Warp strike in New Zealand trawl fisheries, 2004–05 to 2006–07

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EXECUTIVE SUMMARY

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Since the 2004–05 fishing year, Ministry of Fisheries observers have been carrying out warp strike observations, recording the numbers of birds that are struck by trawl warps during 15 minute observation periods. In 2004–05, the observations were aimed at exploring the relation between offal discharge and warp strikes. In 2005–06, monitoring of mitigation devices was introduced and the observations include those made as part of an experiment exploring the efficacy of warp-strike mitigation devices. In 2006–07, regulations requiring the use of warp mitigation devices were introduced, and the observations are from ongoing monitoring. In this report, a summary is presented of all the strike data collected from 2004–05 to 2006–07. The analysis provides an overview of the strike data and an indication of the main trends. During this period a total of 12 097 strike observations were made. Most observations (58.8%) were made in the squid trawl fishery, with some also being carried out in hoki (16.9%) and other trawl fisheries.

The average warp strike rate has decreased since 2004–05, when warp strike observations were first made in New Zealand fisheries. For small birds (all birds other than albatrosses and giant petrels), the average warp strike rate has decreased from 3.03 to 0.55 strikes per hour. For large birds (albatrosses and giant petrels), the average warp strike rate has decreased from 2.35 to 0.39 strikes per hour. The decrease is 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. In 2004–05 mitigation was not compulsory and was used during 48% of the observations. In 2006–07, mitigation was used during 92% of observations. The most frequently used mitigation devices in 2006–07 were tori lines, which were used during 56% of observations. Statistical modelling confirms that the strike rate of both large and small birds is reduced when tori lines are used as a mitigation device. Other devices such as warp scarers and bird bafflers are not found to significantly reduce the warp strike rate.

The warp strike dataset provides strong evidence that the increased use of tori lines has led to a reduction in the number of albatross mortalities. From 2004–05 to 2006–07, there was a decrease in large bird warp capture rate from 6.7 to 0.4 birds per 100 tows. Capture rates of small birds on the warps are too low to infer a trend in the rate. Statistical modelling of large bird warp captures shows that they decrease when tori lines are used, and increase when there is continuous discharge. While the warp capture rate of large birds has decreased, there has been no consistent change in the net captures.

The analysis also shows 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 is 0.02 strikes per hour when there is no discharge, compared with 3.22 strikes per hour when discharge is continuous. 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 7 birds per 100 tows when offal or discards were discharged.

For every large bird captured on the warps, there are 208 (95% c.i.: 150 to 290) warp strikes, and for every small bird captured on the warps there are 7610 (95% c.i. 3800 to 36 000) warp strikes. It is likely that birds are killed by warp strike but not brought on board, and so not counted as captures. 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 estimate of the ratio of warp strikes to warp mortality is needed to allow total mortality to be assessed.

1. INTRODUCTION

In trawl fisheries, seabirds are killed by being hit by the trawl warps during fishing (Wienecke & Robertson 2002, Sullivan, Reid & Bugoni 2006, Watkins et al. 2008, Melvin et al. 2007). While some of these birds are brought on board the vessels when the net is hauled, it is likely that many birds are struck and killed without being landed (Watkins et al. 2008). 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. 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).

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. Following trials in the Falkland Islands, analysis of warp strike showed that these devices could successfully reduce the interactions of seabirds with the warps (Sullivan, Brickle et al. 2006). 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. The three legally permitted devices include tori lines, bird bafflers (Crysel 2002) and warp scarers (Carey 2005). 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.

In addition to this work within the squid fishery, some warp strike observations have been made in other regions. These have been carried out both as part of routine observations and to help assess the benefits of different offal treatment practice (Abraham et al. 2009). In this report, a summary is presented of all the warp strike data collected in the 2004–05, 2005–06, and 2006–07 fishing years. The analysis provides an overview of the warp strike data and an indication of the main trends.

2. METHODS

2.1 Warp strike protocol

The warp strike protocol was detailed by Abraham & Kennedy (2008) and Middleton & Abraham (2007). To carry out a warp strike observation, observers watch either the warp or the mitigation device for 15 minutes and count the number of strikes made by seabirds on the gear. The strikes are defined as heavy contacts, where the bird:

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

Strikes can occur on the water or in the air, and either when the bird contacts the gear, or when the gear moves to contact the bird. Seabirds striking the observed gear are 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 is made to determine whether or not the bird was killed by the interaction. Strike observations are carried out during the fishing phase of the tow (i.e., when the net is in the water and warps are not being paid out or hauled). Observers are encouraged to spread seabird strike observations throughout the daylight hours. For each seabird strike observation period, observers record environmental and other covariates as detailed in Table 1. If conditions change significantly during an observation period (e.g., the vessel turns or a factor such as the offal discharge rate changes significantly) observation periods are terminated. The observation protocol requires observers to select a single warp and mitigation device to observe for the entire trip. This should be on the side of the vessel from which most offal is typically discharged, assuming a safe observation position is available. 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, 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 been altered to include recording of capture location. The requirement to also record captures in 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 may be used relatively intensely. At other times, strike observations are carried out as the observer's other duties permit.

