Polar Biol (2006) 29: 745–753
DOI 10.1007/s00300-006-0111-z

ORIGINAL PAPER

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Mitigation of seabird mortality on factory trawlers: trials of three devices to reduce warp cable strikes

Received: 22 June 2005 / Revised: 9 January 2006 / Accepted: 9 January 2006 / Published online: 7 February 2006

Abstract Experimental trials were conducted onboard a stern trawler to identify the relative efficacy of three emerging mitigation measures (tori lines, warp scarer and Brady baffler) designed to reduce seabird mortality caused by warp cable strikes. The use of mitigation measures was clearly shown to substantially reduce seabird mortalities from collisions between seabirds and warp cables. Based on an established significant relationship between contact rate and seabird mortality, when using contact rate as an index of mortality there was a clear performance hierarchy of the three measures. Tori lines and the warp scarer were significantly more effective at reducing contacts than the Brady Baffler, whilst tori lines represent a smaller, but still significant, improvement on the warp scarer. While further testing would be required under local environmental and operational conditions, our findings are likely to have application for many trawl fisheries around the world.

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Introduction

Efforts to reverse recent declines in the populations of many albatross and petrel species have understandably focused on reducing mortality caused by longline fishing. If used without appropriate mitigation measures, this fishing technique can cause significant seabird mortality and its use, particularly in unregulated fisheries, threatens many albatross and petrel populations throughout the world (Croxall et al. 1990; Brothers 1991; Weimerskirch et al. 1997, 1999; Robertson and Gales 1998; Nel et al. 2002). Although several recent reports have documented significant levels of mortality caused by both pelagic and demersal trawl fisheries (Weimerskirch et al. 2000; CCAMLR 2001, 2002; Sullivan et al. in press) a lack of development and rigorous testing of mitigation measures has hampered attempts to reduce trawler mortality.

Traditionally, high levels of seabird mortality caused by trawlers have been associated with netsonde cable collisions (e.g. Bartle 1991; Weimerskirch et al. 2000), which are now prohibited in many Southern Hemisphere fisheries (e.g. Weimerskirch et al. 2000, CCAMLR 1998). However, recent reports have documented significant levels of trawler mortality caused by net entanglements (SC-CCAMLR 2001, 2002) and warp cable strikes (Sullivan et al. 2006). Most net related mortality recorded in recent years has been caused by pelagic trawlers. Pelagic nets remain at or near the sea surface for extended periods, in contrast to demersal nets which are weighted to sink quickly. Mortality is predominantly caused by birds diving into the net and becoming entangled, particularly in the intermediate size meshes (Weimerskirch et al. 2000; SC-CCAMLR 2001, 2002). Recent advances have been made in the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) waters that may lead to effective mitigation measures to reduce this type of mortality (Hooper et al. 2003).

In 2001, Falklands Conservation's Seabirds at Sea Team (SAST) documented significant levels of mortality

