Assessing the effectiveness of seabird mitigation devices in the trawl sectors of the Southern and Eastern Scalefish and Shark Fishery in Australia

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Executive summary

Seabirds can be injured and killed by interacting with fishing gear, including trawl nets and warp cables. Given the threatened and protected classifications of seabirds, these mortalities can be of significant conservation concern. In 2009, the Australian Fisheries Management Authority became aware that interactions between seabirds and fishing gear were occurring in the South East Trawl and Great Australian Bight Trawl sectors of the Southern and Eastern Scalefish and Shark Fishery (SESSF). Seabird Management Plans (SMPs) were developed in response. These SMPs include provision for bycatch reduction measures intended to limit seabird access to risk areas around trawl warps. To contribute to assessments of the efficacy of SMP provisions, two bycatch reduction devices were tested at sea: the warp deflector and the warp scarer. The warp deflector comprises a plastic "pinkie" buoy that is attached to the trawl warp by a clip and connected back to the vessel on a rope. The warp scarer is a rope interlaced with semi-stiff streamers that is clipped onto the trawl warp for much of the warp's exposed length.

At-sea trials were implemented during 124 shots conducted from mid-2012 to mid-2013 aboard nine trawlers operating in the SESSF. Normal fishing practices were carried out throughout at-sea trials, with the exception of the deployment of mitigation devices. The mitigation devices, and the control treatment of no mitigation, were selected for deployment

in accordance with a randomised block design in which a block comprised one shot conducted under each of the three treatments. The performance of the devices was compared to the control based on a series of seabird observations conducted throughout the fishing cycle. Seabird interactions with trawl gear were categorised according to what birds made contact with (warp, net), the location of the interaction (air, water), the severity of the contact (heavy, light), and the likely outcome of the contact (e.g., bird unharmed, injured or killed). In addition, observers recorded information on variables that may influence the risk of seabird interactions with trawl gear, such as the number of birds attending vessels, weather, fish catch, and the presence of other vessels in the vicinity. Shy-type albatross accounted for 77 percent of observed interactions with a much lower incidence involving Short-tailed Shearwater and the Black-browed Albatross. Data describing shy-type albatross (*Thalassarche*) interactions with trawl warps were analysed using exploratory methods, and by developing Bayesian statistical models with poisson distributions while accounting for the zero-inflated nature of the data.

Shy-type albatross interactions with trawl warps were largely restricted to daylight hours when fish processing waste was being discharged. The data collected in this study shows that the risk of interactions between shy-type albatross and trawl warps appeared to be much lower at night. Also, out of a total of 176 seabird interactions with nets recorded during this study, none of those interactions were considered likely to cause injury. Preliminary models showed that when shy-type albatross were feeding aggressively, warp scarers were effective in reducing warp interactions that did not result in birds being pushed underwater. In periods of more relaxed feeding, as well as when interactions led to birds being submerged, warp scarers were not effective in reducing warp contacts.

Warp deflectors ('pinkies') reduced heavy contact around 75percent, depending on how birds were feeding. Warp deflectors were effective in reducing contacts between shy-type albatross and trawl warps that did not result in birds being submerged, during periods of both relaxed and more aggressive feeding, including when two covariates (seabird abundance and duration of observations periods) were considered. For contacts with trawl warps that did result in the submergence of albatross, the deflector was ineffective in reducing interactions during relaxed feeding. During aggressive feeding, the deflector was effective in reducing warp contacts.

This study is the first to evaluate the efficacy of the warp deflector in reducing seabird interactions on trawl warps. It is the second to examine the performance of the warp scarer, and broadly concurs with the findings of previous work on that device.

The development of effective bycatch reduction measures such as those tested in this study facilitates the continuation of fishing while reducing its broader ecological impacts. Minimising the impacts of fishing on non-target species is a key component of global best practice and is central to Australia's fishery management framework.

Introduction

Seabirds are accidentally captured and killed in commercial fisheries utilising a variety of different fishing methods including longlines, gillnets, and trawls (Bull 2007, 2009; Løkkeborg 2011). While the extent of such captures is often not well known, fishing-related mortalities have been linked to potential and observed declines in seabird populations (e.g., Croxall et al. 1990; Lewison and Crowder 2003; Richard and Abraham 2013). Consequently, these mortalities can be of considerable conservation concern (e.g., Croxall 2008; Anderson et al. 2011).

Early reports of seabird mortalities in trawl fisheries emerged from New Zealand in the 1990s (Bartle 1991). From 2000 onwards, reports of such mortalities became more widespread and included trawl fisheries operating around the Falkland and Kerguelen Islands and off the coast of Argentina (Weimerskirch et al. 2000; Gonzalez-Zevallos and Yorio 2006; Sullivan et al. 2006b). While seabird interactions have been recognised as an issue in international fisheries the impact from trawl fisheries in Australia has gone largely unnoticed. This is largely due to the difficulty in observing interactions and subsequent mortalities. The cryptic nature of interactions with warp cables adds another layer of difficulty in determining mortality rates as there is often little evidence of the result of the interaction as seabirds are rarely recovered on the warp (Parker et al. 2013). Amongst Australian trawl fisheries, seabird mortalities were first reported from around Heard and McDonald Islands where factory trawlers were targeting Patagonian toothfish (*Dissostichus eleginoides*) (Wienecke and Robertson 2002). Operational requirements such as the prohibition of offal discharge have been used to minimise these mortalities (AFMA 2012). The Australian Fisheries Management Authority (AFMA) became aware of interactions occurring between seabirds and fishing gear on inshore wet-boat trawlers in the South East Trawl (SET) and Great Australian Bight Trawl (GAB) sectors of the Southern and Eastern Scalefish and Shark Fishery (SESSF) in late 2009.

Internationally, responses to the detection of seabird bycatch in trawl fisheries have included research, e.g., documenting the nature and extent of seabird interactions on trawl warps, (Abraham and Thompson 2009; Abraham 2010), testing mitigation measures to reduce bycatch (Sullivan et al. 2006a; Pierre et al. 2012), creating a legal requirement to utilise bycatch reduction measures (Department of Agriculture, Forestry and Fisheries 2010; New Zealand Government 2006, 2010), and establishing operational frameworks to manage the risk of trawl gear to seabirds (Deepwater Group 2009; Akroyd et al. 2012).

In response to the detection of seabird interactions with trawl gear in the SET and GAB sectors of the SESSF, AFMA has worked in conjunction with industry and seabird experts to develop and implement Seabird Management Plans (SMPs) on all SESSF otter board trawl vessels. These AFMA-approved SMPs are in place to minimise bycatch of seabird species and comprise both operational and physical mitigation bycatch reduction approaches. At the operational level, the cause of seabird attraction to trawl vessels is addressed through the development and implementation of offal management procedures. Physical mitigation measures (i.e., warp scarers and warp deflectors or pinkie buoys) are deployed with the intention of limiting seabird access to risk areas around trawl warps.

