THE EFFICACY OF WARP STRIKE MITIGATION DEVICES: TRIALS IN THE 2006 SQUID FISHERY

David A. J. Middleton

New Zealand Seafood Industry Council, Seafood Industry House, 74 Cambridge Terrace, Wellington

Edward R. Abraham

Dragonfly, 10 Milne Terrace, Island Bay, Wellington

This report serves as the Final Research Report for Ministry of Fisheries contract IPA2006-02

11 February 2007

EXECUTIVE SUMMARY

Recent research has shown that collisions with trawl warps are a source of seabird mortality in trawl fisheries. To minimise this mortality, a number of devices have been developed to prevent seabirds from being struck by the trawl warps, or from congregating at the stern of the vessels. Designs currently used in New Zealand include twin tori lines, bird bafflers and warp scarers. Legislation now requires that at least one of these devices is used by trawlers fishing within New Zealand waters.

Experimental trials of warp strike mitigation devices were carried out in the 2006 southern squid trawl fishery, involving 18 observed vessels. The trials were developed co-operatively by a group that included representatives from the fishing industry, the Ministry of Fisheries, the Department of Conservation and WWF-NZ. Tori lines, bird bafflers (the 4 boom variety) and warp scarers were compared using standardised seabird strike measurements: the number of birds that struck either the warps or the mitigation device during a 15 minute observation period. On the participating trips, different warp strike mitigation treatments were used on different tows according to a randomised experimental design.

Key results from the trial are:

- Tori lines were most effective at reducing seabird strikes on trawl warps. They reduced the warp strikes to between 5% and 20% of their frequency without mitigation.
- Both bird bafflers and warp scarers produced a significant reduction in the number of large bird strikes on the warps, to 35 – 90% of the level in the absence of mitigation.
- Bird bafflers and warp scares also reduced small bird strike rates on the warps, but this reduction was either not statistically significant (for bafflers) or only marginally significant (for warp scarers).
- Although there is limited data, the analysis suggests that the bird bafflers are more effective on vessels where the trawl block is closer to the waterline.
- Strikes on the mitigation devices themselves were generally less than 20% of the no mitigation strike rates on the trawl warps. The clear exception was the tori lines, which had a strike rate similar to that recorded on the trawl warps without mitigation.
- There is no information on whether seabird strikes on tori lines are as dangerous as those on trawl warps. Observer opinion on this was divided. Recorded comments indicate that at least some seabird interactions with tori lines are dangerous for seabirds. However, no dead or injured birds were retrieved from the tori lines, or any of the mitigation devices, during the experiment.
- The trials again highlighted the discharge of offal as the main factor influencing seabird strikes. Almost no strikes were recorded when there was no discharge, and strike rates were low when only sump water was discharged.
- There was considerable between vessel variability in strike rate. When no mitigation was being used, the vessels that had bafflers on board had a higher strike rate than other vessels in the trial.

- Five of the seven bafflers in the trial did not comply with the required specification as the dropper lines did not reach to with 0.5 m of the water surface. Some bafflers had dropper lines that were prone to tangling.
- The weights used on warp scarers typically did not allow them to be deployed sufficiently down the warp without entanglement. This often left the few meters of the warp closest to the water unprotected. The clips were not sufficiently robust, and did not pass splices etc. Some vessels had trouble deploying the warp scarers safely. The devices should prove more effective if these technical problems are solved.
- Warp scarers and tori lines must be well maintained to meet the required specification (i.e. replacing lost/damaged/dirty streamers etc.)

INTRODUCTION

Incidental mortality of seabirds as a result of collisions with net-sonde monitoring cables was identified in the early 1990s (Bartle, 1991). The use of net monitor cables by New Zealand trawlers was subsequently prohibited, and net monitors that communicate with the vessel acoustically have been widely adopted in New Zealand and other southern hemisphere fisheries.

Recent research has highlighted other sources of incidental mortality in trawl fisheries, including collisions with trawl warps (Wienecke and Robertson, 2002; Sullivan et al, 2003). A number of devices have been developed to prevent seabirds from congregating at the stern of vessels, where they are at risk from warp strikes. However, there are relatively few scientific studies on the efficacy of these devices.

In June-July 2004 the Hoki Fishery Management Company undertook observer and video-based monitoring of warp strike aboard the New Zealand factory trawler FV *Rehua* (Robertson & Blezard, 2004). The use of a Bird baffler mitigation device[1] (Anonymous, 2002) and the discharge of offal were experimentally manipulated. The use of the baffler appeared to reduce the overall rate of warp strikes in both the offal discharge and no-discharge treatments, although the inability to control discharge via the "sump pump" complicated interpretation of the no-discharge treatment.

Sullivan et al. (2006) carried out trials of three devices designed to reduce seabird collisions with warp cables during trawling (Falkland Islands warp scarer, Brady baffler and tori lines). This is the only previous study where the efficacy of different mitigation devices has been experimentally compared. In that study, paired tori lines were the most effective mitigation device, achieving significantly greater reductions in warp contact rates than the Brady Baffler, and slightly greater reductions than the Falkland Islands warp scarer.

In the 2005 squid season in New Zealand, observers on board factory trawlers operating in the SQU 6T and SQU 1T fisheries carried out warp-strike observations as part of their routine observer duties. In that case the use of mitigation devices, and conditions of offal discharge, were observed rather than experimentally manipulated. This was primarily intended as a trial of the warp strike recording protocol, and the initial data set did not allow observer and vessel effects to be accounted for in the model. The bafflers in use varied from vessel to vessel; nevertheless, these data provide good evidence that use of bafflers was associated with lower warp contact rates, with bafflers reducing warp strikes by a factor of approximately two (Abraham, 2005).

By standardising the conditions of experimental trawls as much as possible, and randomising the treatments, the Falklands and *Rehua* studies provide confidence that the differences in strike rates observed are the result of the different mitigation devices employed. However, the restricted conditions of the studies (single vessel/fishery/etc.) provide no information on the extent to which the results can be generalised to other vessels and fisheries. As a result Sullivan el al. (2006) concluded that while "*our findings are likely to have application to a range of trawl fisheries around the world*", "*further testing would be required to identify any local variations in the cause and nature of trawler related seabird mortality*".

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[1] "Bafflers" is used here generically to refer to both the Brady Bird Baffler (NZ patents 508603, 523711, current status: voided pre-acceptance) and similar devices.

The analysis reported by Abraham (2005) used data from 19 different vessels operating in broadly the same fishery. However, in these data the use of warp strike mitigation devices was not randomised over tows. In general vessels either used Bird bafflers, or no mitigation device, and this was consistent throughout the observed trip. In addition, data from individual observers was generally from a single vessel. Thus, the effect of the mitigation device was partly confounded with vessel and observer effects.

A recognised limitation of twin tori lines is the fact that they are not attached to the trawl warps and so may provide limited protection in cross-winds, when the lines are deflected from the warps. Warp scarers, where the mitigation device is attached to the warp, have the potential to outperform tori lines in these conditions. Anecdotal reports have indicated that a recently developer warp scarer, dubbed "Carefree's Cunning Contraption" has proved effective (Carey, 2005).

In late 2005 the regulated use of twin tori lines by trawlers of lengths 28 m and above operating in New Zealand Fisheries Management Areas (FMAs) 3 to 7 was introduced, primarily on the strength of the Falklands study. Following reports of practical difficulties in the use of tori lines, concerns regarding their effectiveness, and potentially harmful interactions between seabirds and tori lines, the regulations were expanded in early 2006 to require the use of at least one of three mitigation devices (Bird Bafflers, twin tori lines, and warp scarers). These regulations were extended to cover the entire New Zealand EEZ in April 2006.

The NZ fishing industry and Government agencies have recognised the importance of carrying out studies which demonstrate the efficacy of warp-strike mitigation devices in New Zealand fisheries, and across a range of vessels. This has resulted in a collaborative approach to the development of the trials reported here. The trials were designed by a Technical Advisory Group comprising scientists from the New Zealand Seafood Industry Council, the Ministry of Fisheries, Department of Conservation and WWF-NZ. They were implemented by the Deepwater Group Ltd., using Ministry of Fisheries observer coverage.

The southern squid fishery, which operates around the Auckland Islands (SQU6T), Stewart-Snares shelf and the East Coast of the South Island from February to June each year, has had consistently higher mean seabird bycatch rates than most other NZ trawl fisheries (Baird, 2005, Table A2), and therefore provides a suitable opportunity to assess the performance of devices designed to reduce seabird captures that result from warp strikes.

Trials to investigate the relative efficacy of seabird warp strike mitigation devices (twin tori lines, the Carey warp scarer and bird bafflers) were carried out in the southern squid fishery (SQU 1T, SQU 6T) from January to May 2006. The trials utilised existing observer coverage to collect data from normal commercial fishing trips where different warp strike mitigation treatments were used on different tows according to a randomised experimental design. This report provides the final results of these trials.

METHODS

The general procedure adopted in this study was the addition of an experimental design (simple randomised treatments) to normal commercial fishing trips, with the use of existing observer coverage and protocols to collect the required data. Participating trips were those in the 2006 southern squid fishery (SQU 1T and SQU 6T) where a Ministry of Fisheries observer was carried as part of normal squid fishery observer coverage. The operational plan for the 2006 SQU 6T fishery required observer coverage of 30% of tows. The timing and duration of these fisheries varies from year to year due to variation in the abundance of squid. The SQU 1T fishery operates from December to June, although most catch is taken from January to March (Langley, 2001). Agreements restrict the SQU 6T fishery from starting before 1 February, and most of the catch is taken between February and April. These trials planned to include all observed squid target trips which departed port in the period 20 January to 15 June 2006, and intended to fish in the SQU 1T or 6T fisheries.

EXPERIMENTAL TREATMENTS

Experimental treatments were applied at random to each tow carried out by participating vessels. Four treatments were considered:

1. Use of twin tori lines
2. Use of warp scarers
3. Use of bird bafflers
4. No warp-strike mitigation device used (control).

The mitigation devices were standardised to the greatest extent possible. Participating vessels supplied their own tori lines, according to the regulated design. A revised warp scarer specification was developed and each participating vessel was supplied with a set built to this specification by a single supplier. It was not considered feasible to implement identical bafflers on the vessels in the trial. However, the experimental schedules of participating vessels only required the use of bird bafflers where the vessel had existing bafflers that met a specified minimum standard. It was also recognised that some vessels might not be able to deploy the standard warp scarers provided for the trial, due to the height of their trawl blocks above the deck. However, in the event, this did not affect any vessels participating in the trials. The device specifications adopted for the trial are provided in Appendix 1.

Other than the tow by tow variation in the warp strike mitigation device deployed, participating vessels otherwise operated normally. This included following the offal management regime specified in their Vessel Management Plan. No other seabird warp-strike mitigation devices on the vessels (e.g. sonic devices) were deployed during the trials.

Participating vessels were issued with an individual, randomly generated list of mitigation treatments to be applied to tows on the trip in sequence. If the vessel's master considered that prevailing weather conditions did not allow the safe deployment of a particular mitigation device, then particular entries in the sequence could be skipped.

SEABIRD STRIKE OBSERVATIONS

During daylight tows, observers carried out seabird strike observations according to the protocol trialled in the 2005 squid fishery (Abraham, 2005). This protocol is intended to be generally usable by fisheries observers rather than requiring specialist seabird observation training.

Observers were instructed to carry out at least one warp strike observation period during each daylight trawl. For the treatments where a mitigation device was deployed, observers also carried out a separate period of observation of any seabird strikes on the mitigation device.

Observers carried out 15 minute observation periods during which they counted heavy seabird strikes on the gear (i.e. either the warp or the mitigation device). A heavy strike was one in which a bird:

- had its path of movement deviated when it came into contact with the gear, *and*
- 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).

Such strikes could occur on the water or in the air, and occurred either when the bird, through active movement, came into contact with the warp/mitigation device, or when the warp/mitigation device moved to contact the bird.

Seabirds striking the observed gear were grouped into two categories:

- Small Birds – including petrels (other than giant petrels), shearwaters, cape pigeons, prions, storm petrels, gulls and shags; and
- Large Birds – including all albatrosses and also giant petrels.

Seabird strike observations were only 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). To randomise the start of observations relative to fishing activity (e.g. to avoid all observations starting immediately after shooting) observers were instructed to start sampling periods on the hour (or half hour). Where sufficient time was available to carry out multiple observations of a tow, observers were instructed to leave at least one hour between sampling periods. However, sampling periods recording contacts with the mitigation device could be carried out immediately after warp strike observation periods. Observers were encouraged to spread seabird strike observations throughout the daylight hours.

For each seabird strike observation period, observers recorded environmental and other covariates as 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. This should have been on the side of the vessel from which most offal was typically discharged, assuming that a safe observation position was available.

A number of trips carried two observers with the aim of quantifying between observer variability. Other than agreeing the side of the vessel for seabird strike observations at the beginning of the trip, observers were instructed to act independently with respect to seabird strike observations. This included carrying out observations at different times and not discussing results or interpretations.

In addition to the recording of all seabird captures on the standard observer non-fish bycatch forms, the seabird strike protocol 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.

Table 1. Environmental and operational covariates recorded 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 x 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 whether they complied with the standard specified for the trial.
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 was 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, 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 fish or squid discards). Multiple categories could be recorded.

Unlike other seabird observation protocols (e.g. Wienecke and Robertson, 2002), observers were not required to make a subjective decision regarding the likely fate of birds that struck the warp or mitigation device. Only captured seabirds recovered on to the vessel were to be recorded.

Observers were also asked to keep a log of other qualitative information relevant to the broader efficacy of warp strike devices, including the durability of the devices. This included deployment problems, entanglements, breakages and repairs.

TRIAL IMPLEMENTATION

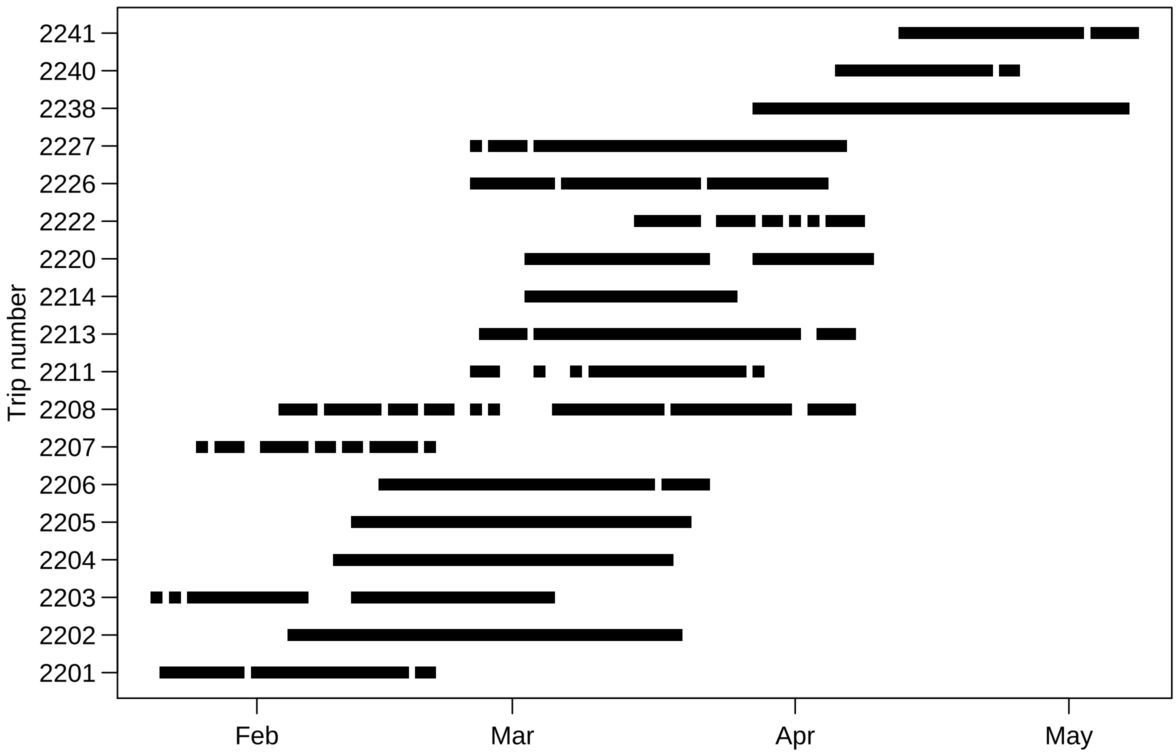
The trials were carried out under Special Permit 352, issued by the Ministry of Fisheries to the Deepwater Stakeholders Group Ltd. This permitted the inclusion of tows with no mitigation devices deployed. All trips which carried Ministry of Fisheries observers (for the purposes of maintaining the minimum of 30% observer coverage in the 2006 SQU 6T fishery required by the SQU 6T Operational Plan (Ministry of Fisheries, 2005)) were included in the trial. This resulted in a total of eighteen observed trips. Three of these trips carried two observers to allow quantification of between-observer differences in the interpretation of the warp strike measurement protocol. Eleven trips used three experimental treatments (tori lines, warp scarers, and the no mitigation control), whilst seven trips included the additional bird bafflers treatment. No vessels that participated in the trial had blocks that were too high to prevent the use of warp scarers. However, use of the warp scarers was discontinued early in one trip (2222) due to concerns over the safety of crew during their deployment.

Few serious problems were reported in the implementation of the trial. A late change in vessel observed resulted in one trip (2220) starting without the required mitigation devices on board. This was rectified at a mid-trip port call, with bird bafflers used exclusively on the early part of the trip. The mitigation devices for trip 2226 were loaded onto the wrong vessel, but transferred across at sea on the second day of the trip. Briefings of both observers and vessel masters in the trial protocol generally resulted in any misunderstandings of the protocols being rapidly resolved.

All participating vessels were supplied with standard warp scarer devices. Most vessels already carried tori lines to a standard specification[2], although these were supplied to one vessel. Bird bafflers were included in the trial where the vessel had an existing four-boom bird baffler system that was considered to comply with the specification gazetted on 12 January 2006[3]. In each observation period the observer was required to assess whether the device complied with the standard specifications defined for the trial (Appendix 1). For tori lines and bird bafflers these specifications mirrored those defined in the Fisheries (Incidental Bycatch of Seabirds by Trawl Vessels 28m+) Notice 2006, but the warp scarer specification was more restrictive, reflecting the standard design deployed in the trial.

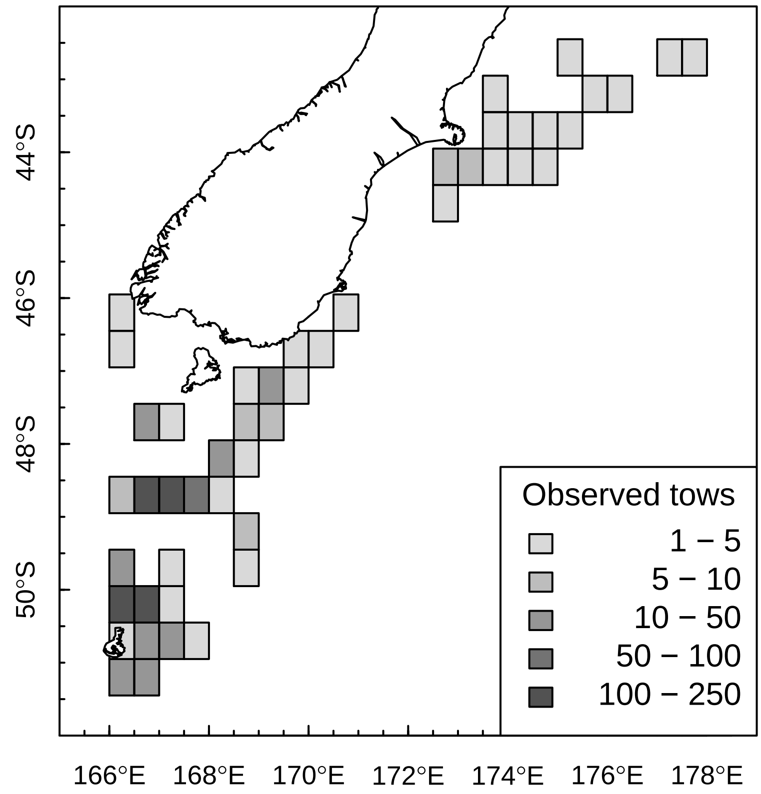
Seabird strike observations during the trial spanned the period from 21 January 2006 to 8 May 2006 (Figure 1), and the majority were during tows around the Auckland Islands or on the Stewart-Snares shelf edge, though some observations were from the east coast of the South Island (Figure 2). The un-groomed trial dataset consists of 3008 observation periods made during the course of 1086 tows. Table 2 records the number of observation periods recorded under each treatment.

Figure 1. Temporal distribution of tows with seabird strike observations for observed trips in the 2006 southern squid fishery. Gaps in the bars indicate days without seabird strike observations.



[2] Fisheries (Incidental Bycatch of Seabirds by Trawl Vessels 46m+) Notice 2005.
[3] Fisheries (Incidental Bycatch of Seabirds by Trawl Vessels 28m+) Notice 2006.

Figure 2. Spatial distribution of tows with seabird strike observations in the 2006 southern squid fishery.



All three mitigation devices were recorded as not meeting the trial specification for some observation periods (Table 2). For two trips (2204 and 2238) the observer consistently recorded that the bird baffler deployed did not comply with the trial specification. Likewise the tori lines deployed on trips 2238 and 2240 were recorded as not to specification for all observations. Observer comments are summarised in Table 3 for those cases where a particular mitigation device was recorded as not meeting the trial specification for the entire trip.

No vessels were observed on more than one trip in the 2006 squid fishery. Seventeen observers were involved in the trial. Four observers undertook two trips, one of whom also participated in a dual observer trip.

Decision rule

To balance the need to allow statistically robust investigations of mitigation efficacy with the avoidance of unnecessary mortalities of protected species that may result from the use of different treatments, the trial design included a decision rule. Observers maintained a running total of dead seabirds recovered from the warps, mitigation device, or unknown sources (not net captures). If the cumulative total on the trip exceeded 20, the use of experimental treatments was suspended, with the vessel reverting to the use of the regulated mitigation measure on all trawls until either the end of the trip or notified by the Special Permit holder that particular treatments should resume. The trial design allowed for the Special Permit holder to instruct vessels to resume trials following an examination of the nature of the captures by the Technical Advisory Group.

The decision rule was triggered on one of the trips (2202). The capture tally was reviewed by the Technical Advisory Group, which recommended resumption of the trials with the bird baffler treatment omitted. The limit of 20 mortalities was retained but tows previously carried out under the bird baffler treatment were not included in the tally, effectively increasing the limit for the trip by six. After resuming the trials the decision rule was triggered again following captures during no-mitigation treatments. As a result trials remained suspended on the vessel until the end of the trip, with tori lines and bird bafflers used on all tows.