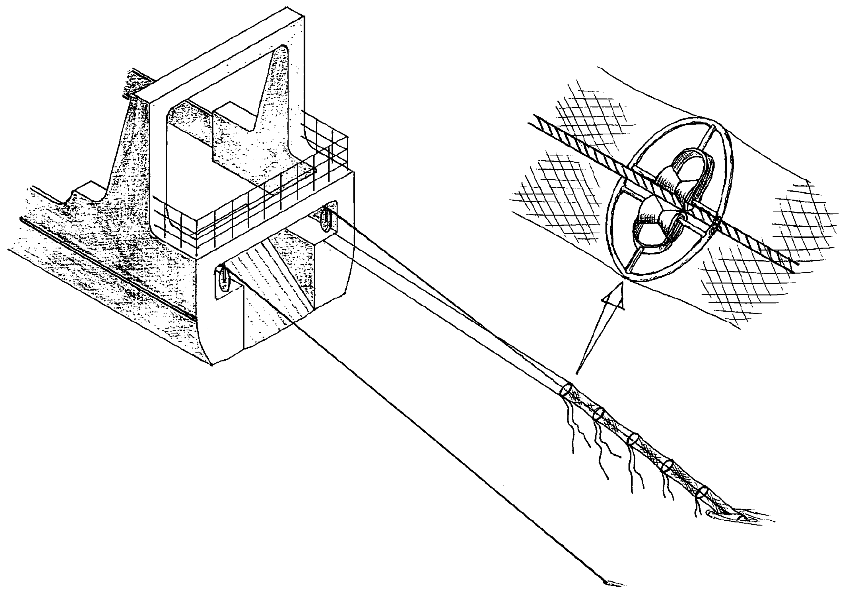

Fig. 1 Warp scarer deployed on the experimental warp

in seabirds feeding on offal discharge at the stern of the ship, which were struck by the warp cable, dragged under water and drowned (Sullivan et al. 2006). Factory trawlers operating in the Falkland's fishery conservation zones do not typically macerate discard species and factory waste (e.g. heads, tails and visceral matter) before discharging it from scuppers, which are located approximately 15–20 m from the stern of the vessels. In addition, mortality was occasionally recorded when birds became entangled around the paravane cable and were drowned after being dragged down the cable and becoming wrapped around the paravane[1] (SAST and Falkland Islands Fisheries Department (FIFD) unpublished data). Scaling of confirmed mortalities, recorded by observers, to the entire finfish fleet resulted in an estimate of over 1,500 seabird deaths in Falkland's waters in 2002/3, the majority of which were black-browed albatross (*Thalassarche melanophris*) (Sullivan et al. 2003)). Eliminating the discharge of offal has been found to greatly lower seabird mortalities (Wienecke and Robertson 2002); however in fisheries without methods for controlling discharge, the implementation of this would be a significant engineering and economic issue (Sullivan et al. 2006).

The trials detailed here represent the first attempt to measure the relative efficacy of three devices designed to reduce seabird collisions with warp cables during trawling operations, and so reduce incidental injury and mortality. The objective of the trials was to identify a mitigation measure for the Falkland Islands trawler fleet that is both operationally effective and economically practicable. Such a device may also have an application in the large freezer trawler fleet operating on the broader Patagonian Shelf, and in other factory trawl fisheries around the world.

[1]Paravanes contain transducers for net monitoring equipment. They are typically suspended just below the surface near the stern of a vessel

Mitigation devices

Falkland islands warp scarer

The Warp Scarer consists of a series of ring style devices, with rollers installed to allow easy cable adjustment (including cable splices). These are joined by a length of square netting (Fig. 1) and a rope with reflective tape hangs from each ring to the sea, scaring birds from the warp as the vessel pitches and rolls. The Warp Scarer is deployed after shooting the net, and retrieved prior to hauling. During trawling it is held in position by two ropes ('lazy lines') tied off to the stern of the vessel. Data collected onboard four vessels over the 18 months prior to the trial suggested that the device was effective at reducing contacts between seabirds and the warp cable (Falkland Islands Government 2002).

Brady Baffler (Patent Pending 508603)

The Brady Baffler was developed by Keith Brady during several years of sea trials in New Zealand waters. It is designed to prevent birds that are scavenging for factory discharge from congregating at the stern of trawlers where the warp cables enter the water.

The Brady Baffler (hereafter, Baffler) consists of a tower fitted to each of the two quarters of the stern gantry. Two steel arms, one aft of the stern and one outboard (aft of the discharge scupper), with ropes and plastic cones at the seaward end are lowered from each tower (Fig. 2). As the vessel pitches and rolls the ropes and cones swing and prevent birds from gathering in the area adjacent to the warp cable (Seafood New Zealand 2002). The Baffler can

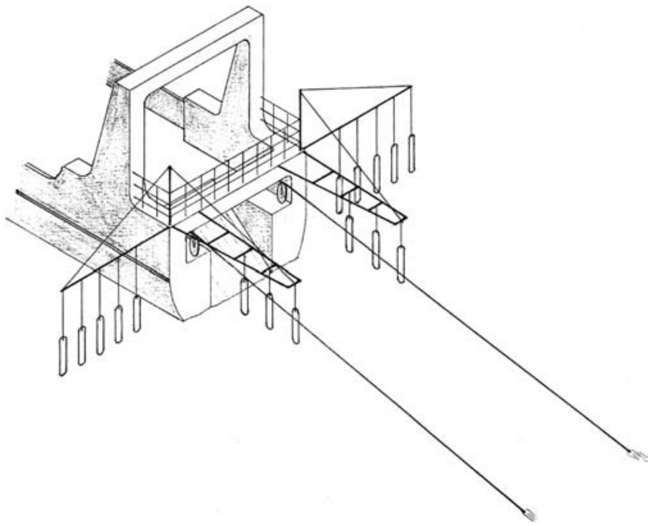

Fig. 2 Brady Baffler deployed on the stern quarters (starboard and port)

be set at the beginning of a fishing trip and, except in extreme weather conditions, does not require retrieval until the end of the trip. In sea trials on several trawlers in New Zealand the Baffler has been shown to be operationally robust in a range of sea states (Fishing News International May 2003). However, to date the effectiveness of the device is based largely on anecdotal reports from crewmembers and captains; there are few empirical data on its effectiveness at reducing seabird mortality.

