul-out	41°20'31.2"S, 174°39'28.8"E	31 March 2022	L. Boren and S. Childerhouse	53	0
Te Whanganui / Port Underwood to Kura te Au / Tory Channel	Haul-out	41°18'54"S, 174°7'4.8"E / 41°16'44.4"S, 174°0'18"E	2 February 2021	L. Boren	75	0
White Bluffs / Te Parinui o Whiti	Haul-out	41°33'57.6"S, 174°8'56.4"E	4 August 2022	P. Crowe	3	0
Te Karaka / Cape Campbell and surroundings	Haul-out	41°43'57.80"S, 174°17'0.15"E	6 October 2022	H. Pavanato and J. Schattschneider	20*	0
Ward Beach – Needles Point	Breeding	41°50'49.56"S, 174°11'0.24"E	6 October 2022	H. Pavanato and J. Schattschneider	316*	36

* including juveniles.

3.2. Data exploration

Before focusing on the inferential analyses, a comprehensive data exploration was undertaken using both the COD and EDW databases. Most of the hoki trawling fleet was represented by vessels larger than 28 m (75% of tows), took place within the FSA 17 (81% of tows) and during winter (63% of tows), and did not perform turns while towing (96% of tows; Table 3). A summary of the numerical variables tow speed, depth and distance from nearest colony is given in Table 4. Of all these covariates, depth had the largest variability.

As reported by fisheries observers, a total of 157 fur seal individuals were caught during 112 hoki trawl tows (Table 5). Most hoki trawling took place in winter (i.e. June to August; 6,688 tows), and this was also the season with the largest number of fur seals bycaught (115 individuals from vessels with fisheries observers). The percentage of trawlers with fisheries observers on board varied between approximately 4% in summer to 20% in autumn (Table 5).

Table 3. Number of hoki tows per level of the categorical covariates used in the logistic regression models to estimate the risk of bycatch in hoki trawls in Cook Strait from 2012 to 2021. Data extracted from the COD database.

Categorical covariate	Number of tows per covariate levels
Vessel size	Small: 499 Large: 1,517
Fisheries Statistical Area	FSA 16: 391 FSA 17: 1,625
Season	Summer: 59 Autumn: 425 Spring: 257 Winter: 1,275
Tow turns	Yes: 78 No: 1,936

Table 4. Mean and standard error (SE) of the numerical covariates used in the logistic regression models to estimate the risk of fur seal bycatch in hoki trawls in Cook Strait from 2012 to 2021. Data extracted from the COD database.

Numerical covariate	Mean	SE
Tow speed (knots)	3.10	0.02
Depth (m)	374.95	2.84
Distance from nearest colony (km)	21.22	0.13

Table 5. Information on number of tows, number of fur seals caught as reported by fishers, number of tows with fisheries observers on board the hoki trawls, percentage of tows with observers, and number of fur seals caught as reported by observers in Cook Strait per season from 2012 to 2021. Data extracted and summarised from the EDW and COD databases.

Season	Total number of tows	Number of tows with observers	Percentage of tows with observers	Number of fur seals caught as reported by observers
Winter	6,688	1,275	19.1	115
Spring	3,162	257	8.13	38
Autumn	2,172	425	19.6	3
Summer	1,562	59	3.8	1

In the period 2012–2021, an annual mean of 16 fur seal captures was reported by observers in the hoki trawls in Cook Strait (Table 6). As observers were present on average during only 15% of the tows during this period (total number of tows = 13,584; number of tows with observers = 2016), a simple extrapolation results in a mean of 124 fur seals estimated to have been caught per year by the whole hoki trawl fleet in Cook Strait (Table 6).

Table 6. Number of fur seals caught as reported by observers and extrapolated to the whole hoki trawl fleet from 2012 to 2021 in Cook Strait. The means per years were rounded.

Year	Number of bycaught fur seals as reported by observers	Estimated number of bycaught fur seals for the whole hoki trawl fleet
2012	16	108
2013	30	248
2014	5	35
2015	6	26
2016	24	239
2017	24	233
2018	17	125
2019	12	73
2020	12	50
2021	11	106
Mean per year	16	124

As reported by fisheries observers, the COD database variables net on board time and event end time (described as point at which net left target depth or point at which breaks came out) were used to derive the entire hauling procedure time. The time difference between net at surface and net on board was also calculated, as this was identified as a high-risk period for seabird capture (William Gibson, FNZ, email to author, 17 January 2023). Both time variables were then plotted against the bycatch response, with ‘1’ representing a fur seal bycatch event, and ‘0’ otherwise.

Through a visual evaluation, most of the bycatch was related to longer hauling procedures and longer time differences between net at surface and net on board (Figure 2).

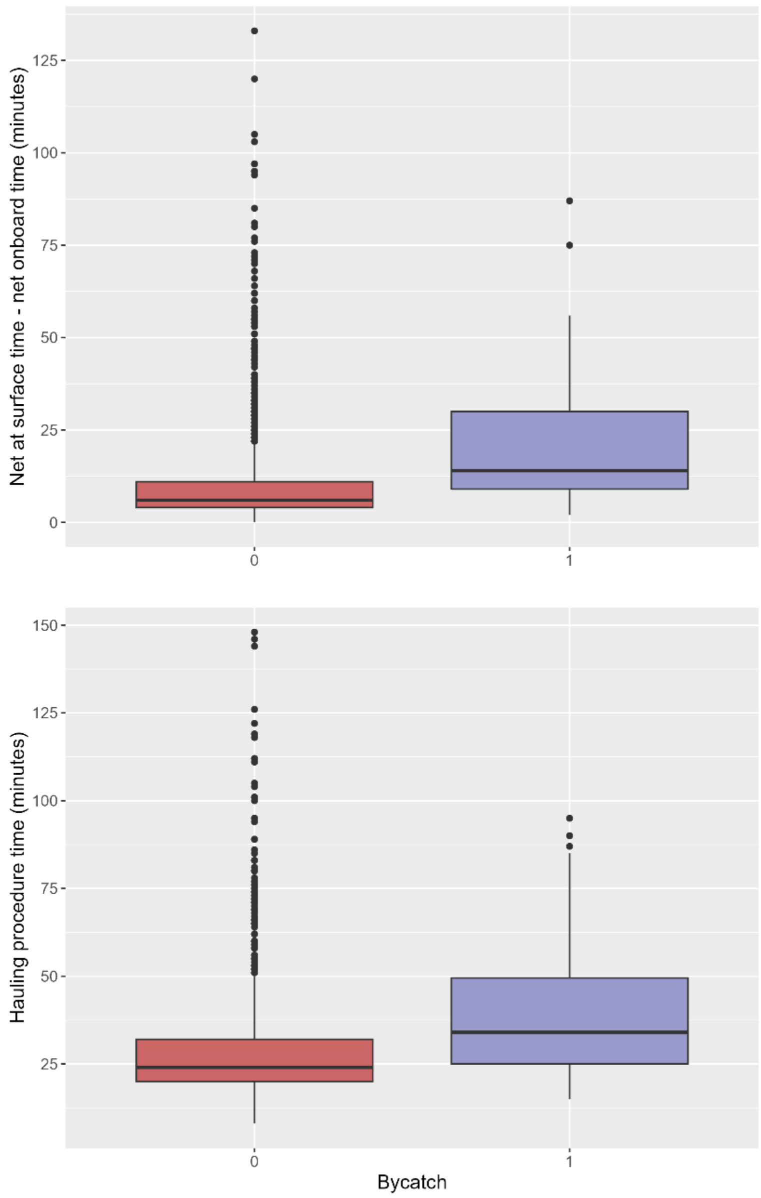

Figure 2. Top: boxplot of time between net at surface and net on board in relation to fur seal bycatch per tow (0 = no bycatch, 1 = at least one bycatch). Bottom: boxplot of hauling procedure time per tow (i.e. time between net on board and point at which net left target depth or point at which breaks came out). Each boxplot is delimited by the first and third quartiles (25th and 75th percentiles), the bold line is the median, the vertical line represents the minimum and maximum estimates, and the dots represent the outliers.

3.3. Spatio-temporal analyses

The boundary between the two FSA appears to be a persistent area of effort across all seasons, as demonstrated in Figure 3. The CPUE analyses (Figure 4) also shows that this area had more captures during the period analysed.

The findings presented in Figure 5 support the results in Table 5, indicating that, despite a high level of fishing activity in the autumn season, captures were more frequent during the winter and spring seasons. It should be noted that only one individual was caught during the summer season (Figure 3, grid near Turakirae Heads); however, this catch was made during the only tow conducted in this area, resulting in a high value of CPUE for that season, as shown in Figure 4.