2.2 Data source

Warp strike data collected by fisheries observers are entered into a Ministry of Fisheries database, administered by the National Institute of Water and Atmospheric Research (NIWA). A complete extract

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.

of the tables related to the warp strike data was obtained, covering all data collected during the 2004–05, 2005–06, and 2006–07 fishing years. The first warp strike observation in the dataset was made on 14 January 2005 and the last observation on 19 September 2007.

The tables include: 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.

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 is then used to characterise the discharge. For example, if sump water, minced material, and offal are recorded on an observation, then the groomed discharge is set to be offal. During modelling, the cutter pump and the minced categories were combined, and the offal and discard categories were combined, in order to reduce the number of levels.

The mitigation was characterised as either 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. Three fisheries were used: squid, hoki, and other target species.

2.4 Data analysis

Data analysis was carried out using the R software package (R Development Core Team 2008). The strike data are tabulated in this report to allow coverage to be assessed, and the association between the strikes and the key covariates is presented. 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 previously 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 uses data at the tow level, rather than individual observations. The total number of strikes are calculated, with the logarithm of the total duration of the observations, d_i, being used as an offset term. This offset accounts for the expected proportional increase in the number of strikes as the observation duration increases. Other covariates included in the model are: the maximum discharge rate; the discharge characterised using the same logic as was used within individual observations; the mitigation used during the tow; the target fishery of the tow; the mean wind speed; and the fishing year. No interaction terms have been included in the models. An automated stepping routine is used to select covariates that minimise the AIC information criterion. A similar statistical model is also built of large bird warp captures.

Aggregating the data to the tow level reduces the serial correlation between successive data points. Because of the infrequent nature of the strike events, the correlation between data from successive tows is low. Warp data are collected by observers for entire trips and so trip level random effects would be important if the model was to be used to make predictions on unobserved tows. The focus of the modelling is, however, on determining the relationship between the warp strike or captures and the key covariates, rather than predicting on unobserved data. Information on the key covariates (mitigation use and discharge) is only available from the strike observations themselves.

3. RESULTS

The full data extract had a total of 12 097 records. Of these, 412 records either had a start or end time missing, or were not of the 15 minute duration specified by the protocol; 196 had unclearly specified whether the warp or mitigation device had been observed; and 223 had missing large bird or small bird contact data. These records were removed from the analysis, leaving 11 309 valid observations. The final data includes 8469 observations made on the trawl warps and 2840 on the mitigation devices.

A breakdown of the number of observations by fishing year and target fishery is given in Table 2. The total number of warp strike observations has fallen, with only 1520 warp observations being made in 2006–07, compared with 4085 warp observations in the 2005–06 fishing year (Table 2(a)). Over all years 58.8% of warp observations were made during squid trawls. The next most frequently sampled fishery is hoki, with 16.9% of warp observations being made during hoki target trawls. Most of the warp observations on hoki trawls were made during the 2005–06 fishing year with only nine warp observations on hoki target trawls in the 2006–07 fishing year.

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. In both the 2005–06 and 2006–07 years, the number of mitigation device observations were similar, with 1366 observations being made during the 2006–07 fishing year.

Table 2: Number of strike observations, broken down by fishing year and target fishery.

(a) Trawl warps

	2004–05	2005–06	2006–07	Total
Squid	1 729	1 953	1 294	4 976
Hoki	378	1 046	9	1 433
SBW	361	107	3	471
Hake	46	370	16	432
Mid-depths	47	270	86	403
Pelagic	267	66	65	398
Scampi	0	171	0	171
Ling	30	46	28	104
Deep	6	39	0	45
Inshore	0	17	19	36
Total	2 864	4 085	1 520	8 469

(b) Mitigation devices

	2004–05	2005–06	2006–07	Total
Squid	0	1 158	1 190	2 348
Hoki	0	113	9	122
SBW	0	0	0	0
Hake	0	0	15	15
Mid-depths	0	174	67	241
Pelagic	0	29	63	92
Scampi	0	0	0	0
Ling	0	0	22	22
Deep	0	0	0	0
Inshore	0	0	0	0
Total	0	1 474	1 366	2 840

Table 3: 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
Strike rate	Warp	3.03	1.75	0.55
	Device		1.25	1.15
% of obs. without strikes	Warp	83.7	88.7	95.7
	Device		89.7	92.2
Max. observed strikes	Warp	59	39	21
	Device		17	18

(b) Large birds

		2004–05	2005–06	2006–07
Strike rate	Warp	2.35	1.08	0.39
	Device		1.02	0.71
% of obs. without strikes	Warp	82.5	94.4	95.9
	Device		92.5	92.9
Max. observed strikes	Warp	35	45	12
	Device		17	11