Tori lines

Tori lines have been used as mitigation devices on longliners since the early 1990s. To adapt these for use on trawlers two lines were used: one attached to a side arm that reached 2 m outboard from the stern of the vessel on the side with the discharge chute, and one line attached to the rail in the centre of the fantail (the deck level above the trawl deck, Fig. 3). Each line consisted of 50 m of rope with a buoy attached to the seaward end for tension, and had six streamers (yellow garden hose) attached at 5 m intervals commencing 5 m from the stern gantry. Each streamer reached the sea surface in calm conditions. Tori lines were deployed after shooting and retrieved prior to hauling.

Methods

Trials of the three mitigation devices were carried out under normal operating conditions on a commercial fishing vessel, the F/V *Hermanos Touza*, which is a 66 m, 1354GRT factory trawler operated by Golden Touza Ltd. The trials took place during the austral spring 2003, when albatross density, and incidental mortality, peaks around fishing vessels in Falkland's waters (Sullivan et al. 2006). Finfish catches also peak in this period (FIFD 2004) leading to a peak in the level and duration of factory discharge.

Two trips (August 11–September 13 2003, and October 7–November 18 2003) were carried out to compare the effectiveness of the three mitigation measures under a range of environmental and operational conditions. During these trips the vessel was primarily targeting finfish to the north and west of the Falkland Islands. A small number of trawls carried out during a short period in the first trip when the vessel targeted the squid, *Loligo gahi*, to the north of the Falklands were excluded from the trial due to the differing location and nature of this fishery, especially a lower discharge regime. The four treatments (three mitigation devices, and a control treatment where no mitigation measures were used) were randomly allocated to observed trawls. The random allocation of treatments was intended to account for differences in the performance of the mitigation devices under varying environmental and operational conditions. For example, the amount and duration of offal discharge influences the density of birds attending trawlers, the strength and direction of the wind (relative to vessel course) influences bird behaviour around vessels (Sullivan et al. 2006), and sea state greatly influences the force and speed at which the stern of the vessel pitches and, therefore, the speed at which the warp pitches and strikes birds. Trawls with no factory discharge were not observed as previous studies showed that significantly fewer contacts, and no warp related seabird mortalities, occur in the absence of factory discharge (Sullivan et al. 2006).

Like most factory trawlers in the Falkland's fisheries the F/V *Hermanos Touza* does not process or macerate discard species or and factory waste (i.e. offal) before it is discharged from scuppers, on both the port and starboard sides, approximately 15 m from the stern. It was not possible for a single observer to accurately record contacts on both the starboard and port warps. After discussions with the Captain and Bosun about the factory design, and 2 days of at-sea observations, it became apparent that the majority of factor waste was

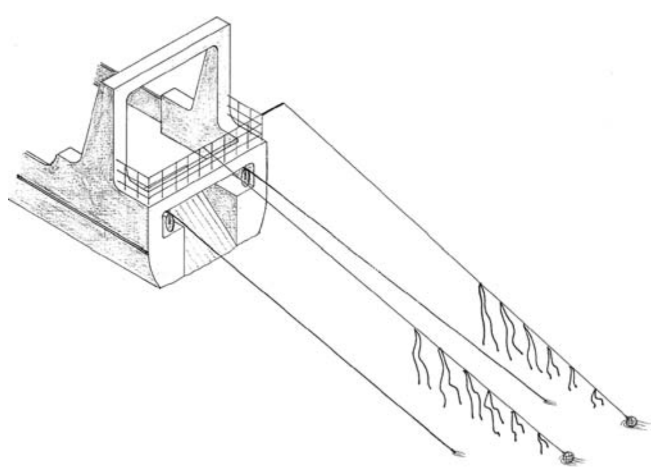

Fig. 3 Tori lines deployed to protect the experimental warp

discharged on the starboard side of the vessel. Therefore, contact observations were only made on the starboard warp ("experimental warp"), and the Warp Scarer and Tori Lines were set on the starboard warp only. However, to comply with the designer's intentions, when Baffler treatments were conducted both the starboard and port side arms were deployed.

Data collection

Seabird mortalities were recorded as the number of birds (or significant parts of birds) hauled onboard and were thus recorded as mortalities per trawl. Contacts (both fatal and non-fatal) between seabirds and the starboard warp cable were also recorded; these data were collected using protocols adapted from those developed by the Australian Antarctic Division and Australian Fisheries Management Authority (Wienecke and Robertson 2002; see Appendix 1). The two SAST observers who conducted all data collection had used these protocols since 2000. Contact observations typically began as soon as the trawl gear reached the bottom and the mitigation device was deployed, and continued until factory discharge ceased. The majority of trawls had a single observation period. However, if factory discharge restarted observations also recommenced leading to additional observation periods for some trawls. Additional observation periods also occurred in long trawls with sustained discharge where an observer rest period was required. Finally, a continuous period of observation was split into sub-periods if environmental conditions changed.