Table 2. Number of sample periods (both warp strike and mitigation device strike) observed under the different mitigation treatments for the trips included in the 2006 warp strike mitigation device trials.

Trip	Sample periods per mitigation treatment								Total sample periods observed	Observers
	No mitigation	Bird bafflers		Tori lines		Warp scarers		Bird bafflers and tori lines		
		To spec.	Not to spec.	To spec.	Not to spec.	To spec.	Not to spec.			
2201	44			53		47			144	1
2202	20	38		55		24		98	235	1
2203	18			45		38			101	1
2204	21		79	49		29	9		187	1
2205	33	119	3	121	9	119	6		410	2
2206	37	34		29		49			149	1
2207	20			31		29			80	1
2208	97			148		103	2		350	1
2211	14			20		24			58	1
2213	27			32		56			115	1
2214	47			56		36			139	2
2220	11	153		29		2	20		215	1
2222	21			41	16	2			80	2
2226	22			31	39	28	12		132	1
2227	30	82		89		76			277	1
2238	33		54		42	44	14		187	1
2240	45				26	8	21		100	1
2241	10			23	2	14			49	1
Total	*550*	*426*	*136*	*852*	*134*	*728*	*84*	*98*	***3008***	

Table 3. Summarised interpretation of observer comments indicating why particular devices were recorded as not meeting the trial specifications for an entire trip.

Trip	*Mitigation device*	*Summary of observer comments*
2204	Bird bafflers	Baffler dropper lines consistently too high above the water.
2238	Bird bafflers	No clear reason given for failure to meet specification. Dropper lines noted to be tangled on occasion.
2238	Tori lines	Streamers do not reach water surface, buoy does not keep backbone taught.
2240	Tori lines	Streamers missing or tied up.

DATA INTERPRETATION AND GROOMING

A number of records were corrected, or omitted from the analysis dataset (Table 4). Of the 3008 recorded observation periods, 67 did not record whether the warp or mitigation device was observed. These records were omitted. Observation time could not be calculated (because of a missing observation start or end time) in 17 records, and a further 89 records had observation times that differed from the intended 15 minutes. In the majority of these latter records, the observer comments indicated that the observation period was terminated early due to the vessel hauling or turning. Although these records could be included in analyses by considering the rate of seabird contacts, rather than the number of contacts per 15 minute observation period, the number of records affected is small and so these were omitted.

Records were not used where the number of large or small bird contacts with the warp or mitigation device was not recorded. In most cases both these response variables were not recorded. Although in some cases these missing values could legitimately be interpreted as zeros, comments in a number of records indicate that the observation was aborted for some reason.

If the side observed was not recorded, then this was replaced with the side recorded for the remainder of the trip, so long as only one observation side was recorded on the trip. Otherwise these records were omitted.

On three trips (2208, 2226 and 2240) the observers deviated from the protocol and carried out seabird strike observations on both sides of the vessel. For trip 2208 four observation periods on a single tow (from a total for the trip of 350) were carried out on the starboard side. It is not clear why this occurred, although the observer does indicate that on this tow the port warp received no coverage from the tori lines due to the warp angles. Comments also indicated that two of these observations were carried out from the deck and two from the bridge. On trip 2226 the first eight observations, over three tows, were made on the starboard side whilst the remainder of the observations on the trip were made on the port side gear. The observer appears to have recorded the reason for the change, but this comment is truncated in the data extract (or in the database). On trip 2240 the observer undertook 12 observations of the port side gear. These were additional observations on tows where observations on the standard starboard side had also been completed.

The seabird strike protocol required observations to be carried out on one side of the vessel only to avoid the possibility that observers might choose to make observations "where the action was", i.e. where they perceive that most strikes are occurring. By sticking to one side the observations should be representative of conditions on that side of the vessel over the course of the trip, and should best sample the range of conditions encountered. The protocol does, however, recognise that offal may be discharged preferentially from one side of the vessel, and indicates this side should be the observation side if safety considerations allow. Thus, it is not the case that the observed strike rate could simply be doubled to get an estimate of the strike rate on the warps or mitigation devices on both sides of the vessel. Environmental conditions that affect the distribution of offal behind the vessel, or the performance of mitigation devices, may have different effects on the two sides of the vessel. The observations carried out during trip 2240 may provide an opportunity to investigate whether these effects are detectable, although the sample size is limited. However, for the analyses reported here, the additional observations from the side of the vessel that was not typically observed on the trip were omitted.

Table 4. Summary of primary data problems identified, and grooming and interpretation undertaken prior to further analyses.

Problem	*Number of records affected*	*Solution*
Observation area not recorded	67	Records omitted
Observation time missing	17	Records omitted
Observation time not 15 mins	89	Records omitted
Large bird contacts not recorded	26	Records omitted
Small bird contacts not recorded	25	Records omitted
Observation side not recorded	21	Inferred from observation side of other records in trip, if only one side recorded for trip. Otherwise omitted.
Observations of the warp/mitigation device on the opposite side to that typically observed on the trip	24	Records omitted
Simultaneous observation of seabird strikes on warp and warp scarer	33	Records omitted
Whether or not tori lines were deployed is not recorded	64	Nulls are treated as not deployed.
Whether or not bird bafflers were deployed is not recorded	91	Nulls are treated as not deployed.
Whether or not warp scarers were deployed is not recorded	69	Nulls are treated as not deployed.
Mitigation device recorded as observed, but no mitigation recorded as deployed	20*	Records omitted
Bird bafflers and tori lines deployed	98	Records omitted

* Excludes records fixed by the changes recorded in Table 5.

On trip 2204 the observer undertook simultaneous observations of seabird strikes and the mitigation device. This was only done during warp scarer treatments, but represents the majority (33 of 37) of observations carried out under this treatment. The close proximity of the warp and the warp scarer backbone (Figure 3) suggests that simultaneous observation of these areas is not unreasonable. However, these observations create analysis difficulties as each of the records would have to be included twice: once as a warp strike observation and once as a mitigation device observation. They were therefore omitted from the analysis dataset.

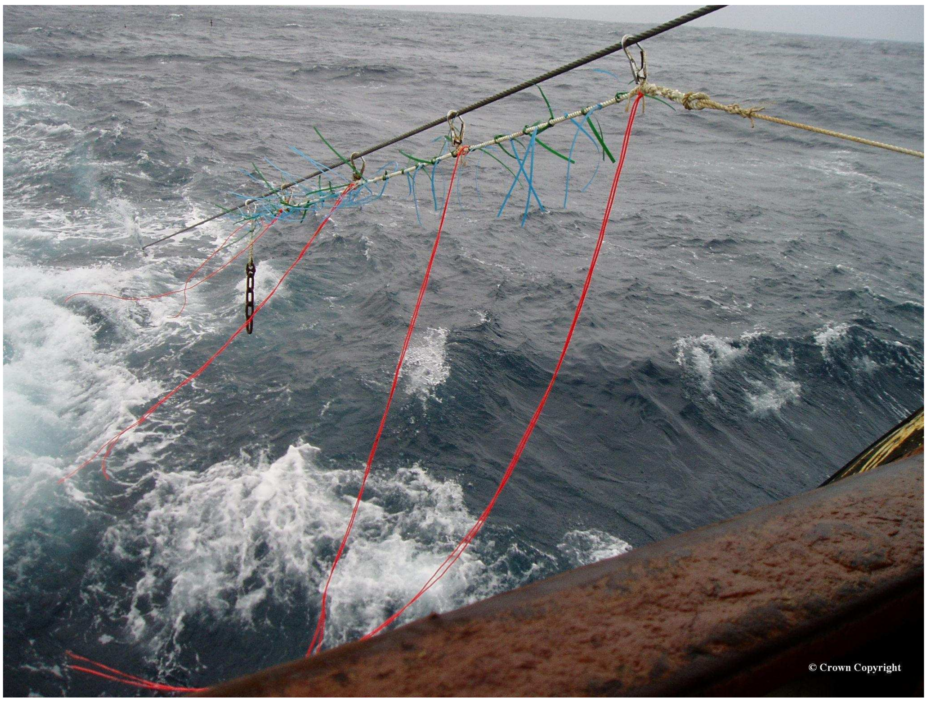
The observation protocol records the mitigation devices deployed at the level of the individual observation periods, as there is potential for the mitigation used to be varied over the course of a trawl. However, data from the trial indicate this was not always adequately recorded on the forms. Although the main devices (tori lines, bafflers and warp scarers) required recording a "yes" or "no" answer to whether a device was deployed, these were frequently left null (Table 4). In particular it appeared that, on occasions, observers might only record the mitigation deployed for the first observation during a particular tow. As the experimental design required the deployment of a single mitigation device per tow, it was expected that a genuine change in mitigation device would be noted in the observer's comments for an observation. As a result of these problems, all nulls in the recording of whether a particular mitigation device was deployed were treated as "N", indicating that the device was not deployed. In many cases where all three mitigation devices were left null, a comment (e.g. "no mitigation" or "control") in the "other mitigation" field specifically indicated that no devices were deployed.

Treating non-recording of mitigation device status as indicating that a device was not deployed also resolved a number of instances where mitigation was recorded differently for samples within a particular tow. The remaining cases were examined manually and a number of records were edited to reflect the interpretation that only a single mitigation device was deployed during a tow (Table 5). Records were retained where a comment explained a genuine change in the mitigation deployed. However, observations from three tows (trip 2205, tow 55; trip 2238, tows 47 and 51) were omitted because records indicated the mitigation deployed had changed within the course of the tow, but no comments were made to confirm this was the case, and no clear interpretation could be made to reconcile the records.

Despite the efforts made to correctly interpret the mitigation deployed during an observation period, a number of records that indicated that strikes on the mitigation device were observed but no mitigation devices were recorded as deployed. These were dropped from the analysis.

The observations carried out on trip 2202 with both bafflers and tori lines deployed (after the decision rule had triggered) were also excluded from the main analysis. Although these were legitimate observations with multiple devices deployed, there were no comparable observations from other vessels.

Figure 3. Trawl warp with warp scarer deployed on trip 2204.



The data grooming summarised in Table 4 removes 363 (12%) of the observations in the trial dataset. However, a number of the remaining records have incomplete recording of covariates (Table 6). As the discharge of offal is known to be an important factor influencing seabird warp strike rate (e.g. Abraham, 2005) all records where discharge was incompletely or inconsistently recorded were dropped from the analysis dataset. For consistency, and because a relatively small number of records were affected, observation periods where other environmental covariates were incompletely or inconsistently recorded (Table 6) were also dropped.

The final analysis dataset consisted of 2570 records, just over 85% of the ungroomed data, representing over 640 hours of observation (Table 7).

Table 5. Specific edits made to the mitigation related field of records in the analysis dataset.

Trip	*Tow*	*Sample*	*Field*	*Comment*
2202	13	2	tori_line	Changed from N to Y. Is a mitigation device observation, but no mitigation device recorded. Changed to match previous sample on this tow.
2204	104	2	tori_line, warp_scarer, bird_baffler	All mitigation was null. Changed to match previous sample (tori_line=N, warp_scarer=N, bird_baffler=X). Supported by comment.
2204	22	2	tori_line, warp_scarer, bird_baffler	All mitigation was null. Changed to match previous and subsequent samples (tori_line=Y, warp_scarer=N, bird_baffler=N).
2204	39	1,2	bird_baffler	Changed bird_baffler from N to X to match samples 3 and 4. Sample 2 is a mitigation device observation.
2205	101	2	tori_line, warp_scarer, bird_baffler	All mitigation was null. Changed to match previous and subsequent samples (tori_line=Y, warp_scarer=N, bird_baffler=N). Is a mitigation device observation.
2208	101	4	tori_line, warp_scarer, bird_baffler	All mitigation was null. Changed to match previous and subsequent samples (tori_line=Y, warp_scarer=N, bird_baffler=N). Is a mitigation device observation.
2214	35	5,6	tori_line, warp_scarer, bird_baffler	All mitigation was null. Changed to match previous samples (tori_line=Y, warp_scarer=N, bird_baffler=N). NB no samples 3 & 4.
2222	9	2	tori_line, warp_scarer, bird_baffler	All mitigation was null. Changed to match previous and subsequent samples (tori_line=Y, warp_scarer=N, bird_baffler=N). Is a mitigation device observation.
2226	19	3	tori_line	Changed from N to X. Is a mitigation device observation, but no mitigation device recorded. Changed to match previous samples on this tow.
2226	21	3	tori_line	Changed from N to X. Is a mitigation device observation, but no mitigation device recorded. Changed to match previous sample on this tow. Supported by comment.
2227	36	4	tori_line, warp_scarer, bird_baffler	Mitigation was given as tori_line=Y, warp_scarer=N, bird_baffler=Y. Changed to match previous and subsequent samples (tori_line=N, warp_scarer=Y, bird_baffler=N). Is a mitigation device observation. No comment indicating change of devices.
2240	45	1	tori_line	Changed from N to X to match subsequent sample on this tow. Supported by comment.

Table 6. Summary of missing or incompatible covariates among the 2645 records remaining after initial grooming (Table 5). These records were also dropped from the final analysis dataset.

Covariate problem	*Number of records affected*
Discharge rate and discharge type are null	14
Discharge rate is null but a discharge type is recorded	12
Discharge rate is 0 ("none") but a discharge type is recorded	2
Discharge rate is greater than 0 but discharge type is not recorded	8
Swell direction not recorded but swell height is greater than zero	11
Wind speed is not recorded	9
Wind direction not recorded but wind speed is greater than zero	18
Discharge side is not recorded but discharge is recorded	3

Table 7. Number of seabird strike observations of trawl warps and mitigation devices periods by treatment and trip retained in the analysis dataset, together with the number of rejected observations per trip.

	Trawl warp observations				*Mitigation device observations*			
Trip	No mitigation	Bird bafflers	Warp scarers	Tori lines	Bird bafflers	Warp scarers	Tori lines	*Observations rejected*
2201	39	0	26	26	0	21	25	7
2202	19	18	13	27	16	11	27	104*
2203	18	0	18	21	0	18	22	4
2204	18	32	1	22	33	1	15	65
2205	32	57	58	62	54	52	55	40
2206	21	14	19	13	12	16	12	42
2207	17	0	11	13	0	11	12	16
2208	86	0	49	70	0	45	57	43
2211	14	0	12	9	0	12	7	4
2213	27	0	27	16	0	27	16	2
2214	44	0	18	25	0	16	21	15
2220	10	85	13	17	56	7	5	22
2222	17	0	1	28	0	1	26	7
2226	17	0	18	31	0	16	31	19
2227	27	37	37	44	37	37	43	15
2238	31	27	29	17	27	29	17	10
2240	33	0	11	13	0	14	11	18
2241	9	0	7	10	0	7	11	5
Total	*479*	*270*	*368*	*464*	*235*	*341*	*413*	*438*

* Includes 98 observations with bafflers and tori lines deployed subsequent to triggering of decision rule.

DATA ANALYSIS

Preliminary summaries of contact rates were carried out to investigate the effect of various factors (including treatment, vessel and discharge) on the numbers of heavy seabird contacts on the warps and mitigation devices. Because of the large number of observations with no observed contacts, simple graphical summaries (such as boxplots) tended to lack resolution. These data were therefore summarised by calculating the sample mean contact rate, and a 95% confidence interval for the mean was estimated by bootstrapping. The bootstrap used here simply resampled individual observation periods. This ignores the nested structure of the dataset, where observations occur within tows which occur within trips. Correlations between observations on the same tow, and from the same trip are likely. As a result the confidence intervals shown should primarily be treated as illustrative data exploration tools, rather than precise indicators of significant differences between means.

Generalised linear models were fitted to take account of the effects of covariates when quantifying the between-treatment differences in seabird strike rate. The appropriate distribution for representing count data which is generated by a process with a constant average rate is the Poisson distribution. Actual animal count data is often over-dispersed relative to the Poisson. There are two approaches that are commonly used for dealing with this situation in regression modelling. Firstly, a negative binomial distribution may be assumed; this was the approach taken to modelling warp strike data by Abraham (2005) and Sullivan et al. (2006). Negative binomial distributions are generated by a Poisson process where the underlying rate is varying. More generally, quasi-Poisson modelling may be applied (see, for example, Venables and Ripley, 2002, p.208). The quasi-likelihood method allows vessel and observer effects to be included as random effects, which is not straightforward for the negative binomial model. Rather than prescribing a fixed distribution, the quasi-Poisson model assumes that the variance of the distribution is proportional to the mean, with the proportionality constant being the dispersion parameter. This is all the information on the distribution which is needed to fit the model. The quasi-Poisson model, with random effects, is used here.

The models were fitted as mixed-effects models using the `lmer` routine in version 0.995-11 of the `Matrix` package (Bates and Maechler, 2006) in R, version 2.3.1 (R Development Core Team, 2006). The 'quasipoisson' family was used, with a log link function. Unless otherwise specified, the models were fitted to the data using the default penalised quasi-likelihood (PQL) method. An alternative scheme, the Laplace method, is also available. This method is slower to fit, but may be more accurate, and was used to check the PQL results. An automated procedure was used to select between potential covariates. This used an iterative 'greedy stepper' routine. At each iteration, the remaining potential covariates were added to the model one at a time. The covariate which caused the greatest decrease in the Mallows' C_p (Mallows, 1973) was added to the model. The procedure was repeated until adding a new term would reduce the C_p by 2% or less. This threshold prevents the addition of terms which have little influence on the model. The value of 2% was chosen by trial and error to retain an intermediate number of terms.

The Akaike Information Criterion, or AIC, is often used in model selection, however it cannot be calculated for the quasi-likelihood models (Venables and Ripley, 2002), and so C_p may be used instead. Confusingly, C_p is referred to within `lmer` as the 'AIC'. It is calculated as *deviance* + 2*p*, where *p* is the number of degrees of freedom. Although C_p should include a factor which is related to the scale of the distribution, this is not included in the `lmer` calculation. Nevertheless, this quantity allows a trade off to be made between a reduction in deviance and an increase in the number of degrees of freedom.

RESULTS

TRIAL ENVIRONMENT

Observations were spread reasonably evenly over daylight hours (Figure 4), generally with the vessel towing in to the prevailing wind and swell with wind speeds of 6 or less (Beaufort scale) and swells of 3 m or less (Figure 5). The port warp was observed on 11 vessels and the starboard warp on 7. Discharge occurred on both sides of the vessel during almost half of the observations (Figure 6), with sump water the discharge type recorded most frequently (Figure 7).

Figure 4. Distribution of observation start hour for the 2570 records in the analysis dataset.

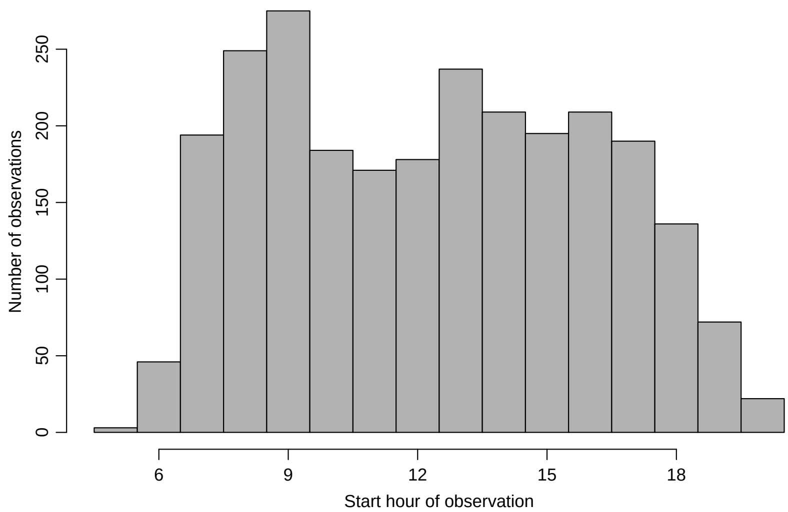
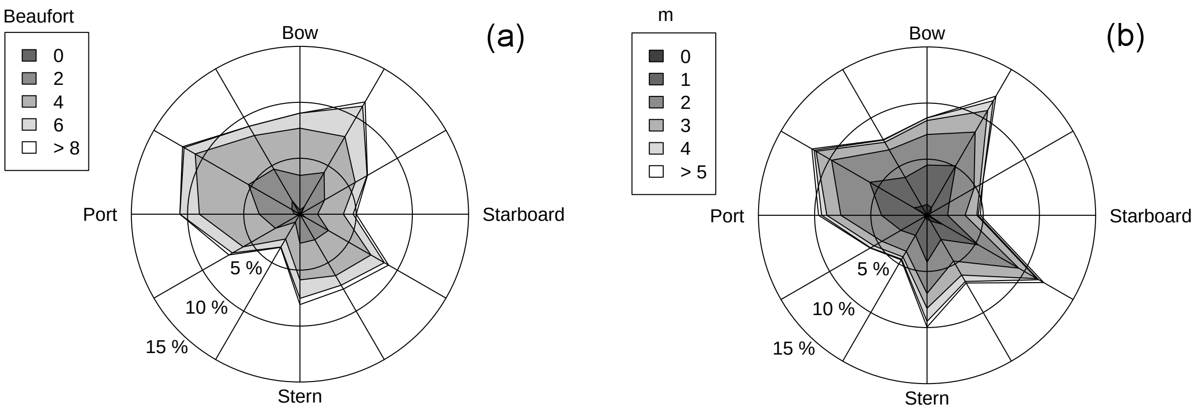


Figure 5. Distributions of (a) wind and (b) swell during observations. Directions were recorded on a 12 point scale relative to the vessel heading.



Although multiple discharge types were sometimes recorded during seabird strike observations, a small number of discharge types dominate the dataset (Table 8). Observations with no discharge (30.5% of observer sample periods), or only sump water discharges (32.4%) were most frequent. Offal was discharged in 21.9% of observation periods, most frequently together with sump water.

Using an assumed discharge type size hierarchy of S < M < C < O < D, all observations were assigned a maximum discharge particle size. The distribution of maximum discharge size recorded during seabird strike observations varied considerably between trips (Figure 8). With the exception of trip 2213, minced and cutter pump discharges were generally not recorded on the same trips.

Figure 6. Distribution of discharge side recorded over all observation periods.