Based on Figure 5, the CPUE was variable throughout the years, with a minimum of 0.02 in 2015 and a maximum of 0.19 in 2017. A sharp increase is noted in 2012–2013, 2015–2016 and 2020–2021.

The maps combining all values of CPUE and number of tows for the whole time series are provided in Appendix 2.

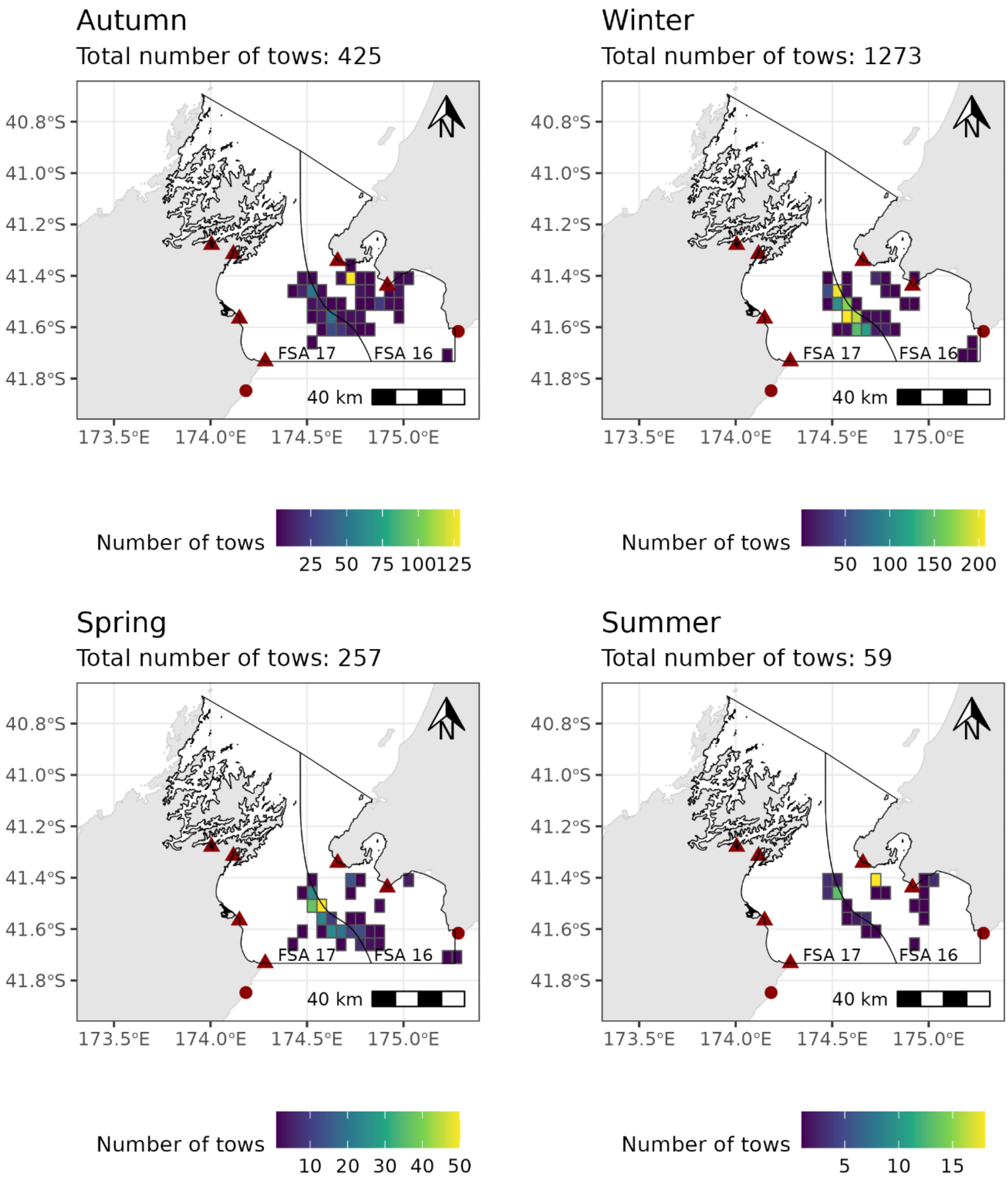

Figure 3. Seasonal spatial distribution of number of observed tows in the Cook Strait hoki trawl fishery from 2012 to 2021. Red dots represent the location of breeding colonies and red triangles the location of non-breeding haul-outs. Note that the scale of 'Number of tows' is not the same among seasons.

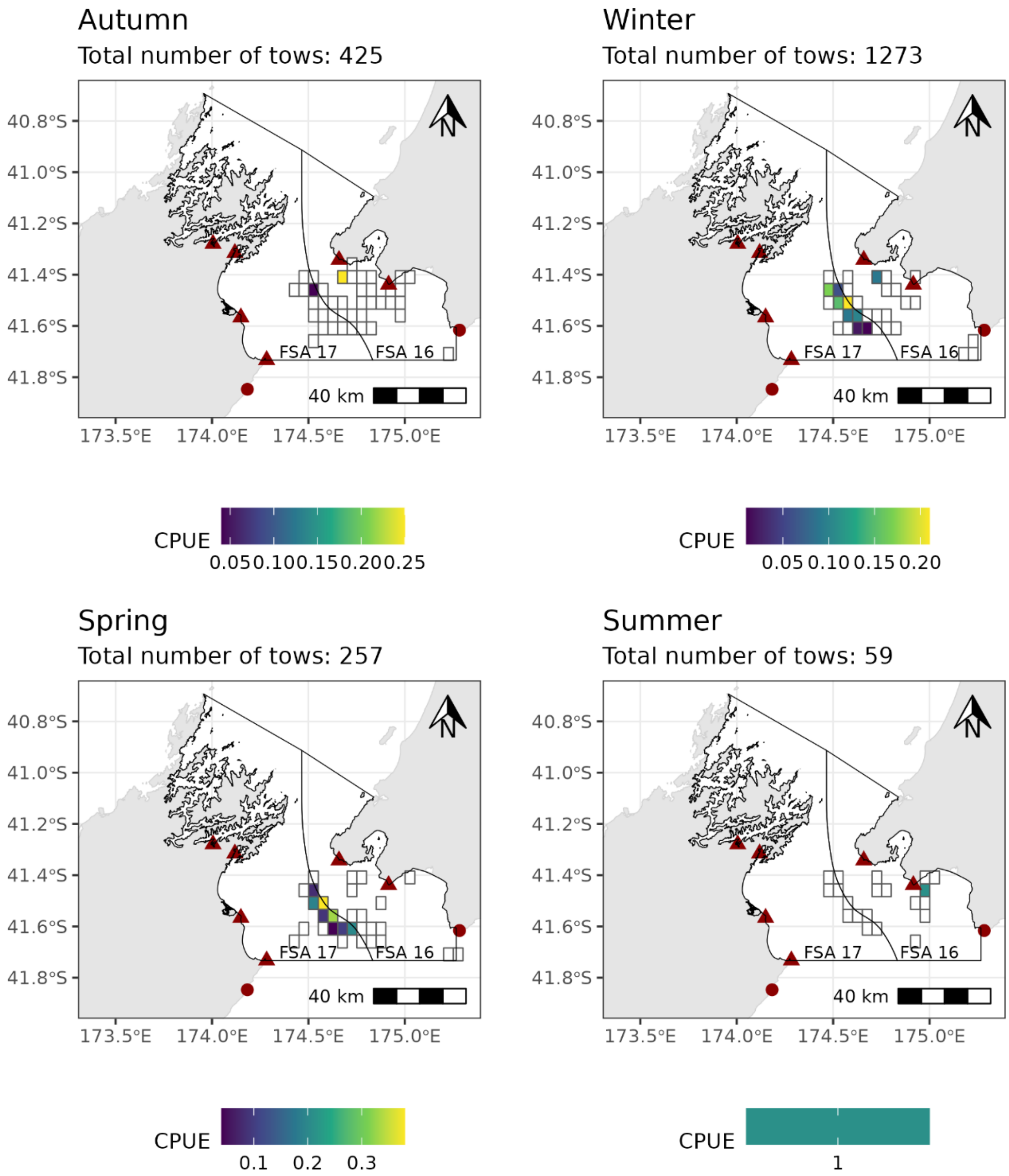

Figure 4. Seasonal spatial distribution of Catch Per Unit Effort (CPUE; number of fur seals caught per combined number of observed tows) in the Cook Strait hoki trawl fishery from 2012 to 2021. The red dots correspond to the colonies' locations and the red triangles to the haul-out locations. The white grids represent areas with fisheries effort that did not catch fur seals. Note that the CPUE scales are not the same among seasons.