A range of environmental variables (Appendix 2) were recorded, together with estimates of the abundance of seabirds around the vessel, during shooting, trawling and hauling operations.

Shooting Shooting is defined as the deployment of trawl gear until the operational trawling depth is reached. Seabird abundance was estimated as accurately as possible in a 500×500 m area (500 m astern and 250 m on the starboard and port sides, which was the standard survey area for shooting, trawling and hauling operations) prior to the net sinking. Counts were conducted for approximately 10 min.

Trawling Hourly estimates of seabird abundance were made during trawl observation periods. During observation periods, environmental conditions [sea state (Beaufort scale), sea height, sea direction, swell height, swell direction, wind speed, wind direction, wind direction relative to the ship's course, day light period] were recorded every three hours or when conditions changed markedly, including changes in vessel course, which resulted in a change in wind direction relative to course.

Hauling Hauling is defined as the retrieval of ground gear. Seabird numbers were estimated for the same time period as for shooting, typically just after the trawl doors were secured.

Data analysis

While the estimated number of mortalities over the whole fleet and year (in the absence of mitigation measures) is considered to be unacceptably high (> 1,500 birds), confirmed mortalities during an individual trawl are nevertheless a statistically rare event and thus provide only limited information for distinguishing between the treatments. However, seabird mortality in the Falkland Islands finfish fishery has been shown to be significantly correlated with heavy contacts between seabirds and warp cables (Sullivan et al. 2006): a heavy contact is clearly a necessary pre-requisite for a mortality to occur. The data analyses thus considered between-treatment differences in the number of contacts between seabirds and the warp in addition to the number of confirmed mortalities. In this analysis mortalities and contacts of all species were included, though the vast majority of interactions were with black-browed albatross.

The raw data confirmed mortalities constitute counts per trawl, and those for warp contacts constitute counts per observation period. Such event counts are clearly constrained to numbers greater than or equal to zero; furthermore zero or low event counts were frequent. This implies that statistical methods assuming a normal distribution are inappropriate. Observation and trawling times varied so comparisons were based on overall mortality and contact rates. Multiple observation periods on a single trawl cannot be considered statistically independent so were aggregated in analyses where environmental co-variates were not being considered, summing the observation time and contacts observed to yield one value per trawl.

Confidence intervals (95%) for the mean mortality and contact rates in each treatment were calculated by bootstrapping. Bootstrapping is a resampling technique that uses the empirical distribution of the observations rather than assuming a particular parametric distribution (see Solow 1989). The bias adjusted mean and adjusted bootstrap percentile (BCa; Efron 1987) confidence interval were calculated using the boot package in the R statistical package (R Development Core Team 2004; version 2.0.0), with 10,000 bootstrap replicates.

A more formal test of significant differences between treatments is possible using a generalised linear model (GLM) framework. Count data are often modelled using the Poisson distribution, but these data are overdispersed (variance > > mean; see Tables 1–3) suggesting the use of a quasipoisson or negative binomial distribution (see Crawley 2002). The analyses here use a negative binomial distribution, fitted via Venables and Ripley's (2002) glm.nb function in the R statistical package (R Development Core Team 2004, version 2.0.0) and using the default log link function. In the GLM analyses the dependent variable was the number of events (mortalities or contacts), with the varying observation time (or trawl time in the case of mortalities) included as an offset term (Crawley 2002, Venables and Ripley, 2002). Although the GLM approach could allow the inclusion of co-variates

Table 1 Confirmed mortalities observed under each treatment, with mean mortality rate (mortalities per hour of trawling) and confidence limits calculated using bootstrap re-sampling

Treatment	Number of trawls	Confirmed mortalities	Trawls with mortalities	Mean	Variance	95% BCa confidence interval
Control	20	14	7	0.082	0.017	0.036–0.152
Baffler	22	3	3	0.022	0.003	0.006–0.054
Warp Scarer	17[a]	1	1	0.007	0.001	0.000–0.022
Tori Lines	19	0	0	0		

[a]Mortalities were confirmed (and mortality rate calculated) for only 16 trawls, due to observer disembarkation

(i.e. environmental conditions) in addition to the main treatment effect, the random assignment of treatments to trawls, together with the avoidance of extreme conditions (e.g. low levels of discharge), results in relatively little resolution in this data. We therefore report only GLMs that compare mean contact rate across treatments, i.e. essentially an analysis of variance. The models were fitted using treatment contrasts (see Venables and Ripley 2002) and the factor levels were coded so that the control treatment was the default factor level. Differences between individual treatments were explored by collapsing factor levels and comparing the Akaike Information Criterion (AIC) of the resulting simplified model with that of the full model, where the model with the lower AIC is preferred (see Venables and Ripley 2002). The models were also compared using Venables and Ripley's (2002) anova.negbin function to perform likelihood ratio tests.