3.1 Strikes

The warp and mitigation device strike data are summarised in Table 3. In 2006–07, the mean warp strike rates were 0.55 small birds per hour and 0.39 large birds per hour. These compare with strike rates of 3.03 small birds per hour and 2.35 large birds per hour in 2004–05. These are the raw strike rates and include effects due to both changing mitigation use and changes in the way observations were made with respect to offal discharge. In 2006–07, strikes on the mitigation devices were more frequent than strikes on the warps, with mean device strike rates being 1.15 small birds per hour and 0.71 large birds per hour. The distribution of strike rates is strongly skewed to the left, with many zeros and a long right tail. In each of the four strike categories in 2006–07, there are no strikes recorded on more than 90% of observations. The percentage of observations with no strikes is higher in 2006–07 than in 2004–05. Across the whole dataset there were no warp strikes recorded on 84% of all warp observations. In 2006–07, the maximum number of strikes per observation for small birds is 21 (warp) and 18 (device), while for large birds the maximum number of strikes per observation is 12 (warp) and 11 (device). These are lower than the maximum numbers of warp strikes observed in 2004–05.

3.2 Mitigation use

The frequency of use of different mitigation devices is shown in Table 4. 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 45.8% of warp observations, and 52% of observations were made when there was no mitigation being used at all. Aside from the use of tori lines during 62 warp observations, bird bafflers were the only mitigation devices that were 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 small number of 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 made when no mitigation was being used fell to 7.8%, and tori lines were used during 63.6% of warp observations. While warp scarers are 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, and were used during only 2% of warp observations in 2006–07.

The association between the use of mitigation and the warp strike rate is given in Table 5. For both large and small birds, the highest warp strike rates are seen when no mitigation is used. The strike rates appear to be reduced when bird bafflers are used, but this is not seen in all years. In contrast, the use of tori lines is associated with strongly reduced strike rates. In 2006–07 there were insufficient observations made when no mitigation was used for a direct comparison to be made between tows with and without

Table 4: Percentage of warp strike observations using different mitigation devices.

	2004–05	2005–06	2006–07
No mitigation	52.0	16.1	7.8
Baffler only	45.8	21.1	26.0
Tori only	0.0	31.9	56.2
Baffler and tori	2.2	12.3	7.4
Warp scarer	0.0	13.2	2.0
Other device	0.0	3.9	0.0

Table 5: 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
No mitigation	5.33	2.24	
Baffler only	0.52	3.97	1.34
Baffler and tori		0.47	
Tori only		0.79	0.16
Other		1.03	

(b) Large birds

	2004–05	2005–06	2006–07
No mitigation	3.49	2.36	
Baffler only	1.08	1.77	0.68
Baffler and tori		0.04	
Tori only		0.24	0.19
Other		1.02	

tori lines, although warp strike rates are lower when tori lines are used than when bird bafflers are used. In 2005–06, warp strike on observations made when tori lines were used was reduced to 35.2% (small birds) or 10.1% (large birds) of the strike rate without mitigation. Observations made when both tori lines and bird bafflers were used had even lower strike rates. Although they reduce warp strikes, there are strikes on the tori lines themselves (Table 6). In 2006–07 the average tori line strike rates were 1.76 small bird strikes per hour and 0.79 large bird strikes per hour. When tori lines are used, there are more strikes on the tori lines than on the warps.

The results in 2006–07 are consistent with the mitigation trials conducted during the 2005–06 season (Middleton & Abraham 2007), which found both that tori lines were the most effective device at reducing warp strikes and that there were considerable numbers of strikes on the tori lines themselves.

Table 6: Average mitigation device strike rates (heavy contacts per hour). Averages are not shown for year-mitigation combinations where less than 200 observations were made.

(a) Small birds

	2004–05	2005–06	2006–07
Baffler only		0.12	0.01
Baffler and tori			
Tori only		2.49	1.76
Other		0.14	

(b) Large birds

	2004–05	2005–06	2006–07
Baffler only		0.16	0.02
Baffler and tori			
Tori only		2.05	0.79
Other		0.03	

3.3 Discharge

In all three years, an increase in the discharge rate is associated with an increase in the warp strike rates of both large and small birds (Figure 1). For example, across all the data the average large bird strike rate is 0.02 birds per hour when there is no discharge, compared with 3.22 birds per hour when the discharge is either intermittent or continuous. The relationship between discharge and warp strike is particularly clear in 2004–05 when there was less mitigation used, but an increase in the strike rate with the discharge rate is still seen in the 2006–07 year when tori lines and bird bafflers were widely used.

The frequency of different discharge types during warp observations is shown in Figure 2. In all years, the three main categories of discharge are no discharge, sump water only, or offal. Discharges of processed offal (minced or put through a cutter pump) or discards occur less frequently. Instructions to observers have changed in each of the three years, so it is not possible to determine discharge trends in the whole fleet from these data. In particular, during the initial warp strike observations in 2004–05, observers were asked to sample across a range of discharge conditions. During 2006–07, there was frequent discharge of offal while trawling, with 27.7% of warp observations in 2006–07 being made while offal was discharged. Data on discharge rates also show that the discharge of offal occurs frequently (Figure 2(b)), with 46.1% of warp observations in 2006–07 being made with either intermittent or continuous discharge.