Following the implementation of SMPs on all SET and GAB otter board trawl vessels, the efficacy of the physical mitigation required assessment. The aim of physical mitigation is to reduce the number of heavy interactions seabirds have with trawl warps. In this paper, we

report on the efficacy of physical mitigation approaches included in SMPs for reducing seabird interactions with trawl gear. Specifically, we:

- evaluate the efficacy of warp scarers and warp deflectors deployed on trawlers in these sectors
- compare the efficacy of these devices determined from this study with the results of other studies focusing on reducing seabird interactions on trawl warps
- assess the temporal distribution of seabird interactions, comparing the incidence of interactions during the day and at night
- examine the extent of net interactions compared to warp interactions.

Methods

Fisheries observers made observations on trawlers at sea in the SESSF (Figure 1) between 22 July 2012 and 13 May 2013. Nine vessels of 17.9 – 26 m in length were involved in the trial. Standard fishing practices were employed throughout observed trips. Trawl shots averaged 4 h 20 min in duration, and ranged from 1 h 55 min to 7 h 25 min. Trawls were demersal and occurred at depths of 100 – 700 m. The five species most commonly targeted by vessels during observed trips were tiger flathead (*Platycephalus richardsoni*), blue grenadier (*Macruronus novaezelandiae*), silver warehou (*Seriolella punctata*), pink ling (*Genypterus blacodes*), and deepwater flathead (*Platycephalus conatus*). Catch was retained whole, gutted, or headed and gutted. Vessels discharged processing waste (offal and unwanted fish bycatch) both as they sorted the catch and sometimes also as a batch at the end of processing. The amount of offal discarded per shot ranged from 60 kg to 4 800 kg. Assemblages of seabirds attending vessels during the trial were dominated by shy-type albatross (*Thalassarche*) and included other species such as black-browed albatross (*T. melanophris*), Indian yellow-nosed albatross (*T. carteri*), wandering albatross (*Diomedea exulans*), cape petrel (*Dation capense*), giant petrel (*Macronectes* spp.), and short-tailed shearwater (*Puffinus tenuirostris*). Seabird abundances ranged from 0 – 700 birds within a 180 degree arc centred on the vessel stern and extending 250 m astern.
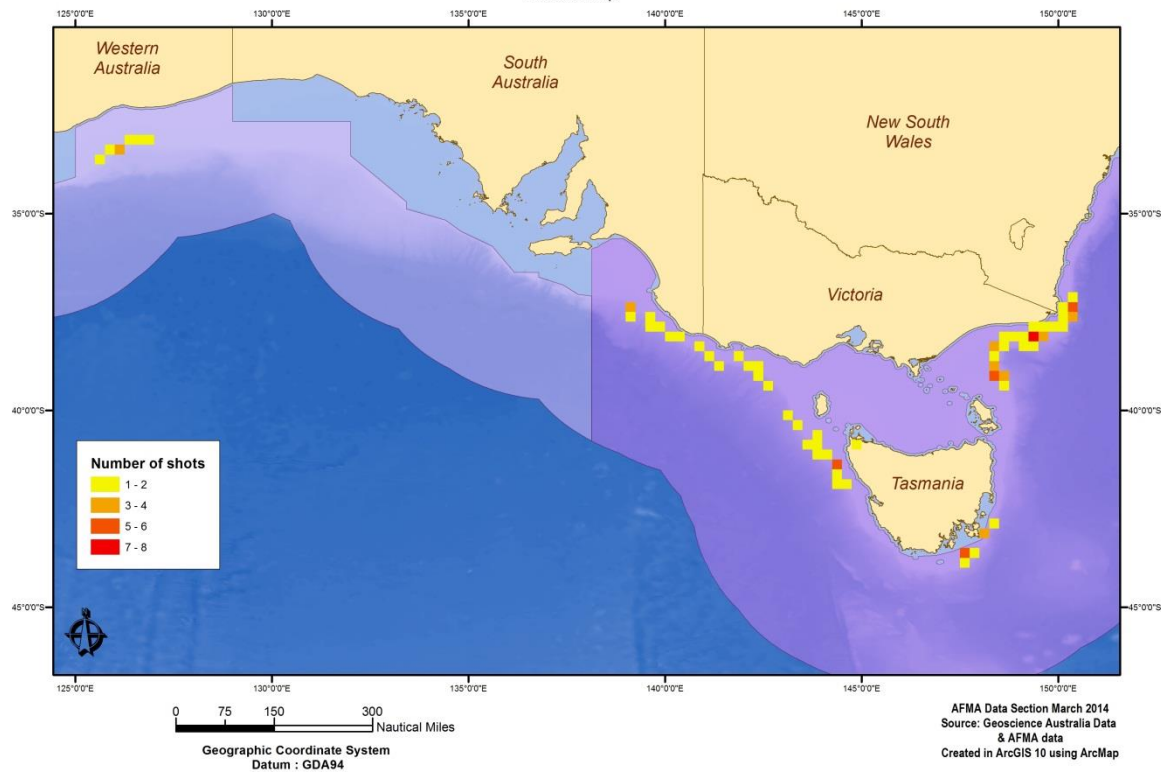
Figure 1: The location of the at-sea trial of warp scarers and warp deflectors in the South East Trawl and Great Australian Bight Trawl sectors of the Southern and Eastern Scalefish and Shark Fishery (Source: AFMA 2014).

Two standardised devices that were intended to reduce seabird interactions on trawl warps were tested during this trial (Table 1). These were the "warp deflector" (Figure 2) and a "warp scarer" (Figure 3). One of each device was used throughout at-sea testing to ensure consistency in specifications and construction. The "pinkie" buoy at the end of the rope-and-buoy arrangement comprising the warp deflector (Figure 2) measured 820 mm from the bottom of the buoy to the centre of the top eye hole. The buoy was 600 mm in diameter. The warp scarer measured 4.4 m in length from the top clip to the weight close to the water surface. Semi-stiff black plastic streamers 70 – 80 cm in length were woven through the scarer's backbone, between the top clip and the bottom clip. Streamers were attached in groups of six, every 10 cm (Figure 3). Both devices were adjusted to suit each vessel on deployment. Specifically, the length of the warp deflector rope that positioned the buoy appropriately on the trawl warps was adjusted for each vessel's warp length. For warp scarers, the length of the device was also matched to the vessel warp length.