Results

Seventy-eight trawls were observed over the course of the two trips, randomly allocated to the four treatments (Table 1). Difficulties experienced with timing of ship transfers resulted in unequal numbers of trawls over the four treatments.

Mortalities

A total of twenty-five seabird mortalities were recorded while observers were on board the vessel, 18 of which were due to contacts with the starboard (experimental) warp. These comprised 22 black-browed albatrosses (16 of which were killed during experimental observations), two southern giant-petrels (*Macronectes giganteus*) (both during experimental observations) and one Cape petrel, which was killed after becoming entangled with a paravane cable. Six seabird mortalities were also recorded on the port (non-experimental) warp (one while using the Baffler, three while using the Warp Scarer, and two during control treatments).

Mortalities were rare with 86% of trawls having no observed mortality (the percentage of trawls with no mortalities ranged from 65 to 100% over the four treatments). All three mitigation devices resulted in a lower mortality rate than under the control (no mitigaton device) treatment (Table 1). No mortalities were observed during Tori Line treatments. In the case of the Warp Scarer treatment the bootstrapped 95% confidence intervals did not overlap with that of the control, whereas the 95% confidence interval for mortality rate in Baffler treatments overlapped slightly with the control. Because of the small number of observed mortalities a GLM was not fitted.

Total contacts

All three mitigation devices reduced the rate of total contacts (i.e. light and heavy contacts combined) relative to that of the control (Table 2; Fig. 4). However, the 95% confidence interval for the mean contact rate with the Baffler overlaps with that of the control, whilst the Warp Scarer and Tori lines have substantially lower mean rates. Mean contact rate was lowest with the Tori lines; the confidence intervals suggest this had a significantly lower mean contact rate than the next best treatment, the Warp Scarer.

A GLM for the number of contacts under each treatment, with observation time included as an offset term, also shows the reduced contact rate under each mitigation treatment, but indicates the difference between the control and Baffler treatments is not significant (Table 3(a)). This is substantiated by collapsing the factors coding for the control and Baffler treatments to a single level; the resulting model (Table 3(b)) has a lower AIC than the four treatment model and is therefore the preferred model. Similarly a likelihood ratio test indicates no significant difference between the models ($P = 0.34$) confirming that there is no advantage in considering the control and Baffler treatments separately. However, considering the Tori lines and Warp Scarer as a single treatment results in an increased AIC (Table 3(c)) which supports the interpretation of the bootstrapped confidence intervals (Table 2),

Table 2 Sample mean and variance of total (light and heavy) contact rate (per hour of observation) for each treatment, with confidence limits calculated using bootstrap re-sampling

Treatment	Mean contact rate	Variance	95% BCa confidence interval
Control	55.78	1111.42	42.64–70.75
Baffler	42.95	998.87	30.95–56.54
Warp Scarer	6.64	67.06	2.68–10.73
Tori Lines	0.91	4.06	0.34–2.49

Table 3 Generalised linear models with negative binomial errors and a single treatment factor for the total number of seabird contacts with the warp cable

Model	Coefficient	Estimate	Std. Error	Pr(>|z|)	Residual (Null) deviance	Fitted theta (Std. Error)	AIC
(a) Four treatments	Intercept	2.8940	0.2403	< 2e−16	91.348 (213.805)	0.877 (0.161)	636.85
	Baffler	−0.3167	0.3322	0.340			
	Tori lines	−4.4066	0.3865	< 2e−16			
	Warp Scarer	−2.4250	0.3637	2.6e−11			
(b) Merged control and Baffler	Intercept	2.7404	0.1671	< 2e−16	91.243 (211.105)	0.864 (0.158)	635.75
	Tori lines	−4.2524	0.3472	< 2e−16			
	Warp Scarer	−2.2711	0.3217	1.66e−12			
(c) Merged (control and Baffler) and (Tori and Warp Scarer)	Intercept	2.7404	0.1904	< 2e−16	92.416 (168.174)	0.664 (0.116)	653.38
	Tori Lines/ Warp Scarer	−2.8934	0.2894	< 2e−16			

Observation time was included as an offset term in each model

that the Tori lines perform significantly better than the Warp Scarer in reducing contacts.

