Warp strike in New Zealand trawl fisheries, 2004–05 to 2008–09

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EXECUTIVE SUMMARY

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Ministry of Fisheries observers have been making warp strike observations since the 2004–05 fishing year. During these observations, they record the numbers of birds that are struck by trawl warps during 15 minute periods. In this report, a summary is presented of all the strike data collected from 2004–05 to 2008–09. Warp strike observations largely ceased in 2008–09, with the only observations being made on a trip that began during the 2007–08 fishing year. The warp strike dataset contains 7266 observations made on the trawl warps until the 2008–09 fishing year, Over all years, 67.4% of warp observations were made during squid trawls. The next most frequently sampled fishery was hoki, with 12.1% of warp observations being made during hoki target trawls. In 2007–08 and 2008–09, 120 warp strike observations were also made on smaller trawlers targeting inshore species.

The use of mitigation devices, which deter seabirds from entering the regions between the stern of a trawler and the trawl warps, was made mandatory in January 2006 for all trawlers over 28 m in length fishing in New Zealand waters. Warp strike rates were highest during the 2004–05 fishing year, before the legislated requirement to use mitigation devices. In that year, in the squid fishery, average strike rates of 1.53 heavy contacts per hour were recorded for small birds (all birds other than albatrosses and giant petrels), with the strike rate of large birds (albatrosses and giant petrels) being 3.41 heavy contacts per hour. By 2007–08, the squid fishery warp strike rates for small and large birds had reduced to 0.36 and 0.52 heavy contacts per hour, respectively. There is strong evidence that this reduction was due to an increased use of mitigation devices, particularly tori lines. The results from statistical modelling are that using tori lines reduces the warp strike rate to less than 25% of the strike rate that occurs when no mitigation is used.

In 2007–08, the warp strike rates recorded in inshore fisheries were higher than the rates recorded in the squid fishery. Although the number of observations was small, these data confirm that warp strikes do occur on smaller inshore vessels. Moreover, there were 3 large bird and 1 small bird warp captures during tows with targeting inshore species that had warp strike observations.

The analysis confirmed the importance of offal management, with few warp strikes or captures being recorded in the absence of offal discharge. Across all the data, the average large bird warp strike rate was 0.03 strikes per hour when there is no discharge, compared with 3.30 strikes per hour when there was intermittent or continuous discharge of factory waste. Corresponding to the reduction in warp strikes when there was reduced discharge, there was also a reduction in warp captures when discharge was low. The large bird warp capture rate when no discharge was recorded during the warp observations was 0.2 birds per 100 tows, compared with an average capture rate of over 6.7 birds per 100 tows when offal or discards were discharged.

For every large bird that was reported by the observers as being captured on the warps, there were an estimated 244 (95% c.i.: 190 to 330) large bird warp strikes. For every small bird reported by the observers as being captured on the warps, there were an estimated 6440 (95% bootstrap c.i.: 3400 to 20000) small bird warp strikes. It is likely that some birds are killed by warp interactions, but not brought on board the vessels. Currently, estimates of seabird mortality in New Zealand fisheries are based solely on landed captures and the true mortality from trawl fishing is likely to be underestimated. An understanding of the fate of birds that have struck the warps is needed before the true seabird mortality in trawl fisheries can be assessed.

1. INTRODUCTION

In trawl fisheries, seabirds are killed by being hit by the trawl warps during fishing (Wienecke & Robertson 2002, Sullivan et al. 2006b, Melvin et al. 2007, Watkins et al. 2008). Mitigation devices have been developed that deter birds from entering the region between the stern of the vessel and where the warps enter the water. Trials in the Falkland Islands showed that these devices could successfully reduce the interactions of seabirds with the warps (Sullivan et al. 2006a). In January 2006, the use of mitigation devices was made compulsory for all trawl vessels over 28 m in length fishing in New Zealand waters (Department of Internal Affairs 2006). The three legally permitted devices include tori lines, bird bafflers (Crysel 2002), and warp scarers (Carey 2005).

Direct observation of interactions between seabirds and trawl warps has been used to determine the incidence of warp strikes, and to understand the factors that are associated with them. Warp strike observations were first made in New Zealand waters in the 2004–05 squid fishery. During the observations, observers watched a warp for 15 minute periods, counting the number of birds that were hit by the warps. The warp strike was defined as a 'heavy contact' where a bird was hit on the body or upper wing and was deflected from its path by the interaction. The protocol did not require the observers to asses the fate of the birds following a warp strike, and many of the strikes would not have harmed the birds.

The initial data showed a clear relationship between the discharge of offal or discards and the frequency of warp strikes (Abraham & Kennedy 2008). Following this trial, the protocol was adapted for general use by observers on trawl vessels. Data from the 2005 calendar year were reported by Abraham (2006). In the 2005–06 squid fishery, an experiment was conducted that used the warp strike protocol to compare the performance of each of the three mitigation devices (Middleton & Abraham 2007). Tori lines were found to be the most effective device, reducing the strike rate to between 3% and 30% of the rate when no mitigation was used. The warp strike protocol continues to be a useful tool for gathering focused data on warp interactions.

As part of their other duties, observers also record any birds that are caught during fishing. On trawlers, birds are caught in the nets and on the warps. The seabird that has been most frequently observed caught in New Zealand trawl fisheries is the white-capped albatross (*Thalassarche steadi*). White capped albatross breed on the Auckland Islands and are caught in the squid fishery. Since the introduction of mandatory mitigation, there has been a decrease in the number of albatrosses caught on trawl warps. In particular, captures of white-capped albatross in the Auckland Islands' squid fishery have fallen (Abraham et al. 2010).

In this report, a summary is presented of all the warp strike data collected in New Zealand waters up to the end of the 2008–09 fishing year. The report is an update of a previous report that analysed the warp strike data to the end of the 2006–07 fishing year (Abraham & Thompson 2009). A feature of the dataset analysed here is that in 2007–08 warp strike observations were made in inshore trawl fisheries. Trawl vessels that are less than 28 m in length are not legally obliged to use warp mitigation devices. Little is currently known about the incidence of warp strike on smaller vessels, and this is the first time that warp strikes have been reported from small vessel fisheries.

The work was completed as part of Ministry of Fisheries project PRO2007/01. This project had the overall objective "to estimate the nature and extent of captures and warp-strikes of seabirds in New Zealand fisheries for the fishing years 2006–07, 2007–08, and 2008-09." This report completes the warp strike analysis component of the project.

2. METHODS

2.1 Warp strike protocol

The warp strike protocol used in New Zealand was first reported by Abraham & Kennedy (2008) and Middleton & Abraham (2007). To carry out a warp strike observation, observers watched either the warp or the mitigation device for 15 minutes and counted the number of strikes made by seabirds on the gear. The strikes were defined as heavy contacts, where the bird:

1. had its path of movement deviated when it came into contact with the gear; *and*
2. the part of the body contacted was above the “wrist” joint of the bird (i.e., on the upper part of the wing or on the head or body).

Strikes occurred on the water or in the air, and either when the bird contacted the gear, or when the gear moved to contact the bird. Seabirds striking the observed gear were grouped into two categories:

1. Small birds: including petrels (other than giant petrels), shearwaters, cape pigeons, prions, storm petrels, gulls, and shags;
2. Large birds: including all albatrosses and giant petrels.

No attempt was made to determine whether or not the bird was killed or injured by the interaction. Strike observations were carried out during the fishing phase of the tow (i.e., when the net was in the water and warps were not being paid out or hauled). Observers were encouraged to spread observations throughout the daylight hours. For each observation period, observers recorded the environmental and other covariates detailed in Table 1. If conditions changed significantly during an observation period (e.g., the vessel turned or a factor such as the offal discharge rate changed significantly) observation periods were terminated. The observation protocol required observers to select a single warp and mitigation device to observe for the entire trip. They were instructed to choose the side of the vessel from which most offal was typically discharged, assuming a safe observation position was available.

Observers also record any seabird or other protected species captures that occur as a result of fishing activities. In addition to recording all seabird captures on the standard observer non-fish bycatch forms, the seabird strike protocol originally required duplicate recording of these captures by specific categories. Large and small seabird captures were divided into those recovered from the warps (warp captures), those from the mitigation device, and those recovered from the net. An ‘unknown’ category included seabirds recovered from the pounds or passed to the observer by the crew. Captured seabirds were also grouped into those dead, injured, and not injured. Since January 2007, the non-fish bycatch form has included recording of capture location. The requirement to also record captures on the warp observation form has been dropped.

Instructions have varied in other ways since the protocol was first developed (Middleton & Abraham 2007, Abraham & Kennedy 2008). In particular, the requirement to watch for strikes on mitigation devices was introduced for the 2005–06 mitigation experiment and has remained part of the protocol. When used as part of an experiment, the warp strike protocol was used relatively intensely. At other times, strike observations were carried out as the observer’s other duties permitted.

Table 1: Descriptions of the environmental covariates recorded by observers for each seabird strike observation period.