Table 1 Summary of observations made during the trial by nine boats of seabird bycatch reduction devices conducted in the Southern and Eastern Scalefish and Shark Fishery.

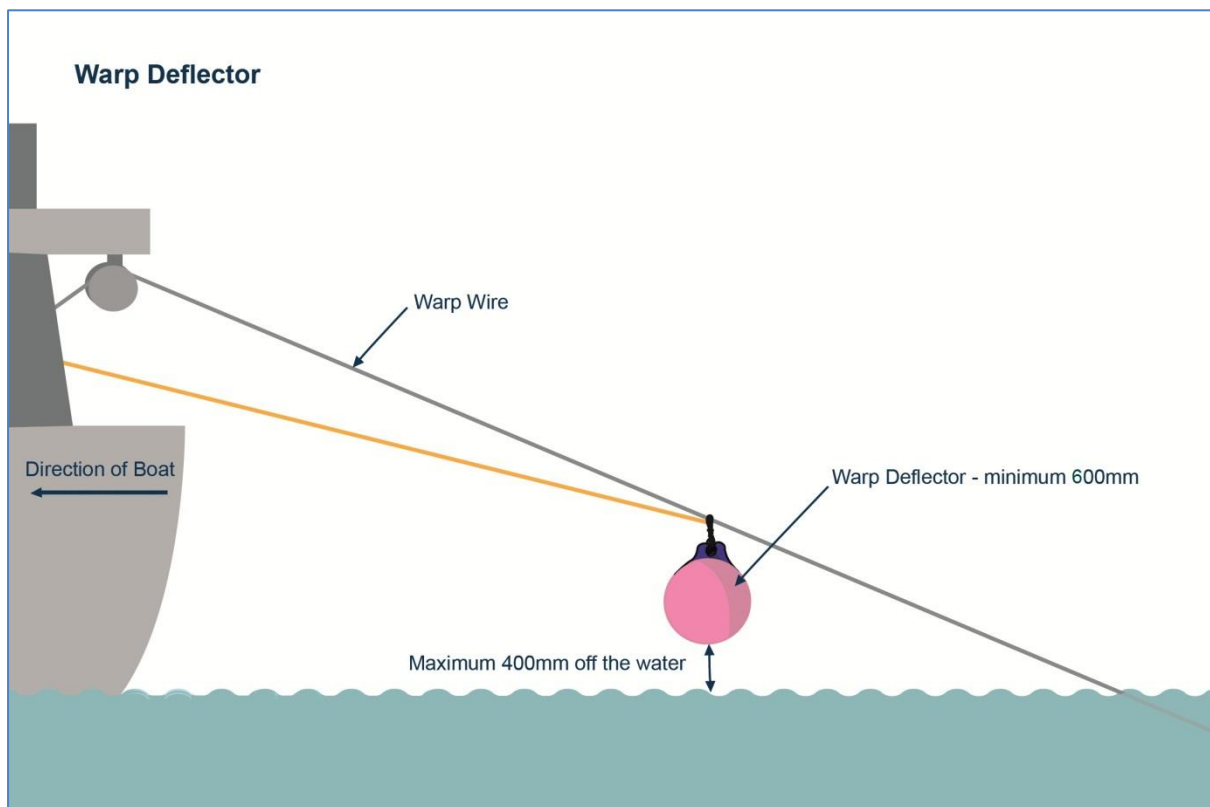|	Number of shots	Night shots	Day shots
Warp deflector deployed	49	15	34
Warp scarer deployed	25	7	18
No warp mitigation deployed	50	12	38
Observations off SE Australian waters (SET)	112	31	81
Observations off far western SA coast (GAB)	12	3	9
Total	124	34	90

Figure 2 The standardised warp deflector tested in the Southern and Eastern Scalefish and Shark Fishery.
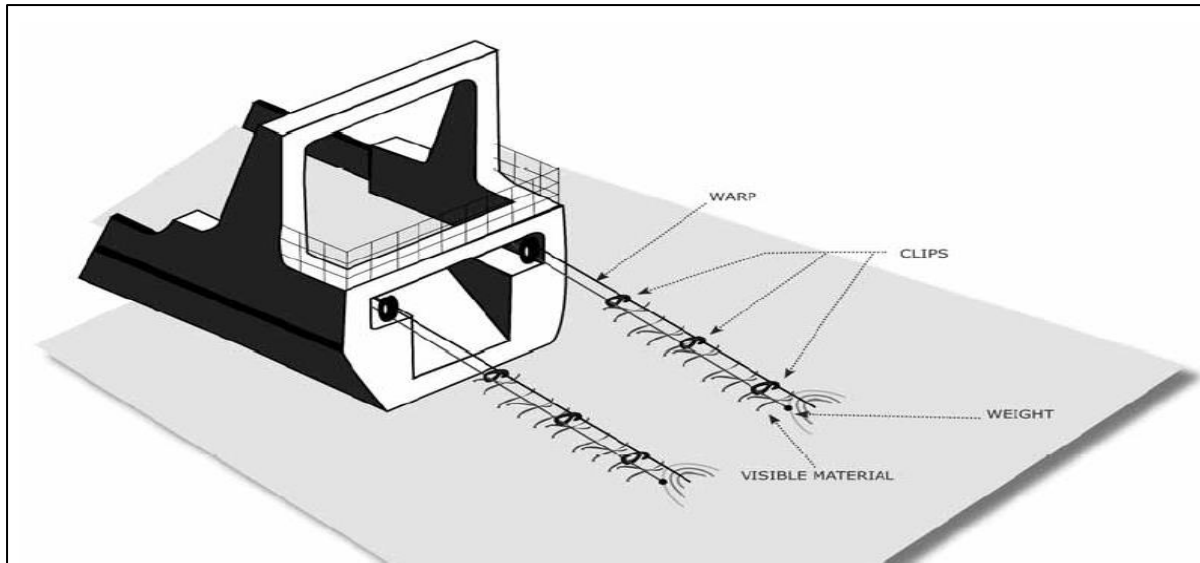
Figure 3 The standardised warp scarer tested in the Southern and Eastern Scalefish and Shark Fishery. (Source: New Zealand Gazette 2010).

Performance of these devices in reducing warp interactions was determined by comparing interactions occurring with mitigation deployed, and interactions occurring when no mitigation was deployed. Seabirds on the mitigation device itself were also considered. One of the three treatments (warp scarer, warp deflector, or no mitigation) was selected for implementation on each trawl shot in accordance with a randomised block design. Randomised treatments were only applied to observed shots. When no treatment was applied, e.g., due to adverse weather conditions or the observer being unavailable to collect data during a shot, the randomised block design continued in the order prescribed when data collection resumed. That is, if the trawl shot last observed was not the last treatment from a block, the remaining treatments in that block were skipped and the first treatment in the next block became the starting point for the next trawl shot. This was because it was assumed that trawl shots adjacent to each other would be more similar than trawl shots more distant from each other.