Heavy contacts

The mean rates of heavy seabird contacts with the warp were lower with all three mitigation devices than in the control treatment (Table 4). As with total contacts, the confidence interval for the mean contact rate with the Baffler overlapped the confidence interval for the control whilst the mean rates were substantially lower for the Warp Scarer and Tori lines. The lowest mean heavy contact rate was achieved with the Tori lines, although in this case the confidence interval overlapped that of the Warp Scarer.

GLMs for the number of heavy contacts are presented in Table 5. In this case the factor for the Baffler treatment is significant at the 10% level (Table 5(a)), and collapsing the Baffler and control treatments to a single level does not lead to an improved model (Table 5(b)): AIC is increased and a likelihood ratio test indicates a difference between the models ($p = 0.07$) at the 10% level. Likewise collapsing the Tori Line and Warp Scarer treatments to a single level (Table 5(c)) indicates that these are best modelled as distinct treatments.

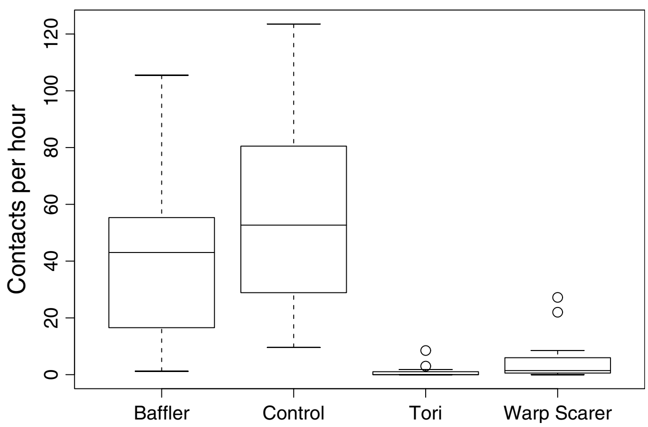

Fig. 4 Boxplots of total contact rates (per hour of observation) under the four experimental treatments

Discussion

Despite the low number of confirmed seabird mortalities observed during these trials it is clear (Table 1) that use of a mitigation device can substantially reduce seabird mortalities caused by collisions with trawl warps. However, these data provide little power for distinguishing between the relative performance of the three mitigation devices tested. Under these circumstances, and with a significant relationship between mortality and heavy contacts identified (Sullivan et al. 2006), we have used data on seabird contacts with the warp to assess the relative performance of the devices.

The contact rate data suggest a clear performance hierarchy of the three mitigation devices in Falklands' waters. The Tori lines and Warp Scarer both perform substantially better than the Baffler whilst Tori lines represent a smaller, but still significant, improvement on the Warp Scarer. These differences are immediately apparent from boxplots of the contact rates in each treatment (Fig. 4), and have been substantiated by fitting, and comparing, appropriate generalised linear models that allow for the overdispersed nature of the count data. Venables and Ripley (2002, p.207) note that deviance based tests are not applicable when the theta parameter of the negative binomial distribution is estimated, so model comparison was based primarily on change in AIC.

Contact rates showed considerable between tow variation, within the control and Baffler treatments in particular. Such variation is not unexpected given the undoubted influence of varying environmental and operational conditions on warp contacts. Offal discharge

Table 4 Sample mean and variance of heavy contact rate (per hour of observation) for each treatment, with confidence limits calculated using bootstrap re-sampling

Treatment	Mean heavy contact rate	Variance	95% BCa confidence interval
Control	16.80	120.47	12.66–22.20
Baffler	9.72	81.23	6.85–14.72
Warp Scarer	0.90	1.85	0.38–1.71
Tori Lines	0.29	0.73	0.03–0.97

Table 5 Generalised linear models with negative binomial errors and a single treatment factor for the number of heavy seabird contacts with the warp cable

Model	Coefficient	Estimate	Std. Error	Pr(> |z|)	Residual (Null) deviance	Fitted theta (Std. Error)	AIC
(a) Four treatments	Intercept	1.7195	0.2413	1.04e−12	87.00 (205.712)	0.896 (0.207)	444.54
	Baffler	−0.6189	0.3351	0.0648			
	Tori lines	−4.3775	0.4491	< 2e−16			
	Warp Scarer	−3.1196	0.4086	2.26e−14			
(b) Merged control and Baffler	Intercept	1.4409	0.1737	< 2e−16	86.022 (193.649)	0.827 (0.186)	445.80
	Tori lines	−4.0871	0.4227	< 2e−16			
	Warp Scarer	−2.8384	0.3803	8.39e−14			
(c) Merged Tori Lines and Warp Scarer	Intercept	1.7199	0.2534	1.15e−11	87.283 (190.473)	0.809 (0.184)	448.23
	Baffler	−0.6192	0.3517	0.0783			
	Tori Lines/ Warp Scarer	−3.6210	0.3549	< 2e−16			

Observation time was included a an offset term in each model

has a major influence on contact rates via its effect on the abundance of seabirds attending the vessel so observations in this study were only carried out when offal was being discharged. Variance was also limited by considering tows on a single vessel in a particular fishery in a limited period. Other sources of variation could not be controlled, but the experimental design, where mitigation devices were randomly allocated to tows, gives confidence that the data reflect a genuine treatment effect.