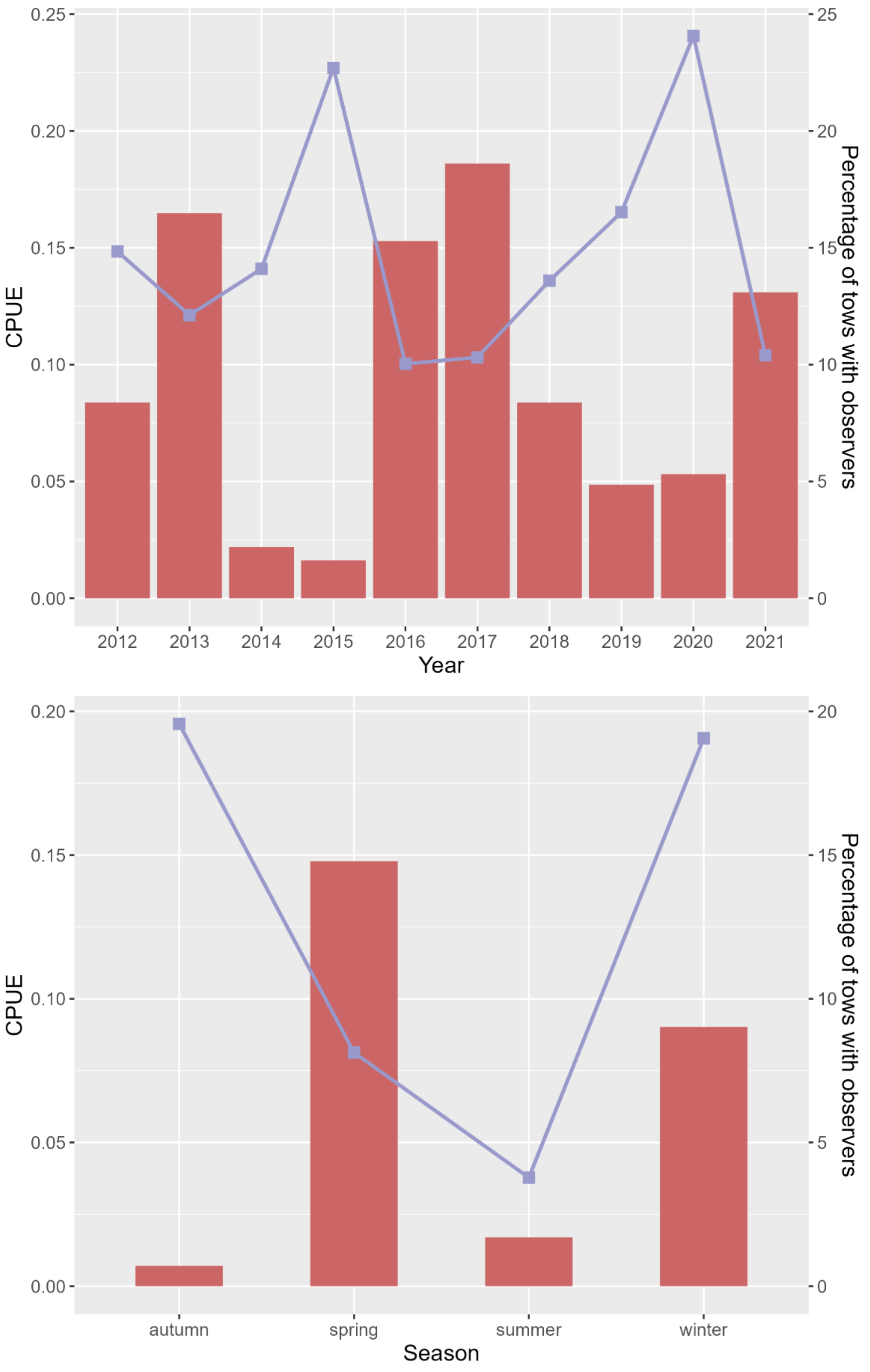

Figure 5. Annual and seasonal Catch Per Unit Effort (CPUE; number of fur seals caught per combined number of tows) in the Cook Strait hoki trawl fishery from 2012 to 2021 from tows with observers. The purple squares correspond to the percentage of tows with fisheries observer per season. Data extracted from the COD and EDW databases.

3.4. Estimated risk of fur seal bycatch

Generalised linear models were used to investigate bycatch probability and potential covariates. Using the Spearman's correlation test, collinearity was not identified among the covariates used (i.e. $r < |0.5|$).

Following the recommendations of Burnham et al. (2011), after fitting all possible covariate combinations, further inference was carried out based on the 43 models with a ΔAICc of less than 7. The 10 top-ranked models are given in Table 7. Using the subset of the 43 models, we summarised the relative importance of the covariates by extracting the number of times that each covariate appears in the models, and the sum of model weights over all models that included each covariate (Table 8). Models containing the covariates vessel length and season had the highest weightings in general (Table 8) and were present in all models. Models containing distance from nearest colony, FSA and depth were present in between 63% and 56% of the top-ranked models. Models with year, tow speed and tow turns were the least favourable in this order, appearing in less than 37% of the top-ranked models (Table 8).

The full model-averaged estimates are given in Table 9. The 'full' model-average can be seen as a type of 'shrinkage estimator', which assumes that a covariate is included in every model, but in some of the models it is simply set to zero. The covariates vessel length (p-value < 0.001) and season (p = 0.005) were the most important to explain the variability of bycatch probabilities. By comparison, there was little to no evidence that the other covariates considered in the models contributed to the observed variability in bycatch (Table 9).

In the logistic regression framework, each level of a categorical covariate can be compared among the others through the odds ratio. The odds ratio represents the odds that an outcome occurs given a particular factor, and it is calculated as the probability of an event occurring divided by the probability of the event not occurring. For this, a baseline needs to be defined so that the odds ratios are relative to a particular level for every categorical covariate included in a model.

For this study, the baseline (i.e. odds ratio = 0) was defined as being the bycatch risk:

- in autumn
- within FSA 16
- and for large vessels ≥ 28 m.

This corresponds to the probability of bycatch on the logit scale[3] given in the estimate intercept of Table 9. An odds ratio greater than one indicates an increase in odds for

[3] The logit is the inverse of the standard logistic function.

a particular level, and an odds ratio smaller than one indicates a decrease in odds. Some of the key results from Table 9 include the estimated odds of bycatch:

- for small vessels of up to 28 m it was $e^{1.60} = 4.93$ times greater than for large vessels ≥ 28 m.
- in relation to season it was:
  - $e^{2.25} = 9.47$ times greater in spring than autumn
  - $e^{1.81} = 6.13$ times greater in winter than autumn.

Note that the calculation of the odds ratio is simply given by exponentiating each estimate in Table 9.

Table 7. Competing logistic regression models ordered on the basis of AICc for the fur seal bycatch data in hoki trawls in Cook Strait from 2012 to 2021. For each model, the table gives the degrees of freedom (DF), the log-likelihood, AICc, ∆AICc and the Akaike weights. For comparison, the full model (i.e. model with all covariates) summary is provided at the bottom row.

Model	DF	Log-likelihood	AICc	∆AICc	Weight
FSA + distance from nearest colony + season + depth + vessel length	8	-342.22	700.51	0.00	0.18
FSA + distance from nearest colony + tow speed + season + depth + vessel length	9	-341.80	701.69	1.18	0.10
FSA + distance from nearest colony + season + depth+ vessel length + year	9	-342.05	702.19	1.68	0.08
FSA + distance from nearest colony + season + depth + tow turns + vessel length	9	-342.21	702.52	2.01	0.06
FSA + distance from nearest colony + season + vessel length	7	-344.51	703.09	2.58	0.05
FSA + distance from nearest colony + tow speed + season + depth + vessel length + year	10	-341.72	703.55	3.04	0.04
distance from nearest colony + season + depth + vessel length	7	-344.75	703.57	3.05	0.04
FSA + distance from nearest colony + tow speed + season + depth + tow turns + vessel length	10	-341.79	703.7	3.19	0.04
season + vessel length	5	-347.05	704.13	3.62	0.03
FSA + distance from nearest colony + season + depth + tow turns + vessel length + year	10	-342.05	704.21	3.70	0.03
FSA + distance from nearest colony + season + depth + vessel length + tow speed + tow turns + year	11	-34.06	710.11	9.60	0.00

Table 8. Relative importance of each covariate considered in the logistic regression model averaging procedure including all 162 models (with a ∆AICc of less than 7) for the fur seal bycatch data in hoki trawls in Cook Strait from 2012 to 2021.