Data collection focused on two indirect metrics and one direct metric describing seabird bycatch risk. These metrics were seabird abundance, behaviour, and interactions with trawl warps. Seabird abundance was recorded within an area defined by a 180-degree arc centred on the midpoint of the vessel stern and extending 250 m astern and 250 m to each side of the vessel. Abundance was estimated by species as a series of snapshot counts conducted at six different points during the fishing process:

- before the net was shot for the first time each fishing day
- after the net was deployed on the first shot of the day (i.e., no discharge or processing prior to this shot)
- immediately after processing on every consecutive shot,
- as the net was being hauled,
- after catch is released from net onto deck, and,
- during offal discharge post processing.

Abundances were estimated with varying levels of accuracy depending on the number of birds present (Table 2).

Table 2 Number of birds present and estimation technique used to quantify seabird abundances astern trawl vessels (based on Melvin et al. 2009).

Number of seabirds present	Quantification method
1 - 5	Count
10 - 30	Estimate by 5s (or count)
30 - 100	Estimate by 10s
100 - 200	Estimate by 25s (or use 10s)
200 - 450	Estimate by 50s
500 - 900	Estimate by 100s
1000 - 1600	Estimate by 200s (or 250s)
2000 - 3000	Estimate by 500s

Seabird behaviour within a 180-degree arc astern the vessel was recorded as the number of birds engaged in each of four activity categories:

- actively feeding or competing for food within 25 m of the vessel,
- actively foraging for food around the vessel within 50 m of the vessel,
- resting on the water or flying at a distance of > 50 m beyond the vessel, or,
- flying on the edge of the 250 m observation range

Observers sought to quantify seabird interactions during four 15 minute periods when the trawl net was deployed (Figure 4). Three periods entailed observations of the warp and mitigation device and one observation period involved observing the trawl net. Offal discharge points varied between vessels and observations were focused on the side of the vessel from which most offal was discharged. Observations encompassed one warp and the mitigation device associated with that warp. Observation periods occurred throughout the fishing process, as follows (Figure 4).

- The first 15 minute observation period comprised three 5 minute intervals of warp and mitigation device observations. This observation period commenced either:
  - once gear was deployed on the first shot, prior to which no processing or offal discharge had occurred; or,
  - immediately after catch processing, sorting and offal discharge on every subsequent shot.
- The second 15-minute observation period also consisted of three 5-minute intervals of warp and mitigation device observations. This period commenced 15 minutes prior to hauling.
- The third observation period was not of fixed duration. This period commenced when the net had reached the sea surface and continued until the net was entirely out of the water. Then, the period recommenced when the net was deployed again. The period ended when the net was submerged after being deployed for fishing. This observation period focused on interactions with the net.

- The duration of the fourth observation period was also not fixed. This period comprised a continuous series of 5-minute intervals during catch processing, sorting and offal discharge. During this period, observations focused on one trawl warp and the associated mitigation device.
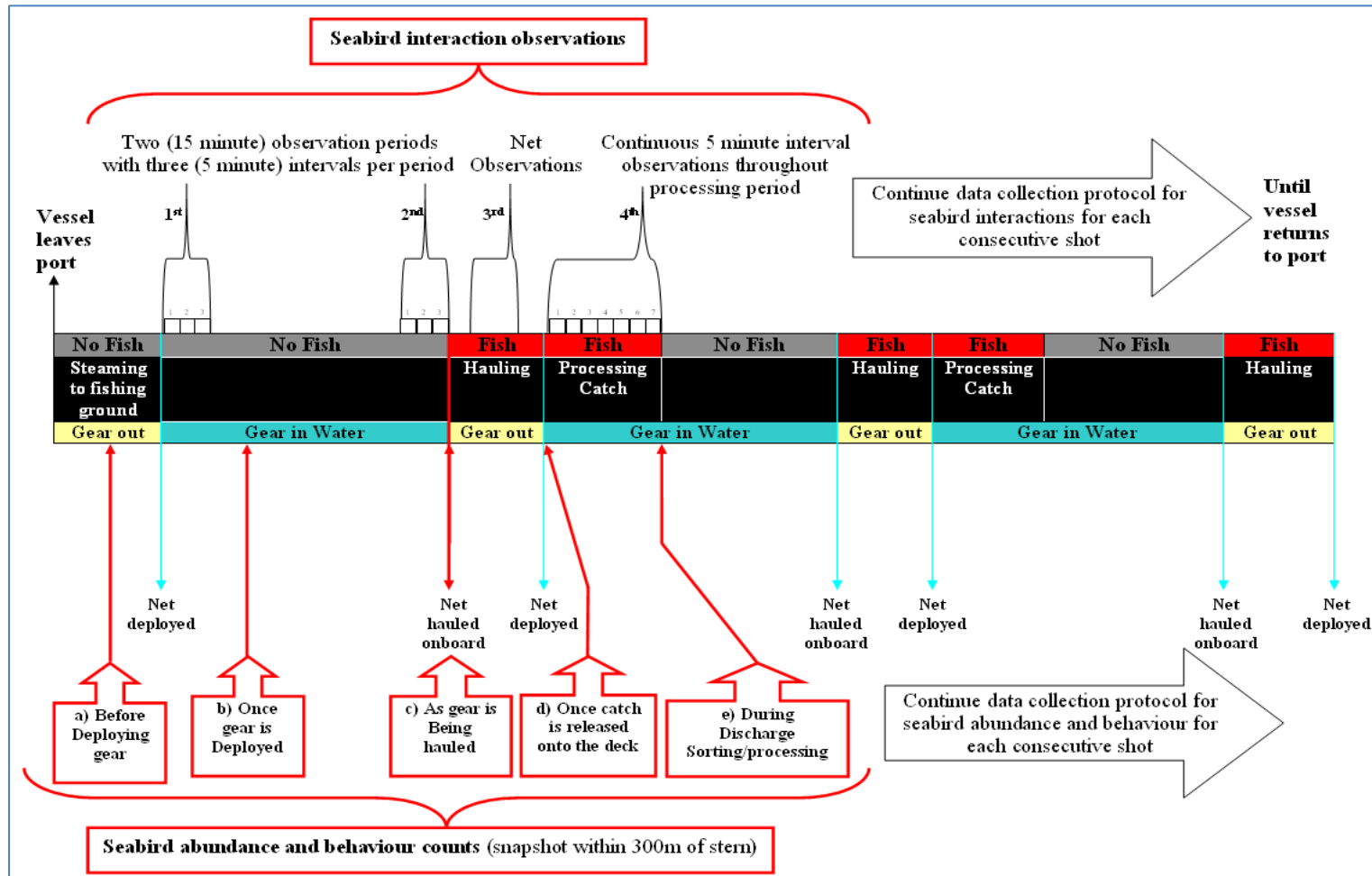
Figure 4 Data collection timeline through the fishing cycle during the trial of seabird warp strike mitigation devices conducted in the Southern and Eastern Scalefish and Shark Fishery

Categories of seabird interactions with the trawl gear were grouped according to the intensity of contact (light or heavy), element of the gear the bird interacts with (warp or net), degree of likely stress or injury, and the bird's short-term fate after the observed interaction. Categories recorded are described in Table 3.