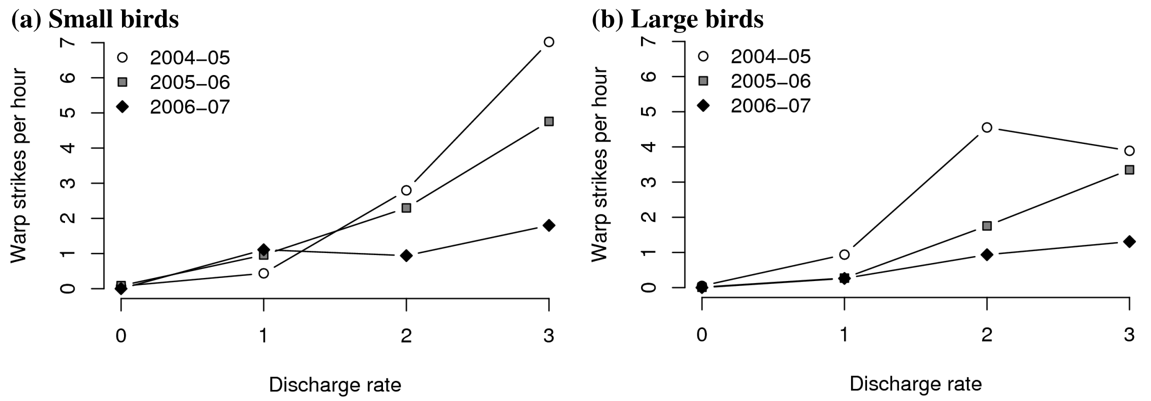

Figure 1: Warp strikes (number of heavy contacts per hour) as a function of the discharge rate for the three different fishing years. The discharge rates are 0 - none, 1 - negligible, 2 - intermittent, 3 - continuous.

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

(a) Small birds

	2004–05	2005–06	2006–07
Squid	1.37	1.09	0.19
Hoki	14.31	2.26	
Other	1.20	2.43	2.69

(b) Large birds

	2004–05	2005–06	2006–07
Squid	3.23	1.66	0.35
Hoki	2.56	0.39	
Other	0.24	0.68	0.66

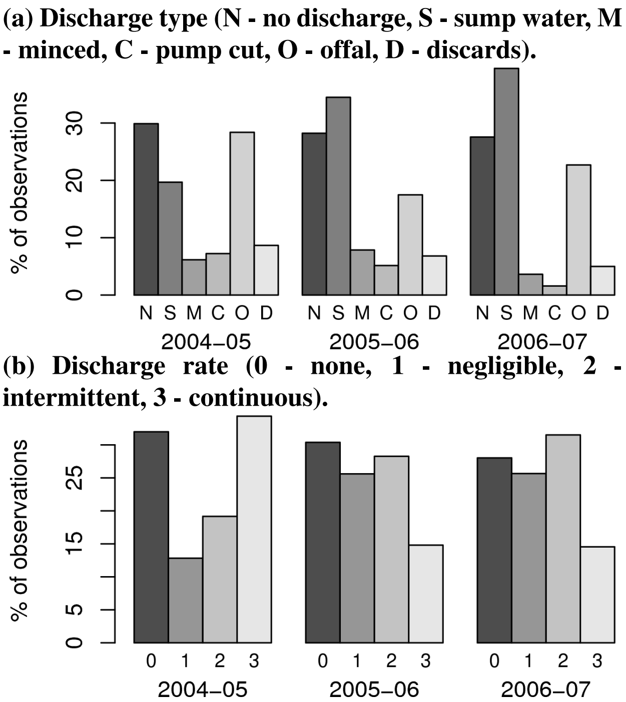

Figure 2: Percentage of warp strike observations with different discharge during each of the three years.

3.4 Strikes by fishery

The average strike rates by fishery are shown in Table 7. 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 the 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. Comments recorded by the observer do not illuminate why such an unusually high strike rate was encountered.

The decrease in the average strike rate between 2004–05 and 2006–07 seen in the squid fishery is not evident in observations made in trawl fisheries other than squid and hoki. Strike rates within the hoki fishery are variable, but there were insufficient data collected in 2006–07 to determine a trend.

3.5 Strikes by vessel

The rates of warp strike are summarised by vessel in Table 8, which is presented in order of increasing total strike rate (large birds and small birds combined). Only the 21 vessels where warp strike observations have been made on more than 50 tows are included. These either mainly fished for squid or target species other than squid or hoki while the observations were made. There is considerable variation in the average strike rate between vessels. On one vessel no strikes were recorded from observations made on 83 tows, on another vessel strike rates reached over eight birds per hour. Strike rates of small and large birds are correlated, so vessels with more large bird strikes also have more small bird strikes (r^2 = 0.45). There is also a positive correlation between the large bird warp strike and capture rates (r^2 = 0.3). Although the strike rate is low when tori lines are used, this pattern is not clear when viewed by vessel. The two vessels with the highest strike rate used tori lines on more than half of all tows, and the vessel which had no recorded strikes had no mitigation for over half of all the tows where warp measurements were made. This apparent lack of a relationship is in part due to the highly variable nature of the warp strikes, which occur during only 16% of warp observations. The six vessels with the lowest strike rates are Korean, Japanese, or have a flag of convenience. Aside from one 90 m vessel, these are all less than 80 m in length. The five vessels with the highest strike rate are all Ukrainian, Russian, or flag of convenience and are all 100 m in length.