Covariate	Sum of model weights	Percentage of all models that the term appears
Vessel length	1.00	100%
Season	1.00	100%
Distance from nearest colony	0.82	63%
Fisheries Statistical Area	0.74	56%
Depth	0.72	56%
Tow speed	0.30	35%
Year	0.26	37%
Tow turns	0.24	35%

In order to visually assess the model results in regard to the important covariates, we used the model-averaged estimates to predict the probability of bycatch. We considered a scenario in which the predicted marginal bycatch probability is described as a function of vessel length (large / small) and season (autumn / winter / spring / summer). For this, we used the mean of all numerical covariates and fixed the tow turns level as 'no'.

The predicted risk of fur seal bycatch per vessel length and season is given in Figure 6. From the plots, it is clear that the probability of bycatch is increased for small boats during winter and spring.

Table 9. Summary of logistic regression model-averaged results for the fur seal bycatch data in hoki trawls in Cook Strait from 2012 to 2021 showing the estimate on the logit scale, standard error (SE), adjusted SE, test statistic (z-value), and p-value. P-values in bold denote evidence for a covariate effect. The estimates are given in the logit scale and are relative to a baseline bycatch probability in autumn, within FSA 16, for large vessels and no turns (intercept). The odds ratio can be computed by exponentiating the estimates.

Covariate	Estimate	Adjusted SE	Z-value	P-value
Intercept	-6.08	0.92	6.23	
Fisheries Statistical Area: 17	0.90	0.79	1.15	0.25
Distance from nearest colony	-0.38	0.28	1.38	0.17
Season: spring	2.25	0.80	2.81	**0.005**
Season: summer	-12.17	544.31	0.02	0.98
Season: winter	1.81	0.79	2.30	**0.02**
Depth	0.22	0.20	1.13	0.26
Vessel length	1.60	0.27	5.96	**< 0.001**
Tow speed	0.03	0.09	0.34	0.73
Year	0.00	0.15	0.06	0.95
Tow turns	0.00	0.37	0.02	0.99

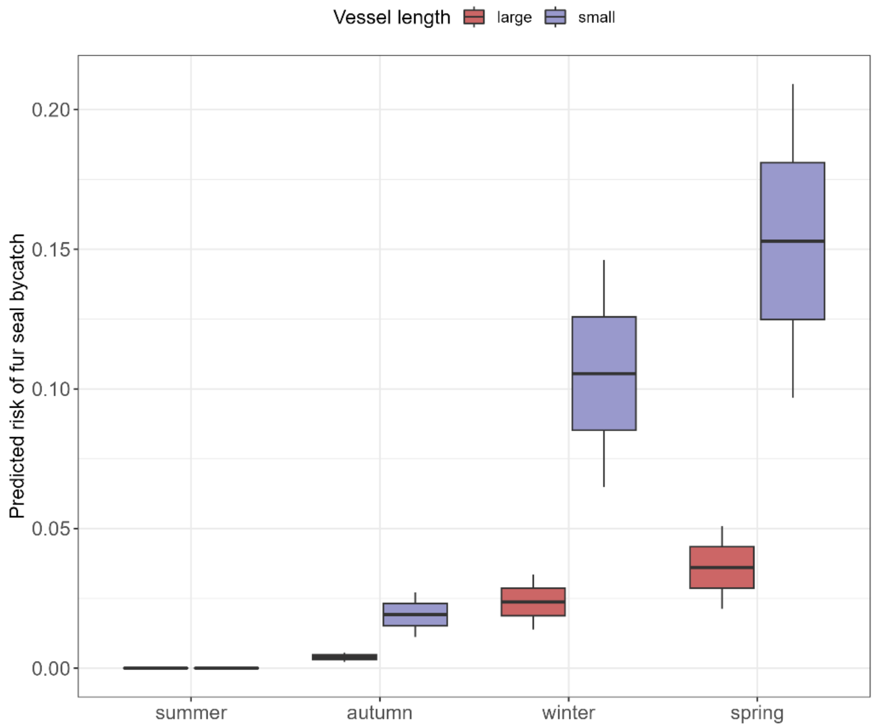

Figure 6. Mean marginal fur seal bycatch probability (risk) per season of the year and vessel length (large / small) in hoki trawls in Cook Strait from 2012 to 2021. Each boxplot is delimited by the first and third quartiles (25th and 75th percentiles), the bold line is the median, and the vertical line represents the minimum and maximum estimates.

3.5. Bycatch variability per sex and age class

Between 2012 and 2021, the observers reported that 78 males and 21 females, comprising 85 adults and 10 juvenile fur seals, were caught. There is strong evidence that the risk of male fur seals being caught is greater than that of females (79%, test of proportions p-value < 0.001), and that the risk of adults of both sexes being caught was greater than that of juveniles (89%, test of proportions p-value < 0.001; Figure 7).

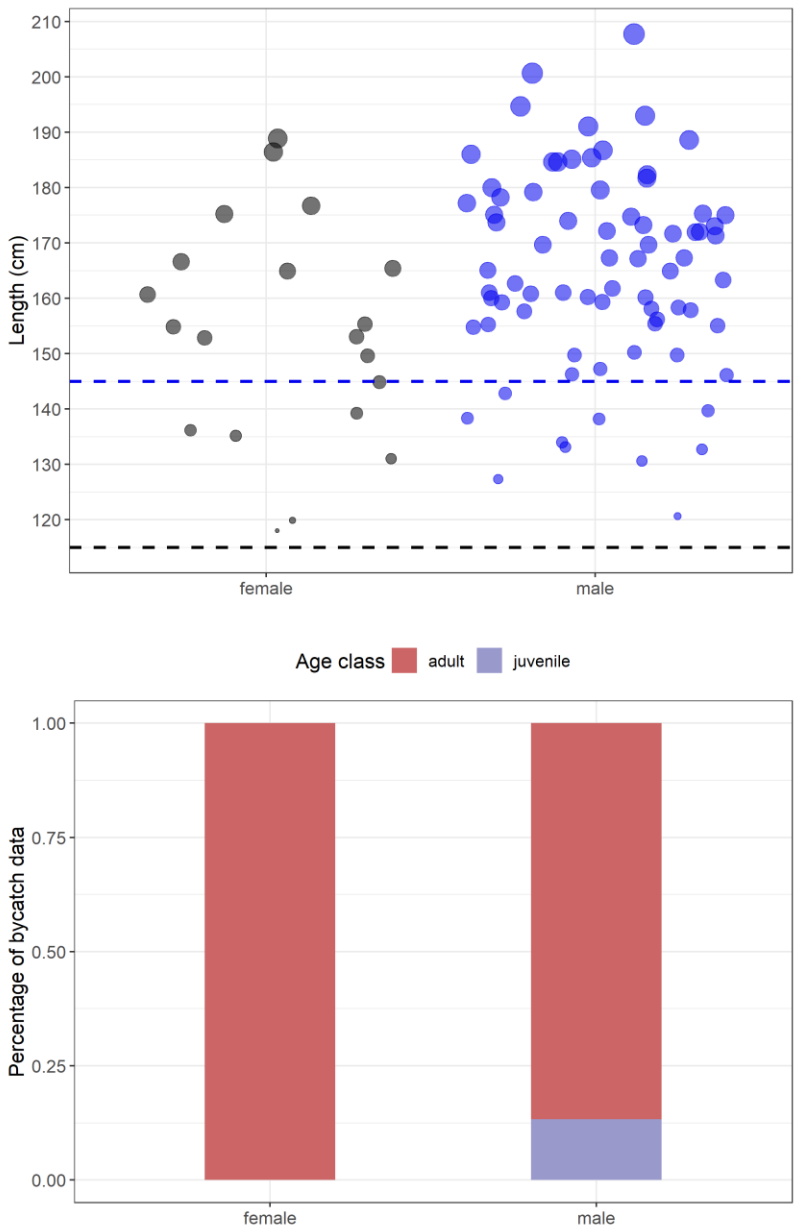

Figure 7. Top panel: fur seal total length (cm) distribution for females and males in the hoki trawls in Cook Strait from 2012 to 2021 as reported by observers. The dashed lines represent the cut-off length to differentiate between juveniles and adults for females (black) and males (blue). Bottom panel: Percentage of bycaught female and male individuals by age class.

4. DISCUSSION

We note that this report reflects a preliminary assessment of the interaction between the hoki fishery and fur seals in the Cook Strait region. The discussion is intended to answer the objectives raised in Section 1.2. In addition, we address data and model issues as follows.

For the bycatch analyses, we combined the COD and EDW data per tow to create a single dataset with all the required information and to derive additional variables such percentage of tows with observers. The process of merging and combining the information from these two datasets was not straightforward, as there is no single and unique identifier per tow commonly used by both datasets, thus the process was time-consuming and complex. In addition, dates for the variables 'net at surface time' and 'net on board time' in the COD database were not available. We considered dates given in the column 'event_end_time' for these events. However, this assumption yielded several negative times when deriving the hauling procedure time (i.e. time difference between net on board time and event end time) and time difference between net on board and net surface times (see Figure 2).