Table 3 Characterisation of seabird interactions as recorded by fisheries observers during the trial of two mitigation devices in the Southern and Eastern Scalefish and Shark Fishery.

Interaction Classification	Contact Location	Gear	Interaction Definitions
Light	On Water	Warp Wire	Bird on water, very light contact, does not deviate from course
Light	On Water	Warp Wire	Bird on water, contact, deviates from course (causes no stress or possible injury)
Heavy	On Water	Warp Wire	Bird on water, heavy contact, dragged under and resurfaces (causes stress or possible injury)
Heavy	On Water	Warp Wire	Bird on water, heavy contact with warp wire dragged under and fate unknown
Heavy	On Water	Warp Wire	Bird on water, heavy contact with warp wire dragged under and remains on warp.
Light	In Air	Warp Wire	Bird flying, light contact with warp wire, does not deviate from course
Heavy	In Air	Warp Wire	Bird flying, heavy contact with warp wire, deviates from course
Light	On Water	Net	bird lands on/touches net while attempting to feed, very light contact (causes no stress or possible injury)
Light	On Water	Net	Bird snagged on net while attempting to feed escapes with no apparent injury
Heavy	On Water	Net	Bird caught in net and causes possible injury.

Information recorded by observers that described each shot included the date, number, start and end times and locations (latitude, longitude) of the shot, shot length, fishing depth

(minimum and maximum during the shot), and vessel speed (knots) and course. In addition, observers noted the presence of other fishing vessels in the vicinity of the sampling vessel. With respect to the catches made, observers recorded shot by shot estimates of total catch, retained catch, bycatch discarded (i.e., total minus retained catch), the start and ends times of both bycatch sorting and processing, and the top five bycatch species caught. The timing of processing waste discharge was also recorded during shots. When discharge occurred, the discharge rate was categorised as high, medium, low or negligible.

Environmental conditions recorded at the start of each shot were wind direction and speed, sea height and direction, swell height and direction, cloud cover (in octares) and sea condition on the Beaufort scale (1 – 12).

Finally, observers also documented vessel characteristics relating to risk factors for seabird bycatch once per observed trip. These included the deck offal storage position, offal storage capacity on vessels, and the level of fish processing undertaken at sea.

During the trial period, several amendments were made to the data collection protocol. First, after collecting data from 42 shots and from 11 November 2012, observers ceased sampling during periods of no offal discharge. This was because no interactions between seabirds and gear were observed during such periods. Therefore, periods with no offal discharge did not provide a compelling test of the efficacy of mitigation devices.

Second, after 80 shots (from 16 January 2013), the warp scarer was removed from the trial. This was because analyses of data collected up to that point suggested that the warp deflector may prove to be a more effective mitigation device, in terms of reducing warp interactions leading to birds being pushed underwater (see Results). Removing the warp scarer from the trials provided the opportunity to collect more data on the performance of the warp deflector.

Third, to maximise the likelihood of detecting seabird interactions with trawl gear, sampling efforts from late 2012 focused on areas considered especially likely to offer high albatross abundance. These were to the south and accessed from Portland, Victoria.

Finally, following preliminary analysis, night-time sampling was excluded from the trial after 115 shots. Night sampling was excluded based on the extremely low numbers of interactions observed between seabirds and trawl gear. Despite the use of deck lights, observations to beyond 50 m astern and 20 m port or starboard of the vessel were precluded by a lack of light. "Night" was considered to be the time between sunset and sunrise, calculated using formulae for latitude and day of the year[1]. Adjustments were then made for daylight saving and displacement from the longitude for which time in a time zone is exact. Using these criteria, only two heavy interactions were observed at night between shy-type albatross and trawl gear. These were not included in the final analysis of the dataset collected during the trial.

Statistical methods

Examination of the data showed that amongst seabirds attending the observed trawl vessels, shy-type albatross most frequently interacted with trawl warps. In addition, most interactions occurred when birds were on the sea surface rather than in flight (see Results). Consequently,

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[1] www.gandraxa.com/length_of_day.xml

statistical analyses presented here assess the efficacy of mitigation devices in reducing interactions between shy-type albatross on the sea surface and trawl warp cables. Amongst the different species of seabirds, interactions were next most frequent between short-tailed shearwaters and trawl warps. However most of these interactions did not result in birds being pushed underwater.

To explore the efficacy of the warp scarer and the warp deflector in reducing shy-type albatross interactions with trawl warps, data collected up to shot 80 were examined while the experiment was underway. Interactions occurring in flight were excluded from analyses. Counts of light and heavy contacts were combined to give the total numbers of interactions for each of the two mitigation devices, and the control of no mitigation. Interactions between shy-type albatross on the water and trawl warps were then evaluated as those that pushed birds under the water and those that did not. These categories were considered the most effective in grouping injured or killed versus uninjured birds. Two zero-inflated poisson models were used, each comparing the performance of one of the two mitigation devices with the control. Non-informative, uniform priors were used. The same dataset for the control treatment was used for both the deflector and scarer models. No covariates were considered in these analyses given the relatively small amount of data available for inclusion. Mitigation treatments were randomised over net shots within treatments blocks within boat trips.

The dataset collected from the entire duration of the experiment that described interactions between shy-type albatross and trawl warps when the warp deflector was deployed, compared to the control treatment of no mitigation, was explored using zero-inflated poisson mixture models. Amongst interactions occurring on the water and analogous to the partial analysis, light and heavy contacts were pooled, and two groupings were used in analyses: interactions resulting in albatross being pushed underwater and those in which albatross remained above the water surface. As for partial analyses, models were fitted using Markov Chain Monte Carlo (MCMC) methods executed in OpenBUGs and uniform priors were assigned.