Significantly more total and heavy contacts were recorded while the Baffler was in use than either the Tori Lines or Warp Scarer. Rates of total contacts showed no significant difference between the Baffler and control treatments, although the rate of heavy contacts was reduced.

Vessels in the Falkland Islands fisheries typically have trawl blocks located around 5 m above the water's surface and, depending on target trawl depth, the warp cable is typically shot at a ratio of between 3:1 and 4:1 (i.e. the net is located 3–4 times further from the stern of the vessel than the vertical distance to the net). Under these conditions the point where the cable enters the water is located, on average, 15–20 m from the stern of the vessel. Both observers noted that the Baffler arm and strapping on the side of the vessel reduced the number of birds flying down the side of the vessel and landing directly adjacent to the warp cable. However, the arm that reached astern was too short (6 m) to prevent birds from landing, and sitting on the water adjacent to the cable when they approached from other directions. Both observers thought that adding a Tori line device from the end of the stern arm would most likely greatly increase the effectiveness of the device. This would most likely mean that the line would have to be set after shooting and retrieved before hauling, which would alter the 'set and forget' nature of the Baffler which, in its current form, can be set at the beginning of a fishing trip and only retrieved in extreme weather or at the end of the trip. However, it may still be the case that a pair of Tori lines would be just as effective as a Baffler with a Tori line extension. On two occasions during the trials several strut welds on the Baffler broke and required fixing.

The rate of total and heavy contacts was significantly less with the Warp Scarer deployed than under the Baffler and control treatments. However, significantly more total and heavy contacts were recorded using the Warp Scarer than with the Tori Lines. The one mortality recorded on the experimental warp during the Warp Cable treatment occurred during shooting, i.e. before the device was deployed, which highlights a limitation of the device.

Total and heavy contact rates were lower using Tori Lines than all other treatments. In addition, this was the only treatment where no seabird mortality was recorded. Because the Tori lines reach approximately 30–50 m astern of the vessel (depending on sea state) they may also help prevent mortality caused by birds diving astern of the point where the warp cable enters the water and becoming wrapped around the warp cable under water, an event that has been recorded in Falkland Islands waters (Sullivan et al. 2006).

After 2 weeks of trials, two of the streamers (yellow hose) closest to the vessel (i.e. the longest streamers) on the centrally located Tori line were lost (due to the knots attaching them becoming untied) and were subsequently replaced with green garden hose. Both observers noted that seabirds, particularly black-browed albatross and giant petrels, were less aware of the green hose, presumably because the green hose did not contrast with the sea as much as the yellow hose. This suggests that yellow streamers (and possibly other high contrast colours) are the most effective coloured streamers for Tori lines (*cf:* Brothers 1996).

As this study aimed to find a device suitable for deployment throughout the Falkland Islands trawl fisheries, it is fortuitous that the effectiveness of the devices tested is inversely related to their cost. At the time of writing a Brady Baffler cost US $4,800 plus fitting, the Warp Scarer approximately US $800, and Tori Lines approximately US $40. In addition, the Warp Scarer and Tori Lines require little space, are easy to maintain and replace, and have no fitting costs. To deploy the Warp Scarer a crew member is required to reach outboard of the stern of the vessel (adjacent to the trawl block), whereas the Tori lines can be deployed by simply throwing buoys into the water although, in rough seas, care must be taken to prevent the buoys from passing under the warp cable. Tori lines also have the added advantage that many fishermen are aware of their application in longline fisheries.

To reduce mortality to negligible levels both warp cables need to be protected onboard vessels that discharge on both port and starboard sides (Sullivan and Reid 2003). Because it was not feasible to simultaneously record contacts on both port and starboard warps these trials were limited to observation of the starboard warp. Nevertheless, during the trials an additional mortality was recorded on the port (non-experimental) warp while the Baffler was deployed on both sides. In comparison, no mortality was recorded with the Tori Lines deployed which suggests that, even in the trial configuration that focussed on protecting the experimental warp, they offered some degree of protection to both warps. Further trials are planned to investigate the efficacy of two versus three tori lines (i.e. port, starboard and central) on vessels that discharge to both port and starboard. Consideration will also be given to the practicalities of deploying two warp scarers to protect both port and starboard warps cables and how each device performs under varying environmental conditions.