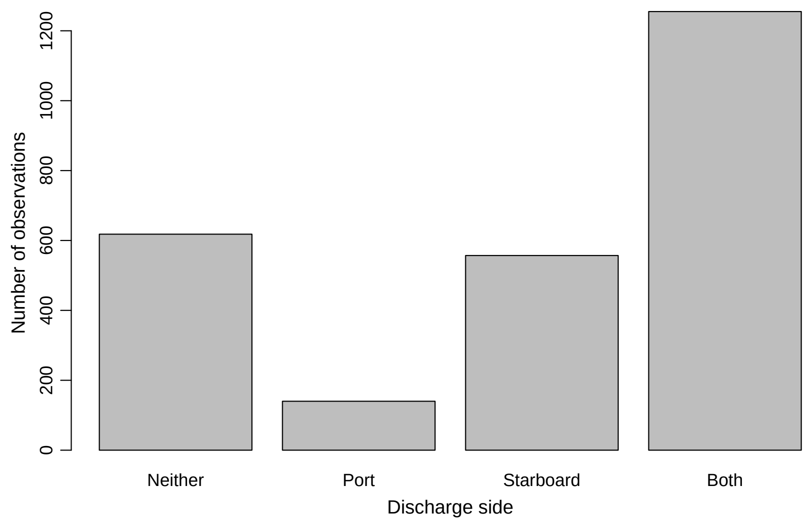
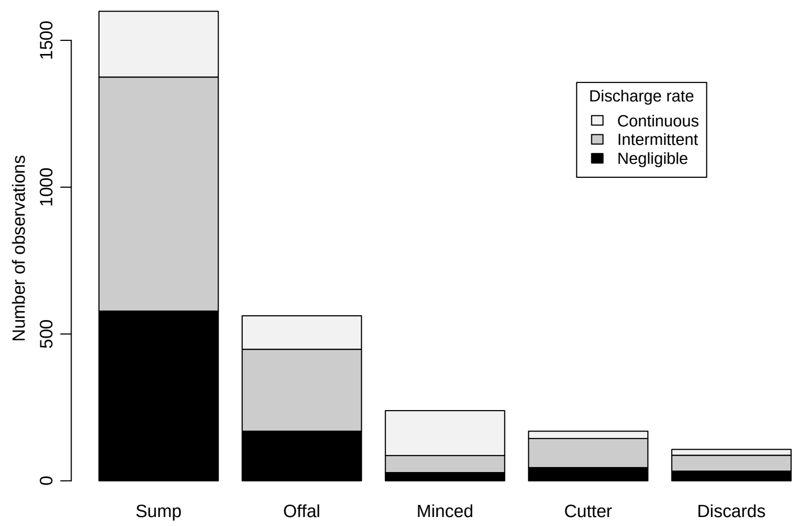


Figure 7. Distribution of discharge type and rate recorded over all observation periods.



The majority (80.7%) of observations took place during tows targeting squid, whilst the remainder were during finfish target tows (Figure 9). In the analysis dataset the mitigation device deployed was recorded as not meeting the trial device specifications during 307 observations. This occurred most frequently for bird bafflers (122 out of 383 observations) followed by tori lines (117 out of 760 observations) and then warp scarers (68 out of 641 observations). No explanation of the failure to meet the specification was provided in 168 (54.7%) of these observations.

Table 8. Discharge types and rates recorded during seabird strike observations. For discharge type, S is sump water, M is minced discharge, C is cutter pump output, O is offal (heads, guts etc.) and D is whole fish discards.

Discharge type	*Discharge rate*				*Total*
	None	Negligible	Intermittent	Continuous	
None	786	0	0	0	*786*
S	0	358	402	72	*832*
SC	0	45	77	17	*139*
SCD	0	0	1	0	*1*
SCO	0	0	6	0	*6*
SD	0	9	25	6	*40*
SM	0	9	26	27	*62*
SMC	0	0	6	3	*9*
SMD	0	0	1	0	*1*
SMO	0	0	3	9	*12*
SO	0	136	237	83	*456*
SOD	0	21	13	7	*41*
C	0	0	3	0	*3*
D	0	1	1	2	*4*
M	0	9	8	95	*112*
MC	0	0	4	5	*9*
MCO	0	0	2	0	*2*
MD	0	2	3	5	*10*
MO	0	8	3	9	*20*
MOD	0	0	2	0	*2*
O	0	4	5	6	*15*
OD	0	0	8	0	*8*
Total	*786*	*602*	*836*	*346*	*2570*

Figure 8. Trip by trip summary of the maximum size of discharge type recorded during seabird strike observations, assuming that the discharge type size hierarchy is S < M < C < O < D.

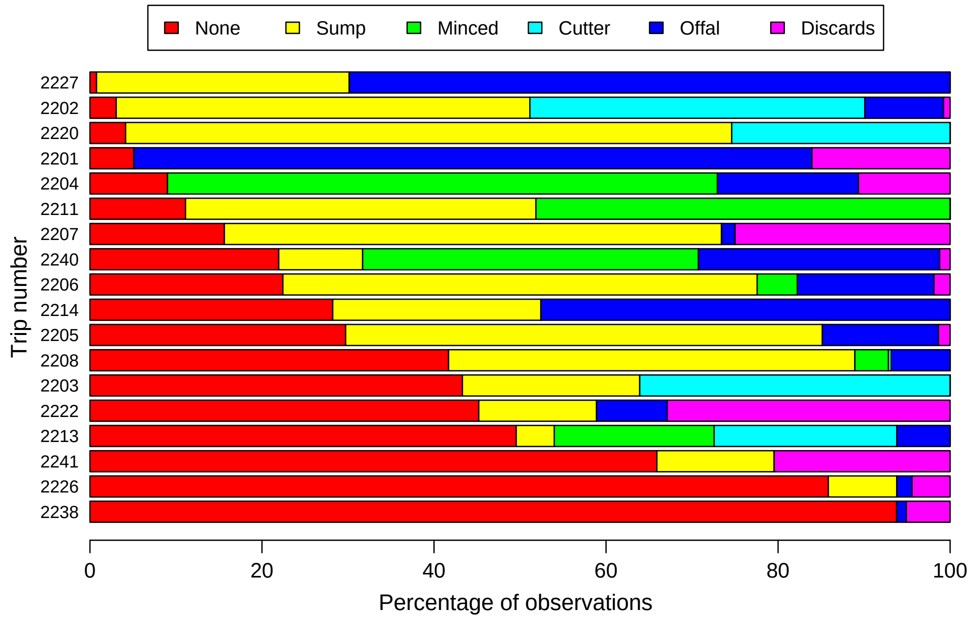
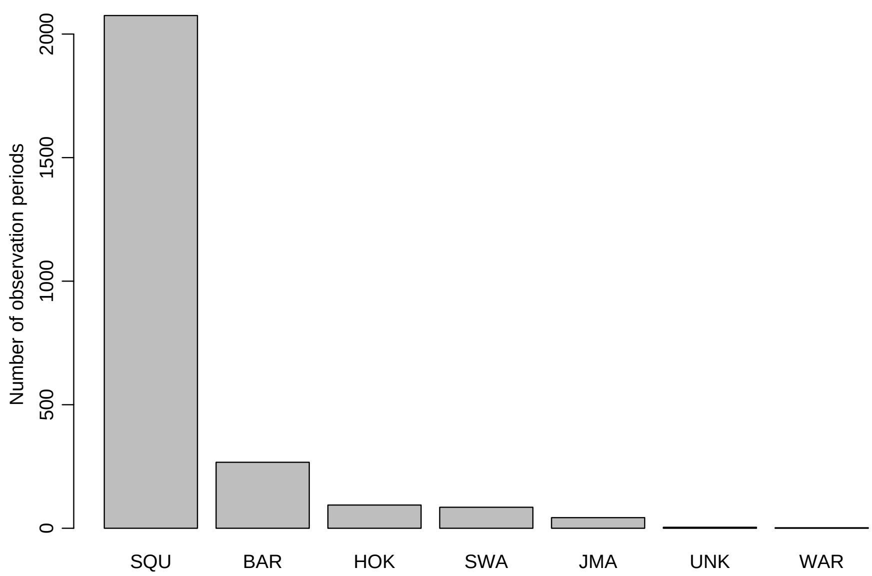


Figure 9. Observer recorded target species of tows during which seabird strike observations were carried out. Species codes are as follows: SQU = arrow squid (*Nototodarus gouldi*, *N. sloanii*), BAR = barracouta (*Thyrsites atun*), HOK = hoki (*Macruronus novaezelandiae*), SWA = silver warehou (*Seriolella punctata*), JMA = jack mackerel (*Trachurus declivis*, *T. novaezelandiae*, *T. murphyi*), WAR = blue warehou (*Seriolella brama*), UNK = not recorded.



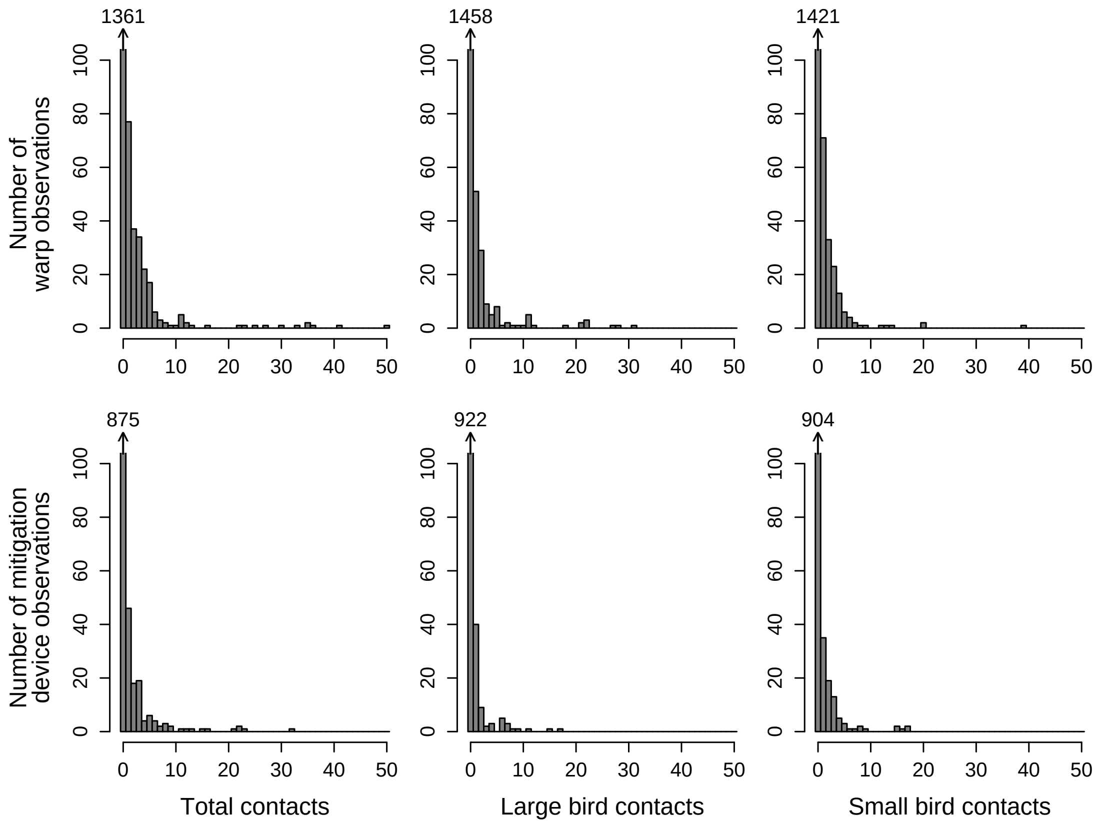
SEABIRD STRIKES: EXPLORATORY ANALYSES

Heavy strikes by seabirds on the warps or mitigation device were rare. Of the 1581 warp observation periods, 1381 (87.3%) had no heavy seabird contacts recorded. There were no recorded seabird strikes in 875 (88.5%) of the 989 mitigation device observation periods. Large numbers of heavy strikes (up to a maximum of 50 in one 15 minute observation) occurred infrequently, producing highly skewed frequency distributions of the number of heavy contacts (Figure 10). No warp strikes were recorded on one trip, and no large seabird warp strikes were recorded on three trips.

The overall means and 95% confidence intervals for total (i.e. large and small seabird) contacts with the warp and mitigation device, under each treatment and using the full trial dataset are illustrated in Figure 11. Mean warp strike rates were similar for the no mitigation and bird baffler treatments. The mean warp strike rate with warp scarers deployed was about half that with no mitigation, but the 95% confidence intervals for these means overlap considerably. The tori line treatment showed a significant reduction in mean warp strike rate, to about 15% of the mean no mitigation rate.

Very few heavy seabird contacts were recorded with either the bird bafflers or warp scarers over the course of the trial. Seabird contact rates with tori lines, however, were similar to contact rates for the warps with no mitigation deployed (Figure 11b).

Figure 10. Overall frequency distributions of the number of heavy seabird contacts per 15 minute warp strike observation period for warps and mitigation devices.



There is considerable between vessel variability in the seabird contact rates observed with the trawl warps and mitigation devices under the different experimental treatments (Figure 12). It is clear that warp strike rates, in the absence of mitigation, vary significantly among vessels. Patterns in the overall dataset (Figure 11), such as the high strike rates on tori lines, are by no means universal across the observed trips. Furthermore, some vessels where a high mean number of tori line strikes are recorded have much lower strike rates on the trawl warps in the absence of mitigation. Figure 12 also provides an indication that the seabird strike rates recorded by different observers on the same trip are not too dissimilar.

Seabird strike rates varied greatly with discharge type and rate (Figure 13). Only three small bird contacts, and one large bird contact were observed in the 786 observation periods with no discharge. Three of these contacts (2 small, 1 large bird) were with the mitigation device. Contact rates were slightly higher when sump water was discharged, and increased with discharge rate. Contacts were much more frequent when the discharge included offal, including minced and cutter pump output, and discards.

Overall, increasing discharge rate is associated with a clear increase in seabird strike rate (Figure 14a). Investigating the effect of the individual discharge types is more complex as several discharge types could occur throughout an observation (Table 8). Figure 14b illustrates overall total seabird contact rates for the different discharge types in two ways. In one method, observations are assigned to the discharge type categories when that discharge type was present in an observation. In this case an observation may be assigned to more than one category. Alternatively observations can be assigned to a discharge category only when that discharge type was the largest discharge present. For sump water discharge these different methods result in quite different mean seabird contact rates, with other types of discharge clearly resulting in higher strike rates than sump water alone. At the other extreme, the two discharge classifications produce an identical set of observations for discards: when present it is always the largest discharge type present. As discards almost always co-occurred with other discharge types, simple data summaries cannot isolate the effect of discards alone.

Figure 11. Mean (x) and 95% bootstrap percentile confidence intervals (based on 5000 bootstrap samples) for the number of heavy seabird strikes on (a) trawl warps and (b) mitigation devices, by treatment for the full trial dataset.

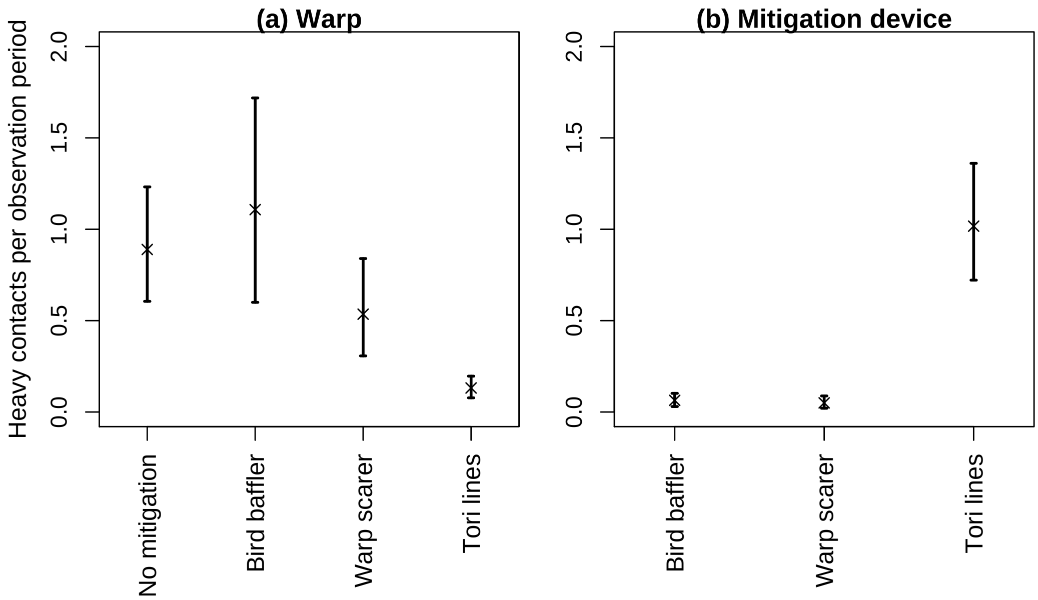


Figure 12. Mean and 95% bootstrap percentile confidence intervals (based on 5000 bootstrap samples) for the number of heavy seabird strikes on trawl warps and mitigation devices, by treatment for individual trips and individual observers on dual-observer trips.

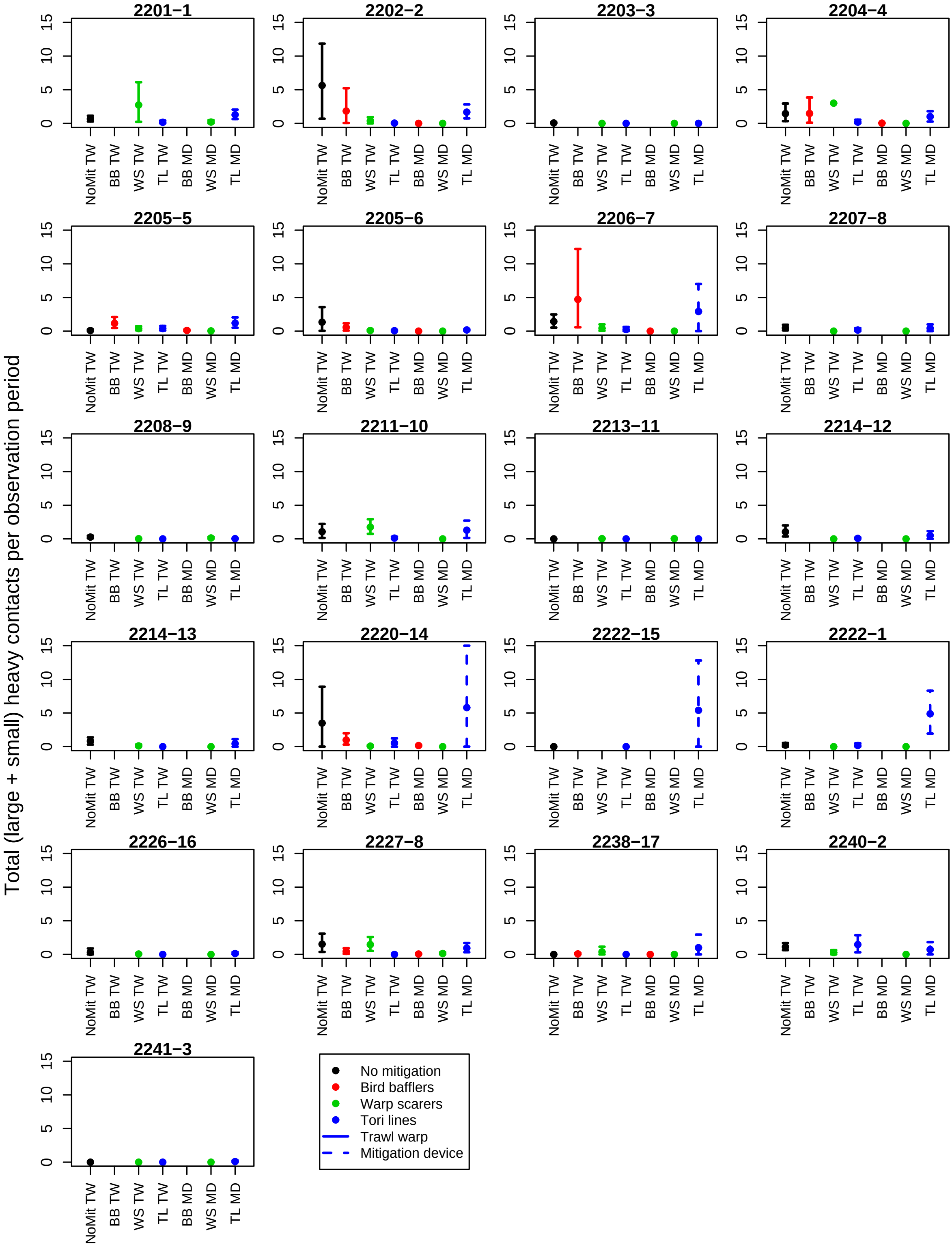


Figure 13. Mean (x) and 95% bootstrap percentile confidence intervals (based on 5000 bootstrap samples) of the number of heavy seabird strikes for all discharge type and rate categories (Table 8) where the number of observations was greater than 10.