For analyses using the partial and full datasets described above, albatross interactions with trawl warps were modelled under two behavioural scenarios. These were relaxed feeding (generally sedate feeding with low interaction rates) and aggressive feeding (competitive feeding under adverse sea conditions). The two behavioural scenarios were considered by observers to be associated with different likelihoods and intensities of seabird interactions with trawl gear. Aggressive feeding was infrequently observed over the first 80 net shots

For all models, the efficacy of the mitigation devices was assessed using 95 percent credible intervals for the number of seabird interactions with the trawl warp per shot under each mitigation treatment compared to the control. If credible intervals overlapped, there was no significant difference in the numbers of interactions occurring with and without a mitigation device fitted.

Results

Overview of interactions observed

Shy-type albatross were observed interacting more frequently with the trawl warps, trawl nets, and associated mitigation devices, than other seabirds observed during the trial (Table 4). Shearwater interactions with trawl gear were next most frequently observed. Other species reported to interact with trawl gear during the trials were black-browed albatross and Indian yellow-nosed albatross (Table 4). Shy-type albatross on the sea surface interacted with trawl

warps more than seven times more often than birds in the air (943 interactions on the water compared to 129 in the air).

Table 4 Number of interactions (light and heavy contacts) observed between seabirds and components of trawl gear during the trial of devices intended to reduce seabird interactions on trawl warps in the Southern and Eastern Scalefish and Shark Fishery.

Species	Total number of interactions between seabirds and gear components				
	Trawl warp (with mitigation device)	Trawl warp (without mitigation device)	Warp scarer	Warp deflector	Net
Shy-type albatross (*Thalassarche*)	431	843	26	84	160
Black-browed albatross (*T. melanophris*)	17	81	5	1	2
Indian yellow-nosed albatross (*T. carteri*)	0	1	0	0	0
Short-tailed shearwater (*Puffinus tenuirostris*)	151	76	44	22	12
Other	23	14	0	0	2
Hours of observation	31.86	22.89	10.39	21.46	14.20

Day/Night observations

Observations were discontinued at night after 115 shots due to the very low number of interactions observed. Amongst heavy contacts between shy-type albatrosses and trawl warps, two of a total of 203 interactions occurred either before sunrise or more than one hour after sunset (Figure 5).
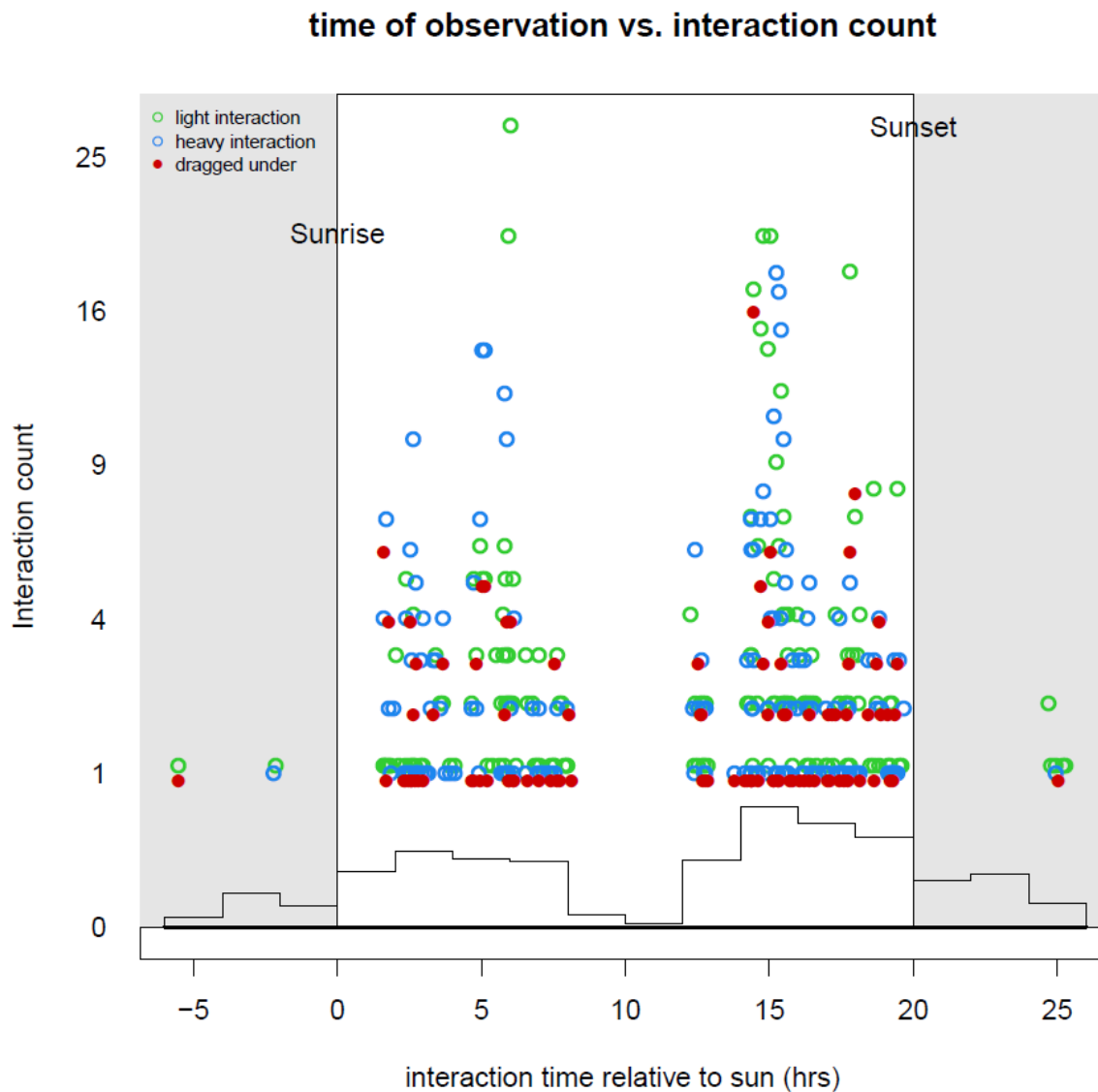

Figure 5 Temporal distribution of 1 144 interactions between shy-type albatross (Thalassarche) on the sea surface and trawl warps during the trial of two mitigation devices in the Southern and Eastern Scalefish and Shark Fishery. Points reflect counts of contacts recorded during 570 observation periods including when the net was shot, during fishing, and as the net was hauled. Two of 203 heavy interactions were observed at night. Time of the day is presented as hours before and after either sunrise or sunset, whichever was closer in time. A histogram (with no fill) records relative observation density over day increments of 2 hours, showing slightly more net-shots were in daylight in the afternoon than in the morning, and fewest net-shots were in the morning prior to sunrise.