The use of model selection was a powerful tool to address the implicit uncertainty in ascertaining a single 'best' model. Although adding a level of complexity to the analysis, the Akaike weights from the fitted models were quite similar, suggesting that simply selecting the best fit model is not the most appropriate option. The approach we adopted for model averaging, known as full model averaging, was particularly necessary due to the high model selection uncertainty (Symonds & Moussali 2011), i.e. the smallest AIC models were not strongly weighted, with weight varying between 3% and 18% for the top-ranked models (Table 7).

4.1. What is the current distribution of fur seals in the Cook Strait region?

The survey data provided a useful preliminary assessment of the distribution of fur seals within the Cook Strait region as defined. The distribution of fur seals spans almost the full length of both the northern and southern sides of Cook Strait between Tongue Point and Kura Te Au / Tory Channel in the west, through to Mātakitaki-a-Kupe / Cape Palliser and Ward Beach in the east. However, the distribution is very patchy over this area, with long stretches of coastline with no fur seals. This often, but not always, coincides with areas of apparently less optimal habitat (e.g. shingle beaches), but there is also an apparent trend with lower numbers of fur seals in areas with higher human interactions (e.g. around the southern reaches of Wellington City). There is a general trend for higher densities of fur seals at the eastern end of Cook Strait compared with the western end. Overall, there also appears to be a higher density of fur seals along the northern side of Cook Strait in comparison to the southern side. Overall, however, there are relatively low densities across the full range, with the notable exception of Mātakitaki-a-Kupe / Cape Palliser (Figure 1; Table 2).

The present observed distribution of fur seals does not appear to be significantly different from previous anecdotal reports of distributions within the region as far back as 20–30 years (Dix 1993; Rollinson 2006). The limited survey data from this period indicates only small increases in abundance and little increase in distribution, with the notable exceptions of Mātakitaki-a-Kupe / Cape Palliser and Needles Point (L. Boren, DOC, pers. comm.; M. Morrisey, pers. comm.).

Interestingly, only two sites with pups were found in the entire area (i.e. Mātakitaki-a-Kupe / Cape Palliser and Needles Point). This was surprising given that both sites have been in existence for more than 30 years and 10 years, respectively (Dix 1993; M. Morrisey, pers. comm.). Increases in the distribution and / or abundance of fur seals have been reported for many other sites around New Zealand over the same period (Chilvers 2018); therefore, there was an expectation that there would have been an increase in the number of pupping sites around the Cook Strait region.

The reason behind the lack of increase in distribution of pupping sites within the region is unclear. It may be that individual fur seals have not sought out new pupping sites, and all regional growth in pup numbers has only occurred at Mātakitaki-a-Kupe / Cape Palliser; this site potentially represents both optimal pupping habitat and provides reproductive females with suitable year-round foraging habitat.

Our definition of the Cook Strait region for the purposes of this preliminary assessment is restricted to those fur seals that occupy the general local area. We have assumed that this area reflects a local and closed population of fur seals from which the bycatch is likely to be drawn. However, it is possible that some fur seals from outside the survey area may immigrate into the region and potentially be caught. Satellite tracking data from one fur seal from Ōhau Point (e.g. just north of Kaikōura) made a single trip as far as Cook Strait (L. Meynier, unpublished data). This suggests that the Cook Strait population may not be completely closed. To correctly answer this question, an additional assessment to determine the extent of immigration from outside the region is necessary, such as deployments of satellite tags on animals from multiple locations.

While the survey work from this project has provided useful data on fur seal distribution and direct counts around the Cook Strait region, it was only preliminary in nature. Notably, given the limited resources across the region, there was a lack of consistency in survey timing between sites, which were also only visited once. Future work could focus on providing more regular and systematic surveys of the two pupping sites in the region to provide baseline data for longer term monitoring.

4.2. What is the current abundance estimate of the fur seal sub-population in the Cook Strait region?

The present research was not set up to provide a robust estimate of the sub-population size of fur seals in the Cook Strait region, as that would have required significantly more funding and resourcing than was available. Notwithstanding this, it is possible to provide an approximation of the sub-population size from scaling up from pup production to sub-population size. There are well-established techniques for estimating the size of pinniped populations from pup production data and scaling using population parameters such as age-at-first breeding, age-related mortality and longevity (Shaughnessy et al. 1995; Taylor et al. 1995; Lalas & Bradshaw 2001). However, these demographic parameters are poorly defined or missing for fur seals in New Zealand (Chilvers 2023), and there is no research on how these parameters may reflect demographics in the Cook Strait region. In the absence of these specific data, it is appropriate to use multipliers from similar studies on New Zealand fur seals from other locations, including 4.76 (Goldsworthy & Page 2007) and 4.9 (Taylor 1982) as the best available information.

A total of 371 pups were recorded at the two breeding sites within the Cook Strait region during this project's surveys (Table 2). The results from using the simple multipliers of 4.76 and 4.9 described above suggest that there may be between 1,766 and 1,818 fur seals in the Cook Strait region. It must be emphasised that the use of these scaling factors provides a very approximate estimate of total sub-population size. Considerable additional work would be required to provide a robust estimate of the total sub-population size. Importantly, this research should include more accurate pup production estimates for Mātakitaki-a-Kupe / Cape Palliser and the potential investigation of region-specific demographic rates. The former is relatively achievable, while the latter would require a well-resourced and significant long-term monitoring programme.

As noted in Section 4.2 above, there is evidence that there may be some degree of immigration of fur seals from outside the region into Cook Strait. This might be particularly true for males due to their diving and swimming capabilities. In the absence of reliable data about the actual level of this immigration, we have taken a precautionary approach and assumed that the regional sub-population is closed to immigration for the purposes of obtaining the first approximate abundance estimate for the region.

The regional estimate of approximately 1,800 fur seals, which used the pup multiplier method, contrasts with the combined total direct count of 1,253, which represents all fur seals (including pups) from all project surveys (Table 2). While these estimates are not directly comparable, the regional estimate is approximately 30% higher than the combined direct count; however, this result is expected, as a variable (but often high) proportion of fur seals will be at sea and therefore not available for shore-based counting. In addition, fur seals are cryptic in rocky terrain, and hence animals that are on land might be missed during boat and helicopter surveys. Therefore, these abundance estimates provide the first regional sub-population estimate for the Cook Strait region and should only be considered as broad-scale approximations of the true regional sub-population size.

4.3. Are there any temporal or spatial effects on bycatch rates?

Overall, bycatch was significantly higher in winter and spring than summer and autumn (Figure 5). Furthermore, the odds of fur seal bycatch per tow was approximately 9 and 6 times greater in spring and winter, respectively, than in autumn (Table 9). Our results corroborate Thompson and Abraham (2010), who estimated a higher bycatch probability in August and September for the period between 2002 and 2009. This may be because summer is the breeding season, and fur seals spend a much higher proportion of their time on shore maintaining territories, mating and pupping and, therefore, are less susceptible to being captured during trawling (Harcourt et al. 2002). Another reason for the higher risk in winter and spring is the females may forage further and for longer periods, as during these seasons they must meet increased nutritional demands as their pregnancies progress and the suckling pups on shore get older. We did not assess the potential impact of the time of fishing (daytime or night-time); however, this may be a useful variable to include for future analysis given that in certain fisheries, bycatch rates for some species can be related to diurnal patterns (e.g. Allen et al. 2014).

There were two weaker spatial variables that were identified in the logistic regression analysis: Fisheries Statistical Area (FSA) and distance from nearest colony. There was a small degree of evidence of higher bycatch risk per tow in FSA 17 than FSA 16 (Table 9), which is consistent with most of the effort in the fishery occurring in FSA 17. Interestingly, the locations with the highest CPUE bycatch in winter and spring were predominantly > 20 km offshore in the centre of Cook Strait, spread over a wide area, and on the boundary between FSA 16 and 17 (Figure 4). By contrast, the locations with the highest CPUE in autumn and summer were inshore on the northern side of Cook Strait, with both areas being highly localised (e.g. generally in a 5 km by 5 km area). Specifically, the highest CPUE bycatch areas were approximately 5 to 10 km off Sinclair Head (in autumn) and approximately 5 km off Turakirae Head (in summer). However, it is important to note that the total observed bycatch in autumn and summer is very low, with only three individuals caught in these seasons over the 2012–2021 period.

4.4. Are there any fishery characteristics that increase the likelihood of bycatch?

Several fishery characteristics were investigated to assess their potential impact on bycatch rates, including vessel length, tow speed and tow turns. The covariates vessel length was the most important to explain the variability of bycatch rates. By comparison, there is little to no evidence that the other fishery covariates considered in the models play an important role in explaining the observed variability in bycatch (Table 8).