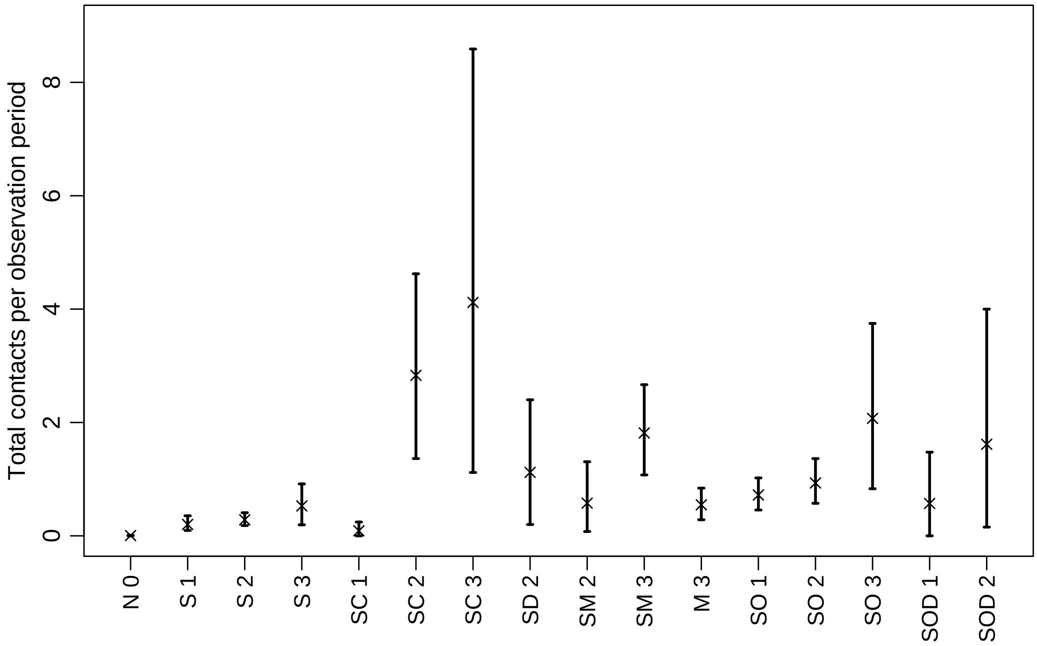
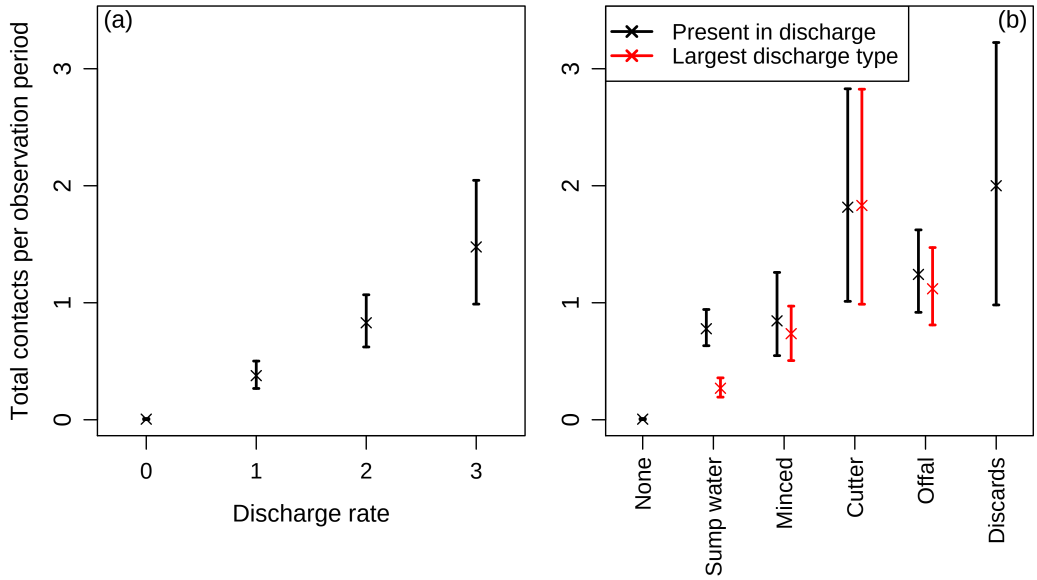


Figure 14. Mean (x) and 95% bootstrap percentile confidence intervals (based on 5000 bootstrap samples) of the number of heavy seabird strikes for (a) the four discharge rates and (b) the different discharge types. Multiple discharge types may be present, so observations are assigned to these categories based on whether the discharge type was present (an observation may fall in more than one category) and also according to whether the discharge type was the largest discharge type present.



SEABIRD ABUNDANCE

As with seabird strikes the distributions of seabird counts were highly skewed (Figure 15), although zero counts were less prevalent than zero strikes. No large seabirds were counted during 203 (7.9%) observation periods, and no small seabirds during 163 (6.3%) observations. Counts of both large and small birds increased with increasing discharge rate (Figure 16a). Seabird abundance also tended to increase as the size of discharge increased (Figure 16b).

Figure 15. Overall frequency distributions of large and small seabird counts prior to seabird strike observation periods.

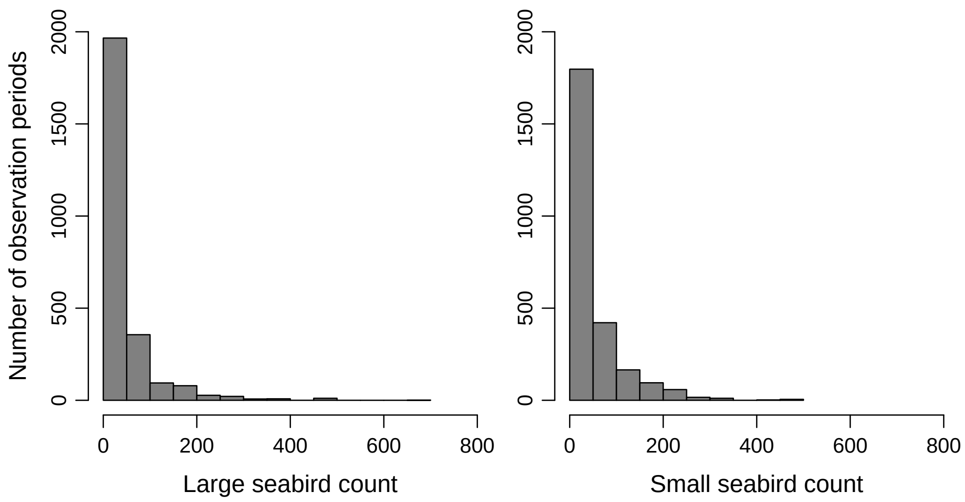


Figure 16. Mean (x) and 95% bootstrap percentile confidence intervals (based on 5000 bootstrap samples) of counts of large and small seabirds for (a) the four discharge rates and (b) the different discharge types. Observations were assigned to discharge categories according to whether the discharge type was the largest discharge type present.

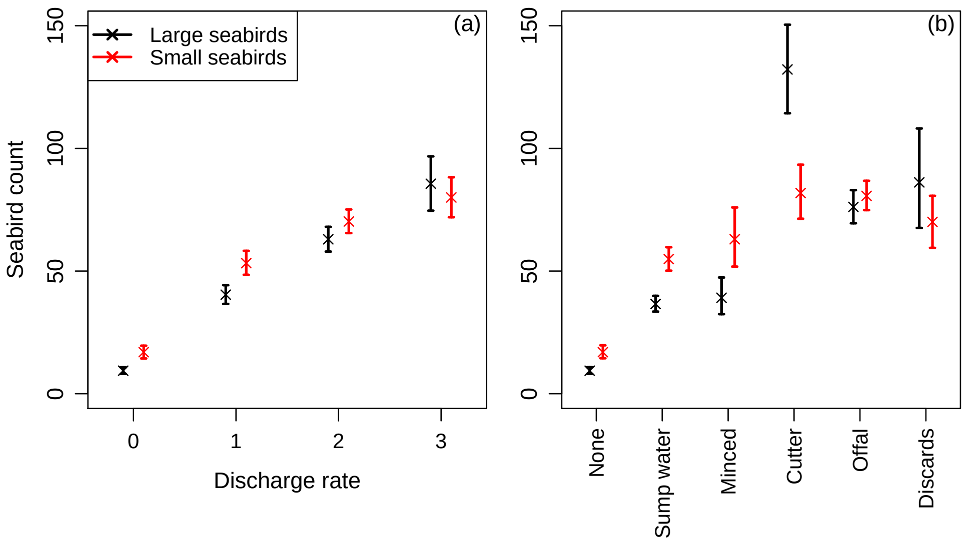
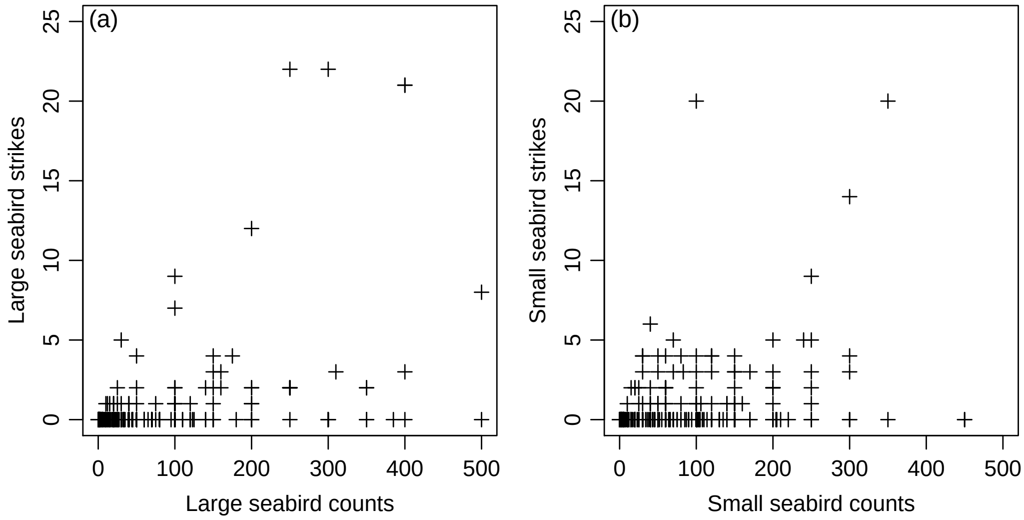


Figure 17. Scatter plots showing the relationship between seabird counts and seabird warp strikes with no mitigation deployed for (a) large seabirds and (b) small seabirds.



Although both seabird counts and seabird strikes show similar responses to vessel discharge, and there is a clear causative relationship with discharge attracting seabirds which are then vulnerable to warp strike, the relationship between seabird abundance and warp strike is nevertheless very noisy (Figure 17).

SEABIRD STRIKES: STATISTICAL MODELLING

The simple data analyses reported above strongly suggest that there is variation in the efficacy of the three mitigation devices (Figure 11). Because a balanced experimental design was used, with multiple devices being trialled on multiple trips and random assignment of treatments to tows, it is expected that these initial results will be robust. Nevertheless, there may be correlations between factors, such as the discharge of offal, and the use of particular mitigation. For example, it is in principle possible that all observations of tori lines were associated with low discharge, in which case their apparent efficacy would then be due to the low discharge. The potential for such confounding is of particular concern given the sparseness of the dataset (i.e. large number of zero observations, Figure 10) and the variability observed between trips (Figure 12).

In order to properly quantify the difference between treatments we built separate regression models for large and small bird contacts. All covariates were included independently. No interaction terms were included.

Selection of observations for modelling

The aim of the modelling is to assess the efficacy of the mitigation. As discussed above, there were very few heavy contacts during observations made when there was no discharge. The average strike rate in the absence of discharge was 0.005 birds per observation, compared with a strike rate of 0.80 birds per observation across all other observations. The no-discharge data do not help discriminate between the mitigation devices, and so the modelling was restricted to observations where discharge was recorded.

Observers were asked to record whether the mitigation devices met the specification or not. This was a binary "yes" or "no" question, with no attempt to quantify the degree to which the mitigation devices failed to meet the specification. For the bird bafflers, a common reason was that they were too short and the droppers were well above the sea. Tori lines were recorded as failing to meet the specifications if they were missing streamers. On one trip they were also sometimes deployed with the buoys forward of the warp entry point. Warp scarers were typically recorded as not meeting the specification when they were deployed too short, with the weight well above the sea surface. Across the whole experiment the mitigation devices failed to meet the specifications on 143 (8%) of the otherwise good observations with discharge. In order to avoid having the model influenced by data from observations where the mitigation deployed did not meet the specification, these were removed from the analysis before carrying out the modelling. This has the most impact on the bird baffler data, with the bird bafflers not meeting the specification in two out of the seven trips on which they were deployed (Table 9).

Table 9. Number and percentage of observations removed from the modelling dataset (first eliminating those with no discharge, then those where the mitigation device was not to specification), and observations remaining, for each trip.

Trip	*Number of observations removed (percentage removed)*				*Observations remaining*
	No discharge	*Device not to specification*			
		Bird baffler	*Warp scarer*	*Tori line*	
2201	7 (5%)		0	0	130
2202	4 (3%)	0	0	0	127
2203	42 (43%)		0	0	55
2204	11 (9%)	59 (100%)	2 (100%)	0	50
2205	110 (30%)	1 (1%)	6 (8%)	8 (12%)	245
2206	24 (22%)	0	0	0	83
2207	10 (16%)		0	0	54
2208	128 (42%)		0	0	179
2211	6 (11%)		0	0	48
2213	56 (50%)		0	0	57
2214	35 (28%)		0	0	89
2220	8 (4%)	0	18 (90%)	0	167
2222	33 (45%)		0	6 (19%)	34
2226	97 (86%)		2 (25%)	4 (67%)	10
2227	2 (1%)	0	0	0	260
2238	166 (94%)	6 (100%)	0	2 (100%)	3
2240	18 (22%)		17 (74%)	12 (100%)	35
2241	29 (66%)			0	15
Total	*786*	*66*	*45*	*32*	*1641*

Covariates

Covariates which could potentially explain variability in the strike rate were selected from the data recorded by the observers, both on the forms particular to this experiment and from their standard station data. The details of the covariates used are discussed below.

Fixed effects

- Mitigation and gear observed `[miti]`

The key covariate for this experiment is the mitigation device itself. A categorical variable was made which combined the mitigation treatment ("No mitigation", "Bird baffler", "Warp scarer" or "Tori line"), and a flag ("TW", "MD") which indicated whether the trawl warp or the mitigation device was observed. There were seven combinations of these two factors in the data, as there are no mitigation device observations when no mitigation is used.

- Bird counts `[log(large_birds + 1), log(small_birds + 1)]`

The counts of both the large and small birds were included. Three forms were tried: the count itself, a categorical variable which grouped the counts into 4 ranges, and a log transform of the count data (log(count + 1)). The log transformed version had the most explanatory power and was included in the model. Because the model has a log link function, this allows for a linear relationship between the bird counts and the strikes.

- Discharge [`discharge_single, discharge_rate`]

Transformation of the discharge data into a form suitable for inclusion in the model was hampered by the fact that multiple discharge types were recorded on single tows. Several different methods were tried, and we settled on a hierarchical scheme for categorising the discharge. Each observation was classified by the highest category from the sequence sump < minced < offal < cutter < discards that appeared in the record. This sequence was derived from the strength of the mean total strike rate, grouped by discharge type (Figure 14b). For example, if the discharge type was recorded as "SM" then `discharge_single` would be "M", and if the discharge type was "MCD" then the factor `discharge_single` would be "D". This scheme minimised the numbers of degrees of freedom associated with the discharge. The discharge rate was included as a separate factor.

- Target species `[simple_target]`

Several target species were included in the data (Figure 9). Although the study was undertaken in the "squid fishery", squid is not the exclusive target species of this fishery. The main species targeted were squid (SQU), barracouta (BAR), hoki (HOK) and silver warehou (SWA). Other target species were grouped into an 'other' category (OTH), which also included tows where a target species was not recorded..

- Position [`lat_s, simple_fma`]

The position of each observation was represented by the decimal latitude of the tow start position, and by a reduced fisheries management area with categories SOI and SOU. All observations in other areas were grouped together in an 'other' category (OTH).

- Time and date [time_sin, time_cos, year_sin, year_cos]

The start time of the observation was included through a cosine (cos(2π hour)/24) and sine (sin(2π hour)/24) transform, where hour is the observation start time in decimal hours. This transform allows for a smoothly varying function of time of day to be represented. Similarly, a cosine (cos(2π day of year)/365.25) and sine (sin(2π day of year)/365.25) transform of the year-day was included, in case there were seasonal variations in the strike rate.

- Wind [wind_spd, wind_cos, abs(wind_sin)]

The wind speed is recorded by the observers on the Beaufort scale. This is included in the potential covariates as a numeric variable. The direction of the wind (recorded between 1 and 12 as a clockface, with 12 representing winds from the bow of the ship) is included as a cosine (cos(2π wind direction)/12) and sine transform. The absolute value of the cross-wind is included, such that the effect of a cross wind does not depend which side it is blowing from (see the directional variables below which represent the effect of discharge side relative to wind direction and the observed warp).

- Swell [swell_ht, swell_cos, abs(swell_sin)]

The other environmental variables that were recorded were the swell height (in metres) and the direction, recorded using the same notation used for the wind. The cosine and sine transformed swell direction was included.

- Directional variables [side_observed_wind, discharge_side_wind]

The number of strikes which are observed may depend on which side is observed, relative to the wind and to the discharge. Two covariates are included to capture this effect. The first, side_observed_wind, records which warp was observed relative to the wind direction. This has the categories of "Near" for the upwind warp, "Far" for the downwind warp, and "Neither" if the absolute value of wind_sin multiplied by the Beaufort wind-speed was less than 0.5 (i.e. essentially winds from the bow or the stern, or weak winds). The second variable relates the discharge side to the wind direction. If the discharge is from both sides of the vessel it has the value "Both". Otherwise, if the wind is blowing the discharge away from the vessel it takes the value "Upwind", and if the wind is blowing the discharge across the vessel then it takes the value "Near" for the observation side on the same side as the discharge side, or "Far" for the observation side across from the discharge side.

- Block height [block]

The height of the trawl blocks above the waterline, grouped into three categories: S (less than 5.0m), M (between 5.0m and 6.5m) and L (greater than 6.5m, with a maximum of 8m). These data were provided by John Cleal (F. V. Management Services) and Richard Wells (Clement & Associates) based on actual measurements (or plan based calculations) of some vessels, and extrapolation to vessels of the same class for the remainder of the fleet. Of the vessels participating in the trials, the numbers in each category were 2 (S), 9 (M), and 7 (L).

- Fishing speed [`fishing_speed`]

The vessel fishing speed in knots, from the observer data. The speed ranged from 3.2 knots to 5.7 knots, with a mean of 4.4 knots.

Random effects

There may be significant differences in the strike rates between vessels (equivalent to trips in these data) and between different observers on the same vessel. Rather than including the trip or the observer as a fixed covariate, they are represented as a random effect. It is assumed that there is a hierarchy, with the observer random effect being nested within the vessel random effect. The trip number and the observer initials (which were sufficient to distinguish the observers) were included as factors in the model, through a random effects term. The specification within the model was `1|trip_no/obs_initials`. All models discussed included this term.

Model results

After carrying out the model selection process described in the methods, the covariates which are retained in both the large bird and small bird models are the bird counts, the mitigation factor, the discharge rate, and the strength of the head or tail wind (Table 10 and Table 11). Other covariates which feature in one of the models are the discharge type, the side observed (relative to the wind), the strength of the head or tail swell, and the cosine and sine functions of the day of the year. The skill of the models is summarized by the amount of the initial deviance which they explain (63.8% for the large bird model and 53.8% for the small bird model). Of this, a relatively small amount is attributable to the random effects (8.4% and 10.0%, respectively). As a qualitative measure, quantile-quantile plots indicate a linear relationship between the modeled expected-values and the observed strike data (Figure 18 and Figure 19). This suggests that the model is capturing the principal variability in the data.

Table 10. Summary of the model building process for large bird strikes, showing the effect of sequentially adding in more terms.

Model	*Deviance*	*Percent of initial deviance*	*Percent reduction in deviance*	*Degrees of freedom*	C_p
Intercept	3619	100		1	
+ random effects	3316	91.6	8.4	2	3322
`+ log(large_birds + 1)`	2123	58.7	36.0	1	2131
`+ miti`	1658	45.8	21.9	6	1678
`+ discharge_rate`	1519	42.0	8.4	2	1543
`+ side_observed_wind`	1446	40.0	4.8	2	1474
`+ wind_cos`	1405	38.8	2.9	1	1435
`+ swell_cos`	1371	37.9	2.4	1	1403
`+ year_cos`	1341	37.0	2.2	1	1375
`+ year_sin`	1309	36.2	2.4	1	1345

Table 11. Summary of the model building process for small bird strikes, showing the effect of sequentially adding terms.

Model	*Deviance*	*Percent of initial deviance*	*Percent reduction in deviance*	*Degrees of freedom*	C_p
Intercept	3279	100		1	
+ random effects	2950	90.0	10.0	2	2956
`+ log(small_birds + 1)`	2166	66.1	26.6	1	2174
`+ miti`	1751	53.4	19.2	6	1771
`+ discharge_single`	1645	50.2	6.1	4	1673
`+ wind_cos`	1585	48.3	3.7	1	1615
`+ discharge_rate`	1536	46.7	3.3	2	1567

Figure 18. Quantile-quantile plot comparing the predicted large bird strikes to the observed strikes.

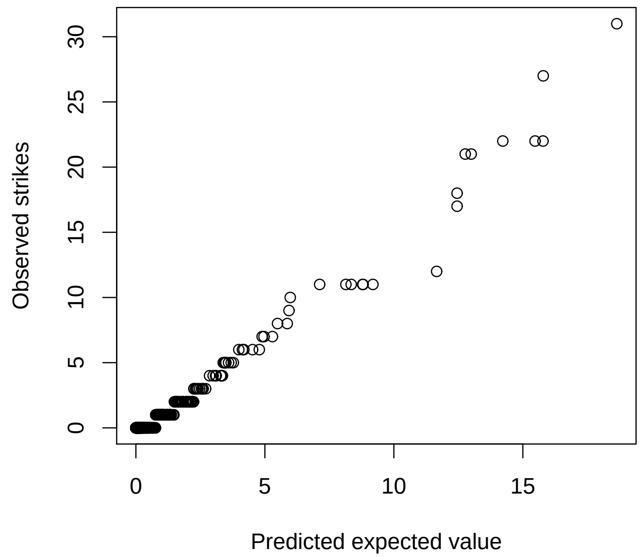
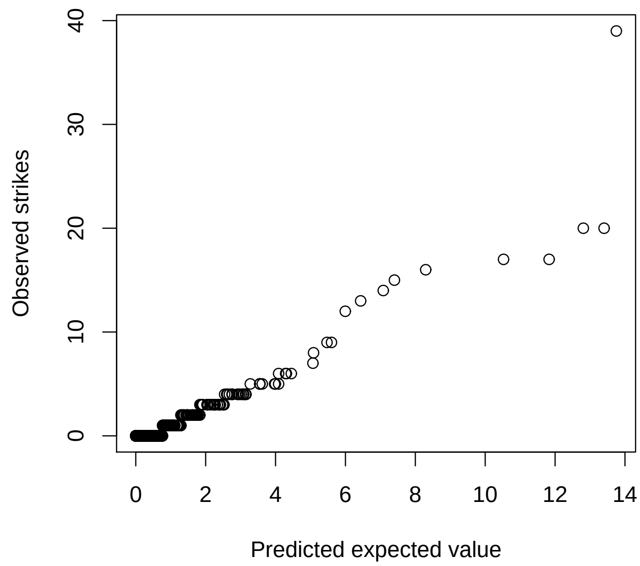


Figure 19. Quantile-quantile plot comparing the predicted small bird strikes to the observed strikes.



Coefficients of the fixed effects

The fitted model coefficients are shown in Table 12 (large birds) and Table 13 (small birds). In order for there to be strikes, there must be birds around the vessel. In both the large bird and the small bird models, a higher bird count is associated with a higher strike rate. The inclusion of the log transformed count makes the strike rate approximately proportional to the bird numbers. As would be expected, the model building selects the large bird count to explain the large bird strikes, and the small bird count to explain the small bird strikes. The coefficient is 1.57 ± 0.10 and 1.47 ± 0.10 for the large birds and the small birds, respectively. Being larger than one, this implies that the strike rate increases in a faster than linear way as the bird count increases.