Covariate	Description
Seabird abundance	The number of large and small seabirds, on the water and in the air, in a 40 m $\times$ 40 m square, centred on the position where the warp entered the water, assessed before seabird strike counting began.
Mitigation deployed	Which seabird mitigation devices were deployed and their measurements.
Swell height	Average swell height (metres) during the observation period.
Swell direction	Direction, relative to the vessel, from which the swell was coming during the observation period. Recorded on a 12 point “clock” scale where 12 is the vessel’s bow.
Wind speed	Beaufort scale.
Wind direction	Recorded as per swell direction.
Discharge side	Whether offal discharge was on the port, starboard, both, or neither sides of the vessel during the observation period.
Discharge rate	The rate of offal or discard discharge during the sampling period, using four categories (none; negligible; intermittent; and continuous).
Discharge type	The type of discharges (sump water; minced material that has been through a macerator; cutter pump material; offal, meaning heads and guts of processed product; whole discards). Multiple categories may be recorded.

2.2 Data source

Warp strike data collected by fisheries observers were entered into a Ministry of Fisheries database, administered by the National Institute of Water and Atmospheric Research (NIWA). A complete extract of tables related to the warp strike data was obtained, covering all data collected to the end of the 2008–09 fishing year. The first warp strike observation in the dataset was made on 14 January 2005 and the last observation was on 4 October 2008, at the start of the 2008–09 fishing year. Warp strike observations were made on only 13 tows in the 2008–09 year, on a trip targeting inshore species that began in the 2007–08 year.

The data collected included: station information; warp and device strike observations; related data such as discharge and environmental conditions; data on any seabirds captured during tows where warp strike observations were made; data on the mitigation devices used; and coding of any incidents involving failure of the mitigation devices.

Records of any seabird captures that occurred during tows with strike observations were obtained from the Centralised Observer Database (COD). Further information on the seabird capture data was reported by Abraham et al. (2010).

2.3 Data grooming

Data were cleaned by removing any observations that were not between 13 and 17 minutes long, any observations where it was unclear whether the warp or the mitigation device was observed, and any observations where there were missing large bird or small bird strike counts. The two sources of seabird capture data were merged. Where captures were recorded on both the strike observation form and the non-fish bycatch form, the strike observation data were accepted as authoritative. In the first season the strike observation form did not divide captures into large and small birds, and the species identification from the non-fish forms was then used to assign the capture to the appropriate group. Where no capture information was recorded on the warp observation forms, non-fish bycatch data were used and was converted into the same information that was recorded on the warp observation forms. This provided a single consistent set of capture data.

The warp observation form allowed for multiple discharge types to be recorded. During the data grooming a single discharge type was determined for each observation. The discharges were given the following order: no discharge; sump water; minced material; material that has been through a cutter pump; offal; and discards. This corresponds to the increasing size of the typical pieces within the discharge. The highest category recorded on an observation was then used to characterise the discharge. For example, if sump water, minced material, and offal were recorded on an observation, then the groomed discharge was set to be offal. The same logic was used to define a single discharge category from multiple observations on the same tow.

The mitigation was characterised as: none; bird baffler only; warp scarer; tori line; bird baffler and tori line; or other. During modelling the warp scarer and other categories were combined. A fishery was assigned to each tow based on the target species. Four fisheries were used: squid, hoki, inshore, and other target species. The methods used for defining the target fisheries followed those by Abraham et al. (2010). Although there were fewer observations in inshore fisheries than in middle-depths, southern blue whiting, hake, or mackerel fisheries, inshore fisheries were separated from the others as there is little other information on seabird bycatch by inshore vessels.

2.4 Data analysis

Analysis followed the methods used by Abraham & Thompson (2009). Data analysis was carried out using the R software package (R Development Core Team 2008). The strike data were tabulated to allow coverage to be assessed, and the association between the strikes and the key covariates was explored. Negative binomial generalised linear models (GLM) of the small and large bird strikes were fitted using maximum likelihood routines from the MASS library (Venables & Ripley 2002). The negative binomial model is appropriate for modelling overdispersed count data, and has been found to give a good representation of the warp strike data (Abraham & Kennedy 2008). The model predicts the mean strike rate (or capture rate) μ_i during a tow, i, as a linear function of a number of covariates x_{ij}:

$$\log(\mu_i) = \beta_0 + \sum_{ij} \beta_j x_{ij} + \log(d_i) \quad , \tag{1}$$

where j is an index over the covariates, and the total duration of the observations on the tow is d_i. The data are assumed to be drawn from a negative binomial distribution with mean, μ_i, and overdispersion, θ. The values of the intercept, β_0, the parameters, β_j, and the overdispersion are estimated by the model fitting. The multiplicative effect of a factor on the mean rate is obtained as the exponent of the corresponding parameter, β.

The modelling used data at the tow level, rather than individual observations. The total number of strikes was calculated, with the logarithm of the total duration of the observations, d_i, used as an offset term in the model. This offset accounted for the expected proportional increase in the number of strikes as the observation duration increased.

Covariates for the models were selected using an automated step routine. At each step, potential covariates were tested and the one that caused the greatest reduction in the AIC criterion was retained (Akaike 1974). This continued until either there were no more covariates remaining, or none of the remaining covariates caused a reduction in the AIC when added to the model. An additional manual selection step was made, rejecting covariates that explained less than 2% of the initial model deviance.

The covariates that were tested for inclusion in the models are defined in Table 2.

A simplified categorisation of the discharge was used that combined the rate and type data. If there was discharge other than sump water, and the rate was intermittent or continuous, then the discharge was categorised as ‘discharge high’. If there was negligible discharge of material other than sump water, then the discharge was categorised as ‘discharge low’. Intermittent or continuous discharge of sump water was categorised as ‘sump high’, and negligible discharge of sump water was categorised as ‘sump low’. If no discharge was recorded, or if the discharge rate was recorded as zero, then the discharge was categorised as ‘none’. There were some observations with contradictory discharge types and rates, for example recording discharge of offal at a rate of ‘no discharge’. These observations were excluded from the modelling.

No interaction terms were included in the models. For both small bird and large bird warp strikes, models were built with and without a covariate proportional to the logarithm of the respective bird abundance recorded by the observers. For both large and small birds, no warp strikes were recorded on tows where the bird abundance was zero. In the models with bird counts, the tows with no birds were excluded. On the original form, bird counts were made in categorical ranges. The form was then modified so that from June 2005 observers recorded the actual counts. To keep the dataset consistent, the early observations with range data were excluded from the models with bird counts. This resulted in 1296 observations from 2004–05 being excluded from these models, 67% of the observations collected during that year. Other records with incomplete covariates were also excluded from the modelling.

Table 2: Covariates included in the step analysis to select the models of small and large bird warp strikes.

Covariate	Description
Bird count	Logarithm of the number of birds behind the vessel (small bird count and large bird counts being used in the respective models)
Discharge	Discharge high (intermittent or continuous discharge of mince or offal); sump high (intermittent or continuous discharge of sump water); discharge low (negligible discharge of mince or offal); sump low (negligible discharge of sump water); none (no discharge).
Mitigation	Baffler, tori line, baffler and tori line together, other mitigation, or no mitigation.
Area	North Island, Chatham Rise, Stewart-Snares shelf, Auckland Islands, West Coast South Island, and southern areas. These areas are shown in Figure 1, and were made by combining the areas used by Abraham et al. (2010).
Fishery	Squid, hoki, inshore, or other target species.
Fishing year	2004–05, 2005–06, 2006–07, or 2007–08. The few tows in the 2008–09 fishing year were included with the 2007–08 data.
Vessel length	$\leq$ 28 m, $>$ 28 m and $\leq$ 60 m, $>$ 60 m and $\leq$ 100 m, $>$ 100 m.
Season	Four quarters: January to March, April to June, July to September, October to December.

To test whether the warp mitigation was also effective in the hoki fishery, models of small bird and large bird warp strikes were fitted to the dataset restricted to the hoki fishery data. These hoki models had only discharge and mitigation covariates.

The same methodology was used to select a model of large bird warp captures. For this model, the data were restricted to the squid fishery, as there were few large bird warp captures recorded in other fisheries during the warp strike observations. The same covariates were used for the model selection process, except that the area was restricted to two factors: in the Auckland Islands area, or outside it.

3. RESULTS

The full data extract had a total of 10 535 records, from a total of 2456 hours of observation. Of the records, 352 either had a start or end time missing, or were not of the 15 minute duration specified by the protocol; 211 had unclearly specified whether the warp or mitigation device had been observed; and 194 had missing large bird or small bird contact data. These records were removed from the analysis, leaving 9825 valid observations. The final data include 6909 observations made on the trawl warps and 2916 on the mitigation devices.

Warp strike observations were made on tows a number of different target fisheries, and across a wide geographic range (Table 3, Figure 1). The number of warp strike observations peaked in 2005–06 (Table 3), and decreased in both 2006–07 and 2007–08. Aside from observations made on a trip that started during the 2007–08 fishing year, no observations were made in 2008–09. Over all years, 67.9% of warp observations were made during squid trawls. The next most frequently sampled fishery was hoki, with 11.8% of warp observations being made during hoki target trawls, most during the 2005–06 fishing year. Although there were a few warp strike observations on tows targeting inshore species in 2005–06 and 2006–07, most observations in inshore fisheries were made in 2007–08.