The estimated odds of bycatch for small vessels (< 28 m) was approximately five times greater than for large vessels (≥ 28 m) (Figure 6). This fact could be related to differences in the management of fish waste discharge and the fishing gear size used between different vessel lengths. We visually explored differences between fishing gear implemented by large and small vessels (see Appendix 2, Figure A2.3). We recommend that subsequent studies investigate the drivers that can explain the relationship between vessel length and bycatch rates observed in this study.

Both distance from colony and depth were included as covariates in most of the higher-ranked models (i.e. in 63% and 56% of all models respectively). However, their actual effect sizes were relatively low, suggesting that neither was a particularly influential covariate (Table 9). Overall, bycatch risk was negatively correlated with distance from colony and positively correlated with depth.

4.5. Is there any pattern of caught fur seals with regard to sex and age class?

We found that males and adults were the sex and age class categories most impacted by the hoki trawl fishery in Cook Strait. As discussed in this report, there are only two known breeding colonies in the Cook Strait and many more haul-outs, which are dominated by sub-adult and adult males, particularly in winter. This is likely the most significant reason for the smaller number of female bycatch.

In addition, these biases could be explained by the foraging strategies of the different sexes and age groups. Foraging competition between males and females and adults and juveniles is minimal (Page et al. 2006). Typically, adult males use deeper waters over the shelf break, and juveniles forage in pelagic waters, which are not used as frequently by male adults. Adults have the capacity to dive deeper and spend more time underwater than smaller individuals (Page et al. 2006). On the other hand, females are mostly constrained to foraging relatively near to the breeding colony, as they suckle their pups during summer and winter (Harcourt et al. 2002). Most bycatch is in deeper waters over the shelf break and further offshore, and this likely explains the small number of juveniles and females bycaught in Cook Strait.

Lastly, accurate sex data is reliant on fisheries observers correctly determining the sex of individuals, and we can expect an unknown degree of error in this process. The sex ratio estimates can only be corroborated through genetic analysis.

4.6. What is the bycatch risk of fur seals in the Cook Strait hoki trawl fishery?

The GLM analysis clearly shows there is a significant level of variation in bycatch risk, and this variation is dependent on a wide range of factors. Therefore, reporting a single, overall level of bycatch risk is not particularly meaningful or useful given the variability in risk driven by several key factors. Based on this assessment, we have not provided a single overall estimate of bycatch risk for the hoki trawl fishery. What we can say is that the median bycatch risk for fur seals in the Cook Strait hoki fishery ranges from a low of approximately 0% in summer through to a high of approximately 15% in spring.

5. RECOMMENDATIONS

In summary from this preliminary assessment, we recommend the following:

- Common and unique tow identifier should be established in the COD and EDW databases to facilitate data integration between the two resources.
- Fisheries observers should record and report date and time data, in conjunction with any recorded time variable (e.g. net on board time, net surface time).
- The sex and age categorisation on the EDW database should be updated according to the DOC project 'Identification of marine mammals captured in New Zealand fisheries', in which an expert identifies and verifies species and demographic parameters such as sex and age class of bycaught marine mammals from animal's photographs taken by the fisheries observers. This will likely decrease the chance of misidentification of fur seal sex.
- Overall, increased levels of observer coverage would considerably improve estimates of bycatch. We strongly recommend the increase of coverage of spring trips due to the high number of fur seal bycatch recorded.
- A long-term, robust programme using drones and / or mark-recaptures methods should be established to estimate abundance and monitor the fur seal breeding colonies in Mātakitaki-a-Kupe / Cape Palliser and Needles Point.
- Given the preliminary nature of this assessment, it would be useful to undertake additional analyses to further explore the interaction. These could include consideration of duration at fishing depth as an additional variable; fur seal immigration into the Cook Strait region, including an assessment of sub-population closure; potential diurnal patterns to bycatch rates; and the impact of a highly skewed sex ratio on the overall sub-population.
- Using a Spatially Explicit Fisheries Risk Assessment approach would improve the efforts to estimate bycatch. However, this method would require additional data inputs; for example, foraging data (e.g. satellite tracking) from male and female individuals from local sites would provide information about the foraging ranges of fur seals within the Cook Strait region, and potentially include fur seals that do not haul-out within the area but come in to feed from outside.

6. ACKNOWLEDGEMENTS

We are thankful to Fisheries New Zealand / Ministry for Primary Industries for providing the databases used in this report. We thank Simon Madill for his help during fieldwork and Olivia Johnston for comments and suggestions on the report. We are also thankful to Richard Wells, Ben Steele-Mortimer and John Cleal for helpful discussions around the operation of the fishery and thoughts about operational interactions with fur seals. We would like also to thank a number of people for their help in accessing various colonies and haul-outs: Barry Insull for support in accessing a 4WD-only section of the Wellington south coast, Brett Solly for 4WD access to Needles Point via Mizra Downs, and Sally Peter for access to Cape Campbell Lighthouse. For access to the Mātakitaki-a-Kupe kekeno colony, a portion of which is wāhi tapu, we wish to thank both the landowners and kaitiaki of the whenua, Te Rūnanga ā Kahungunu ki Wairarapa, Ngati Hinewaka, and Rangitāne o Wairarapa, and in particular, Sam Ludden and Kara Kenny and rangitahi, Keilah No'oroa, Anahera Nepia, Te Arohatia Kerr, Hineari Te Whaiti and Isabella Rangimarie Ludden.

7. REFERENCES

Allen SJ, Tyne JA, Kobryn HT, Bejder L, Pollock KH, Loneragan NR. 2014. Patterns of dolphin bycatch in a north-western Australian trawl fishery. PLoS ONE. 9(4):e93178.

Baker SC, Boren L, Childerhouse S, Constantine R, van Helden A, Lundquist D, Rayment W, Rolfe J. 2019. Conservation status of New Zealand marine mammals 2019. Wellington (NZ): Department of Conservation. New Zealand Threat Classification Series 29. https://www.doc.govt.nz/globalassets/documents/science-and-technical/nztcs29entire.pdf

Bartoń K. 2022. MuMIn: Multi-Model Inference. R package version 1.46.0. https://CRAN.R-project.org/package=MuMIn

Burnham KP, Anderson DR, Huyvaert KP. 2011. AIC model selection and multimodel inference in behavioral ecology: some background, observations, and comparisons. Behavioral Ecology and Sociobiology. 65:23–35.

Chilvers BL. 2018. New Zealand fur seal *Arctocephalus forsteri*. In: Wursig B, Thewissen J, Kovacs K, editors. Encyclopedia of marine mammals. 3rd ed. London (UK): Academic Press; p. 632–634.

Chilvers BL. 2023. Pup numbers, estimated population size, and monitoring of New Zealand fur seals in Doubtful / Pateā, Dusky and Breaksea Sounds, and Chalky Inlet, Fiordland, New Zealand 2021. New Zealand Journal of Marine and Freshwater Research. 57(1):75–87.

Cleal J, Clement G, Wells R. 2009. Mitigating incidental captures of fur seals in trawl fisheries. Auckland (NZ): Clement & Associates Ltd. Report to Department of Conservation. Project MIT 2006/09.

Dix B. 1993. Population changes and diet preferences of the New Zealand fur seal *Arctocephalus forsteri* in eastern Cook Strait [master's thesis]. Wellington (NZ): Victoria University of Wellington.

Dobson AJ, Barnett AG. 2008. An introduction to generalized linear models. 3rd ed. Boca Raton (FL): Chapman & Hall / CRC.

Fisheries New Zealand [FNZ]. 2022. Aquatic environment and biodiversity annual review 2021. Wellington (NZ): Fisheries New Zealand. Compiled by the Aquatic Environment Team.

Goldsworthy SD, Page B. 2007. A risk-assessment approach to evaluating the significance of seal bycatch in two Australian fisheries. Biological Conservation 139(3-4):269–285.

Harcourt R. 2005. New Zealand fur seals. In: King CM, Barrett P, editors. The handbook of New Zealand mammals. 2nd ed. Melbourne (Vic): Oxford University Press; p. 225–235.

Harcourt RG, Bradshaw CJA, Dickson K, Davis LS. 2002. Foraging ecology of a generalist predator, the female New Zealand fur seal. Marine Ecology Progress Series. 227:11–24.

Lalas C, Bradshaw CJA. 2001. Folklore and chimerical numbers: review of a millennium of interaction between fur seals and humans in the New Zealand region. New Zealand Journal of Marine and Freshwater Research. 35:477–497.

McKenzie J, Page B, Shaughnessy PD, Hindell MA. 2007. Age and reproductive maturity of New Zealand fur seals (*Arctocephalus forsteri*) in Southern Australia. Journal of Mammalogy. 88(3):639–648.