The next term in both of the models is the mitigation factor, explaining 21.9% and 19.2% of the remaining deviance for the large and small birds, respectively. This factor includes which mitigation was used, as well as whether the observations were made on the warps or the mitigation device. For the large birds, all the mitigation devices significantly reduce the strikes on the trawl warps (Figure 20). The tori lines are the most effective device, reducing warp strikes to between 5% and 20% of their frequency in the absence of mitigation. There are few strikes on the bird bafflers or warp scarers, however strikes on the tori lines occur at a similar frequency to strikes on the trawl warps themselves. In general, the mitigation devices appear to be less effective at reducing the strikes on small birds (Figure 21). The mean coefficient for the reduction of warp strikes by bird bafflers and the warp scarers is less than one, but the bird baffler does not significantly reduce the warp strikes relative to no mitigation, and the warp scarers only just have a significant effect. For small birds, tori lines are also the most effective device at reducing strikes on the trawl warps.

In both models a higher discharge rate is associated with more strikes. This is in addition to any effect which is captured by the bird count data. The discharge type only appears in the small bird model. Although all discharge types are associated with significantly more strikes than sump water, they are not different from each other.

The other factor which appears in both models is the strength of the head or tail wind. For large birds a head wind is associated with more strikes, whereas for small birds a head wind is associated with fewer strikes.

Other factors in the large bird model are an association between a following sea and increased strikes, and a dependence of the strike rate on the time of year.

Table 12. Summary of the model terms for large bird strikes. The estimated values and the standard errors are of the linear predictor, and need to be exponentiated to obtain the strike rates. The significance values used are: $0.10 > p > 0.05$ (·), $0.05 > p > 0.01$ (*), $0.01 > p > 0.001$ (**), $p < 0.001$ (***).

Covariate	*Value*	*Estimate*	*Standard Error*	*Significance*
Intercept		-3.44	1.35	**
log(large_birds + 1)		1.57	0.11	***
Miti (relative to no mitigation)	Bird baffler:MD	-3.20	0.52	***
	Bird baffler:TW	-0.60	0.21	**
	Tori line:MD	-0.17	0.19	
	Tori line:TW	-2.29	0.40	***
	Warp scarer:MD	-4.14	0.87	***
	Warp scarer:TW	-0.51	0.21	*
discharge_rate (relative to negligible)	Intermittent	0.86	0.27	**
	Continuous	1.70	0.28	***
side_observed_wind (relative to Far)	Near	0.63	0.15	***
	Neither	0.67	0.21	**
wind_cos		0.43	0.15	**
swell_cos		-0.49	0.14	**
year_cos		-3.62	0.69	***
year_sin		-5.02	1.33	***

Table 13. Summary of the model terms for small bird strikes. The estimated values and the standard errors are of the linear predictor, and need to be exponentiated to obtain the strike rates. The significance values used are: $0.10 > p > 0.05$ (·), $0.05 > p > 0.01$ (*), $0.01 > p > 0.001$ (**), $p < 0.001$ (***).

Covariate	*Value*	*Estimate*	*Standard Error*	*Significance*
Intercept		-8.02	0.60	***
log(small_birds + 1)		1.47	0.10	***
Miti (relative to no mitigation)	Bird baffler:MD	-2.97	0.64	***
	Bird baffler:TW	-0.21	0.21	
	Tori line:MD	0.40	0.15	**
	Tori line:TW	-1.87	0.32	***
	Warp scarer:MD	-2.09	0.40	***
	Warp scarer:TW	-0.42	0.20	*
discharge_single (relative to Sump)	Cutter	0.85	0.42	*
	Discards	0.99	0.31	**
	Minced	1.06	0.24	***
	Offal	0.89	0.19	***
wind_cos		-0.25	0.08	**
discharge_rate (relative to negligible)	Intermittent	0.29	0.20	
	Continuous	0.96	0.19	***

Figure 20. Summary of the predicted effects of the mitigation for large bird strikes, relative to strikes on the trawl warps with no mitigation. Error bars indicate 95% confidence intervals. The dark shaded bars show the strikes on the trawl warps whilst the light shaded bars show strikes on the mitigation devices.

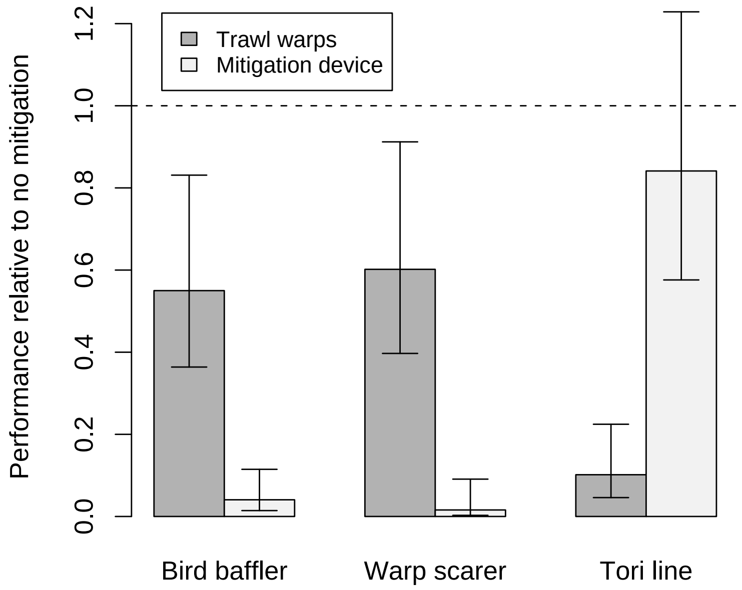
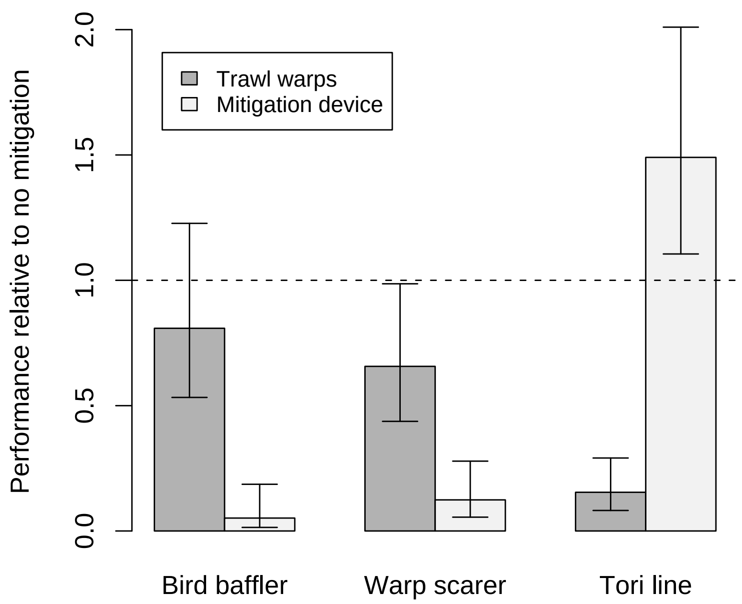


Figure 21. Summary of the predicted effects of the mitigation of small bird strikes, relative to strikes on the trawl warps with no mitigation. Error bars indicate 95% confidence intervals. The dark shaded bars show the strikes on the trawl warps whilst the light shaded bars show strikes on the mitigation devices.



Random effects

For the large birds, the trip level random effects in the best model have a standard deviation of 1.46, and for the observer-trip random effect the standard deviation is 0.32. For the small bird model the standard deviations are 1.53 and 0.31 respectively. When the random effects are included in the model in the way that was done here, the variability that is attributed to different observers on the same trip is relatively low. For large birds the range, when exponentiated, is between a factor of 0.66 and 1.59. For small birds the range is from 0.62 to 1.94. In contrast, the trip level random effects vary from 0.080 to 8.82 for large birds and from 0.16 to 6.8 for the small bird model (Table 14). We have not explored the reasons for the large differences between the trips, but with a ratio of over 100 between the largest and smallest trip level random effect in the large bird model, there is considerable variability which is not being explained by any of the fixed effects. However, it should be noted that the modelling presented here is primarily aimed at distinguishing between the mitigation devices. Random effects were included in all models, and the estimated vessel effects could capture systematic between-vessel variation in discharge, for example, in addition to unmeasured between-vessel differences.

Table 14. Trip level random effects for the large bird and small bird models.

Trip number	*Trip random effect for large bird model*	*Trip random effect for small bird model*
2201	1.74	0.94
2202	2.81	0.91
2203	0.58	0.56
2204	0.57	0.79
2205	8.82	6.84
2206	1.91	1.78
2207	0.78	0.355
2208	0.08	0.16
2211	0.68	1.57
2213	0.24	0.23
2214	0.32	0.33
2220	2.19	1.20
2222	2.46	3.09
2226	8.36	3.91
2227	4.18	0.93
2238	1.25	4.83
2240	0.31	1.75
2241	0.15	0.27

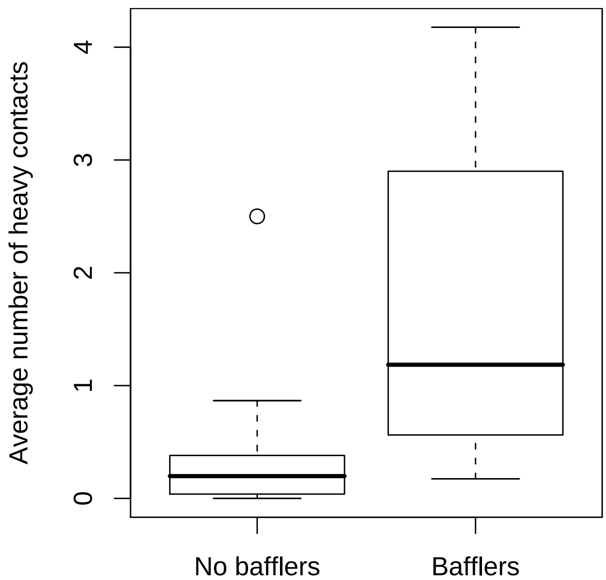
The bird bafflers

Many of the results seen from the model are already evident in the preliminary data analysis (Figure 11). The exception is the performance of the bird bafflers. The raw strike rate for large birds is 0.42 birds per observation without mitigation, but is 0.67 birds per observation when bird bafflers are used. In contrast, the modelling finds that bird bafflers are effective at reducing the large bird strikes on the trawl warps.

In the models, the leading covariate is the bird count. The large bird count is smaller on observations when bafflers are used (an average of 29) than when there is no mitigation (an average of 42), so this does not explain the discrepancy between the simple data analysis and the model. Similarly, there is less discharge during observations when bird bafflers are used (an average numerical rate of 1.6) than when there is no mitigation (an average rate of 2.0). The high numbers of large bird strikes seen when bafflers are deployed are not due to increased numbers of birds or increased discharge during those observations.

If the trips are selected where the to-specification bird bafflers are deployed (trips 2202, 2205, 2206, 2220 and 2227), then the average vessel random effect on trips with bafflers is 3.6 compared with an average random effect of 0.73 on trips without bafflers. According to the model, trips where bafflers are used have a higher strike rate. The reasons for this aren't captured by any of the model covariates. As a check, the contact rates during observations without mitigation can be compared between the trips with bird bafflers and the trips without (Figure 22). The plot compares the number of strikes per observation, averaged across a trip, between trips with and without bafflers. The rate is markedly higher on the trips which had the bafflers. The mean rate of 1.80 large birds per observation is over 4 times higher than the mean rate of 0.42 birds per observation seen on the other trips. Without the modelling, this would have masked the efficacy of the bafflers. There is a clear systematic difference between the vessels with and without bafflers. Because of the trial design, only vessels with four boom bafflers deployed bafflers during the trip. These vessels tended to be among the larger vessels in the trial.

Figure 22. The distribution of large bird contacts during no mitigation observations. The comparison is between trips without bafflers and the 5 trips with bafflers which met the specification.



Block height

At a conference organized by Southern Seabird Solutions (Nelson, September 27, 2006), some fishers were surprised at the apparent poor performance of the bird bafflers. During presentations of the initial results from the trial it was suggested that they may be more effective on vessels where the block is lower to the water. On these vessels the bafflers give better protection to the region where the warps enter the water, as this region is closer to the stern.

In order to determine how block height above water interacts with baffler performance, a factor was made which combined the bird baffler mitigation with the block height category. In effect, the bird bafflers on vessels with different block heights are treated as different mitigation devices. The full model building procedure was repeated for data from the 7 trips where bird bafflers were used (Table 15). These trips only included vessels with medium (4 trips) and large (3 trips) block height above water. To increase the data available, observations were included from all tows with discharge, even where the mitigation had been declared by the observers to be substandard. The full greedy stepping model selection algorithm was used, with the Laplace method being used to fit the models.

The results for large birds show that bafflers are effective on vessels with medium block heights (Figure 23). In contrast, on vessels with high blocks, the warp strike rate with the bird bafflers deployed is not significantly different from that with no mitigation. For small bird warp strikes, the mean value suggests that bafflers are also effective (Figure 24), however the confidence intervals are large. This is likely to be due to the small sample size. Because of the low replication, with only 3 or 4 vessels in each block height category, these results must be treated as preliminary. Nevertheless, they support the observation made by the fishers that the bafflers work best on vessels where the blocks are close to the water.

The results for all the mitigation devices are detailed in Table 16. Although the model was only fitted to the data on trips with bird bafflers, and observations with substandard mitigation were included, the results are similar to those from the model of the full dataset (Figure 20 and Figure 21).

Table 15. Number of good observations on trips with different block heights. All observations with discharge are included, even where the mitigation was recorded as not meeting the trial specification..

Block height	*Trip number*	*No mitigation*	*Bird baffler*	*Tori line*	*Warp scarer*
M	2202	17	34	52	24
	2220	10	133	22	20
	2227	27	74	85	74
	2238	0	6	2	3
L	2204	15	59	35	2
	2205	23	90	69	78
	2206	16	24	19	24

Figure 23 Performance of the bafflers at reducing strikes on large birds. A separate fit is made for vessels with large and medium block heights. The error bars give the 95% confidence interval.

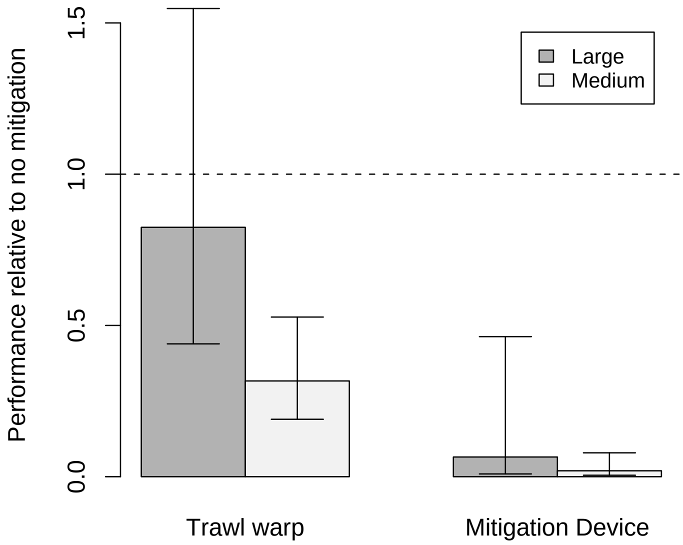


Figure 24 Performance of the bafflers at reducing strikes on small birds. A separate fit is made for vessels with large and medium block heights. The error bars give the 95% confidence interval.

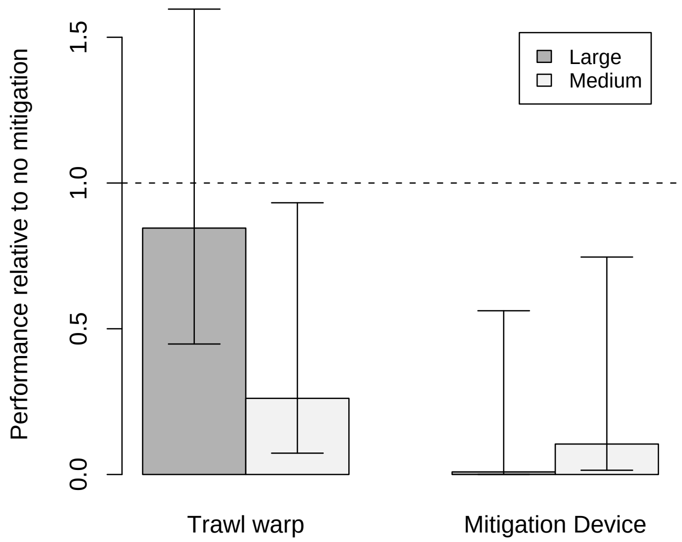


Table 16 Performance of the mitigation in a model of the trips with bird bafflers. The bird bafflers on vessels with different block heights are treated separately. Figures in brackets give the 95% confidence intervals.

Mitigation	*Observed*	*Large birds*	*Small birds*
Bird baffler – Medium block	Warp	0.32 (0.19 - 0.53)	0.26 (0.07 - 0.93)
	Mitigation	0.02 (0.00 - 0.08)	0.10 (0.01 - 0.75)
Bird baffler – Large block	Warp	0.82 (0.44 - 1.55)	0.85 (0.45 - 1.60)
	Mitigation	0.07 (0.01 - 0.46)	0.01 (0.00 - 0.56)
Warp scarer	Warp	0.51 (0.31 - 0.85)	0.37 (0.14 - 0.97)
	Mitigation	0.02 (0.00 - 0.16)	0.06 (0.01 - 0.50)
Tori lines	Warp	0.10 (0.04 - 0.26)	0.19 (0.06 - 0.56)
	Mitigation	0.73 (0.47 - 1.16)	1.20 (0.67 - 2.15)

ALTERNATE MODELS

In order to explore the sensitivity of the model to some of the assumptions that have been made, other model variations were built:

1) Reselect the model terms and refit the model, including all observations where the mitigation is not to specification. This tests how excluding the below specification observations has influenced the results.
2) Account for potential correlations between observations from the same tow. Weight the observations so that the sum of the weights is 1 for all the trawl warp observations and for all the mitigation device observations on the same tow. For example, if three observations were made of the trawl warps during a tow then they would each have a weight of 1/3, whereas if only one warp observation were made, it is given a weight of 1. The same scheme is used for weighting observations of the mitigation devices.
3) Check that the model selection scheme is not distorting the results. An extreme model is calculated, which contains all the covariates that were presented to the initial model. The exception is the bird counts, where the large bird counts are only included in the large bird model, and similarly for small birds. The model does not converge unless the `discharge_side_wind` covariate is excluded.
4) At the other extreme, derive a model where the only fixed effect is the mitigation covariate.

To explore the sensitivity of the results to the data from particular trips, a trip-level jackknife analysis was also carried out where the model building and fitting process was repeated 21 times, leaving out one observer-trip at a time (trips with two observers are treated as two separate observer-trips). The fixed effect term for the mitigation deployed was retained by the model selection procedure in all replicates for both large bird contacts (Table 17) and small bird contacts (Table 18). The fitted mitigation effects for each jackknife replicate are given in Table 19 (large birds) and Table 20 (small birds).

Table 17. Number of times fixed terms are retained by the model selection process in the 21 jackknife replicate models for large birds.

Term	*Number of inclusions*
log(large_birds + 1)	21
miti	21
discharge_rate	21
side_observed_wind	19
wind_cos	17
swell_cos	16
year_cos	11
year_sin	10
discharge_side_wind	9
abs(wind_sin)	2
discharge_single	1

Table 18. Number of times fixed terms are retained by the model selection process in the 21 jackknife replicate models for small birds.

Term	*Number of inclusions*
discharge_single	21
log(small_birds + 1)	21
miti	21
discharge_rate	19
wind_cos	19
abs(wind_sin)	2
abs(swell_sin)	1

Although the primary purpose of the jackknife analysis was to investigate whether particular trips have particular influence on the fitted mitigation effects, it also provides an alternative estimate of the uncertainty in the mitigation effects. The standard errors of the parameter of interest (i.e. the mitigation effects) can be estimated as $(n-1)/\sqrt{n}$ times the standard deviation of the same parameter, from the n = 18 repeats. These jackknife standard errors are considerably larger than those found from the model fitting procedure, as they include uncertainty that is introduced during model selection, rather than just the uncertainty due to fitting a particular model.

The results of fitting the alternate models are shown in Table 21 and Table 22, together with the overall jackknife estimates. With the exception of the wider confidence intervals from the observer-trip level jackknife, the results are broadly in agreement with the best model:

- In all cases, for large and small birds, the tori lines are the most effective method for reducing strikes on the trawl warps. With a single exception, there is no overlap in the confidence intervals for tori lines and other mitigation devices, for warp contacts.
- In all cases, for large and small birds, the strikes on the tori lines themselves are either not significantly different from, or are greater than, the strikes on the trawl warps in the absences of mitigation.
- In all cases, for large birds, the bird bafflers significantly reduce strikes on the warps (at the 95% level), although this only just holds for the weighted model and the model that only includes mitigation.
- In all cases, for small birds, bird bafflers can not be shown to be effective at the 95% level.
- For large birds, the warp scarers can be shown to be effective in some models and not in others
- For small birds, the warps scarers are significant at the 95% level for all models, except the one which includes the below specification mitigation.
- In all cases, for both large and small birds, there are few strikes on either bird bafflers or warp scarers themselves. The highest upper confidence interval reaches 0.33, but the highest mean value is only 0.12.

Table 19. Fitted mitigation effects for each jackknife replicate model, for large bird strikes. The columns give the coefficient of the best fitting model when the data from the corresponding observer-trip is left out of the model.

	2201:1	*2202:2*	*2203:3*	*2204:4*	*2205:5*	*2205:6*	*2206:7*	*2207:8*	*2208:9*	*2211:10*	*2213:11*	*2214:12*	*2214:13*	*2220:14*	*2222:1*	*2222:15*	*2226:16*	*2227:8*	*2238:17*	*2240:2*	*2241:3*
Bird baffler:TW	-1.13	-0.68	-0.87	-0.64	-0.69	-0.96	-1.01	-0.65	-0.85	-0.94	-0.63	-0.64	-0.64	-0.21	-0.8	-0.54	-0.63	-0.95	-0.87	-0.51	-0.63
Bird baffler:MD	-3.74	-2.94	-3.46	-3.23	-3.6	-3.49	-3.55	-3.26	-3.45	-3.53	-3.23	-3.23	-3.24	-3.02	-3.37	-3.09	-3.25	-3.52	-3.46	-3.08	-3.24
Warp scarer:TW	-0.76	-0.08	-0.60	-0.56	-0.59	-0.52	-0.61	-0.51	-0.59	-0.62	-0.55	-0.55	-0.49	-0.22	-0.55	-0.46	-0.49	-0.98	-0.62	-0.45	-0.49
Warp scarer:MD	-4.38	-3.67	-4.24	-4.20	-4.17	-4.15	-4.19	-4.12	-4.23	-4.21	-4.18	-4.18	-4.12	-3.86	-4.18	-4.09	-4.13	-5.2	-4.20	-4.09	-4.12
Tori line:TW	-2.44	-1.96	-2.22	-2.28	-2.67	-2.21	-2.24	-2.49	-2.20	-2.24	-2.33	-2.31	-2.35	-2.91	-2.25	-2.15	-2.34	-2.13	-2.22	-2.29	-2.35
Tori line:MD	-0.33	-0.03	-0.12	-0.17	-0.30	-0.13	-0.17	-0.25	-0.11	-0.15	-0.21	-0.21	-0.24	-0.12	-0.21	-0.24	-0.23	-0.14	-0.12	-0.19	-0.23

Table 20. Fitted mitigation effects for each jackknife replicate model, for small bird strikes. The columns give the coefficient of the best fitting model when the data from the corresponding observer-trip is left out of the model.