Observations of strikes on mitigation devices were first made during the 2005–06 fishing year, as part of the experimental trial of different mitigation devices in the squid fishery. There have been few observations of strikes on mitigation devices made outside of the squid fishery.

Table 3: Number of strike observations, broken down by fishing year and target fishery.

(a) Trawl warps

	2004–05	2005–06	2006–07	2007–08	2008–09	Total
Squid	1 361	1 502	1 028	803	0	4 694
Hoki	193	613	8	0	0	814
Mid-depths	26	233	51	27	0	337
SBW	184	58	3	0	0	245
Hake	23	186	16	1	0	226
Pelagic	141	40	34	9	0	224
Inshore	0	9	19	106	14	148
Ling	15	44	26	5	0	90
Scampi	0	90	0	0	0	90
Deep	3	38	0	0	0	41
Total	1 946	2 813	1 185	951	14	6 909

(b) Mitigation devices

	2004–05	2005–06	2006–07	2007–08	2008–09	Total
Squid	0	893	953	690	0	2 536
Hoki	0	57	8	0	0	65
Mid-depths	0	158	36	16	0	210
SBW	0	0	0	0	0	0
Hake	0	0	15	1	0	16
Pelagic	0	18	33	8	0	59
Inshore	0	0	0	5	0	5
Ling	0	0	20	5	0	25
Scampi	0	0	0	0	0	0
Deep	0	0	0	0	0	0
Total	0	1 126	1 065	725	0	2 916

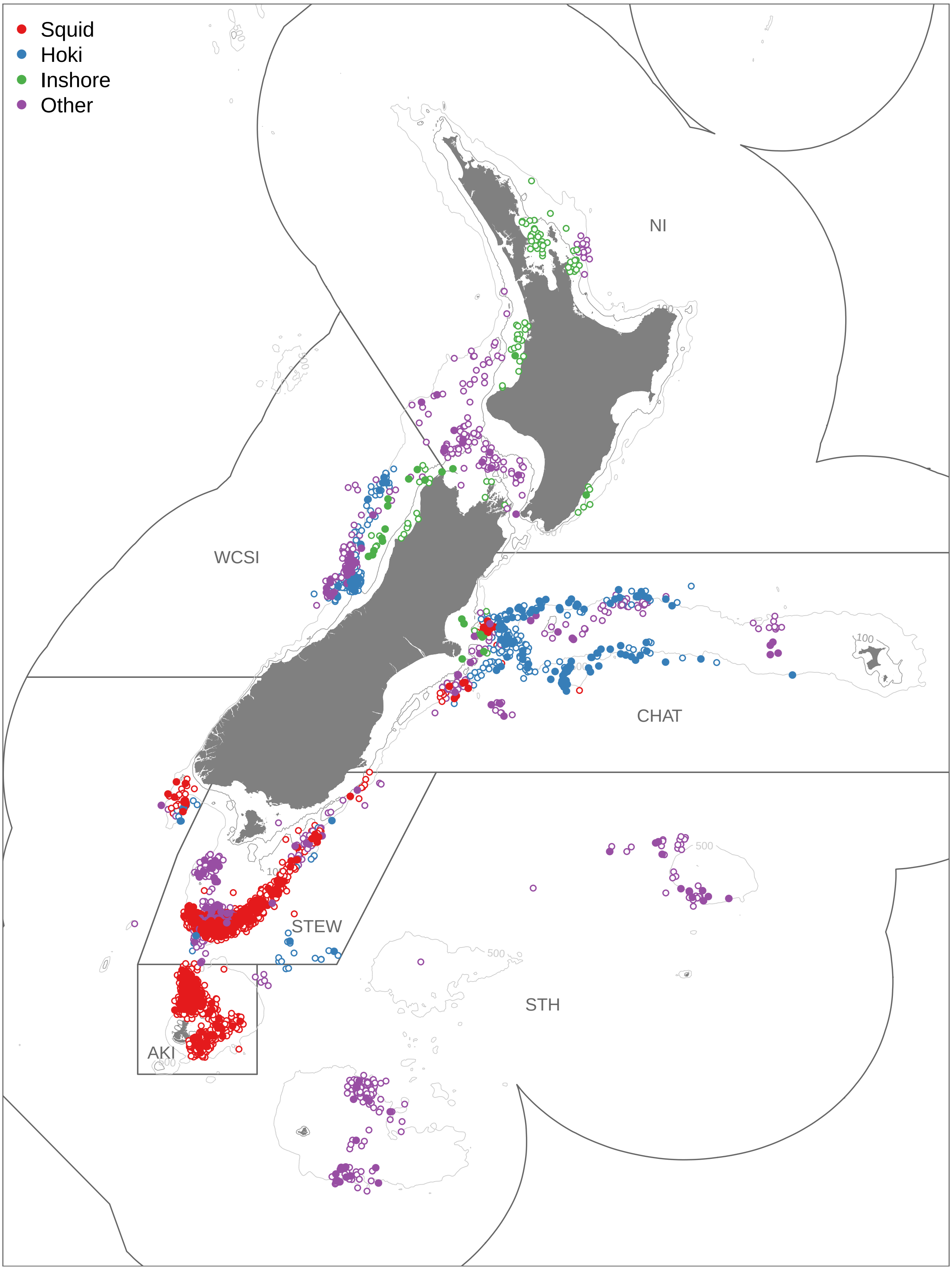

Figure 1: Locations of tows with warp strike observations. The colours indicate the target species of each tow, with filled symbols being used if strikes were recorded during a tow. The positions of the points have been jittered by $\pm 0.2°$ to meet Ministry of Fisheries data confidentiality requirements. The 100 m and 500 m isobaths are shown. The areas shown were used for grouping the warp strike data during analysis and modelling (NI - North Island, CHAT - Chatham Rise, STH - southern, STEW - Stewart-Snares shelf, AKI - Auckland Islands, WCSI - West Coast South Island).

3.1 Strikes

In 2006–07 and 2007–08, the mean warp strike rates were less than 1 small bird strike per hour and less than 1 large bird strike per hour (Table 4). This compared with strike rates of 2.71 small birds per hour and 2.68 large birds per hour in 2004–05 before the introduction of warp mitigation in larger vessels. No strikes were recorded during the few of observations made in 2008–09. In 2006–07 and 2007–08, strike rates on the mitigation devices were similar to strike rates on the trawl warps.

The distribution of strike rates was strongly skewed, with many zeros and a long right tail. In each of the four strike categories in 2006–07 and 2007–08, there were no strikes recorded on more than 90% of the 15 minute observation periods. Across the whole dataset there were no warp strikes recorded on 84.6% of all warp observations. Despite the frequency of zero observations, there were occasional observations with high numbers of strikes. Multiple strikes on the mitigation devices were also recorded.

Table 4: Summary of strike data, giving the average strike rate (birds per hour); the percentage of observations without strikes; and the maximum number of strikes observed in any 15 minute observation period. Data are summarised for each fishing year and for strikes on warps and the mitigation devices.

(a) Small birds

		2004–05	2005–06	2006–07	2007–08	2008–09
Strike rate	Warp	2.71	1.62	0.52	0.88	0
	Device		1.2	0.98	0.79	
% of obs. without strikes	Warp	84	88.9	95.6	93.1	100
	Device		89.9	92.4	91.2	
Max. observed strikes	Warp	59	39	21	37	0
	Device		17	18	19	

(b) Large birds

		2004–05	2005–06	2006–07	2007–08	2008–09
Strike rate	Warp	2.68	1.15	0.49	0.81	0
	Device		0.91	0.76	0.57	
% of obs. without strikes	Warp	81	93.8	95.1	94.7	100
	Device		92.5	92.6	95	
Max. observed strikes	Warp	35	45	12	17	0
	Device		17	11	29	

Table 5: Percentage of warp strike observations using different mitigation devices. Columns may add to more than 100% as multiple devices were used during some observations.

	2004–05	2005–06	2006–07	2007–08	2008–09
No mitigation	54.3	20.4	6.5	14.4	7.1
Baffler only	44.1	22.0	25.3	21.7	0.0
Tori only	0.0	30.2	56.3	28.4	92.9
Baffler and tori	1.6	12.0	9.5	21.7	0.0
Warp scarer	0.0	14.2	2.6	14.5	0.0
Other device	0.0	3.0	0.0	0.0	0.0

Table 6: Average warp strike (heavy contacts per hour) when different mitigation devices were used. Averages are not shown for year-mitigation combinations where fewer than 200 observations were made.