The GLMs fitted to the total and heavy contact rate data accounted for $>56\%$ of the null deviance with the factor coding for treatment, and an offset term for observation time, as the only explanatory variables. Although data on accompanying environmental conditions was collected during each observed trawl, there is currently insufficient data for a full analysis of the variation in the performance of the mitigation devices under different conditions: the environmental variables recorded have between three and six levels (Appendix 2), and interactions between variables are likely. Future analyses could make use of the fact that a variety of environmental states may be encountered during a single trawl and recorded in different observation periods. However, it would be necessary to take account of the fact that observation periods from a single trawl are not independent, potentially by the use of mixed models with a random trawl effect (e.g. Venables and Ripley 2002, chapter 10). Although a formal analyses of these factors was not possible, there are indications that contact rates increased with increasing sea state and swell height. There were also indications that the rate of contacts increased with the Warp Scarer deployed in tail winds, and that contacts increased in cross winds with the Tori lines deployed. Further trials have commenced to assess the efficacy of Tori lines and the Warp Scarer under varying environmental conditions.

This study represents the first attempt to collect quantitative data on the effectiveness of mitigation measures developed to reduce mortality caused by warp strike on stern factory trawlers. While further testing would be required to identify any local variations in the cause and nature of trawler related seabird mortality, our findings are likely to have application to a range of trawl fisheries around the world.

Acknowledgements The Falklands Conservation Seabirds at Sea Team's component of the trials was jointly funded by the International Association of Antarctic Tour Operators (IAATO) Save the Albatross Fund, the Falkland Islands Government, Fortuna Ltd., and Peter Harrison MBE and we appreciate their support. The support of the Falkland Islands Fisheries Department (FIFD), especially John Barton MBE (Director of Fisheries) has been critical to these trials. Thanks also to the crews of the Fishery Patrol Vessels *Dorada* and *Sigma*, and operators Byron Marine, for transfers. Thanks also to the Australian Antarctic Division and Australian Fisheries Management Authority for supporting our use of their data collection protocols. Tim Stenning provided line drawings and his assistance constructing the warp scarer was vital. Dr. David Agnew (Renewable Resources Research Group, Imperial College) and Dr. Graham Robertson (Australian Antarctic Division) provided helpful feedback on earlier analyses of these data. We are particularly grateful to the management Golden Touza Ltd. and the crew of the *Hermanos Touza*, particularly Alberto Vazquez (Captain) and Angel (Bosun) for their assistance and support.

Appendix 1

Contact codes describing interactions between seabirds and trawlers (AFMA protocol; Wienecke and Robertson 2002) .

Field	Code	Definition
Age	A	Adult
	SA	Sub-adult
	J[a]	Juvenile
Contact code (birds)	1	Bird on water, very light contact with vessel/gear
	2	Bird on water, heavy contact with vessel/gear, causing at least part of the bird to be dragged underwater
	3	Bird flying, light contact with vessel/gear, bird does not deviate from course
	4	Bird flying, heavy contact with vessel/gear, bird deviates from course and/or dragged underwater
	5	Bird snagged on loose wire ends (eg. splice ends)
	6	Bird has high speed collision with vessel gear
	7	Bird caught in net
	8	Bird snagged on net while attempting to feed
	9[a]	Bird hauled on trawl door
Contact point	1	Warp wire
	2	Trawl doors
	3	Backstops, brides and sweeper
	4	Net
	5	Vessel
	6	Paravanes (includes towing wires)
	7[a]	Ropes on bird scaring device
	8	Other
Fate of bird	1	No apparent damage
	2	Possible minor injury
	3	Possible major injury
	4	Death
	5	Unknown
	6[a]	Bird seen wrapped around warp wire (suspected death)

[a]categories added by SAST

Appendix 2

Environmental variables recorded during observation periods .

Variable	Code	Level
Relative wind direction	1	Ahead
	2	45°
	3	90°
	4	135°
	5	Stern
BBA abundance	1	1–10
	2	11–50
	3	51–200
	4	201–500
	5	501 +
	6	Present
Sea state (Beaufort scale)	1	≤ 2
	2	3
	3	4
	4	≥5
Sea height (m)	1	0
	2	> 0, < 0.5
	3	≥0.5
Swell (m)	1	0
	2	0.5
	3	> 0.5, < 1
	4	1
	5	> 1

BBA Black-browed albatross

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