	2201:1	*2202:2*	*2203:3*	*2204:4*	*2205:5*	*2205:6*	*2206:7*	*2207:8*	*2208:9*	*2211:10*	*2213:11*	*2214:12*	*2214:13*	*2220:14*	*2222:1*	*2222:15*	*2226:16*	*2227:8*	*2238:17*	*2240:2*	*2241:3*
Bird baffler:TW	-0.25	-0.09	-0.24	-0.27	-0.52	-0.06	-0.72	-0.24	-0.20	-0.31	-0.25	-0.22	-0.25	0.01	-0.27	-0.28	-0.24	-0.27	-0.24	-0.28	-0.24
Bird baffler:MD	-3.11	-2.80	-2.99	-3.01	-2.81	-2.74	-2.95	-2.98	-2.92	-3.03	-3.00	-2.97	-2.99	-4.33	-3.02	-3.12	-2.99	-3.2	-2.99	-3.02	-2.99
Warp scarer:TW	-0.86	-0.21	-0.43	-0.46	-0.46	-0.36	-0.37	-0.43	-0.42	-0.61	-0.45	-0.40	-0.42	-0.42	-0.46	-0.44	-0.43	-0.43	-0.46	-0.44	-0.44
Warp scarer:MD	-2.21	-1.88	-2.09	-2.13	-2.11	-1.99	-2.00	-2.09	-2.55	-2.01	-2.17	-2.06	-2.07	-2.09	-2.11	-2.13	-2.10	-2.25	-2.07	-2.10	-2.10
Tori line:TW	-2.08	-1.66	-1.86	-2.02	-2.03	-1.89	-2.08	-1.85	-1.77	-1.88	-1.87	-1.84	-1.82	-1.82	-1.87	-1.84	-1.87	-1.8	-1.87	-1.87	-1.86
Tori line:MD	0.22	0.62	0.40	0.37	0.47	0.48	0.19	0.42	0.49	0.35	0.39	0.45	0.42	0.35	0.35	0.29	0.39	0.42	0.40	0.40	0.41

Table 21. Alternate models for large bird contacts, giving the best estimate and the 95% confidence intervals for the mitigation factors. The models include the best model, a model with all the observations where the mitigation was below specification included, a model where multiple observations in the same tow are down-weighted, a model with all the covariates included, a model where the only fixed effect is the mitigation covariate, and a summary of the results of a jackknife analysis.

Mitigation	*Observed*	*Best model*	*Include below spec mitigation*	*Weight observations from the same tow*	*Model with all covariates*	*Model with only mitigation*	*Trip level jackknife*
Bird baffler	Warp	0.55 (0.36 - 0.83)	0.61 (0.41 - 0.89)	0.63 (0.40 - 1.00)	0.50 (0.32 - 0.79)	0.57 (0.33 - 0.99)	0.51 (0.10 - 2.60)
	Mitigation	0.04 (0.01 - 0.11)	0.04 (0.01 - 0.11)	0.04 (0.01 - 0.10)	0.04 (0.01 - 0.11)	0.04 (0.01 - 0.20)	0.04 (0.01 - 0.21)
Warp scarer	Warp	0.60 (0.40 - 0.91)	0.65 (0.43 - 0.98)	0.70 (0.47 - 1.04)	0.66 (0.43 - 1.03)	0.83 (0.50 - 1.38)	0.62 (0.18 - 2.11)
	Mitigation	0.02 (0.00 - 0.09)	0.02 (0.00 - 0.10)	0.01 (0.00 - 0.10)	0.02 (0.00 - 0.10)	0.02 (0.00 - 0.28)	0.02 (0.00 - 0.06)
Tori lines	Warp	0.10 (0.05 - 0.22)	0.12 (0.06 - 0.25)	0.10 (0.05 - 0.20)	0.09 (0.04 - 0.21)	0.07 (0.02 - 0.21)	0.10 (0.02 - 0.51)
	Mitigation	0.84 (0.58 - 1.23)	1.11 (0.79 - 1.57)	0.98 (0.69 - 1.41)	0.83 (0.55 - 1.24)	0.68 (0.42 - 1.10)	0.86 (0.50 - 1.48)

Table 22. Alternate models for small bird contacts. Details as per Table 21. The bold value indicates that the coefficient is significantly different from the expected value in the best model.

Mitigation	*Observed*	*Best model*	*Include below spec mitigation*	*Weight observations from the same tow*	*Model with all covariates*	*Model with only mitigation*	*Trip level jackknife*
Bird baffler	Warp	0.81 (0.53 - 1.23)	0.89 (0.61 - 1.30)	0.81 (0.51 - 1.29)	0.70 (0.46 - 1.08)	0.86 (0.49 - 1.52)	0.79 (0.22 - 2.91)
	Mitigation	0.05 (0.01 - 0.19)	0.05 (0.02 - 0.17)	0.07 (0.02 - 0.20)	0.04 (0.01 - 0.16)	0.05 (0.01 - 0.33)	0.05 (0.00 - 0.72)
Warp scarer	Warp	0.66 (0.44 - 0.99)	0.69 (0.47 - 1.02)	0.66 (0.44 - 0.98)	0.66 (0.44 - 1.00)	0.51 (0.29 - 0.89)	0.66 (0.24 - 1.83)
	Mitigation	0.12 (0.06 - 0.28)	0.12 (0.05 - 0.26)	0.05 (0.02 - 0.17)	0.12 (0.06 - 0.28)	0.10 (0.03 - 0.32)	0.12 (0.04 - 0.38)
Tori lines	Warp	0.15 (0.08 - 0.29)	0.26 (0.16 - 0.43)	0.20 (0.11 - 0.36)	0.16 (0.09 - 0.30)	0.13 (0.05 - 0.31)	0.15 (0.06 - 0.37)
	Mitigation	1.49 (1.11 - 2.01)	1.58 (1.19 - 2.10)	**2.05 (1.51 - 2.79)**	1.56 (1.15 - 2.12)	1.35 (0.90 - 2.02)	1.49 (0.66 - 3.34)

- Including the below specification mitigation increases the expected trawl warp strike rate for all mitigation devices, for both large and small birds. The size of this increase is less than the 95% confidence interval, however.

The individual jackknife fits indicate that no one observer-trip has undue leverage on the fitted mitigation effects. However, although the mean values are close to the mean value of the best model, the jackknife estimates of the standard errors are large. For both small and large birds, strikes on bird bafflers, warp scarers, and on trawl warps when tori lines are used, are significantly lower. In all other cases the confidence intervals overlap one. Note that because of the multiplier used in estimating the jackknifed standard error, the extremes of the confidence intervals are not seen in any individual calculation.

SEABIRD CAPTURES

Although seabird strikes are used as the primary index of seabird interactions with the trawl warp and mitigation devices in this study, seabird captures recorded are also of interest. Observers primarily record seabird captures observed during a trip on the Stock Monitoring Programme Non-Fish Bycatch form. However, for tows where seabird strike observations are carried out, observers were also asked to record the captures on the rear of the warp strike observation form. This is because the current Non-Fish Bycatch form does not record where the birds were captured (i.e. net, warp or mitigation device), other than in comments. Seabird strike observations were not carried out on all tows so the total number of seabirds reported from a trip on the seabird strike observation forms should be less than or equal to the total reported on the Non-Fish Bycatch forms. Reconciling the two data sources (Table 23) showed this was generally the case, although two seabird captures appear to have been recorded on the seabird strike observation forms only. Unfortunately, recording of the captures on the seabird strike observation forms appears to have been done poorly. A number of seabirds were recorded only on the Non-Fish Bycatch forms for some tows when seabird strike observations were carried out. Even worse was that, in many cases, the captures were not simply omitted from the seabird strike observation forms, but seem to have been recorded as zeros.

Total recorded seabird captures by species (as per observer's identification, and after reconciling the two data sources) for all trips that participated in the trial are given in Table 24. The seabird strike observation forms did not record any captures from the mitigation devices, and no comments in the Non-Fish Bycatch data suggest captures from the mitigation devices.

For tows where strike rate observations were carried out, 30% of captures recorded on the seabird strike observation form were of large seabirds landed dead from the trawl warps (Table 25). Most recorded warp captures occurred either when no mitigation was deployed or when bird bafflers were deployed, and most came from trip 2202 – the trip that triggered the decision rule. The majority of small seabirds captures recorded were net captures. No small birds were reported captured from the warps on the seabird strike observation forms.

As a result of concerns over the reporting of seabird captures on the seabird strike observation forms, all captures recorded on the Non-Fish Bycatch forms were also manually categorised by seabird size (based on observer species identification) and capture location, when this could be inferred from comments (Table 26). The mitigation device deployed for a tow is only known for those tows where seabird strike observations were carried out.

Using these data, 18% of captures during the trial were large birds recovered dead from the warps, whilst 60% were small bird net captures.

Table 23. Seabird captures on non-fish bycatch and seabird strike observation forms.

Trip	*Recorded captures Non-Fish*	*Recorded captures Strike obs.*	*Diff.*	*Notes on difference between Non-Fish Bycatch form total captures and seabird strike observation form total captures*	*Total captures for trip*
2201	17	0	17	Four of the eight tows with captures had seabird strike observations, but captures were recorded as zero on the warp strike form. Observer report states "*The vessel captured 17 birds for the trip, which were all caught in the net during the shooting of the gear.*"	17
2202	51	44	7	Four captures from tows without seabird strike observations. Three captures from tows with seabird strike observations where warp strike forms recorded zero captures.	51
2203	18	16	2	Two captures from tows without seabird strike observations.	18
2204	7	3	4	Three captures from two tows without seabird strike observations. One capture recorded on warp strike form only. Appears warp strike form captures left blank except for one recorded capture.	8
2205	21	12	9	Two captures from tows without seabird strike observations. Otherwise difference represents captures recorded on nonfish form where zeros were recorded on warp strike form.	21
2206	20	11	9	Five captures from four tows without seabird strike observations. Four captures from nonfish forms that were not recorded on warp strike forms. Empty cells left blank.	20
2207	6	3	3	One capture from a tow without seabird strike observations. Two captures recorded on nonfish form – captures not completed on warp strike form.	6
2208	16	8	8	Five captures from four tows without seabird strike observations. Three captures recorded on nonfish forms for tows where warp strike form recorded zero captures.	16
2211	8	2	6	Six captures from six tows without seabird strike observations.	8
2213	6	2	4	Two captures from two tows without seabird strike observations. Four captures recorded on nonfish forms for tow where warp strike form recorded two captures.	6
2214	11	5	6	Four captures from four tows without seabird strike observations. Two captures recorded on nonfish form for a tow where warp strike form recorded zero captures.	11
2220	2	1	1	One captures recorded on nonfish form for a tow where warp strike form captures were not recorded.	2
2222	18	3	15	Sixteen captures from five tows without seabird strike observations. One capture recorded on warp strike form only.	19
2226	11	5	6	Four captures from a tow without seabird strike observations. Two captures recorded on nonfish form for a tow where warp strike form recorded zero captures.	11
2227	27	20	7	Two captures from two tows without seabird strike observations. Four captures recorded on nonfish form for three tows where warp strike form did not record captures. One additional capture on a nonfish form where the warp strike form recorded two captures.	27
2238	19	18	1	One captures recorded on nonfish form for a tow where the warp strike form recorded zero captures.	19
2240	12	8	4	Four captures from a tow without seabird strike observations.	12
2241	61	29	32	Thirty two captures from six tows without seabird strike observations.	61

Table 24. Total seabird captures recorded on Non-Fish Bycatch forms for trips participating in the trial, grouped by observer species identifications. Two additional large seabirds have been added to account for captures reported on the seabird strike observation form only.

Code	*Common name*	*Scientific name*	*Alive*	*Dead*	*Total*
XAL	Albatross (unidentified)	*Diomedeidae* family	0	4	*4*
XBM	Southern bullers albatross	*Diomedea bulleri bulleri*	1	3	*4*
XBP	Black petrel	*Procellaria parkinsoni*	2	0	*2*
XFT	Black bellied storm petrel	*Fregetta tropica*	3	0	*3*
XKM	Black-browed albatross	*Diomedea melanophrys*	0	3	*3*
XPE	Petrel (unidentified)	*Procellariidae* family	3	6	*9*
XPN	Prion (unidentified)	*Pachyptila*	2	0	*2*
XRA	Southern royal albatross	*Diomedea epomophora epomophora*	0	2	*2*
XSA	Salvin's albatross	*Diomedea salvini*	1	1	*2*
XSB	Seabird		0	2	*2*
XSH	Sooty shearwater	*Puffinus griseus*	34	108	*142*
XSL	Seabird large		0	7	*7*
XSP	Southern giant petrel	*Macronectes giganteus*	1	0	*1*
XSS	Seabird small		0	1	*1*
XST	Storm petrel	*Pachyptila* sp.	1	1	*2*
XSY	Shy albatross	*Diomedea cauta cauta*	0	46	*46*
XTP	Giant petrel	*Macronectes giganteus*	1	0	*1*
XWC	White-chinned petrel	*Procellaria aequinoctialis steadi*	25	39	*64*
XWM	New Zealand white capped albatross	*Diomedea cauta steadi*	7	29	*36*
		Total	*81*	*252*	*333*

Table 25. Mitigation deployed, recovery location and status for large and small seabird captures recorded on the seabird strike observation forms.

Seabird size category	*Recovered from*	*Status*	*Mitigation deployed*					*Total*
			None	*Bird bafflers*	*Tori lines*	*Warp scarers*	*Tori lines and bird bafflers*	
Large	Warps	Dead	21	24	2	7	3	*57*
	Net	Alive	1	0	1	0	0	*2*
	Net	Dead	4	3	2	6	0	*15*
	Unknown	Dead	1	1	0	0	0	*2*
Small	Net	Alive	11	4	12	4	1	*32*
	Net	Dead	23	11	13	11	4	*62*
	Net	Injured	0	3	1	0	0	*4*
	Unknown	Dead	8	0	7	1	0	*16*
		Total	*69*	*46*	*38*	*29*	*8*	*190*

Table 26. Mitigation deployed (if known), assigned recovery location and size, and status for large and small seabird captures recorded on the Non-Fish Bycatch forms.

Seabird size category	*Recovery location*	*Status*	*Mitigation deployed*						*Total*
			Unknown	*None*	*Bird bafflers*	*Tori lines*	*Warp scarers*	*Tori lines and bird bafflers*	
Large	Warps	Dead	2	22	24	1	7	3	*59*
	Net	Alive	3	1	0	1	0	0	*5*
	Net	Dead	10	2	4	4	3	0	*23*
	Unknown	Alive	1	0	0	0	0	0	*1*
	Unknown	Dead	3	3	2	1	2	0	*11*
	Deck	Alive	0	0	2	0	3	0	*5*
Small	Net	Alive	18	13	7	15	6	1	*60*
	Net	Dead	59	31	13	20	11	5	*139*
	Unknown	Dead	4	1	2	6	2	0	*15*
	Deck	Alive	3	0	1	4	3	0	*11*
	Deck	Dead	0	0	0	0	0	1	*1*
Unknown	Unknown	Dead	0	0	0	0	2	0	*2*
		Total	*103*	*73*	*55*	*52*	*39*	*10*	*332*
		Number of tows		286	165	313	273	38	

QUALITATIVE INFORMATION ON MITIGATION DEVICES

In addition to the quantitative seabird strike observations, observers were asked to record other, qualitative, information relating to the performance of the mitigation devices included in the trials. A Mitigation Device Record Sheet (Appendix 2) was provided to collect these observations. Over the course of the trial 314 observations were recorded on these forms, though there was considerable between-trip variability in the number of comments made (Table 27). Although the majority of observations recorded did relate to the performance and durability of the mitigation devices, a number of observers also used the sheets for more general logs relating to the trial implementation, seabird strikes and captures. There was also some overlap with, and duplication of, comments captured on the seabird strike observation forms.

Observers' comments on the mitigation devices showed reasonable consistency, with a number of common themes reported from the trips. Most (240) comments could be categorised into nineteen groups of comments on similar aspects of device performance (Table 28). Some comments were assigned to more than one group. Overall, warp scarers and tori lines attracted approximately four times as many notes as bird bafflers. However, as observers clearly differed in their use of this form, the number of comments cannot be regarded as truly quantifying the degree of interest in a particular issue.

Table 27. Number of qualitative observations of mitigation device performance provided by observers using the Mitigation Device Record Sheets (Appendix 2) for each trip included in the trial.

Trip	*Mitigation device observations*
2201	4
2202	12
2203	11
2204	36
2205	34
2206	27
2207	13
2208	40
2211	5
2213	7
2214	4
2220	5
2222	2
2226	17
2227	49
2238	28
2240	11
2241	9

General performance and durability

Mitigation device entanglement was a commonly reported problem. For bird bafflers this typically referred to the dropper lines becoming entangled with each other (Figure 25b) or, less commonly, the booms. In the case of tori lines entanglements included a variety of situations including streamer lines becoming wrapped around the tori line backbone or the warp, the backbone becoming wrapped around the warp (Figure 26b), and the port and starboard tori lines becoming entangled. Only one case of the tori line becoming pulled under the vessel was reported.

Entanglements of warp scarers were to the result of the device becoming wrapped around the warp (Figure 27b). Warp scarer entanglement was closely related to problems with the weights used, and the gap left between the end of the warp and the water. Many vessels seemed to have difficulty finding a weight that was small and heavy enough to hold the warp scarer down without increasing the tendency for entanglement with the warp. As a result many warp scarers tended to be set leaving an area of exposed warp near the waterline, where seabird warp strikes could still occur (Figure 27c).

Damage and maintenance of devices was reported more frequently for warp scarers and tori lines than bafflers. Typical maintenance included replacing lost or broken streamers. The clips supplied with the standard warp scarer devices proved inadequate to the task (Figure 27d), and several vessels manufactured replacements. The warp scarer attachments were also related to several of the problems during hauling as the clips were unable to pass splices in the warps.

Difficulties in deploying warp scarers, and related safety concerns, were reported from several trips. A second hand report of a safety issue in tori line deployment (a crew member's foot being caught in a loop of line) was also noted.

Several observers noted that one set of baffler droppers would be blown up into the arm, or the side of the vessel, in high winds, thus rendering that part of the baffler ineffective. However, the majority of environmental effects on device efficacy noted related to tori lines. There were frequent observations of the lines being out of alignment with the warps due to wind or current (Figure 26c), and so providing no cover to one of the warps.

Device specification recording

Several observer comments related to the failure of mitigation devices to meet the trial specifications. In the case of bird bafflers, some aft dropper lines were considerably shorter than required (Figure 25c). Short streamers were noted on several tori lines. One vessel had inadequate streamer spares and replaces some damaged streamers with blue packing tape, whilst another vessel had white streamers instead of the colours required. A number of observers noted that the tori line streamers became quite dirty over time, rendering them much less brightly coloured.

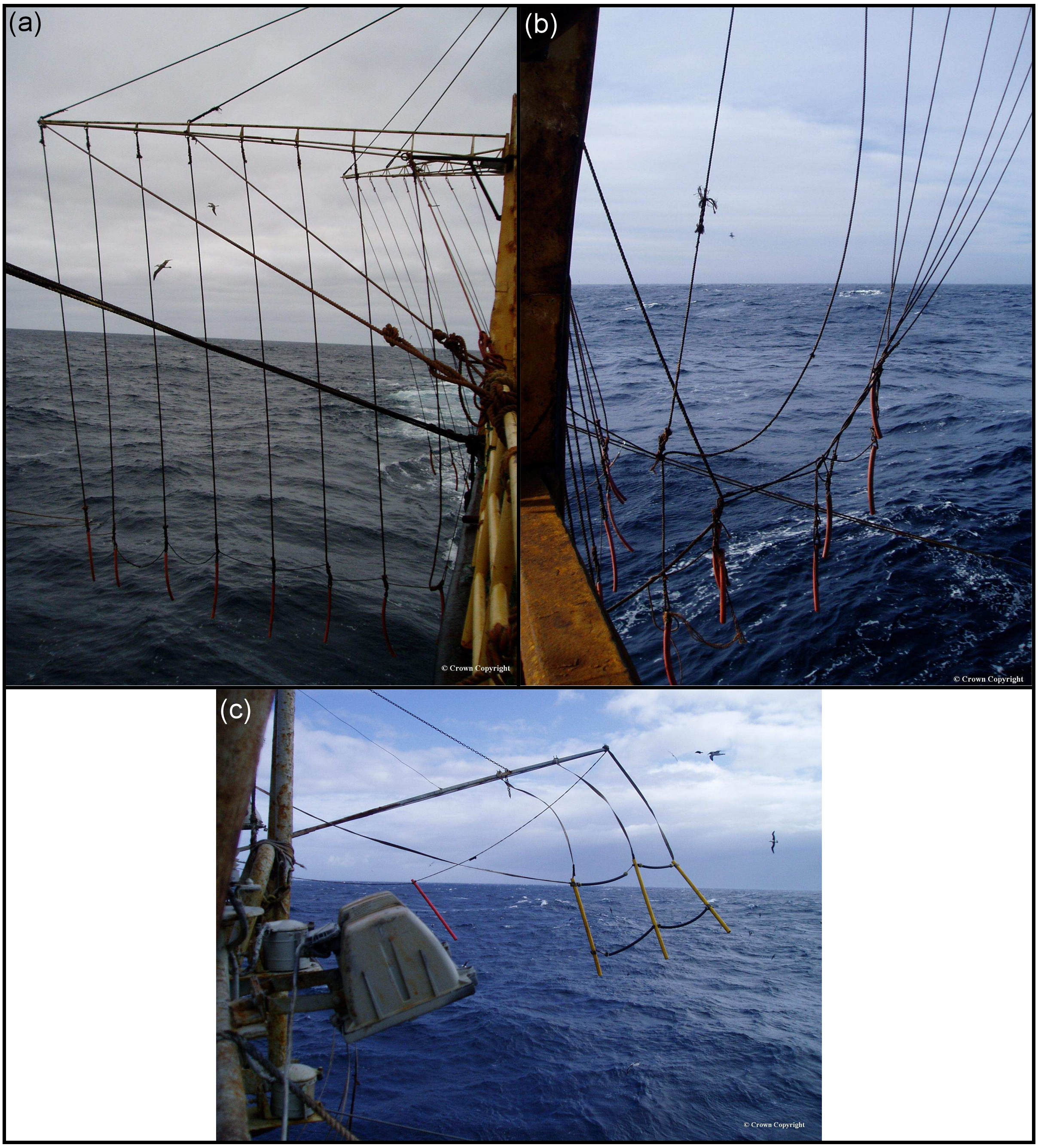
The Mitigation Device Event Log form allowed comments to be made for a particular tow, or for a particular time (as some relevant events, such as repairs, may not occur during a tow). The majority (94%) of events recorded were associated with a particular tow. These allow an initial assessment of the extent to which observer recording of whether mitigation devices met the trial specification during seabird strike samples was consistent and reliable.