(a) Small birds

	2004–05	2005–06	2006–07	2007–08
No mitigation	4.44	2.17		
Baffler only	0.65	3.51	1.09	1.28
Baffler and tori		0.37		0.02
Tori only		0.66	0.19	0.90
Other		1.01		

(b) Large birds

	2004–05	2005–06	2006–07	2007–08
No mitigation	3.79	2.22		
Baffler only	1.35	2.00	0.84	1.69
Baffler and tori		0.06		0.12
Tori only		0.21	0.23	0.30
Other		1.22		

3.2 Mitigation use

The frequency of reported use of different mitigation devices is shown in Table 5. During the first year of the warp strike observations, vessels operated a voluntary code of practice that included the use of mitigation devices. During the 2004–05 fishing year, bird bafflers were used on 44.1% of warp observations, and on 54.3% of observations no mitigation was reported. Aside from the use of tori lines during 31 warp observations, bird bafflers were the only mitigation devices that were then in use. Mitigation devices were made compulsory for trawl vessels over 28 m in length in January 2006, at the start of the 2005–06 squid season (Department of Internal Affairs 2006). During the mitigation device trials in the 2005–06 year, mitigation usage was determined by the experimental treatments, and so the recorded frequencies of mitigation device usage do not reflect practice within the wider fishery. Tows without mitigation were included in the experimental design under the terms of a special permit. Outside of the experiment, a few observations were made when other devices were being used. These included acoustic deterrents and devices made by clipping buoyed rope to the warps. In 2006–07, the number of observations where no mitigation was recorded fell to 6.5%, and tori lines were used during 65.7% of warp observations. While warp scarers were a permitted mitigation device, they were tested during the mitigation trials in 2005–06 and were found to have only limited efficacy. They have not been widely adopted; however, they were used during 14.5% of observations in 2007–08, by vessels in squid, inshore, and other fisheries.

In 2007–08, the number of observations made when only tori lines were recorded decreased, but there was a marked increase in the number of observations made when both tori lines and bafflers were in use. The increase in the number of observations where no mitigation was reported to have been used increased in 2007–08. This was partly due to the increase in the observations made on small vessels targeting inshore species that were not required to use mitigation devices. The 'no mitigation' data in 2007–08 also includes 54 warp strike observations made on large (over 90 m) trawlers targeting squid. This highlights a problem with the way the mitigation data have been stored in the database. A normalised form has been used for the data, and it was not possible to determine whether the observer failed to record the use of mitigation, or whether no mitigation was used.

The association between the use of mitigation and the warp strike rate is given in Table 6. Due to the low number of observations, the 2008–09 data are not shown. For both large and small birds, the highest warp strike rates were seen when no mitigation was used. The strike rates were reduced when bird bafflers were used, but this was not seen in all years. In 2007–08, the lowest warp strike rates were on observations made when both tori lines and bafflers were used together, for both large and small birds. The raw strike rates in Table 6 do not account for variation in factors associated with warp strike. Despite this, the results in 2006–07 and 2007–08 are consistent with the mitigation trials conducted during the 2005–06 season (Middleton & Abraham 2007), which found that tori lines were the most effective device at reducing warp strikes. The continued appearance of this pattern in the raw data supports the experimental results.

In previous analyses (Middleton & Abraham 2007, Abraham & Thompson 2009) it was noted that there are strikes on the tori lines themselves. In all years where there was sufficient data, there were more strikes on the tori lines than on the warps (Table 7) when only tori lines were deployed. There were relatively few strikes recorded on the bafflers.

Table 7: Average mitigation device strike rates (heavy contacts per hour). Averages are not shown for year-mitigation combinations where fewer than 200 observations were made.

(a) Small birds

	2004–05	2005–06	2006–07	2007–08
Baffler only		0.10	0.02	0.27
Tori only		2.40	1.43	1.12
Other		0.16		

(b) Large birds

	2004–05	2005–06	2006–07	2007–08
Baffler only		0.15	0.03	0.29
Tori only		1.86	0.77	0.96
Other		0.03		

3.3 Discharge

(a) Small birds **(b) Large birds**

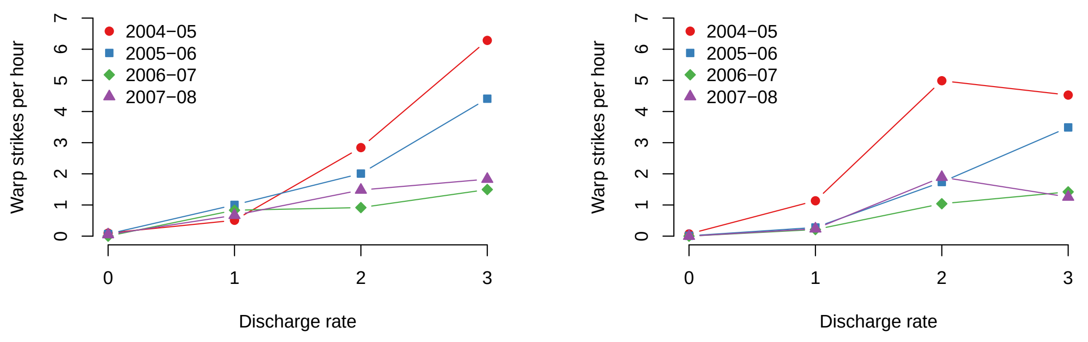

Figure 2: Warp strikes (number of heavy contacts per hour) as a function of the discharge rate for four different fishing years. The discharge rates are 0 - none, 1 - negligible, 2 - intermittent, 3 - continuous.

In all four years, an increase in the discharge rate was associated with an increase in the warp strike rates of both large and small birds (Figure 2). For example, across all the data the average large bird warp strike rate was 0.025 birds per hour when there was no discharge, compared with 3.3 birds per hour when the discharge of waste was either intermittent or continuous. The relationship between discharge and warp strike was particularly clear in 2004–05 when there was less mitigation used, but an increase in the strike rate with the discharge rate was still seen in the 2006–07 and 2007–08 years when tori lines and bird bafflers were widely used.

The frequency of different discharge types during tows with warp strike observations is shown in Figure 3. In all years, most tows had either no discharge during any of the observations or high discharge (intermittent or continuous discharge of offal or other processing waste during at least one of the warp observations). In 2004–05, there was an exceptionally high proportion of tows with high discharge. This is likely to have been due to the instructions given to observers in that year, which asked them to sample a range of discharge conditions.

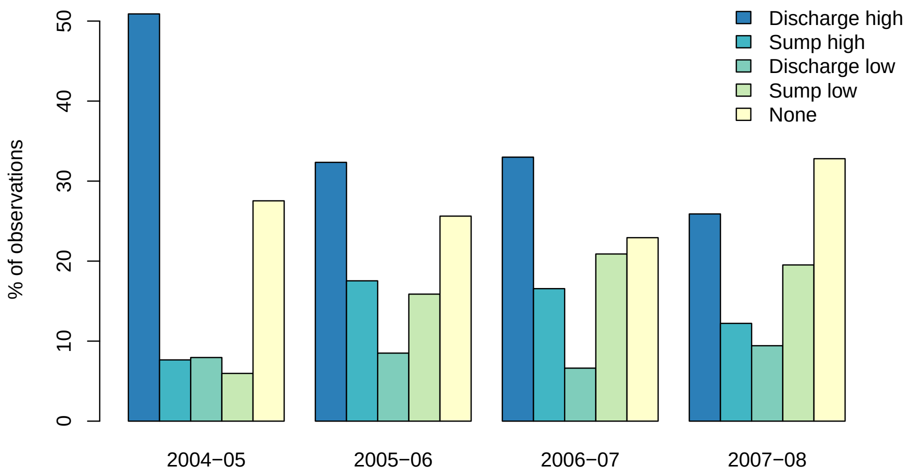

Figure 3: Percentage of tows with different discharge categories recorded during warp strike observations during each of the four years. The discharge categories are those used in the modelling.

While there appears to have been a steady decrease in the proportion of tows with high discharge, this was due to the changing fisheries with warp strike observations. When restricted to the squid fishery, there was no apparent trend in the proportion of tows with offal discharge, with between 26% and 31% of tows having intermittent or continuous processing waste discharges in 2005–06, 2006–07, and 2007–08. Similarly, when restricted to the squid fishery, the proportion of tows having either no discharge or only sump discharge remained between 62% and 63% in 2005–06, 2006–07, and 2007–08.

3.4 Strikes by fishery

The average strike rates by fishery are shown in Table 8. An exceptionally high small bird strike rate was observed in the 2004–05 hoki fishery. In this year, observations were made on four hoki vessels, with most observations (67%) being from a single trip on the Chatham Rise. During this trip, small bird contacts were reported from 72% of all warp observations, and in one 15 minute observation period 59 small bird contacts were counted. No mitigation was used during the trip, and there was discharge of sump water during every observation, with discards being discharged during 38% of observations.

In 2007–08, more than 100 observations were made in inshore fisheries. The observations were made on 93 tows, on 8 different vessels ranging from 14.1 m to 32 m long. Warp strikes were recorded during 17 tows, with strikes being recorded on 5 of the 8 vessels. Two vessels used tori lines, one vessel used tori lines and warp scarers, and the other five vessels were not recorded as using mitigation. Although the number of observations was relatively small, warp strike rates were higher on these inshore vessels than on squid target tows (Table 8).

Table 8: Average warp device strike rates (heavy contacts per hour) within each target fishery. Averages are not shown for year-fishery combinations where fewer than 100 observations were made.