Page B, McKenzie J, Summer MD, Coyne M, Goldsworthy SD. 2006. Spatial separation of foraging habitats among New Zealand fur seals. Marine Ecology Progress Series. 323:263–279.

Percy C. 2021. EDW Fisheries data dictionary external users. https://www.mpi.govt.nz/dmsdocument/45553-EDW-Electronic-Data-Warehouse on 2022-08-15

Rollinson D. 2006. Notes on New Zealand mammals 2. New Zealand fur seal (*Arctocephalus forsteri*) pups at Turakirae Head, North Island. New Zealand Journal of Zoology 33(3):233.

Sanders BM, Fisher DO. 2020. Database documentation for the Ministry for Primary Industries Centralised Observer Database (COD). NIWA Fisheries Data Management Database Documentation Series.

https://www.mpi.govt.nz/dmsdocument/15532-database-documentation-cod on 2022-08-07

Shaughnessy PD, Goldsworthy SD, Libke JA. 1995. Changes in the abundance of New Zealand fur seals, *Arctocephalus forsteri*, on Kangaroo Island, South Australia. Wildlife Research. 22:201–215.

Symonds MRE, Moussali A. 2011. A brief guide to model selection, multimodel inference and model averaging in behavioural ecology using Akaike's information criterion. Behavioral Ecology and Sociobiology. 65:13–21.

Taylor RH. 1982. New Zealand fur seals at the Bounty Islands. New Zealand Journal of Marine and Freshwater Research. 16(1):1–9.

Taylor RH, Barton KJ, Wilson PR, Thomas BW, Karl BJ. 1995. Population status and breeding of New Zealand fur seals (*Arctocephalus forsteri*) in the Nelson – north Marlborough region, 1991–1994. New Zealand Journal of Marine and Freshwater Research. 29:223–234.

Thompson FN, Abraham ER. 2010. Estimation of fur seal (*Arctocephalus forsteri*) bycatch in New Zealand trawl fisheries, 2002–03 to 2008–09. Wellington (NZ): Ministry of Fisheries. New Zealand Aquatic Environment and Biodiversity Report 61.

Wilson GJ. 1981. Distribution and abundance of the New Zealand fur seal, *Arctocephalus forsteri*. Wellington (NZ): New Zealand Ministry of Agriculture and Fisheries. Fisheries Research Division Occasional Publication 20.

8. APPENDICES

Appendix 1. Fur seal surveys

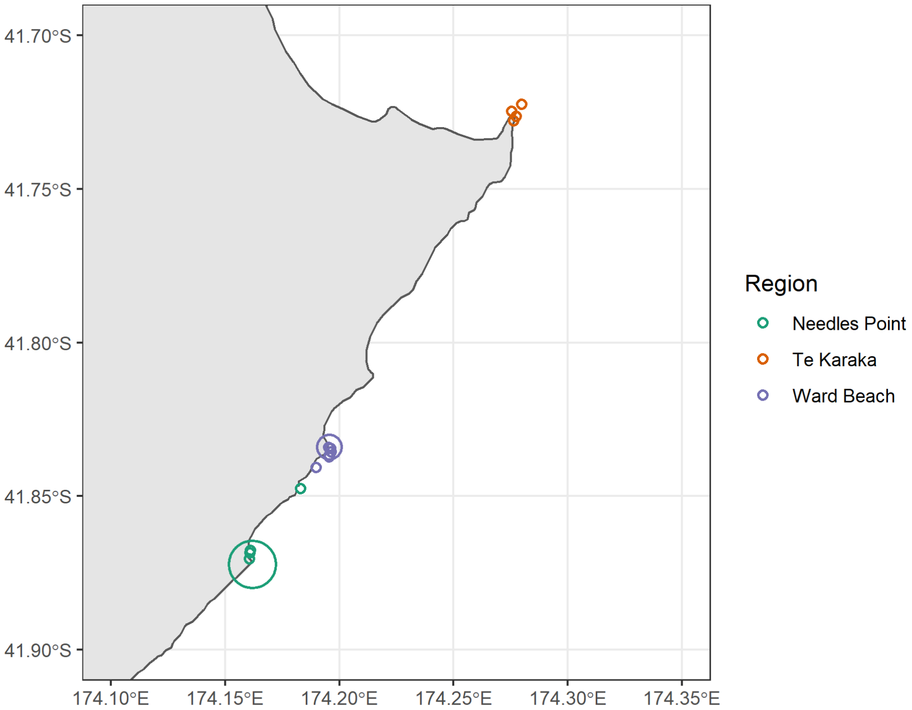

Figure A1.1 Location of observed fur seals in the surveys carried out around Te Karaka / Cape Campbell haul-out and Ward Beach – Needles Point breeding colonies conducted on 6 October 2022. Different colours represent the different sites surveyed, and the three circle sizes indicate the number of animals observed in each point (small = < 15 animals; medium = 16–30 animals; large > 250 animals).

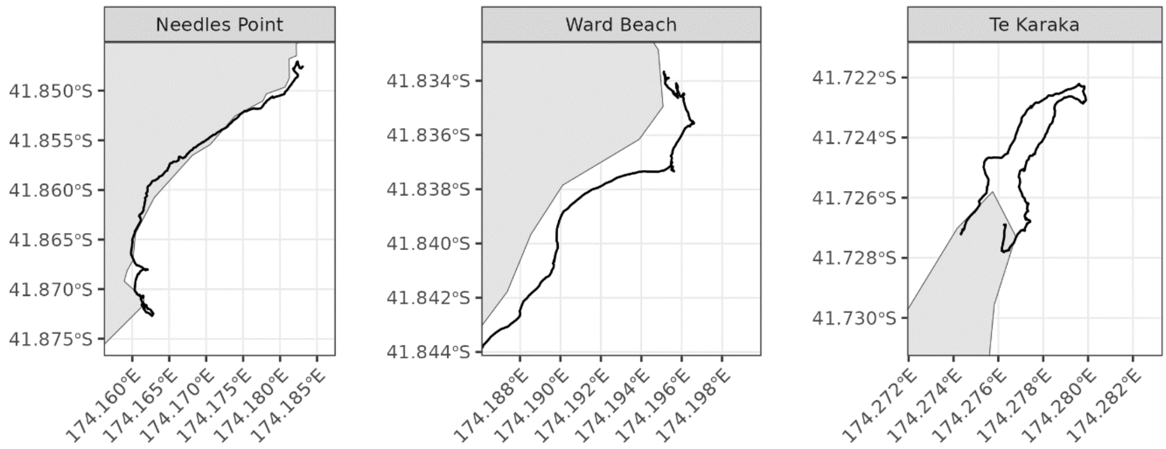

Figure A1.2 Tracks of the surveys carried out on 6 October 2022 around Te Karaka / Cape Campbell haul-out and Ward Beach – Needles Point breeding colonies.

Appendix 2. Hoki trawl effort and CPUE

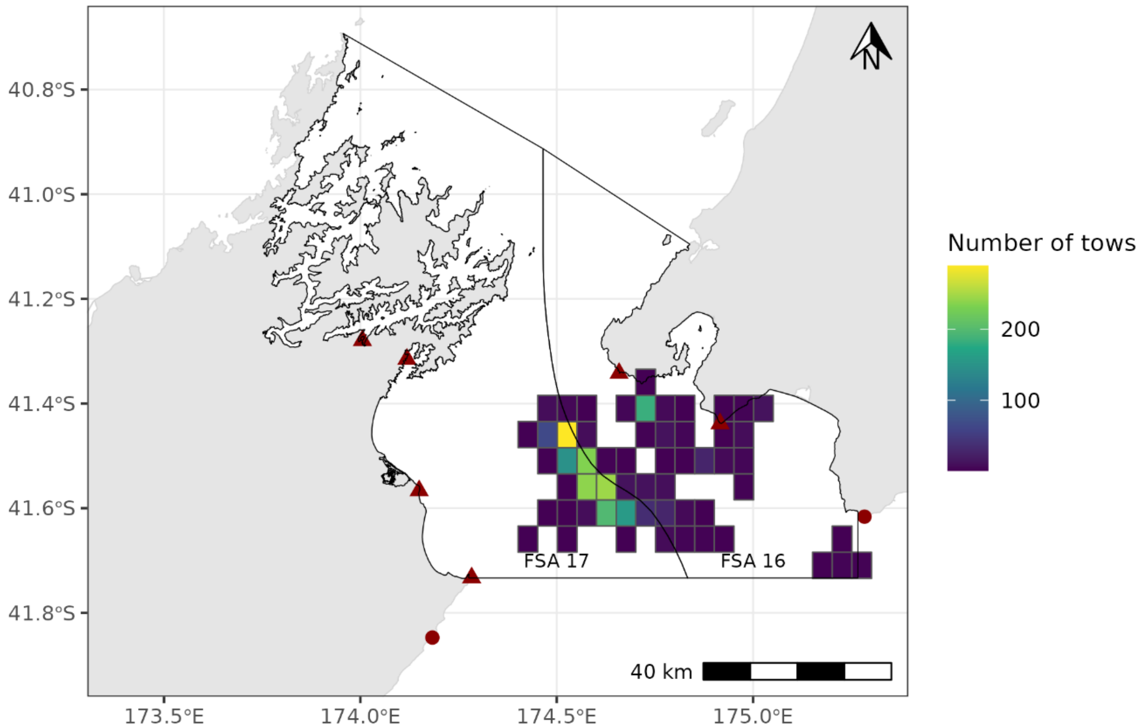

Figure A2.1 Spatial distribution of total number of tows of fishing effort (i.e. combined number of tows) in the Cook Strait hoki trawl fishery from 2012 to 2021 from tows with observers. Red dots represent the location of breeding colonies and red triangles the location of non-breeding haul-outs.