Warp scarers

Analyses conducted part-way through the trial didn't find evidence for two methods of feeding behaviour, but did find evidence that warp deflectors may be more effective than warp scarers at reducing seabird interactions with trawl warps (Table 5). When birds were not pushed underwater, deflectors appeared effective in reducing the total number of interactions between seabirds and trawl warps ($P < 0.05$), but the effect was not significant when birds were pushed underwater. Warp scarers were not significantly different from the control in interactions with the warp wire (Table 5), so were dropped from further testing.

Table 5 Comparisons of the efficacy of warp scarers compared to no mitigation ("Control") based on observations conducted during 80 shots, in reducing seabird interactions on trawl warps. Interactions per shot are presented for the combined total of light and heavy interactions (a) when birds were not pushed underwater, and, (b) when birds were pushed underwater. Only one behavioural feeding state was detected (presumably relaxed feeding). Covariates are not considered. Median values and 95% credible intervals (in parentheses) are shown. Statistical significance is reflected by a lack of overlap in credible intervals.

(a) Birds not pushed underwater				
	Control	**Warp Scarers**	**Warp Deflector**	**Significance**
Relaxed feeding	8.76 (7.25–10.5)	7.56 (6.00–9.38)	4.25 (2.94–5.89)	NS & P < 0.05
(b) Birds pushed underwater				
	Control	**Warp Scarers**	**Warp Deflector**	**Significance**
Relaxed feeding	3.22 (2.17–4.53)	3.86 (2.60–5.44)	2.32 (1.01–4.32)	NS & NS

Warp deflectors

The efficacy of warp deflectors was established using data quantifying albatross interactions on trawl warps during deployments of this device throughout the entire trial period.

The warp deflector resulted in a statistically significant reduction in the number of warp contacts made by shy-type albatross where birds were not pushed under the sea surface. Contacts were significantly reduced when the deflector was deployed during periods of both relaxed and aggressive feeding (Table 6).

Table 6 Comparisons of the efficacy of warp deflectors compared to no mitigation ("Control") in reducing interactions by shy-type albatross (Thalassarche) on trawl warps. Interactions per shot are presented for interactions following which birds were not pushed underwater and two behavioural states: relaxed feeding and aggressive feeding. The median values and 95 % credible intervals (in parentheses) are shown. Statistical significance is reflected by a lack of overlap in credible intervals.

(a) Birds not pushed underwater				
	Control	**Warp Deflector**	**Significance**	**Per cent reduction**
Relaxed feeding	9.17 (7.81-10.7)	2.78 (1.22-4.82)	*P* < 0.05	69.7%
Aggressive feeding	81.3 (74.3-89.0)	17.7 (14.7-21.8)	*P* < 0.05	78.3%

For contacts resulting in birds being pushed underwater, two feeding states were detected with the control treatment, but only one state with warp deflectors. The one feeding state with warp deflectors had the same interaction rate with the warp as the relaxed feeding state with the control (no mitigation device) (no significant difference). However, the aggressive feeding state with no mitigation device had a significantly higher interaction rate with the warp than the single interaction rate with the warp deflector. That is, under aggressive feeding, the warp deflector had a significantly lower interaction rate with the warp, than when there was no mitigation, but no significant difference under relaxed feeding (Table 7).

Table 7 Comparisons of the efficacy of warp deflectors compared to no mitigation ("Control") in reducing interactions by shy-type albatross (*Thalassarche*) on trawl warps. Interactions per shot are presented for contacts resulting in birds being pushed underwater and two behavioural states: relaxed feeding and aggressive feeding. The median values and 95 % credible intervals (in parentheses) are shown. Statistical significance is reflected by a lack of overlap in credible intervals.

Birds pushed underwater				
	Control	**Warp Deflector**	**Significance**	**Percent reduction**
Relaxed feeding	4.53 (2.6 – 6.0)	2.26 (0.17-4.17)	Not significant	n/a
Aggressive feeding	22.83 (13.0-41.9)	5.69 (3.45-11.1)	*P* < 0.05	75.1%

The intent of the mitigation devices tested here is to reduce injurious and lethal interactions between seabirds and trawl warps. However, Middleton and Abraham (2007) highlighted the potential for displacement of these interactions from the warp to the mitigation device itself. In the current study, shy-type albatross interactions with warp scarers occurred at, on average, approximately 7 percent of the rate of warp interactions when no mitigation was used and 20 percent of the strike rate on the mitigated warp. For warp deflectors, these values were 11percent and 29 percent, respectively. For shearwaters, interactions occurred on the warp scarer, on average, approximately 30 percent more frequently than on the unmitigated warp and at 90 percent of the rate observed on the mitigated warp. For the deflector, these values were 31 percent and 22 percent respectively.

Discussion

The analysis reported here shows that warp deflectors tested in this trial are effective in reducing shy-type albatross interactions on trawl warps. The efficacy of these devices differed in accordance with the nature of seabird foraging observed, i.e., relaxed or aggressive foraging.

Warp deflectors

Warp deflectors reduced interactions in which birds were not submerged between shy-type albatross and trawl warp wires during periods of both relaxed and aggressive feeding.

When warp deflectors were deployed during periods of relaxed feeding, no significant reduction occurred in contacts between shy-type albatross and trawl warps that resulted in birds being submerged. However, these interactions were significantly reduced during periods of aggressive feeding when deflectors were deployed. This result contrasts with that for warp scarers, where comparisons with no mitigation were neither consistent nor significant.

Warp scarers

Warp scarers were not found to be effective in reducing contacts made with warp wires in this study, but were not tested as thoroughly as were warp deflectors. Given more extensive testing, they might have been shown to have some efficacy, but presumably not to the same extent as deflectors. Due to a relatively limited dataset, the performance of scarers could not be evaluated alongside covariates known to be important in assessments of the efficacy of mitigation measures from this and other studies (e.g., seabird abundance - no interactions can occur in the absence of seabirds (Middleton and Abraham 2007; Pierre and Debski 2013)).

Warp scarers have previously been tested in two published studies. One of these tested a design of warp scarer that completely enclosed the trawl warp (Sullivan et al. 2006a), precluding the comparison of results with this study. The second study was conducted in fisheries operating south and east of New Zealand (Middleton and Abraham 2007), and used a very similar design of warp scarer as deployed in the trials reported here. The only difference in the warp scarer design used in the Middleton and Abraham (2007) study was that occasional longer streamers were sometimes used on scarers, as well as the shorter "bottle-brush" type. Warp scarers were found to be effective in significantly reducing warp interactions by albatross and giant petrel (analysed together as "large birds" (Middleton and Abraham 2007)) in some models presented in that study, including when covariates such as seabird abundance and the rate of discharge of fish processing waste were considered. Overall, scarers reduced large bird interactions to 40 – 90 percent of the level observed when no mitigation was used. For petrels and shearwaters ("small birds" in the Middleton and Abraham (2007) study), warp scarers resulted in barely significant reductions in warp interactions; interactions continued at levels of 40 – 99 percent of those occurring in the absence of mitigation. In comparison, paired streamer lines reduced interactions to approximately 5 – 20 percent and 10 – 30 percent of the number occurring in the absence of mitigation for large birds, and small birds, respectively (Middleton and Abraham 2007).