(a) Small birds

	2004–05	2005–06	2006–07	2007–08
Squid	1.53	1.11	0.23	0.36
Hoki	14.18	2.26		
Inshore				4.30
Other	1.17	2.17	1.75	

(b) Large birds

	2004–05	2005–06	2006–07	2007–08
Squid	3.41	1.59	0.44	0.52
Hoki	2.53	0.46		
Inshore				1.09
Other	0.23	0.81	0.46	

3.5 Mitigation events

Observers have reported many problems with the mitigation devices, such as the dropper lines of the bafflers being too short, tori lines being blown away from the warps in crosswind, and mitigation devices becoming tangled (Table 9). At the beginning of January 2007, the warp form was modified to allow for mitigation events to be coded. Since then there have been 1813 observations made when a mitigation event was recorded, out of a total of 4124 observations.

The most frequently reported event was bird bafflers not reaching close to the water, followed by tori lines not being taut, or the streamers being tangled. The next most frequent events relate to strong winds affecting the performance of the devices. This would include both tori lines and bafflers being blown so that they no longer protected the region between the stern and the warps.

3.6 Relation between bird count and warp strikes

During observations, estimates were made of the number of large and small birds in a 40 m by 40 m area surrounding the entry point of the warp into the water. Across all the data the average number of large birds behind the vessel was 40.6, with a median of 15 and an inter-quartile range of 4 to 42. The maximum recorded number of large birds was 2000. There were observations made on 273 tows where no large birds were close to the vessel. There were no large bird warp strikes recorded during these tows. Similarly, the average number of small birds close to the stern was 58.8, with a median of 26 and an inter-quartile range of 8 to 73.25. The maximum recorded number of small birds was 1900. There were observations made on 187 tows where no small birds were close to the vessel. There were no small bird warp strikes recorded during these tows.

The relation between bird abundance and warp strike is explored in Figure 4. In Figure 4(a) the data are grouped by the area of the fishing. There was a clear association between the average warp strike in an area, and the abundance of birds in the same area. The pattern appeared to be similar for large and small birds. The lowest abundance was of large birds in the North Island area, and this area and group correspondingly had the lowest average warp strike rate. The groups with the highest abundance were

Table 9: Summary of mitigation events, giving the number of observations that reported each different mitigation event occurring following the introduction of mitigation event reporting in January 2007. The descriptions were taken from the warp strike database (with corrections made to spelling and grammar).

Mitigation event	Obs.
Bird baffler observed to not reach within 0.5 m of water (aft booms)	799
Tori line observed not taut for some of the time	664
Tori line observed with tangled streamers for some of the time	519
Strong winds having a negative impact on the effectiveness of the mitigation device	333
Streamers of tori line observed not to reach water	285
Bird baffler observed to not reach within 0.5 m of water (side booms)	231
Bird baffler dropper lines observed tangled for some of the time	210
Aerial extent of tori line less than 10 m beyond warp for some of the time	203
Warp scarer main-line did not extend to within 1 m of warps entering water	46
Tori line main-line observed tangled with warp for some of the time	33
Warp scarer observed with tangled streamers for some of the time	22
Warp scarer streamers observed not to reach water	20
More than 6 mitigation events or mitigation events not in existing codes	14
Warp scarer main-line tangled with warp for some of the time	7
A delay between brakes on and tori line deployment	7
An acoustic deterrent used	3
A delay between warp scarer removal and hauling	2
A delay between tori line removal and hauling	2
A delay between brakes on and warp scarer deployment	1

(a) Grouped by area **(b) Grouped by discharge rate and by mitigation**

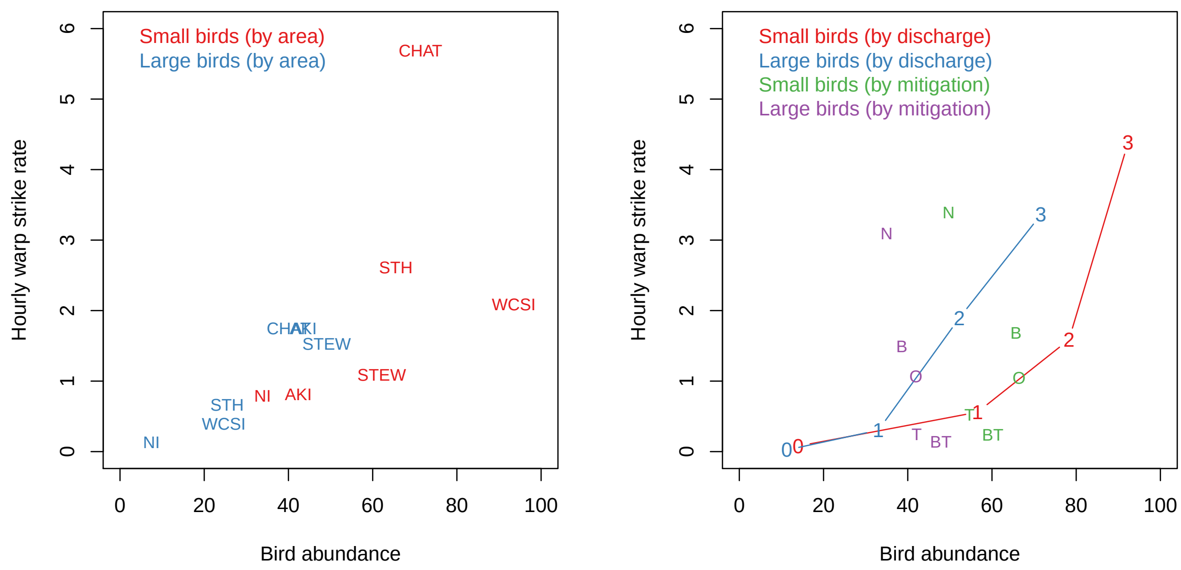

Figure 4: Relation between bird abundance during warp observations, and the warp strike rate (heavy contacts per hour). The average values are shown, grouping the data by (a) area and (b) discharge rate and mitigation use. The areas used in (a) are illustrated in Figure 1. The discharge rates in (b) are 0 - None, 1 - Negligible, 2 - Intermittent, and 3 - Continuous. The mitigation types in (b) are BT - Bird bafflers and tori lines, T - Tori lines, B - Bafflers, O - Other mitigation, N - No mitigation.

small birds in the southern, Chatham Rise, and West Coast South Island areas. Small birds in these areas also had the highest average strike rates.

When the data were grouped by the discharge rate, there was also a clear relation between bird abundance and warp strike. The relationship was again similar for large and small birds. As the discharge rate increased, so did both the bird abundance and the warp strike rate. When grouped by mitigation, the effect of the mitigation on warp strike rates was seen (with bird bafflers and tori lines together being associated with the lowest levels of warp strike). There was, however, no direct effect of the mitigation on the abundance.

3.7 Modelled warp strikes

There were several consistent results that appeared from the model selection process applied to both the small and large bird warp strike data (Tables 10 and 11):

- When bird count terms were not included, a discharge related covariate explained the most deviance.
- When bird count terms were included, they were the covariate that explained the most deviance.
- The mitigation covariate always explained between 4% and 11% of the original deviance, irrespective of whether or not the bird counts were included.
- The season and fishing year covariates never explained more than 2% of the deviance.
- When bird counts were included, there was still an influence of discharge on the strike rate.

The target fishery was not important, except in the model of small bird strikes with the bird count included. This was the only model in which it explained more than 2% of the deviance. Vessel length also appeared as a minor term in the models of small bird strikes, explaining more than 2% of the deviance in both cases. In the final models, all the terms that explained more than 2% of the original deviance were included. In addition, area was included as a covariate in the model of large bird warp strike, without bird abundance.

A summary of the fitted model parameters is given in Appendix A. The results of the modelling confirm the previous conclusions that tori lines were the most effective mitigation device (Figure 5). In the full models, tori lines and bird bafflers together are also effective. The results were similar for small and large birds, and for models with and without the bird counts being included. When the modelling was restricted to data from the hoki fishery, tori lines (with or without bafflers) were again found to be more effective. In every model, the upper limit for the effect of tori lines was less than 50%, with the best estimate ranging between 3% and 24%. Across all models the best estimate for the effect of bird bafflers ranged between 40% and 65%, for other mitigation between 10% and 43%, and for bird bafflers and tori lines together from 0% to 24%.

As expected, there was a decrease in the number of strikes when there was less discharge (Figure 6). The effects of high sump and low waste discharge were similar. In all cases, reduced discharge was associated with a greater reduction in the large bird warp strike rate than the small bird warp strike rate. In all cases, discharge was associated with a smaller reduction in the warp strike rate when the model also included a bird count term. This was either because of the correlation between the discharge and the bird counts, or because of the reduced data set used in the models with bird counts. The fact that there was still an association between discharge and the warp strikes when bird count was included in the model suggests

Table 10: Summary of small bird warp strike models, giving the results of the step analysis. The ANOVA tables give the deviance explained as terms were sequentially added to the model. Only terms that caused a reduction in the AIC when they were added to the model are shown. All terms were significant at $p < 0.001$.