3.6 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. In the remainder of the 2006–07 fishing year there were 1270 observations made when a mitigation event was recorded, out of a total of 2307 observations.

The most frequently reported event was the tori line not being taut, or the streamers being tangled. The next most frequent events relate to the way the gear is set, with the baffler droppers or the tori line streamers not reaching close to the water. In some cases, observers have commented that the baffler

Table 8: Warp strike rates by vessel. The warp strike data are summarised for each vessel that had more than 50 tows during which warp observations were made. The table is ordered by the total strike rate (both large birds and small birds). The columns are the flag state of the vessel (Kor/Jap, Korean or Japanese; NZ, New Zealand; FoC, Flag of convenience such as Malta or Belize; Ukr/Rus, Ukrainian or Russian), the length of the vessel to the nearest 10 m, the fishery that most tows with warp observations were targeting (possible values are Squid, Hoki or Other), the mitigation that was used most frequently (B, baffler; T, tori line; BT, both bafflers and tori lines; O, other), the percentage of tows that used mitigation, the warp strike rate in heavy contacts per hour for both the large and small bird groups, and the large bird warp capture rate.

Flag	Length	Fishery	Mitigation	% Miti.	Strikes per hour		Lge. warp cap. rate
					Large birds	Small birds	Birds per 100 tows
Kor/Jap	60	Squid	BT	45.8	0.00	0.00	0.0
Kor/Jap	70	Squid	T	83.2	0.03	0.06	0.0
Kor/Jap	60	Squid	BT	91.1	0.14	0.14	0.0
FoC	90	Squid	T	61.2	0.35	0.18	0.7
Kor/Jap	70	Squid	B	98.1	0.33	0.33	0.0
Kor/Jap	50	Squid	B	100.0	0.27	0.64	0.0
Ukr/Rus	100	Squid	T	75.0	0.88	0.65	0.5
NZ	70	Other	T	42.9	1.51	0.22	0.0
NZ	60	Squid	B	91.8	0.81	0.96	4.7
Ukr/Rus	100	Squid	B	89.6	1.39	0.62	5.7
Kor/Jap	80	Squid	B	88.6	0.48	1.54	8.1
Ukr/Rus	100	Other	O	48.0	2.24	0.22	0.0
Kor/Jap	60	Squid	B	95.7	0.41	2.37	2.2
FoC	100	Squid	T	27.5	1.22	1.74	9.3
NZ	60	Squid	BT	93.3	1.61	1.83	21.2
Kor/Jap	80	Squid	T	65.4	0.92	2.72	0.0
Ukr/Rus	100	Other	B	89.0	3.54	0.72	0.6
FoC	100	Squid	B	92.5	3.67	1.86	0.6
Ukr/Rus	100	Other	B	49.7	2.93	2.92	11.6
Ukr/Rus	100	Squid	T	79.8	3.65	5.13	2.0
FoC	100	Squid	T	59.8	7.41	1.95	1.1

droppers do not reach within 4 m of the water. A common failure of tori lines is that they are blown sideways by crosswinds and leave the warps exposed. This is not recorded by any of the event codes, but is sometimes commented on by observers.

Table 9: Summary of mitigation events, giving the number of observations reporting when each mitigation event was reported between January 2007 and the end of the 2006–07 fishing year.

Mitigation event	Obs.
Tori line not taut	602
Tori line with tangled streamers	457
Bird baffler not reaching within 0.5m of water (aft booms)	348
Bird baffler not reaching within 0.5m of water (side booms)	231
Streamers of tori line not reaching water	193
Aerial extent of tori line less than 10m beyond warp	174
Bird baffler dropper lines tangled	153
Warp scarer main-line not extending to within 1m of warps entering water	46
Warp scarer streamers not reaching water	20
Tori line main line tangled with warp	18
Other mitigation events, or more than 6 mitigation events	11
Warp scarer with tangled streamers	10
Warp scarer main line tangled with warp	5
A delay between start of fishing and deployment of the tori line	4