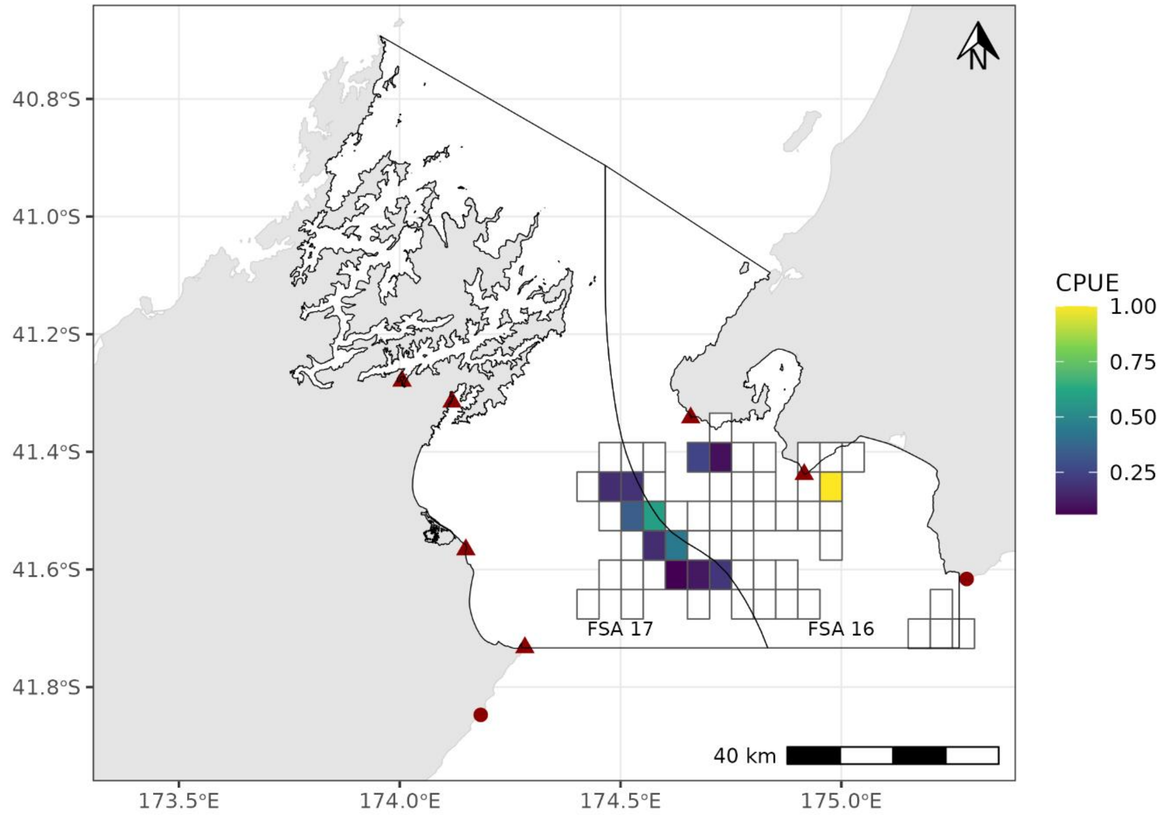

Figure A2.2 Spatial distribution of Catch Per Unit Effort (CPUE; number of fur seals caught per total number of tows) in the Cook Strait hoki trawl fishery from 2012 to 2021 from tows with observers. The white grids represent areas with fisheries effort that did not catch fur seals. Red dots represent the location of breeding colonies and red triangles the location of non-breeding haul-outs.

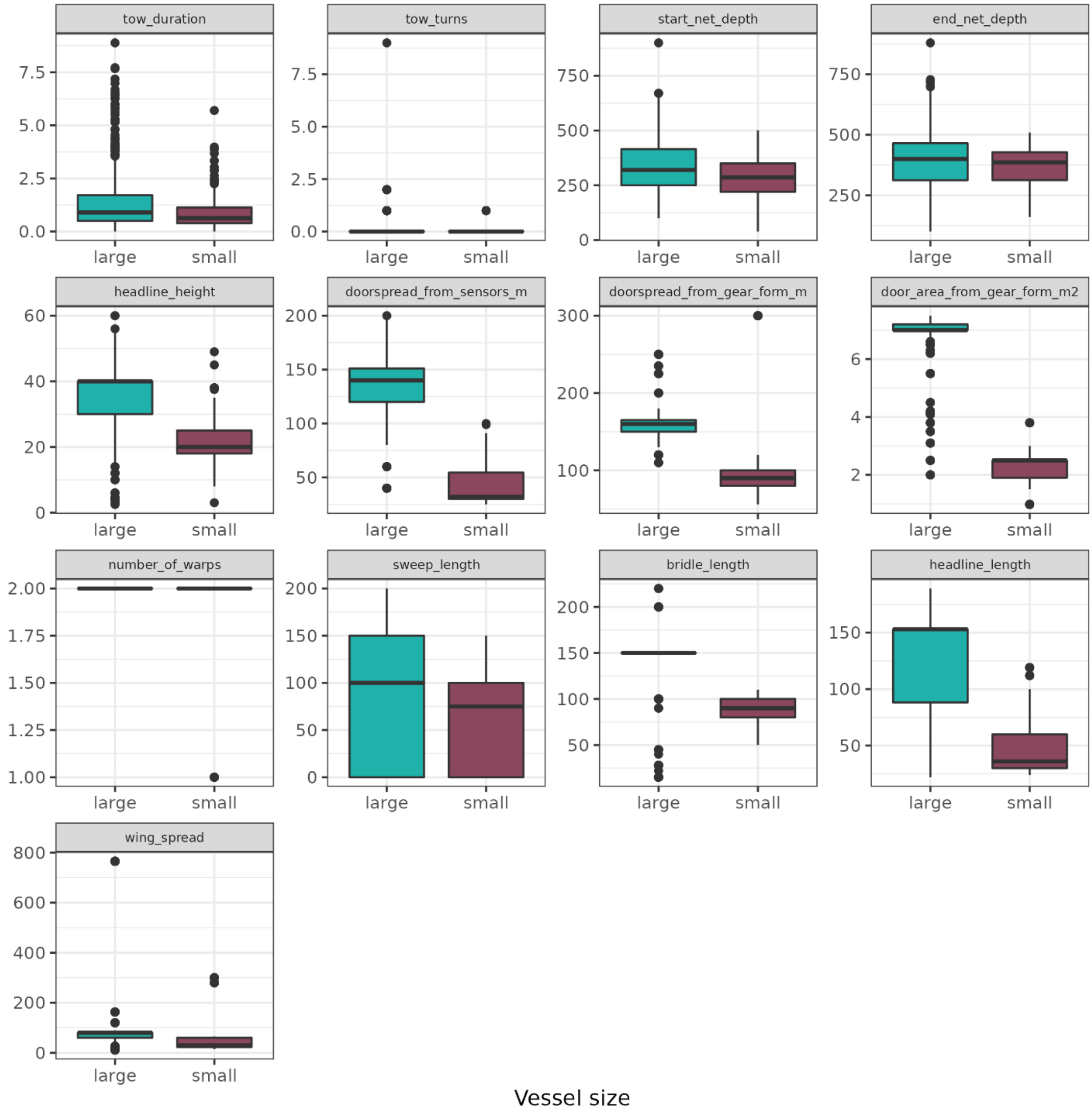

Figure A2.3 Comparison between fishing gear size used in large and small hoki trawl vessels. The top of the boxplot indicates the third quartile, the bold horizontal line indicates the median, and the bottom of the boxplot indicates the first quartile. The vertical lines indicate the maximum and minimum values, and the points represent outliers. These data were sourced from the COD database.