(a) Without bird abundance

	DOF	Deviance	Resid. dev.	% explained
			2525	
Discharge	4	607	1918	24.05
Mitigation	4	187	1731	7.40
Area	5	178	1553	7.06
Vessel length	3	64	1489	2.52
Fishing year	3	28	1461	1.10
Fishery	3	14	1448	0.54
Season	3	8	1440	0.31

(b) With bird abundance

	DOF	Deviance	Resid. dev.	% explained
			2361	
Log(small bird abundance)	1	584	1778	24.72
Discharge	4	233	1544	9.88
Fishery	3	171	1373	7.26
Mitigation	4	146	1227	6.18
Vessel length	3	66	1161	2.81
Area	5	37	1123	1.58
Season	3	31	1092	1.32
Fishing year	3	27	1065	1.15

Table 11: Summary of large bird warp strike models, giving the results of the step analysis. The ANOVA tables give the deviance explained as terms were sequentially added to the model. Only terms that caused a reduction in the AIC when they were added to the model are shown. All terms were significant at $p < 0.001$.

(a) Without bird abundance

	DOF	Deviance	Resid. dev.	% explained
			2523	
Discharge	4	865	1658	34.29
Mitigation	4	256	1402	10.15
Area	5	48	1354	1.89
Season	3	24	1330	0.96
Vessel length	3	20	1310	0.79
Fishing year	3	25	1285	0.98

(b) With bird abundance

	DOF	Deviance	Resid. dev.	% explained
			1670	
Log(large bird abundance)	1	609	1060	36.50
Discharge	4	148	912	8.88
Mitigation	4	85	827	5.12
Vessel length	3	34	792	2.06
Area	5	27	765	1.63
Season	3	14	751	0.85

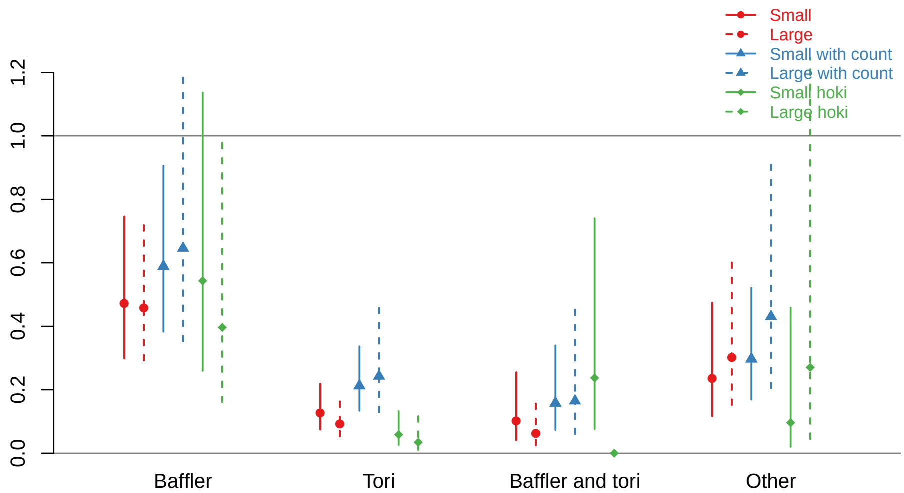

Figure 5: Effect of mitigation on the warp strike rate, summarising the results from the six different models. This gives the expected ratio of the number of warp strikes when the mitigation is used to the number of warp strikes when no mitigation is used, other factors being the same. The confidence interval of the other mitigation effect has been truncated for the large bird hoki only model.

that there was an effect of discharge on warp strikes beyond simply attracting more birds to the stern of the vessel.

The results of the models restricted to the hoki data are not shown in Figure 6, as the uncertainties were high. In the hoki models (Table A-3), the high sump and low discharge effects were either not significantly different from one, or were higher than one. It is likely that the higher coefficient for the low discharge effect is indicative of model overfitting. Despite this, the best estimates of the effect of low sump or no discharge were less than 20%, with no large bird warp strikes being recorded in the hoki fishery during these discharge conditions.

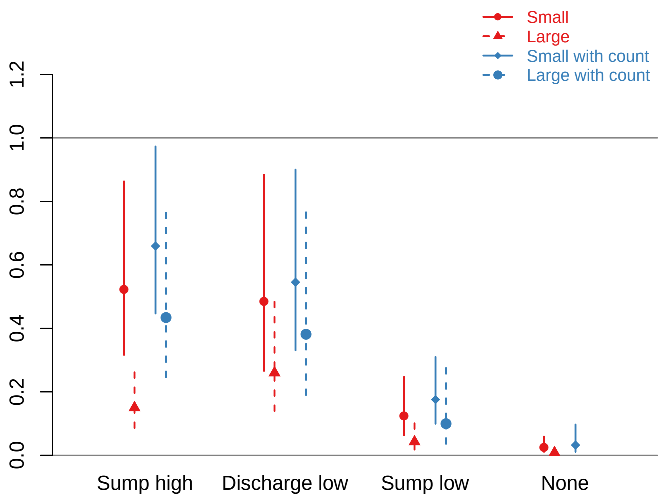

Figure 6: Effect of discharge on the warp strike rate, summarising the results of the four different full models. This gives the expected ratio of the number of strikes during the various discharge conditions, to the number of strikes during continuous or intermittent discharge of waste (discharge high), other factors being the same.

In the small bird model without bird counts (Table A-1(a)), there were higher expected warp strikes in areas other than the Auckland Islands, with the exception of the North Island. Expected small bird warp strikes in the Chatham Rise and West Coast South Island areas were over 6 times higher than in the Auckland Islands, other factors being equal. In the large bird model without bird counts (Table A-2(a)), expected warp strike rates were similar in the Chatham Rise and West Coast South Island areas to those in the Auckland Islands. In other areas they were lower, and in the North Island region the best estimate was that the warp strike rate was 10% or less of the warp strike rate in the Auckland Islands region.

The fishery covariate was included only in the model of small bird captures with bird counts. In this case there were expected to be higher captures in all of the fisheries, relative to the squid fishery. The best estimate of the hoki and inshore fisheries effects was that small bird warp strike rates in those fisheries were approximately 6 times higher than in the squid fishery, other factors being equal. Vessel length was included in three models. In both of the small bird warp strike models the effects for vessels between 28 m and 100 m were less than one. The effects for small vessels (less than 28 m) in all three models were not significantly different from one, although in each case the best estimate was greater than one. Vessel length was also included in the model of large bird warp strike with bird count included, and in that case the only significant effect was a reduction in the warp strike rate for vessels greater than 28 m, but less than 60 m.

3.8 Captures

To produce a consistent dataset, information from the strike observation and non-fish bycatch forms was merged. Captures were recorded on 369 tows. Included in these were 46 tows where captures were recorded only on the warp strike form, and 144 tows where captures were recorded only on the non-fish bycatch form. Where possible, information from the non-fish bycatch form was used to determine whether captures recorded on the strike observation form from 2004–05 were of small or large birds.

Across all tows with warp strike observations, 246 small birds and 265 large birds were captured. A summary of these captures is shown in Table 12. Most small birds were caught in the net, with only six small birds being caught on the warps (2.4% of all small bird captures). In 2004–05, 67 large birds (53.2% of all large bird captures) were caught in the warps. By 2006–07 the number of large birds caught in the warps had fallen to 3, or 10% of large bird captures. In 2007–08, there were 9 large birds caught on the warps, 3 of them in inshore fisheries.

Table 12: Capture of birds by location for each of the three fishing years.

(a) Small birds

	2004–05	2005–06	2006–07	2007–08
Warp	4	1	0	1
Net	38	86	49	37
Other	3	24	1	2
Total	45	111	50	40

(b) Large birds

	2004–05	2005–06	2006–07	2007–08
Warp	67	59	3	9
Net	39	17	27	14
Other	20	8	0	2
Total	126	84	30	25

The capture rate of large birds on the warp, grouped by discharge and mitigation use, is shown in Table 13. These data refer to birds that were brought back on board the vessel (warp captures), as distinct from heavy contacts (warp strikes) recorded during the strike observations. There were few large bird warp captures when there was no discharge (0.2 large bird warp captures per 100 tows), or when there was sump discharge (0.6 birds per 100 tows). Similarly, there were few large bird warp captures when tori lines were used as mitigation. When tori lines were used, there were no captures reported from tows where there was either no discharge, sump discharge, or negligible discharge of processing waste. Large bird warp captures were highest when no mitigation was used and offal, discards, or minced material was discharged either intermittently or continuously.

Most of the captures recorded during tows with warp strike observations were on tows targeting squid (Table 14). These data include data from before the widespread use of warp mitigation. For small birds, there were few warp captures in any fishery. On tows targeting inshore species, there was one small bird warp capture however, inshore fisheries had the highest small bird warp capture rate. For large birds, the highest warp capture rate was on tows targeting squid, but warp capture rates in the inshore and other target fisheries were similar. Warp capture rates in hoki fisheries were lower.

Table 13: Large bird warp captures per 100 tows, for all tows with warp strike observations, grouped by tow-level discharge and by the use of mitigation. The column and row headed "All" show the average capture rate for all discharge conditions and all mitigation types, respectively.