3.7 Modelled warp strikes

A summary of the coefficients of the fitted model of small bird warp strikes is shown in Table 10. The multiplicative effect of each factor on the mean strike rate, μ, is obtained by exponentiating the estimate from the linear predictor, β. As expected, the warp strike rate increases as the discharge rate increases. The warp strike rate when the discharge is continuous is exp(1.91) = 6.75 times higher than the strike rate when there is no discharge. All the mitigation devices are effective, with the greatest reduction in strikes occurring when tori lines are used. Tori lines reduce the small bird warp strike rate by a factor of 0.16. Strike rates in both the hoki and the other fisheries are higher than during squid target trawls. The strike rate increases as the discharge type changes from sump water to mince to offal. Despite the inclusion of the other covariates, there is a year effect that remains after all the other factors have been accounted for, with the base strike rates in 2006–07 being a factor of 0.52 lower than the 2004–05 rate for comparable discharge and mitigation use. There is also a positive effect of wind speed on strike rate, with the strike rate increasing as the wind increases. An analysis of variance (ANOVA) table, showing the reduction in deviance caused by sequentially adding terms to the model is given in Table 10(b). Terms are included in order of decreasing explanatory power. The term that explains most of the deviance is the discharge rate, followed by the type of the mitigation and the fishery. The other terms explain a relatively small amount of the deviance.

A similar summary of the model for large bird warp strikes is given in Table 11. As with small bird warp strikes, discharge rate has the most explanatory power, with the strike rate being highest when the discharge is continuous. The strike rate also increases with the discharge rate, with continuous discharge increasing the strike rate by a factor of 31.3 over the strike rate when there is no discharge. In this model, none of the discharge type terms are significant, but the discharge of offal is still associated with higher strike rates than the other discharge types. As with the small bird warp strikes, rates are lower in 2006–07 than in 2004–05 and increase with increasing wind speed. Discharge rate explains the most deviance (Table 11(b)), followed by mitigation type. Discharge type is the only other term which explains more than 2% of the deviance.

3.8 Block height

Following the mitigation trials, the height of the warp blocks above the water was identified as a factor which could influence the efficacy of bird bafflers at reducing warp strike (Middleton & Abraham 2007). On vessels with higher warp blocks, the warps enter the water further from the vessel, and so bird bafflers provide less protection. During the mitigation experiment, it was found that strike rates were reduced for both small and large birds when bafflers were used on vessels with low blocks (less than 6.5 m), but not on vessels with blocks more than 6.5 m above the waterline. However, there were only seven vessels that used bafflers during the experiment. For the full dataset, block heights were identified for all but two of the 24 vessels that had used bird bafflers. The number of vessels, and the number of tows with trawl warp observations, is shown in Table 12. There are close to 400 tows with warp strike observations made for each of the two block height categories. To check whether block height influences baffler performance, the models were refitted with additional mitigation categories; one for bafflers on vessels with low blocks and one for bafflers on vessels with high warp blocks. The resulting model estimates of the effects are shown in Table 13. For small birds the bafflers on vessels with low blocks appear to be more effective, whereas for large birds the model suggests that there have been fewer strikes on vessels using bafflers with higher blocks, all else being equal. This analysis, across a larger number of vessels, does not support

Table 10: Small bird warp strike model.

(a) Coefficients of the terms in the linear predictor, relative to no discharge, no mitigation, the squid fishery, the 2004–05 year, and no wind. Significance is indicated by stars, with three stars indicating $p < 0.001$, two stars indicating $p < 0.01$, one star indicating $p < 0.05$, a dot $p < 0.1$, and no stars indicating $p \geq 0.1$.

		Estimate	Std. err.	Significance
Intercept		-4.00	0.39	***
Discharge rate	Negligible	0.51	0.50	
	Intermittent	1.24	0.48	*
	Continuous	1.91	0.48	***
Mitigation	Baffler only	-0.55	0.16	***
	Tori only	-1.86	0.22	***
	Baffler and tori	-1.83	0.30	***
	Other	-0.91	0.27	***
Fishery	Hoki	1.45	0.18	***
	Other	0.61	0.16	***
Discharge	Sump	1.83	0.54	***
	Minced	2.32	0.56	***
	Offal	2.71	0.54	***
Year	2005-06	0.39	0.17	*
	2006–07	-0.65	0.24	**
Log(wind speed + 1)		0.62	0.17	***

(b) ANOVA table giving the deviance explained as terms are sequentially added to the model. All terms are significant at $p < 0.001$.

	Deg. of freedom	Deviance	Resid. dev.	% explained
Initial			2049	
Discharge rate	3	462	1587	22.54
Mitigation	4	130	1457	8.20
Fishery	2	90	1367	6.16
Discharge	3	43	1324	3.13
Year	2	30	1294	2.27
Log(wind speed + 1)	1	12	1282	0.92

Table 11: Large bird warp strike model.

(a) Coefficients of the terms in the linear predictor, relative to no discharge, no mitigation, the squid fishery, the 2004–05 year, and no wind. Significance is indicated by stars, with three stars indicating $p < 0.001$, two stars indicating $p < 0.01$, one star indicating $p < 0.05$, a dot $p < 0.1$, and no stars indicating $p \geq 0.1$.