Table 28. Categories identified in the qualitative observations of mitigation device performance and durability recorded by observers, and number of observations assigned to each category.

Mitigation Device	*Event category*	*Number of observations assigned to category*
Bird bafflers	Entanglement of lines and droppers	15
	Droppers too short	11
	Coverage of one or more baffler arms reduced due to wind	7
	Damage requiring repair	2
Tori lines	Tori lines and warps not aligned	69
	Entanglement (includes entanglement of tori lines and warps, tori lines with each other, and streamers with backbone or warp)	25
	Damage requiring repair	14
	Seabird interactions with tori line	9
	Streamer lengths wrong or streamers missing	9
	Wrong streamer material	2
	Streamers dirty and less visible	2
	Damaged due to entanglement with vessel	1
Warp scarers	Entanglement	36
	Damage requiring repair	21
	Warp deflector clips inadequate	19
	Gap between end of deflector and warp entry into water	15
	Problems at haul	14
	Problem with weight (e.g. lost, inadequate, increased)	9
	Difficulty deploying warp deflector	4

Of the 314 comments from the Mitigation Device Event Log, 28 were considered to indicate that the device did not meet the trial specification whilst a further 18 indicated that it may not meet the specification. The latter group related either to comments on the gap between the end of the warp scarer and the water (recognising that the determination of whether the device was deployed as close to the water "as practicable" is somewhat subjective) or to the classification of entanglements. The comments were assessed blindly, without reference to the observer's assessment of compliance with the specification during seabird strike sampling.

Figure 25. (a) View of starboard side and aft bird baffler arms (trip 2238); (b) entangled baffler dropper lines (trip 2238); (c) Short droppers on stern baffler boom (trip 2204).

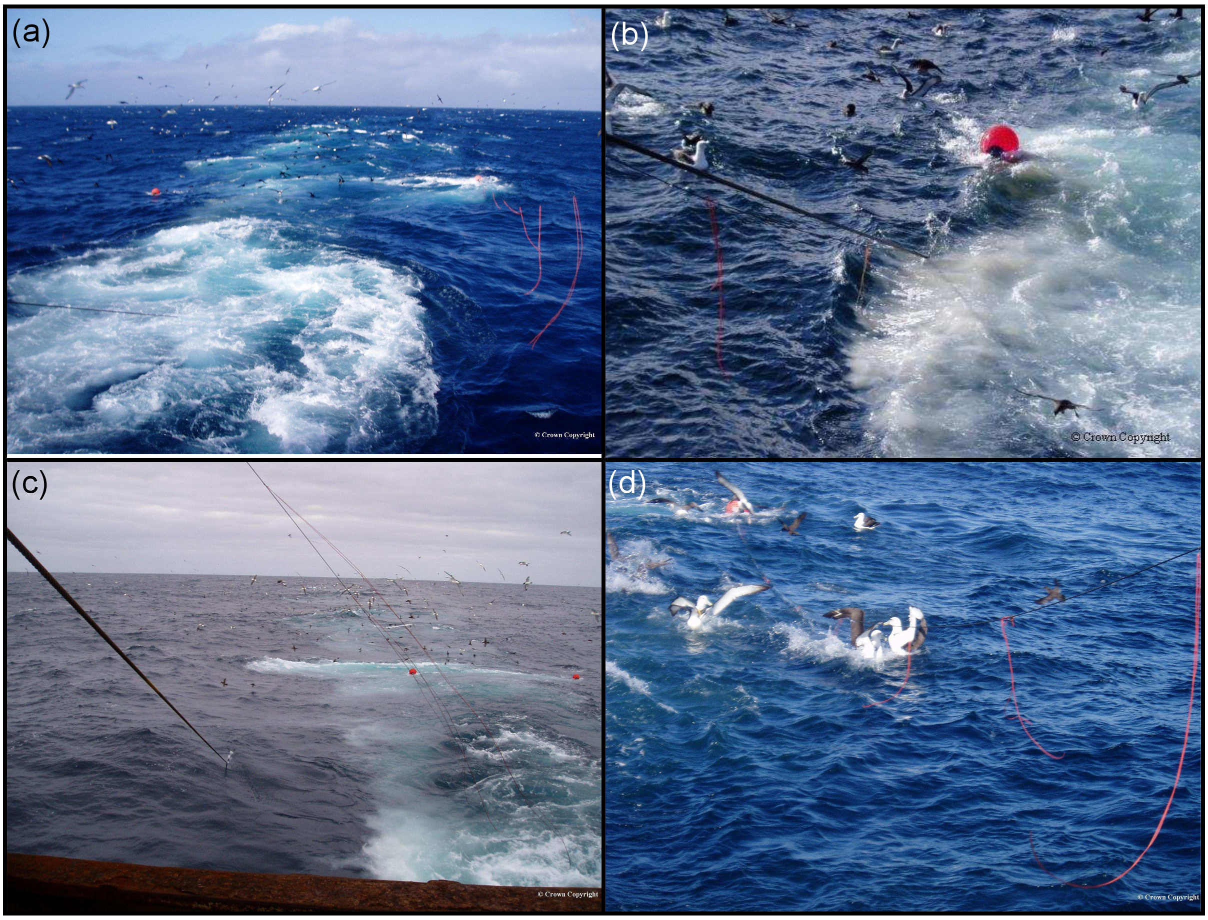


Comments where device compliance with the specification could be assigned related to 37 tows during which 158 seabird strike observations were carried out. For the 100 samples where comments suggested that the device was not to specification, observers recorded that the device was to specification for 24 samples. The majority of these discrepancies arose for tows where comments indicated that tori line streamers were missing or were the wrong colour. For the 58 samples where the event recorded could possibly have led to the observer determining that the device was not to specification, this had been done in 38 cases.

Table 29. Comparison of the number of samples where tow level comments from the Mitigation Device Event Log form suggest a device was not (or possibly was not) to specification, with the observer's recording of whether the device met the specifications during seabird strike observations.

Classification assigned from comment \ Observer determination at sampling	Device not to specification	Device to specification
Not to specification	76	24
Possibly not to specification	20	38

Figure 26. (a) Tori lines in use (trip 2201); (b) starboard tori line tangled around warp (trip 2240); (c) starboard tori line blown across to port (trip 2211); (d) seabird interactions with tori line (trip 2222).



Seabird interactions with tori lines

Nine comments on the Mitigation Device Event Log forms related to seabird interactions with the tori lines (Figure 27d). These observations (Table 30) include interactions with both the tori line itself, and the buoy, and include both heavy contacts and lighter touches. A number of similar observations were recorded as comments during seabird strike observations (Table 31).

Figure 27. (a) Warp scarer deployed, port warp (trip 2203); (b) warp scarer wrapped around warp (trip 2238); (c) seabird strike on unprotected part of warp near water (trip 2201); (d) damage to original warp scarer attachment clips (trip 2220).

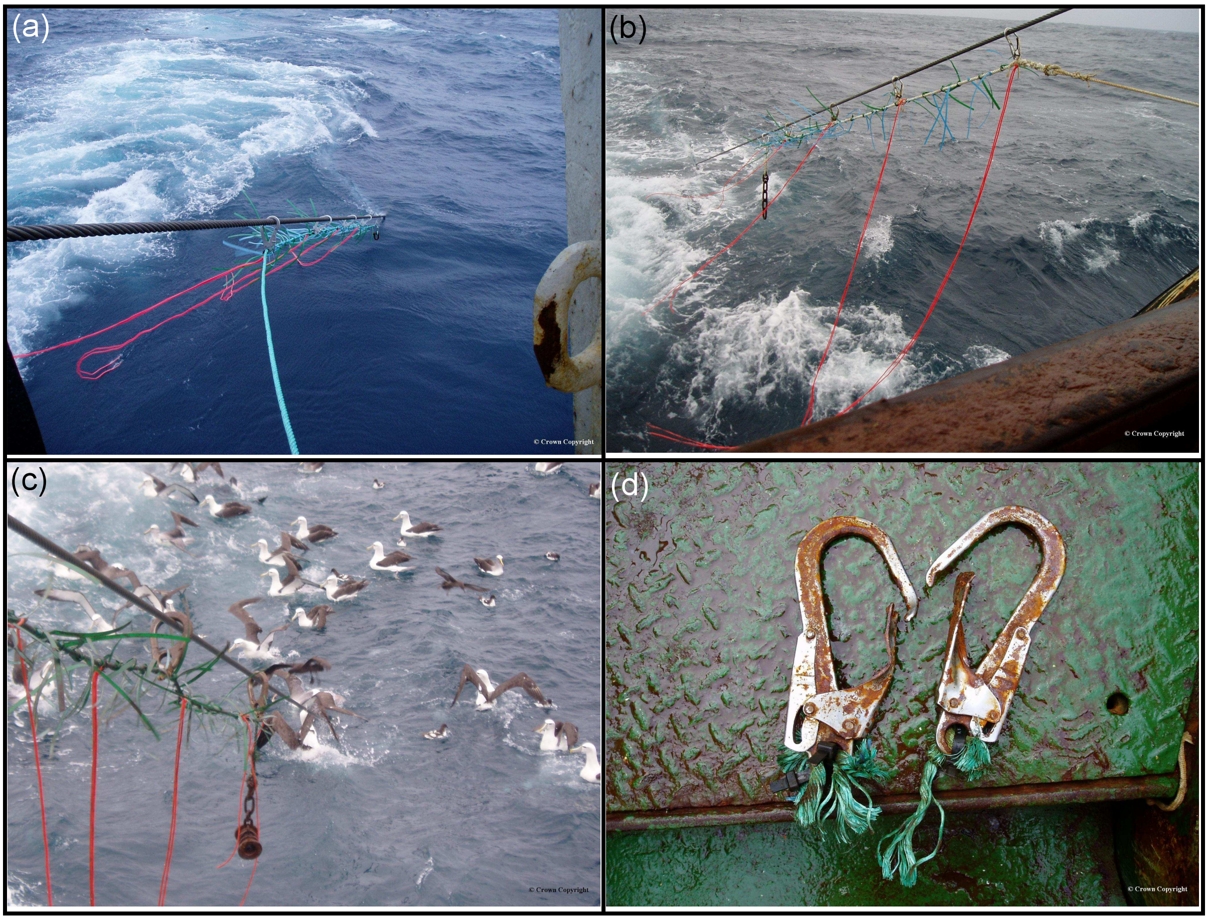


Table 30. Verbatim observer comments from the Mitigation Device Event Logs relating to seabird interactions with tori lines. The codes used in the comments refer to Ministry of Fisheries codes for seabird species: XSH – Sooty Shearwater (*Puffinus griseus*), XCP – Cape Pigeon (*Daption capense*), XWM – White-capped albatross (*Thalassarche steadi*), XWC – White-chinned petrel (*Procellaria aequinoctialis*).

Trip	*Tow*	*Description of mitigation device event*
2202	32	So many birds colliding with the starboard tori-line that at times it is collapsing under the weight of them onto the surface of the water.
2204	22	XWM x 1 caught against buoy, unable to free itself. Not brought on board at haul but probably killed, before hauling.
2206	10	Side wind pushing tori line off port side warp for both sample 1 and 2. Largely ineffective and a hazard to birds.
2206	70	Wind blowing tori line off port warp giving no mitigation for sample #1. Observed 1x XSH entangled in streamer and dragged under water for about 30 seconds. Managed by luck to free itself.
2208	31	Tori line flicked up from swell. 1x XCP was struck. Bird uninjured.
2208	122	Birds are hungry, can smell food. Diving recklessly at nothing, flying into mitigation device. Just lightly tipping the line. Mainly XWC XSH. No offal from vessel.
2208	122	A few small bits of bar guts floated pass. Birds colliding with tori line to race for it. XWC XSH. 2 heavy contacts. XWC's.
2208	128	Many birds this morning. Can smell fishmeal plant, and sun just up. Birds are in feeding frenzy looking for food. Diving recklessly at absolutely nothing. Colliding with tori lines just clipping them, no heavy contacts XWC=XSH
2240	11	Starboard -very short. Port side -correct distance out but streamers tied while observer at stern saw 3 XWM get their wings or bills very tangled in windy buoy -birds very distressed when entangled.

Table 31. Verbatim observer comments from seabird strike observations relating to seabird interactions with tori lines. The codes used in the comments refer to Ministry of Fisheries codes for seabird species: XSH – Sooty Shearwater (*Puffinus griseus*), XWM – White-capped albatross (*Thalassarche steadi*) , XAL – Albatross.

Trip	*Tow*	*Sample*	*Comment*
2203	17	2	Sny [*sic*] mollymork hit mainline of tori-line as lifted up quickly, line stopped bird and fell to water, bird flew away unharmed
2204	22	4	1 x XWM caught on tori line against buoy during observation time
2204	51	2	3 x XSH hit tori line 3-4m in front of buoy whilst diving for food - tori line on surface. 2 hit by buoy diving for food just in front of it 2 x XSH
2204	51	4	1 x XSH hit by tori line 2-3m above sea
2204	112	2	16 soft small bird contacts with slack tori line on sea. Birds feeding around buoy area. Only one body contact on tori line above sea that knocked bird off course.
2204	112	3	17 small bird soft contacts with slack tori line on sea ahead of buoy. Tori lines having pink streamers replaced with white same ones as in photo 84, tow 90.
2226	21	3	XAL hit on belly by tightening tori-line.

DISCUSSION AND RECOMMENDATIONS

TRIAL FRAMEWORK

The experimental work reported here was carried out as a co-operative process between industry and government. As a result the implementation of a large scale experimental evaluation of mitigation device efficacy was achieved at relatively low cost.

Although, the trial design was implemented relatively smoothly throughout the observed fleet, there are a number of lessons for future projects that adopt a similar approach: (i) It proved indispensable to have separately briefed the vessel officers and the observers on the trial protocols. This allowed any initial confusion over procedures to be noticed and resolved. (ii) Once the observed trips had departed port, the observers only had to contact the Observer Programme staff if they encountered a problem with the trial implementation, or the decision rule was triggered. In retrospect, a regular reporting schedule specifically related to the trials would have been helpful. For example, the decision to remove the warp scarer treatment from trip 2222 was not communicated to shore at the time.

The original analysis and reporting schedule proposed in the trial design proved optimistic, largely due to the speed with which keyed data became available. The current Ministry of Fisheries Observer Programme is not set up to provide data in real time, and it can be some time after trips are completed before the complete set of trip observations is available in the relevant databases. Management of the seabird strike data was newly introduced into the `obs_lfs` database during the course of the trials.

One clear effect of the current observer data capture process is that the delay from the end of the trip to data entry effectively eliminates the opportunity to clarify any incomplete or potentially inaccurate records with the observer, or to solve similar problems on subsequent trips in the same season. Although the instructions for the seabird strike observations required all fields on the form to be completed a particular problem was records with null entries in important fields. Our data grooming eliminated about 15% of records from the initial dataset, equivalent to almost 110 hours of observation.

WARP STRIKE OBSERVATIONS

Warp strike observations have become a standard technique in providing an index of seabird interactions with trawl warps (Wienecke and Robertson, 2002; Abraham, 2005; Sullivan et al., 2006). The standardised procedure for these observations, in particular the known observation time, provides more consistent data than those available from recording of incidental captures. However, the seabird strike protocol employed here does rely on the somewhat subjective assessment of a “heavy strike”, and observer interpretations of these may vary. The modelling of seabird strikes in this study allowed for an observer effect. This indicated that between observer variability in seabird strike observations does occur, although between vessel variability in strike rate was of greater magnitude.

Seabird capture data is sparse - with most fishing events reporting no captures - and variable - with occasional events reporting a large number of captures. These same features apply to the warp strike observations collected in these trials. The sparseness of these warp strike data implies that the average information content of an individual observation is low. One of the expectations of warp strike observations is that warp interactions are more frequent than warp captures and so provide more power for assessing mitigation performance (Sullivan et al., 2006). Adaptations to the current warp strike protocol could provide less sparse data with more power to distinguish the factors related to seabird interactions with the warp. For example, longer observation poeriods or counts of all seabird contacts with the warp, rather than only heavy strikes, may lead to fewer zero observations. However there are known practical problems with both these suggestions, including observer time availability, attention spans, and the ability to count all contacts when seabirds are frequent.

COMPARISON WITH 2005 WARP STRIKE DATA

The warp strike observations were first collected in 2005, and these data have been analysed separately (Abraham, 2005). It is tempting to compare the results between the years to determine whether seabird interactions within the squid fishery are decreasing. Unfortunately, this is not feasible. In both years the warp strike data has been collected primarily to investigate the factors influencing warp strike, and aspects of the protocol confounds the use of these data for comparing strike rates between years. In particular, a key factor influencing warp strikes is the discharge of offal while towing. During 2005, observers were asked to sample a range of discharge conditions, with a specific targeted of at least 25% of observations without discharge occurring. The strike rates they observed are therefore not representative of the fishery as a whole. In the 2006 trial, the mitigation devices were experimentally manipulated. There were many tows where no mitigation devices were deployed, and many where vessels were using mitigation devices that were not their standard practice. The warp strike observations are again not representative of what would have otherwise occurred within the fishery, or within the unobserved part of the fleet. Important covariates, in particular the mitigation devices deployed and offal discarding practiced, were not recorded from tows on unobserved vessels, or on observed vessels where seabird strike observations were not carried out. The modelled results cannot therefore be used to predict strike rate in unobserved tows.

Although the inability to compare overall strike rates between years may be perceived as a shortcoming, we note that experiment results – such as those reported here – are more considerably more powerful than monitoring data for understanding the mechanisms behind observed changes. Experiments are not always possible, but where they are an option they should provide much stronger information for management decisions.

The seabird strike data collection could be used as a monitoring tool, provided the protocol was changed to reflect that purpose. A key issue is ensuring that the sampling is fully representative, or alternatively (but less realistically) that the required covariates are collected from unobserved tows. Given the variability which was seen between vessels during the mitigation trial, a high level of observer coverage may be required to achieve a satisfactory level of representation of the fleet. Both because of this variability, and because key factors such as discharge may not be recorded on vessels which were not observed, extrapolation from the observed data set to the whole fishery would be difficult.

Collection of representative warp strike observations implies that observers will continue to carry out a large number of observations when no interactions are occurring. In contrast, if the focus remained specifically on the factors affecting interactions an obvious efficiency, in light of the analyses carried out here, would be to only carry out further observations when discharge was occurring.

VESSEL TURNS

The protocol required observers to abandon observations during which conditions changed. In particular, if the vessel turned during an observation then the observation was stopped. This requirement meant that consistent conditions were encountered during the observation, which suited the analysis and modelling. It was noted by the observers, however, that a higher strike rate could occur when the vessel was turning. Discharge may flow down the side of the vessel, and during a turn the warps may cross into this region. The mitigation devices may also offer less protection during a turn, with tori lines, in particular, moving away from the warps. If the strike rates increase during a turn, then the protocol used here will be under sampling the strikes.

OFFAL DISCHARGE

These trials again confirm the primary role of discharges of offal (including minced and cut offal) and whole fish discards, in determining the rate of seabird interactions with trawl warps, and also with tori lines. For observations where no discharge was occurring, almost no seabird strikes were recorded. Mitigation devices, such as those considered in this trial, can only be effective when there are potential warp strikes to mitigate. In the preliminary analyses of the trial data, both discharge rate and discharge type showed clear effects on strike rate with some evidence for differences between large and small seabirds. In the modelling, which primarily sought to quantify the differences between mitigation treatments, discharge variables were less important. However, this arises primarily through the inclusion of seabird counts as an explanatory variable in the models – much of the variation in seabird numbers around the vessel is attributable to discharge.

It is apparent that there is some ambiguity in the recording of offal types during seabird strike observations. It is possible that the minced and cutter pump discharge categories are primarily being used to indicate offal size classes, rather than the product of particular machines.

MITIGATION DEVICE EFFICACY

This study shows clear differences in seabird strike rates under the different experimental treatments. It is notable that, despite the experimental design, there are both qualitative and quantitative differences between the treatment effects suggested by the simple analysis of mean strike rate (Figure 11) and the results of the statistical modelling of the seabird strike observations. These arise primarily because of the incomplete and non-random availability of bird bafflers on trial vessels, but are also related to the sparseness of the data and the influential covariates, especially discharge. We consider that the modelling results provide the better quantification of device efficacy.

The results of this trial confirm the findings of Sullivan et al. (2006), demonstrating that tori lines were the most effective device in reducing the rate of heavy seabird contacts with the trawl warps to 5 – 30% of the rate in the absence of mitigation. For large birds, both bird bafflers and the warp scarers also significantly reduced warp strikes to 40 – 90% of the no mitigation rate. A reduced rate of heavy strikes of small birds on the trawl warps was also apparent, but for bird bafflers the number of contacts was not significantly reduced relative to no mitigation, and for warp scarers the reduction was only marginally significant at the 95% level.

However, whilst heavy seabird strikes on bird bafflers and warp scarers were rare, heavy strikes of large seabirds on tori lines occurred at a similar rate to that of warp contacts in the absence of mitigation. For small birds the rate of heavy strikes on tori lines significantly exceeded the no mitigation warp strike rate.

To assess the overall efficacy of the mitigation devices in reducing total seabird contacts with fishing gear, heavy strikes on the mitigation devices must be added to those on the warps. Overall, therefore, this trial demonstrated no reduction in heavy strikes of large seabirds when tori lines were deployed, and a significant increase in heavy strikes of small birds, relative to no mitigation. The overall effects of the bird bafflers and warp scarer were not significantly different for either large or small birds, although for large birds the baffler performance was slightly better than that of the warp scarers.

In light of these results, an important question is whether heavy strikes on a tori line are of equivalent severity to heavy strikes on a trawl warp. These trials provide no quantitative information on this issue. However, the intention of the seabird strike observation protocol is that observers apply the same criteria in counting a heavy strike on a mitigation device as they do in counting a heavy strike on a trawl warp. We note that heavy strikes on tori lines were recorded throughout the trial, rather than only by particular observers.