Mitigation	Discharge					All
	Discharge high	Sump high	Discharge low	Sump low	None	
None	14.5	1.8	9.4	0.0	0.0	6.8
Baffler	9.1	0.7	0.7	0.6	0.7	4.0
Tori	0.6	0.0	0.0	0.0	0.0	0.2
Baffler and tori	6.2	1.9	0.0	0.0	0.0	2.2
Other	3.4	2.4	2.6	3.3	0.0	2.2
All	8.0	1.0	2.3	0.3	0.2	3.3

Table 14: Summary of captures by fishery, giving the number of captures recorded during tows with strike observations, and the rate (expressed as captures per 100 tows). Total captures and warp captures are summarised for small birds (a) and large birds (b).

(a) Small birds

	All		Warp	
	Captures	Rate	Captures	Rate
Squid	197	6.76	1	0.03
Hoki	17	3.69	1	0.22
Inshore	1	1.02	1	1.02
Other	31	4.19	3	0.41

(b) Large birds

	All		Warp	
	Captures	Rate	Captures	Rate
Squid	233	7.99	111	3.81
Hoki	2	0.43	2	0.43
Inshore	3	3.06	3	3.06
Other	27	3.65	22	2.98

As with the warp strikes, large bird warp captures were primarily associated with discharge, mitigation, and bird abundance (Table 15). When bird abundance was not included, there were a range of covariates that explained more than 2% of the deviance. When bird abundance was included, the number of significant covariates was restricted to the bird count, the warp mitigation, and the area effect. During selection of this model, fishing year was excluded as it created problems with model convergence.

A summary of the coefficients of the fitted large bird warp capture model is given in the Appendix (Table A-4). As with the warp strikes, the warp capture rate also decreased when there was less discharge. There were also fewer expected captures when mitigation devices were used, with tori lines being the most effective (Figure 7). When bird captures were included in the model, the uncertainties in the mitigation coefficients were high.

Table 15: Summary of large bird warp capture models, giving the results of the step analysis. The ANOVA tables give the deviance explained as terms are sequentially added to the model. Only terms that caused a reduction in the AIC when they were added to the model are shown. All terms are significant at $p < 0.001$.

(a) Without bird abundance

	DOF	Deviance	Resid. dev.	% explained
			398	
Discharge	4	98	300	24.62
Mitigation	4	44	256	11.05
Vessel length	2	13	243	3.22
Squid areas	1	9	234	2.19
Fishing year	3	10	225	2.44
Season	1	5	220	1.21

(b) With bird abundance

	DOF	Deviance	Resid. dev.	% explained
			200	
Log(large bird abundance)	1	65	135	32.55
Mitigation	4	19	116	9.53
Squid areas	1	3	113	1.41

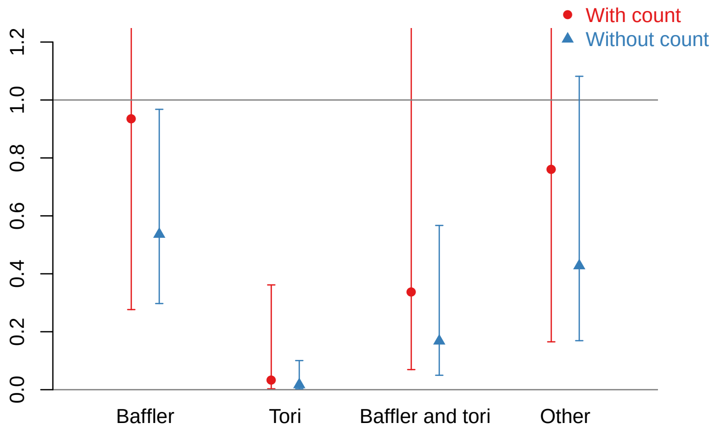

Figure 7: Effect of mitigation on the warp strike rate, summarising the results of the model fitting. This gives the expected ratio of the number of warp strikes when the mitigation is used to the number of warp strikes when no mitigation is used, other factors being the same. Confidence levels that extend above a relative effect of 1.2 are truncated.

3.9 Ratio of warp strikes to warp captures

From the warp strike and capture data a recovery ratio can be estimated (Table 16). This is the number of warp strikes that occur for every bird that is caught on the warps. To first order, this ratio may be expected to be independent of the mitigation used, the discharge of offal, or of other covariates. To calculate the ratio, the overall large bird and small bird warp strike rates were used. Capture rates (birds caught per hour) were calculated by dividing the total captures of large and small birds on tows with warp strike observations by the total duration of those tows. From the ratio of the two rates, a ratio of warp captures to warp strikes was obtained. No correction was made for the fact that the observers watched only a single warp during warp strike observations, whereas birds are caught on both warps. It was not possible to simply double the number of strikes as observers typically watch the warp where most discharge is occurring. There were some tows where the tow length appeared to be either unreasonably long (more than 24 hours) or very short (less than 1 hour). These tows were not included when estimating this ratio. From the remaining 4162 tows, the ratio of large bird warp strikes to large birds caught on the warps was found to be 244 (95% c.i.: 190 to 330, calculated from 5000 bootstrap samples). For small birds, the ratio was 6440 strikes per capture (95% bootstrap c.i.: 3400 to 20000).

Table 16: Ratio of warp captures to warp strikes, calculated for both large and small birds. The mean and the lower and upper bounds of the 95% confidence interval of the recovery ratio are given. Uncertainties were calculated as the quantiles of a set of 5000 simple bootstrap samples.

	Strikes per hour	Captures per hour	Recovery ratio		
			Mean	Lower	Upper
Small birds	1.63	0.00025	6440	3400	20000
Large birds	1.42	0.0058	244	190	330

4. DISCUSSION

In this report, all warp strike data collected to the end of the 2008–09 fishing year in New Zealand trawl fisheries were analysed. Warp strike observations were first made during the 2004–05 fishing year. With the exception of some observations made on a trip that began during the 2007–08 fishing year, there were no warp strike observations made during 2008–09, and so the analysis effectively covers four fishing years of data.

Over the period, there was a decrease in the warp strike rate, associated with an increase in the use of mitigation devices, which were made mandatory in January 2006 for all trawlers over 28 m in length fishing in New Zealand waters (Department of Internal Affairs 2006). Over the same period, there was a decrease in the capture of large birds (principally albatrosses) on trawl warps. In 2004–05, there were 67 large birds caught on trawl warps during tows that had warp observations. In 2007–08, there were only 9. This was a decrease in catch rate from 6.7 albatross warp captures per 100 tows in 2004–05 to 1.2 albatross warp captures per 100 tows in 2007–08. Capture rates of small birds on the warps were too low to infer a trend in the rate.

Statistical modelling shows that the strike rate of both large and small birds was reduced when tori lines were used as a mitigation device. This result supports previous analysis of a subset of these data (Middleton & Abraham 2007, Abraham & Thompson 2009). In 2004–05, no trawl vessels used tori lines, and by 2006–07 tori lines were recorded as being used on over 50% of all tows with warp strike observations. In 2007–08, tori lines and bird bafflers were often used together. The warp strike dataset continues to provide strong evidence that the increased use of tori lines in the squid fishery has led to a reduction in the number of albatross mortalities. When analysis was restricted to data from the hoki fishery, the use of tori lines was also found to be associated with a decrease in the warp strike rate.

The analysis again shows the importance of offal management, with few warp strikes or captures being recorded in the absence of offal discharge. As the discharge rate increases from negligible to continuous, the warp strike rate rises. Across the whole data set, the large bird warp capture rate when no discharge was recorded during the warp observations was 0.2 birds per 100 tows, compared with an average capture rate of 8 birds per 100 tows during intermittent or continuous discharge of processing waste. Given the importance of managing offal discharge to reducing warp captures, it is interesting to look at trends in the discharges with time. If the data are restricted to the squid fishery then, other than in 2004–05, the percentage of tows where there has been either no discharge or only sump discharge has remained steady at between 62% and 63%, while the percentage of tows where intermittent or continuous discharge of processing waste has varied between 26% and 31%. While the warp strike observations are a crude way for monitoring discharge, there is no evidence from these data for a consistent reduction in the discharge of processing waste during towing.

The key relationships that were seen in the data are now well understood, and have been reported on previously (Abraham & Thompson 2009). A new feature of this dataset was the inclusion of a few warp strike observations (148) made in inshore fisheries. These observations showed that warp strikes occur on vessels less than 28 m in length. They also showed that there are warp captures in these fisheries, with 3 large birds and 1 small bird being caught on the warps during tows on which warp strike observations had been made. In 2007–08, there were 50 125 tows targeting inshore species, 56% of all trawl effort in New Zealand waters (Abraham et al. 2010). If the observed warp captures were representative of capture rates across all inshore fisheries, then warp captures on inshore vessels would be a substantial component of fisheries seabird mortality in New Zealand waters. However, because inshore trawling is carried out by a range of different vessel types, for a range of target species, and in many different geographic regions, the numbers of warp strike observations were insufficient to characterise warp strike in inshore fisheries.