		Estimate	Std. err.	Significance
Intercept		-4.02	0.45	***
Discharge rate	Negligible	1.81	0.74	*
	Intermittent	3.08	0.72	***
	Continuous	3.44	0.72	***
Mitigation	Baffler only	-0.48	0.16	**
	Tori only	-1.81	0.23	***
	Baffler and tori	-1.54	0.34	***
	Other	-0.40	0.26	
Fishery	Hoki	-0.28	0.20	
	Other	-0.56	0.17	***
Discharge	Sump	0.09	0.80	
	Minced	1.39	0.80	.
	Offal	1.92	0.79	*
Year	2005-06	-0.33	0.17	*
	2006–07	-1.02	0.24	***
Log(wind speed + 1)		0.60	0.18	***

(b) ANOVA table giving the deviance explained as terms are sequentially added to the model. All terms are significant at $p < 0.01$.

	Deg. of freedom	Deviance	Resid. dev.	% explained
Initial			2167	
Discharge rate	3	610	1557	28.16
Mitigation	4	219	1338	14.07
Discharge	3	131	1206	9.81
Year	2	15	1192	1.24
Fishery	2	9	1182	0.77
Log(wind speed + 1)	1	11	1172	0.91

Table 12: Summary of data from tows made with either no mitigation, or with bird bafflers only. The table gives the number of distinct vessels, trips, and tows made without mitigation, for the two classes of block height, and where the block height is unknown. The average strike rate is given for all tows within each category.

	No mitigation	Bird baffler		
		Block > 6.5 m	Block < 6.5 m	Unknown
Vessels	33	6	16	2
Trips	56	18	27	2
Tows	930	431	517	58
Small bird strikes (contacts per hour)	4.1	2.5	1.5	1.2
Large bird strikes (contacts per hour)	3.0	0.8	1.7	0.1

the results presented by Middleton & Abraham (2007) that found bafflers were more efficient on vessels with lower blocks. In that analysis, there were only seven vessels that used bafflers and the result does not hold when a larger group of vessels is included.

Table 13: Expected percentage change in the warp strike rate when bafflers are used on vessels of differing block height, compared to tows without mitigation.

		Estimate (%)	95% c.i.
Large birds	High block	49.4	(32.3 – 75.7)
	Low block	79.4	(54.5 – 115.9)
Small birds	High block	95.2	(62.9 – 144.1)
	Low block	43.9	(29.4 – 65.6)

3.9 Captures

To produce a consistent data-set, information from the strike observation and non-fish bycatch forms was merged. Captures were recorded on 319 tows. There were 94 tows where captures were recorded only on the non-fish bycatch form, and these were used to complete the warp capture records. In addition, 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. There were 9 tows where different numbers of captures were recorded on the two forms, with a net difference of 7 birds between the two data sets.

Across all the warp observation forms, 232 small birds and 248 large birds were captured. A summary of captures on tows where warp strike observations were made is shown in Table 14. Most small birds are caught in the net, with only five 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 three, or 10% of large bird captures.

The capture rate of large birds on the warp, grouped by discharge and mitigation use, is shown in Table 15. There are few captures when there is no discharge, and the capture rate is less than one bird per 100 tows when there is only sump discharge. Similarly, there are few large bird warp captures when tori lines are used as mitigation. When tori lines were used, there were no captures reported from tows where

Table 14: Capture of birds by location for each of the three fishing years.

(a) Small birds

	2004–05	2005–06	2006–07
Warp	4	1	0
Net	38	86	49
Other	3	27	1
Total	45	114	50

(b) Large birds

	2004–05	2005–06	2006–07
Warp	67	59	3
Net	39	17	27
Other	20	9	0
Total	126	85	30

either no discharge or sump discharge was recorded during warp observations. Large bird warp captures are highest when no mitigation is used and offal, discards, or minced material is discharged.

From the warp strike and capture data a recovery ratio can be estimated. This is the number of warp strikes that occur for every bird that is landed on deck. To first order this ratio is expected to be independent of the mitigation used, the discharge of offal, or of other covariates. To calculate the ratio, the warp strikes observations are scaled up to give a number of warp strikes per tow, multiplying by the ratio between the tow duration and the time spent observing the trawl warps. No correction is made for the fact that the observers watched only a single warp, whereas birds are caught on both warps. It is

Table 15: 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
	None	Sump	Offal	Minced	
Tori	0.0	0.0	0.7	0.0	0.2
Baffler and tori	0.0	0.8	4.7	5.6	2.0
Other	0.0	3.9	3.4	4.8	2.7
Baffler	1.0	0.7	7.4	8.5	4.4
None	0.0	1.1	12.4	17.3	7.4
All	0.2	0.8	7.1	8.0	3.7

Table 16: Model of large bird warp-captures.

(a) Coefficients of the terms in the linear predictor, relative to no discharge, no mitigation, the Auckland Islands SQU 6T area and the 2004–05 year. Significance is indicated by stars, with three stars indicating $p < 0.001$, two stars indicating $p < 0.01$, one star indicating $p < 0.05$, a dot $p < 0.1$, and no stars indicating $p \geq 0.1$.