Although no seabird captures were recorded from tori lines, the qualitative comments recorded about tori line interactions (Table 30 and Table 31) confirm that heavy strikes are occurring. Birds were recorded interacting with all parts of the tori line (backbone, streamers and buoy). During presentation of initial results from this trial at the Ministry of Fisheries observers' conference, an opinion was sought from the observers on the relative impact of strikes from the tori lines, compared with strikes from the warps. There was disagreement among the observers. Some thought that strikes on the tori lines were relatively benign, as the backbone is made of polypropylene, and the birds bounce off it. In contrast, one observer described seeing a bird get lassoed by a tori line as it suddenly snapped tight in the swell. The movement of the lines in the swell makes them unpredictable, and so effective at scaring the birds, but may also make them dangerous. The tori lines used in the trials had trailing windy buoys to provide drag to keep the lines aloft. One observer reported seeing a bird held on the tori line against the buoy, being dragged through the water. These comments, together with those recorded during the trial (Table 30 and Table 31), indicate that the seabird interactions with the tori lines cannot be assumed to be benign. Observers comments from warp strike observation periods carried out before the trial also indicate that interactions with tori lines have been observed in other New Zealand fisheries (Table 32), although these were not quantified before this trial.

The observation that bird bafflers may be more effective on vessels with a low block height deserves further exploration. If this result was found to hold more generally then, given the comparative performance of devices in this trial, bird bafflers would be the mitigation device of choice on these vessels. As data on tows with bird bafflers was collected in 2005, there may be an opportunity to explore this further with existing data.

Table 32. Verbatim observer comments from seabird strike observation forms relating to seabird interactions with tori lines in trips during the latter part of 2005.

Trip	*Tow*	*Sample*	*Comment*
2162	28	1	Nil contacts with warp but several heavy contacts with bird baffler and tori line
2162	34	1	3 x lg seabird dragged under tori line
2162	65	1	1 XWC caught and dragged under by tori line for 30 seconds lts. 1 XCP caught and dragged under by tori line for 7 minutes nlts
			1 heavy strike XSH on tori line lts
2162	66	1	2 heavy birds on tori line
2162	68	1	5 small bird heavy strikes on tori line. 1 juvenile XAL dragged under by tori line for 10 seconds
2162	69	1	3 small bird heavy contacts with tori line
2162	71	1	6 heavy strikes on tori line including 1 XCP fouled in streamers and hung up for 10 seconds. uninjured, lts
2162	72	1	1 heavy hit, small bird, on tori line
2162	73	1	20 small bird heavy strikes on tori line. 1 tori line port side only

TECHNICAL ISSUES WITH THE MITIGATION DEVICES

Qualitative information collected as part of these trials highlighted some technical issues with all the mitigation devices deployed. Both tori lines and warp scarers required ongoing maintenance, in particular replacing lost or discoloured streamers.

Variation in the length and style of baffler dropper-lines was apparent, and lines on the aft booms on some vessels were too short. It is clear that although bafflers do not need to be redeployed each tow, they do require regular attention to ensure the dropper lines are not tangled. Photographs from the trial indicate that various approaches to interconnecting the dropper lines may make them less susceptible to entanglement.

It appears that addressing some of the technical problems with the warp scarers deployed in the trial could make them more effective. A common problem was that, to prevent entanglement, the warp scarers were deployed shorter than intended and left an unprotected area of warp near the waterline. Further investigation of the weighting required to hold the device in place whilst minimising the risk of entanglement is required. The clips used to attach the trial warp scarers to the warps were clearly inadequate for long term use in a fishing environment. Alternative attachments might also solve the problem of the device getting caught in splices in the warps, so removing some deployment problems and allowing the device to remain in place during warp length adjustments and potentially some of the haul. Many of these attachment problems were successfully solved in the "Falkland Islands warp scarer" tested by Sullivan et al. (2006). That device was attached using a series of ring style devices, with rollers installed to allow easy warp adjustment including passing splices. The rings were joined by a length of square netting which reduced entanglement. In that study the warp scarer proved almost as effective as tori lines in reducing warp contacts. A means of safely deploying warp scarers on all vessels would also be desirable.

ACKNOWLEDGEMENTS

These trials relied on data collected by seventeen Ministry of Fisheries observers, and the co-operation of the masters and crews of eighteen vessels in the 2006 squid fishery, together with their vessel managers. The trials were designed collaboratively by a Technical Advisory Group which, in addition to the authors of this report, included scientists from the New Zealand Ministry of Fisheries (Susan Waugh), Department of Conservation (Johanna Pierre) and WWF-NZ (Nathan Walker and Caren Schröder). Members of the NPOA-TWG provided useful input to the trial design, in particular the inclusion of bird bafflers as an experimental treatment. The trials were implemented by the Deepwater Stakeholder Group Ltd (now Deepwater Group Ltd.). John Cleal, seabird liaison officer for DSG, ensured vessels received the required mitigation devices and a briefing on the trial protocols. Nigel Hollands was the principle liaison between SeaFIC, as trial co-ordinator, and the Ministry of Fisheries observer programme. Members of the MFish Deepwater Fisheries management group, in particular John Taunton-Clark and Jim Cornelius, gave advice on Special Permit requirements and ensured this was issued in a timely manner. Kim George from the Ministry of Fisheries Research Data Management Group provided access to the observer data, and David Fisher and Brian Sanders, of NIWA, assisted in interpreting some aspects of these data. David Middleton's work on these trials was supported by the Deepwater Stakeholders Group, and Edward Abraham's analysis of the data was supported by Ministry of Fisheries contract IPA2006-02.

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APPENDIX 1 - DEVICE SPECIFICATIONS

WARP-STRIKE MITIGATION DEVICE TRIALS – 2006 SQUID FISHERY

18 January 2006

This document provides the specifications for the three mitigation devices included in the warp strike mitigation device trials that are being carried out aboard observed vessels in the 2006 southern squid fishery. These specifications are similar, but not identical, to those included in the *Fisheries (Incidental Bycatch of Seabirds by Trawl Vessels 28m+) Notice 2006*. In particular, the warp deflector described here is a standard device built for these trials, and the bird baffler specification is more restricted than that in the Gazette notice.

For the duration of these trials, when observers determine whether or not the device deployed in a particular observation period is "to specification" (as required when completing the *Seabird Warp-Strike Observations (Trawl)* form), the devices should be judged against the specifications in this document.

DEVICE TERMINOLOGY

Devices to mitigate seabird warp strikes are known by a variety of names. Some of the names used for the three devices included in these trials tabulated here.

Name used in warp strike protocol	*Alternative names*
(a) Tori lines	Twin Tori lines Paired streamer lines
(b) Warp scarer	Warp deflector Warp scarer Carey device Carefree's Cunning Contraption
(c) Bird bafflers	Bafflers Brady Bird Bafflers

SPECIFICATIONS

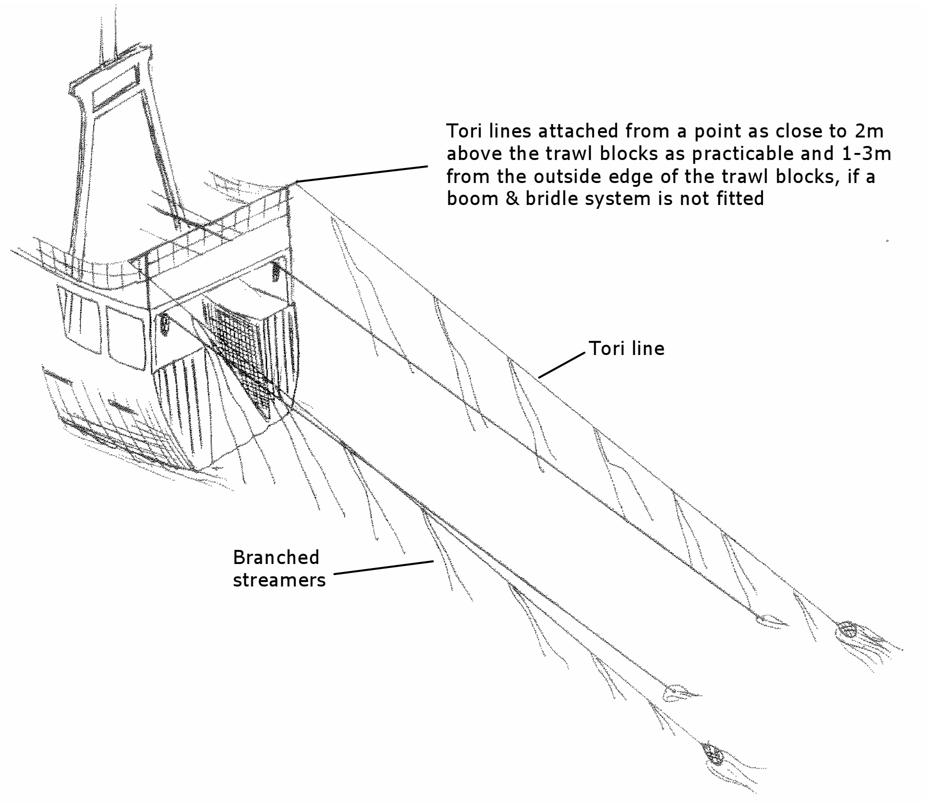
Tori lines

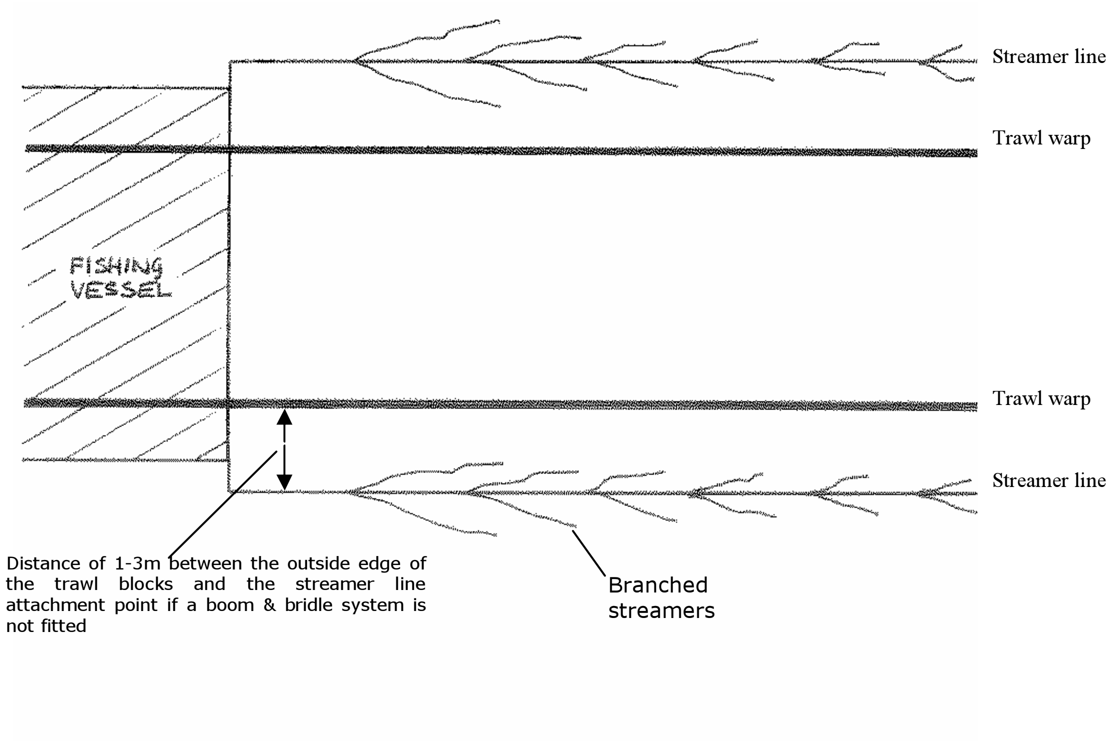
1) Tori lines comprise two lines, of a minimum of 8 mm diameter, each of a length so that when deployed they have an aerial extent of at least 10 metres behind the point at which the trawl warps enter the water, in the absence of wind or swell.
2) The lines are attached to the port and starboard sides of the vessel from a point as close to 2 metres above the trawl blocks as practicable and as close to the stern as practicable. The lines are attached either:
   i. between 1 – 3 metres from the outside edge of the trawl blocks on both sides of the vessel, on a sidearm if necessary; or
   ii. to a "boom and bridle" system that allows the lines to be adjusted on a horizontal plane in order to vary the distance between the streamer line attachment point and the outside of the trawl blocks and is positioned to ensure maximum protection of the trawl warps at all times.

3) An object is attached at the seaward end of each of the lines. The object must create sufficient drag on the line to ensure that the line is taut behind the vessel at all times.

4) Branched streamers, each comprising of two strands of fluorescent red, yellow, orange or pink plastic tubing of a minimum of 3 millimetres in diameter, are attached no more than 5 metres apart commencing no more than 5 metres from the point of attachment of the streamer line to the vessel and thereafter along the seaward extent of the line. When a Tori line is deployed, each of the branched streamers must reach the sea surface, in the absence of wind and swell. Branched streamer length will therefore vary depending on the height of its attachment point above the water but, in any event, every branched streamer must be at least 1 metre in length.

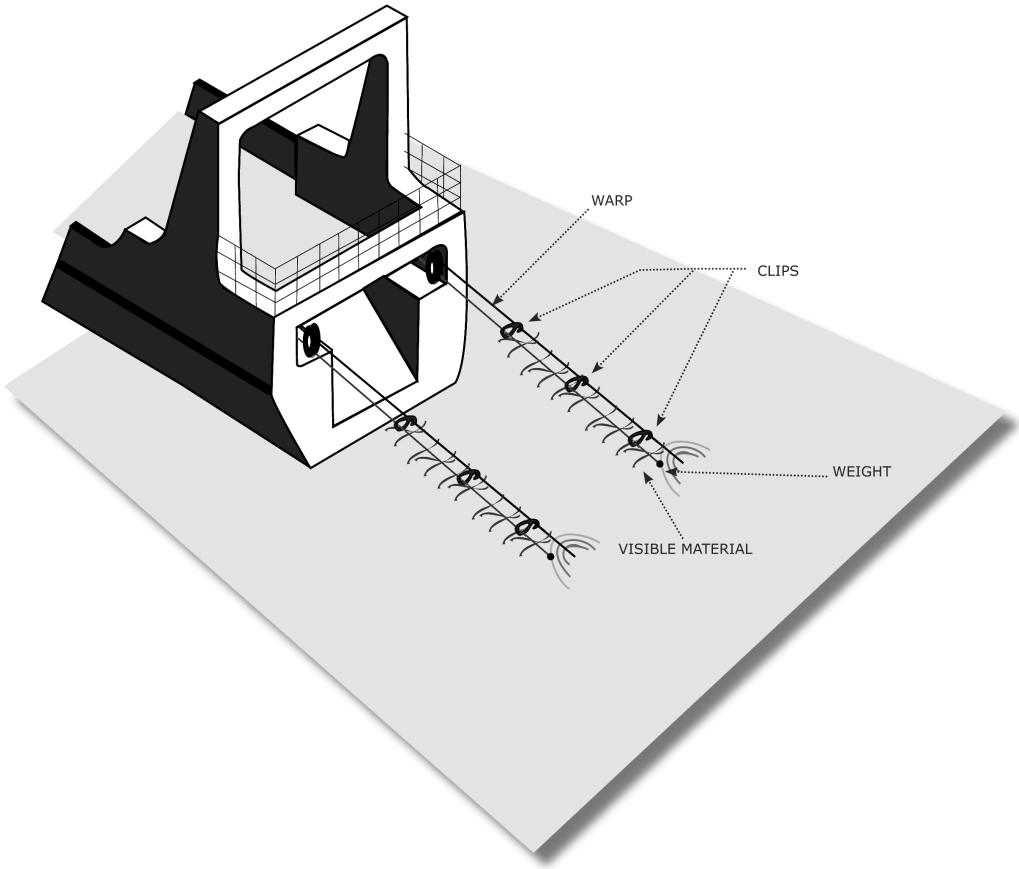
5) Each branched streamer must be attached to the line in a manner to prevent fouling of individual branched streamers on the main line, and to ensure vertical displacement of individual branched streamers to the waterline in the absence of wind and swell.

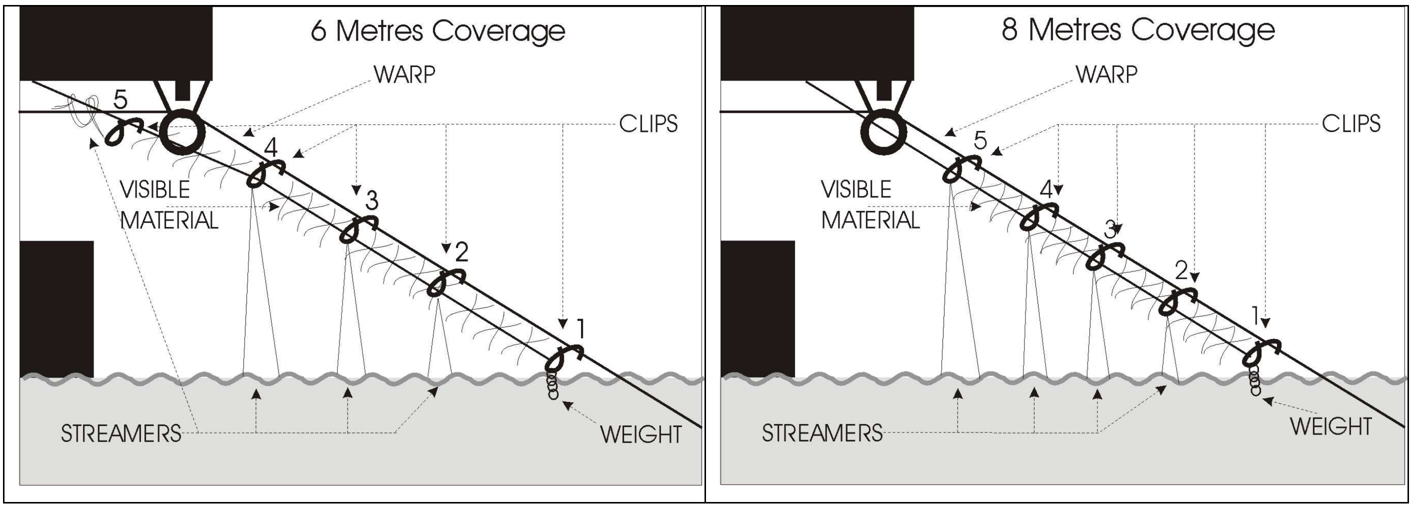




Warp scarer

1) A warp scarer is a weighted device fixed to each warp with clips or hooks, which allow for the device to slide up and down the warp freely and to stay aligned under each warp.
2) When set, the backbone of the device must extend under the warps from a point not less than 4 meters behind the stern and extend as close as practicable to the point where the warps enter the water, in the absence of wind or swell.
3) The backbone of the device is made of rope and fitted with colourful durable material of no less than 300 mm in length, woven or tied to the backbone at spacings of no less than 250 mm apart in a manner designed to create a visible deterrent.
4) Branched streamers, each comprising of two strands of fluorescent pink plastic tubing are attached to four of the clips and hang to the waterline.
5) A 4–6 kg weight is attached to the seaward clip. This weight must be reasonably compact to avoid being swept around the warp causing entanglement, and must hold the device tightly under the warp stopping it moving back up the warp during fishing operations.
6) The device is clipped to the warp and tied off to the vessel such that weight holds the device as close as practicable to the point where the warps enter the water, but does not enter the water too far.





Bird baffler

1) Bird bafflers consist of four booms attached to the stern quarter of the vessel, two attached to the starboard stern quarter and two attached to the port stern quarter. Two booms extent out from the sides of the vessel and two extend backwards from the stern.

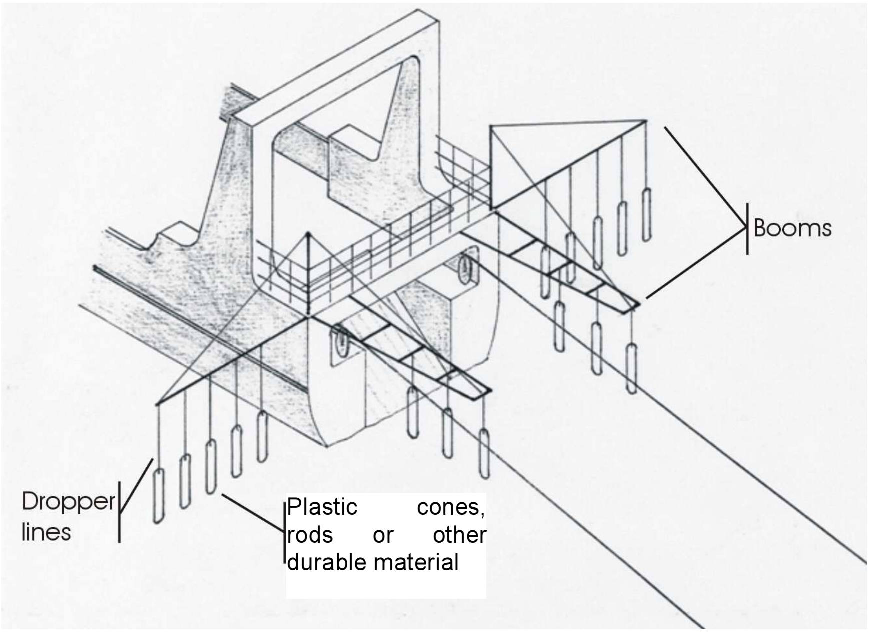
2) The booms are able to be lifted and lowered over the sides and stern of the vessel. When deployed the booms are lowered to a horizontal position.

3) Each boom extends outwards not less than four meters from the side or stern of the vessel.

4) Dropper lines are attached to the booms no more than 2 metres apart.

5) Plastic cones, rods or other brightly coloured and durable material are be attached to the ends of the dropper lines, so that the bottom of the cone, rod or material is not more than 500 millimetres above the water, in the absence of wind and swell.

6) Lines or webbing may be attached between the dropper lines to prevent tangling.



APPENDIX 2 – MITIGATION DEVICE EVENT LOG FORM

Mitigation Device Record Sheet for Observers

Trip number ______ Observer initials ______ Sheet ____ of _____

Instructions

Use the table below to keep a log of events relevant to the durability and operation of the seabird warp strike mitigation devices deployed in these trials. For each event please record the date, time (or time range if relevant), and tow number. Relevant events include loss, damage, repairs, alteration, entanglement, and other circumstances that may affect device performance. Please provide a full description of the event. If a photograph illustrating the event was taken record the photograph number. Record the devices as “T” (Tori lines), “W” (Warp scarer”), or “B” (Bafflers).

Date	Time (24 hr)	Tow number	Photograph number	Device affected	Event description