Differences between the results of this study and the New Zealand study may be due to several factors. First, the New Zealand study did not consider different seabird behavioural

states. Second, warp scarers with occasional longer streamers may have been more effective in reducing seabird interactions than those with shorter bottle-brush style streamers alone. Third, the vessels in the New Zealand study were much larger than those in the trial described here. The effects of vessel size are unknown, however, the length of exposed warp astern is expected to have been greater amongst the larger vessels. Consequently, the warp scarer would have been larger and more obvious astern. Finally, the scale of the New Zealand study was larger, involving both more vessels and more tows. This meant that covariates could be more thoroughly considered than was possible in the SESSF trial. Additional data collection on warp scarers in the SESSF area would help clarify the extent of any differences between these two studies once covariates could be more extensively considered.

While seabird interactions on mitigation devices are generally considered to be less severe than warp interactions, this is not the case for every strike (Middleton and Abraham 2007). In the work reported here, the extent of seabird interactions on warp scarers was analogous to interaction rates reported for the pooled total of airborne and waterborne interactions by Middleton and Abraham (2007). In that study, albatross and giant petrel interacted with warp scarers at rates of up to 10 percent of the unmitigated warp. For shearwaters and other petrels, this rate was up to approximately 30 percent (Middleton and Abraham 2007). No comparative information is available for warp deflectors. However, despite the efficacy of paired streamer lines in reducing seabird interactions on trawl warps, Middleton and Abraham (2007) found that seabird interactions on these devices occurred at higher levels than interactions on warps with no mitigation.

Day/Night Observations

In addition to the results for the two mitigation devices tested, the data collected in the current study show that the risk of interactions between shy-type albatross and trawl warps is much lower at night, compared to during daylight hours. Out of 115 shots and 203 interactions, only two interactions were observed at night. This reduction in albatross activity at night is consistent with the findings of other studies investigating seabird bycatch patterns. Albatross activity is reduced at night to a greater extent than shearwater and petrel activity, resulting in commensurate reductions in bycatch risk for these species groups (e.g., Ryan and Watkins 2002; Baker and Wise 2005). Further, during bright clear nights, e.g., around full moon, the efficacy of night-fishing as a mitigation measure is reduced for certain species (Klaer and Polacheck 1998).

Net Interactions

A total of 176 seabird interactions with nets were recorded during this study. None of those interactions were considered likely to cause injury. Globally, the nature and extent of net captures is poorly known. Few studies have quantified lethal seabird interactions with trawl nets and the work described in this trial is an important contribution to global knowledge. Albatross, petrel and shearwater captures in mid-water trawl nets in New Zealand trawl fisheries have been reported (Abraham and Thompson 2011), but no assessment has been made of the fate of seabirds encountering nets more broadly, i.e., injuries or mortalities occurring as a proportion of overall interactions. In addition to this global lack of knowledge, methods to mitigate net captures are at the preliminary stages of development (e.g., Hooper et al. 2003; Clement and Associates 2006; Pierre et al. 2013) and warrant further exploration.

Offal management and other considerations

The results of this study concur with previous work showing the importance of the discharge management as a way of reducing seabird interaction during trawl fishing. In this study, no interactions occurred in the absence of processing waste discharge and processing waste production was naturally influenced by the size and composition of the catch. Further, dumping location (i.e., where vessels had more than one discharge point) was also reported to affect seabird interaction rates with trawl warps. Other work confirms that warp interactions occur at extremely low rates if at all, and that seabird abundance astern of vessels is also greatly reduced, in the absence of offal discharge (Middleton and Abraham 2007; Abraham et al. 2009; Bull 2009; Pierre et al. 2010). While retaining offal onboard trawl vessels when gear is in the water is an ideal approach to reducing seabird interactions, this is often not possible without major changes in operational practices and vessel configurations (e.g., retrofitting storage capacity). For example, vessels operating in bulk fisheries, as well as smaller vessels, can readily generate more processing waste than can be held for an entire tow (e.g., Pierre et al. 2010). Such constraints highlight the importance of deploying effective mitigation devices especially during processing waste discharge. The relationship between batch discharge versus continuous or *ad hoc* discharge (Pierre et al. 2012) and the efficacy of mitigation devices may be a worthwhile avenue for further work.

In addition to seabird abundance and the presence and type of processing waste discharge, the dataset collected during this study includes a number of other covariates, e.g., wind speed and direction, which may influence the nature and extent of seabird interactions on trawl warps and the efficacy of devices intended to reduce these interactions. For example, Middleton and Abraham (2007) found that, head winds were associated with more warp interactions for albatross and giant petrel, but fewer interactions for shearwaters and smaller petrels. The potential importance of weather effects on seabird interactions with fishing gear were also raised by Sullivan et al. (2006a) who worked around the Falkland Islands, and Melvin et al. (2011) from their work in the Bering Sea. Future analyses of the data collected in this study could investigate the importance of such covariates, which would increase broader understanding of seabird bycatch risks.

In addition to the efficacy of mitigation devices in reducing seabird interactions with trawl gear, crew safety is paramount. In this and previous work, concerns have been raised relating to the safety of deploying and retrieving physical mitigation devices from the stern of trawl vessels (ACAP 2013). In this study, observers reported that deploying both devices in rough weather was difficult. Ideally, the efficacy of mitigation devices would be complemented by their straightforward and safe operation in all weather conditions.

This study provides the first test of the efficacy of the warp deflector, and the second of the warp scarer, in reducing seabird interactions on trawl warps. Interactions between trawl gear and all seabirds were recorded, and given the limited number of interactions recorded with other seabird species, the analysis focused on the shy-type albatross. The warp deflector showed the most promise in terms of reducing interactions between this species and trawl warps. Testing these devices in other locales where fisheries overlap with other seabird species would facilitate demonstration of the devices' broader mitigation potential. This is especially important for the warp deflector for which no other studies have been conducted.

Measures such as those tested in this study facilitate the continuation of fishing while reducing its broader ecological impacts. Minimising the impacts of fishing on non-target species is a key component of global best practice (e.g., FAO 2007) and is central to Australia's fishery management framework.

Acknowledgements

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