The small size of the inshore dataset means that it is currently not possible to determine the efficacy of warp mitigation in these fisheries. There are likely to be differences in how warp mitigation performs on small vessels, and there will also be marked differences in how offal may be managed on small trawl vessels, compared to larger factory vessels. Warp strike observations, carried out within the framework of a structured experiment, were instrumental in demonstrating the efficacy of tori lines at reducing warp strike in the squid trawl fishery (Middleton & Abraham 2007). The warp strike protocol could also provide a method for exploring how the warp mortality of seabirds in inshore trawl fisheries may be reduced.

In the previous analysis of part of this data, it was noted that there was a high ratio of warp strikes to warp captures (Abraham & Thompson 2009). This analysis has been repeated, and similar results were obtained on the larger dataset. For every large bird that was reported by the observers as being captured on the warps, there were an estimated 244 (95% c.i.: 190 to 330) large bird warp strikes. For every small bird reported by the observers as being captured on the warps, there were an estimated 6440 (95% bootstrap c.i.: 3400 to 20000) small bird warp strikes. For small birds in particular, this ratio is extremely high, and it is possible that many more birds are being killed by warp interactions than are being recovered on board the vessels. During the warp strike observations, no attempt was made to determine the fate of the birds following a strike. The only currently available information on the ratio between warp strikes and warp recoveries is from study of warp interactions in South African waters. During this study 30 birds were killed by warp interactions, and of these only 2 were subsequently brought back on board (Watkins et al. 2008). Currently, estimates of seabird mortality in New Zealand trawl fisheries are based on landed captures. If accurate estimates of seabird mortality are to be made, then the number of birds that are killed by fishing but not brought on board the vessel must be determined.

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APPENDIX A: Warp strike model coefficients

Table A-1: Summary of small bird warp strike models (a) without bird abundance being included and (b) with bird abundance. All coefficients are given as multiplicative effects (with the exception of the coefficients for the bird abundance that are given in linear form). A coefficient of 1 is equivalent to no effect. The tables give the mean values of the coefficients, and the lower and upper bounds of the 95% confidence interval, calculated as the mean ± 1.96 times the standard error. The base case is for a vessel over 100 m long, targeting squid in the Auckland Islands area, continuously discharging offal and not using mitigation. In (b) the intercept gives the warp strike rate (heavy contacts per hour) when there is 1 bird behind the vessel.

(a) Without bird abundance

Covariate	Level	Mean	Lower	Upper
Intercept		4.6	2.8	7.6
Discharge	Sump high	0.52	0.32	0.86
	Discharge low	0.48	0.27	0.88
	Sump low	0.12	0.063	0.25
	None	0.025	0.011	0.059
Mitigation	Bafflers	0.47	0.3	0.75
	Tori lines	0.13	0.074	0.22
	Baffler and tori lines	0.1	0.041	0.26
	Other	0.24	0.12	0.47
Area	Stewart-Snares	1.4	0.88	2.2
	Southern	2.4	1.1	5.3
	Chatham Rise	6.2	3.2	12
	West Coast South Island	7	3.5	14
	North Island	0.6	0.21	1.7
Vessel length	≤ 28 m	1.5	0.49	4.7
	> 28 m and ≤ 60 m	0.18	0.085	0.4
	> 60 m and ≤ 100 m	0.53	0.34	0.81

(b) With bird abundance

Covariate	Level	Mean	Lower	Upper
Intercept		0.31	0.15	0.63
Log(small bird abundance)		0.64	0.5	0.78
Discharge	Sump high	0.66	0.45	0.97
	Discharge low	0.55	0.33	0.9
	Sump low	0.18	0.099	0.31
	None	0.032	0.011	0.097
Fishery	Hoki	6.2	4.1	9.3
	Inshore	6	1.2	32
	Other	1.9	1.3	2.8
Mitigation	Bafflers	0.59	0.38	0.91
	Tori lines	0.21	0.13	0.34
	Baffler and tori lines	0.16	0.073	0.34
	Other	0.3	0.17	0.52
Vessel length	≤ 28 m	1.4	0.36	5.8
	> 28 m and ≤ 60 m	0.1	0.038	0.27
	> 60 m and ≤ 100 m	0.37	0.26	0.53

Table A-2: Summary of large bird warp strike models (a) without bird abundance being included and (b) with bird abundance. All coefficients are given as multiplicative effects (with the exception of the coefficients for the bird abundance that are given in linear form). A coefficient of 1 is equivalent to no effect. The tables give the mean values of the coefficients, and the lower and upper bounds of the 95% confidence interval, calculated as the mean ± 1.96 times the standard error. The base case is for a vessel targeting squid in the Auckland Islands area, continuously discharging offal and not using mitigation. In (b) the intercept gives the warp strike rate (heavy contacts per hour) rate when there is 1 bird behind the vessel.

(a) Without bird abundance

Covariate	Level	Mean	Lower	Upper
Intercept		7.3	4.7	11
Discharge	Sump high	0.15	0.086	0.26
	Discharge low	0.26	0.14	0.48
	Sump low	0.043	0.018	0.1
	None	0.0081	0.0027	0.025
Mitigation	Bafflers	0.46	0.29	0.72
	Tori lines	0.093	0.053	0.16
	Baffler and tori lines	0.062	0.025	0.16
	Other	0.3	0.15	0.6
Area	Stewart-Snares	0.96	0.61	1.5
	Southern	0.32	0.14	0.76
	Chatham Rise	1.2	0.62	2.3
	West Coast South Island	1	0.48	2.3
	North Island	0.09	0.022	0.37

(b) With bird abundance

Covariate	Level	Mean	Lower	Upper
Intercept		0.091	0.036	0.23
Log(large bird abundance)		0.88	0.69	1.1
Discharge	Sump high	0.43	0.25	0.76
	Discharge low	0.38	0.19	0.77
	Sump low	0.1	0.036	0.27
Mitigation	Bafflers	0.65	0.35	1.2
	Tori lines	0.24	0.13	0.46
	Baffler and tori lines	0.16	0.06	0.45
	Other	0.43	0.2	0.91
Vessel length	≤ 28 m	2.3	0.7	7.4
	> 28 m and ≤ 60 m	0.14	0.038	0.48
	> 60 m and ≤ 100 m	1.2	0.74	1.9

Table A-3: Summary of hoki fishery warp strike models for (a) small birds and (b) large birds. All coefficients are given as multiplicative effects. A coefficient of 1 is equivalent to no effect. The tables give the mean values of the coefficients, and the lower and upper bounds of the 95% confidence interval, calculated as the mean ±1.96 times the standard error. The base case is for a vessel continuously discharging offal and not using mitigation.

(a) Small birds

Covariate	Level	Mean	Lower	Upper
Intercept		0.23	0.12	0.46
Discharge	Sump high	0.98	0.51	1.9
	Discharge low	1.4	0.45	4.2
	Sump low	0.16	0.061	0.42
	None	0.014	0.0021	0.095
Mitigation	Bafflers	0.54	0.26	1.1
	Tori lines	0.059	0.026	0.13
	Baffler and tori lines	0.24	0.076	0.74
	Other	0.096	0.02	0.46

(b) Large birds

Covariate	Level	Mean	Lower	Upper
Intercept		0.043	0.019	0.099
Discharge	Sump high	1.1	0.48	2.6
	Discharge low	5.4	1.3	22
	Sump low	0		
	None	0		
Mitigation	Bafflers	0.4	0.16	0.98
	Tori lines	0.034	0.01	0.12
	Baffler and tori lines	0		
	Other	0.27	0.045	1.6

Table A-4: Summary of large bird warp capture models (a) without bird abundance being included and (b) with bird abundance. All coefficients are given as multiplicative effects (with the exception of the coefficients for the bird abundance that are given in linear form). A coefficient of 1 is equivalent to no effect. The tables give the mean values of the coefficients, and the lower and upper bounds of the 95% confidence interval, calculated as the mean ± 1.96 times the standard error. The base case is for a vessel targeting squid in the Auckland Islands area, continuously discharging offal and not using mitigation. In (b) the intercept gives the warp strike rate (heavy contacts per hour) rate when there is 1 bird behind the vessel.

(a) Without bird abundance

Covariate	Level	Mean	Lower	Upper
Intercept		0.16	0.094	0.26
Discharge	Sump high	0.14	0.049	0.41
	Discharge low	0.28	0.12	0.68
	Sump low	0.069	0.018	0.26
	None	0.03	0.0085	0.11
Mitigation	Bafflers	0.54	0.3	0.97
	Tori lines	0.017	0.003	0.1
	Baffler and tori lines	0.17	0.05	0.57
	Other	0.43	0.17	1.1
Vessel length	> 28 m and ≤ 60 m	0.24	0.065	0.86
	> 60 m and ≤ 100 m	2	1.1	3.5

(b) With bird abundance

Covariate	Level	Mean	Lower	Upper
Intercept		$5e-04$	$5.5e-05$	0.0045
Log(large bird abundance)		1.2	0.71	1.7
Mitigation	Bafflers	0.93	0.28	3.2
	Tori lines	0.033	0.0031	0.36
	Baffler and tori lines	0.34	0.069	1.6
	Other	0.76	0.17	3.5
Squid areas	Not Auckland Islands	0.48	0.18	1.2