		Estimate	Std. err.	Significance
Intercept		-5.04	0.78	***
Discharge rate	Negligible	1.93	0.85	*
	Intermittent	3.81	0.78	***
	Continuous	3.32	0.79	***
Mitigation	Baffler only	0.09	0.34	
	Tori only	-2.65	0.80	***
	Baffler and tori	-0.28	0.68	
	Other	-0.57	0.55	
Area	Stewart-Snares	-0.82	0.31	**
	Chatham Rise and Subantarctic	-3.14	0.67	***
	Other	-2.40	0.66	***
Year	2005-06	0.01	0.33	
	2006–07	-2.10	0.68	**

(b) ANOVA table giving the deviance explained as terms are sequentially added to the model. All terms are significant at $p < 0.01$.

	Deg. of freedom	Deviance	Resid. dev.	% explained
Initial			428	
Discharge rate	3	68	360	15.94
Mitigation	4	51	308	14.32
Area	3	35	273	11.37
Year	2	12	261	4.32

not possible to simply double the number of strikes as observers typically watch the warp where most discharge is occurring. There are some tows where the tow length appears to be either unreasonably long (more than 24 hours) or very short (less than 1 hour). These tows are not included when estimating this ratio. From the remaining 3424 tows, the ratio of large bird warp strikes to landed large birds is found to be 208 (95% c.i.: 150 to 290, calculated from 5000 bootstrap samples). For small birds, the ratio is 7610 strikes per capture (95% bootstrap c.i.: 3800 to 36 000).

Results from a model of the capture of large birds in trawl warps are given in Table 16. As with the warp strikes, capture rates are related to the discharge rate and mitigation. The area and the fishing-year covariates are also significant, with captures being lower in 2006–07 and higher in the SQU 6T area. In total, the model explains 38.9% of the initial deviance. Discharge has a marked effect on the number of captures that are recorded. When the discharge is continuous, the number of large bird warp captures increases to 27.8 (95% c.i.: 5.72 to 135) times the number that are caught when there is no discharge. The only mitigation that can be shown to significantly reduce the landed capture rates are tori lines. The number of large bird warp captures when tori lines are used is 7.08% (95% c.i.: 1.44% to 34.9%) of the number that are caught when no mitigation is used, assuming the other covariates remain the same.

4. DISCUSSION

The number of warp strikes has decreased since 2004–05, when warp strike observations were first made in New Zealand fisheries. The decrease is 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 has been a decrease in the capture of albatrosses and giant petrels on trawl warps. In 2004–05, there were 67 albatrosses caught on trawl warps during tows that had warp observations. By 2006–07, this had reduced to three. This was a decrease in catch rate from 6.7 albatross warp captures per 100 tows in 2004–05 to 0.4 albatross warp captures per 100 tows in 2006–07. 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 is reduced when tori lines are used as a mitigation device. This result supports previous analysis of a subset of these data (Middleton & Abraham 2007). The performance of bird bafflers was not found to be consistently better on vessels with low block height. Across all trawl observer data the capture rate of white capped albatross, the most frequently caught albatross, reduced from 3.2 birds per 100 tows in 2004–05 to 0.71 birds per 100 tows in 2006–07 (Abraham & Thompson 2009). In 2004–05, no trawl vessels used tori lines, and in 2006–07 they were used during 63.6% of all warp strike observations. The warp strike dataset provides strong evidence that the increased use of tori lines within the squid fishery has led to a reduction in the number of albatross mortalities.

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 3.7 birds per 100 tows.

If warp strike levels recorded in the squid fishery in 2006–07 continue, then warp strike measurements will be an inefficient use of observer time. The large bird strike rate of 0.39 birds per hour is equivalent to a single strike in every 2.5 hours, or one strike every 10 observation periods. Within the squid fishery, a clear relation between the use of tori lines, the discharge of waste, and the warp capture of large birds has emerged. It may be more efficient to monitor the factors that are associated with warp strike, rather than the strikes themselves.

A source of uncertainty in understanding fisheries-related seabird mortality is the high ratio of warp strikes to captures. For a bird that is killed by warp strike to be counted as a capture it must be held on the warp for the remainder of the tow and then brought back on board the vessel, passing through the warp block. For every large bird captured on the warps, there are 208 (95% c.i.: 150 to 290) warp strikes. For every small bird captured on the warps there are 7610 (95% c.i. 3800 to 36 000) warp strikes. During the warp strike observations, no attempt was made to quantify whether or not birds were killed by the interactions. In a study of warp interactions in South African waters, 30 were birds confirmed killed by warp interactions. Of these, only two were subsequently brought back on board (Watkins et al. 2008). Currently, estimates of seabird mortality in New Zealand trawl fisheries are based solely on landed captures (Baird & Smith 2008). In trawl fisheries, it is likely that the warp mortalities are being underestimated. This may be especially important for petrels, which have a similar warp strike rate to the albatross and giant petrel, but which are recovered much less frequently on board the vessel. 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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