Rory Lines:

A silver lining for seabirds in South Africa's demersal trawl fisheries

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Table of contents

Abstract

Seabird bycatch in commercial fisheries is one of the major factors causing decreases in many seabird populations. In trawl fisheries, high mortalities have been recorded as a result of seabirds being struck by trawl warps (the cables used to tow the trawl net). *Tori* (bird-scaring) lines have been used to decrease seabird mortality in some trawl fisheries by up to 90%. However, *tori* lines are not effective at reducing the number of birds that drift towards the trawl warps while feeding on factory discards alongside the vessel. The Albatross Task Force (ATF) helped to develop and test a new device, the Rory Line (RL), to be used in conjunction with *tori* lines, and designed to reduce warp strikes by placing a physical barrier between the scupper (where factory discards are released) and the danger zone (where the trawl warps enter the water) at the stern of the vessel.

This study tests the efficacy of the RL at reducing the number of birds drifting into the danger zone and the number of birds being struck by the trawl warps. RLs significantly reduced the numbers of albatrosses (*Thalassarche* spp.), White-chinned Petrels (*Procellaria aequinoctialis*) and Cape Gannets (*Morus capensis*) that drifted into the danger zone by 16, 16 and 14%, respectively. RLs significantly reduced warp collision rates for White-chinned Petrels by 68% and Great Shearwaters (*Puffinus gravis*) by 84%. There was significant seasonal variation in the number of albatrosses that drifted into the danger zone and the probability that albatrosses moved >1 m away from the side of the vessel. The presence of Cape Fur Seals (*Arctocephalus pusillus*) increased the probability of birds moving >1 m away from the side of the vessel. The efficacy of RLs at reducing trawl warp strikes may be related to the feeding behaviour of each species. Warp strike rates for Cape Gannets, being plunge divers, were not reduced by using RLs. Further testing of the RL with an adjusted position is suggested. Recommendations are given for future studies of seabird bycatch mitigation.

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Chapter 1. General introduction and literature review

Almost every form of commercial fish harvest leads to the incidental mortality of non-target species, known as bycatch (Huang 2011). Bycatch becomes a problem from a conservation perspective when it removes more individuals from non-target populations than is sustainable and results in population declines (Hall *et al.* 2007). This is particularly likely where species with conservative life histories (e.g. albatrosses, cetaceans) are affected, because they can only sustain much lower levels of additional mortality than the target species (Croxall *et al.* 1990; Moloney 1994; Weimerskirch *et al.* 1997). Bycatch levels in fisheries typically are significant for marine mammals, sharks, seabirds and sea turtles (Gilman, 2011; Huang 2011). Increased fishing effort, coupled with the development of technology to make fishing operations more efficient, has led to increased bycatch in some fisheries.

Improved and novel measures for reducing bycatch are being developed for various fisheries and types of bycatch. Some bycatch mitigation measures have proven to be effective and have been adopted widely in fisheries (Bull, 2007, Lewison *et al.*, 2011). High levels of seabird bycatch occur in some trawl fisheries (e.g. Weimerskirch *et al.* 2000; Sullivan *et al.* 2006a; Gonzalez-Zevallos *et al.* 2007; Watkins *et al.* 2008) and unless this threat is mitigated it will continue to contribute towards decreasing populations of several seabird populations, mainly albatrosses and petrels. There is still the need to develop and test bycatch mitigation devices in certain fisheries. Compared to longline fisheries, there has been little research on the development and testing of successful mitigation devices to reduce seabird mortality in trawl fisheries (Sullivan *et al.* 2006a).

History of bycatch

The first major concerns over bycatch arose in the 1960s in the purse-seine fishery for tuna (*Thunnus* spp) in the eastern Pacific Ocean, when an annual mortality of about 350 000 dolphins was reported (Joseph 1994). Bycatch of sea turtles became a concern during the 1970s, when the extent of bycatch in the shrimp trawl fishery became apparent (Cox and Mauerman 1976). It was also in the 1970s that the levels of cetacean (whales, dolphins, and porpoises) and seabird bycatch associated with gillnet fisheries became a conservation concern (Lear and Christensen 1975; Bibby 1972).

During the 1980s, the bycatch issue drew increasing interest from researchers and fisheries scientists, and there has been a steady increase in publications and public understanding of the issue since (Roberts 2007).The focus of these publications has shifted over time. Initially, most papers centred on cetacean bycatch, with little attention to birds and turtles. Recent decades have seen increasing focus on birds and turtles (Northridge 1991; Anderson *et al.* 2011). In the 1990s, seabird bycatch in longline fisheries was recognized as a serious conservation issue (Brothers 1991). Apart from bycatch of specific species, there is a history of fishing methods that have been destructive over entire ecosystems. Heavy trawl gear and explosives used to exploit reef fish are extremely destructive to bottom communities, especially coral reefs (Attwood *et al.* 1997).

The threat that fisheries pose to the long term survival of many marine animals has resulted in the establishment of organizations such as the International Whaling Commission (IWC), the Commission for the Conservation of Antarctic Marlne Living Resources (CCAMLR) and numerous inter-governmental Regional Fisheries

Management Organisations (RFMOs). Most RFMOs are primarily concerned with managing target species, although bycatch species are part of their mandate. In addition, bycatch concerns have contributed to the establishment of organizations such as the International Union for the Conservation of Nature and Natural Resources (IUCN) and international conventions such as the Convention on the Conservation of Migratory Species of Wild Animals (CMS) (Lewison & Cowder 2003; Cooper *et al.* 2006).

Concerns over the destructive nature of some types of fishing have been met by changes in fishing practices. Extreme cases have seen the outlaw of fishing methods. The bycatch of cetaceans by driftnets led Australia to ban Taiwan from fishing in its Exclusive Economic Zone (EEZ) in 1986. Reports of significant driftnet bycatch of birds, mammals, turtles and sharks resulted in the UN introducing a global moratorium on high-seas driftnets in 1992 (Bellido *et al.* 2011; Huang 2011). The use of explosives for killing or stunning (blast fishing) is largely illegal, but still occurs locally in parts of East Africa and Southeast Asia (Fox *et al.* 2005).

A common problem with laws related to the sea is that they are difficult to enforce globally. Enforcement of laws often results in a shift in fishing pressure from developed countries to developing countries that have weaker laws or lack the ability to enforce them (Worm *et al.* 2009). Problems also have been experienced with enforcing laws on the high seas, outside the EEZs of coastal countries (Cullis-Suzuki & Pauly 2010). Fisheries on the high seas have to abide by regulations of RFMOs, which are the only legally mandated fisheries management bodies in these waters (Small 2005; Cullis-Suzuki & Pauly 2010). Many RFMOs have adopted measures that request and encourage the reduction of bycatch by fisheries operating within their waters, but enforcement is problematic (Small 2005; Huang 2011).

Bycatch mitigation measures

Bycatch mitigation measures usually are either species- or fishery-specific, and their success varies greatly. The reduction of sea turtle bycatch in United States of America (USA) fisheries is a reassuring example. Before the implementation of mitigation devices, an estimated 346 500 sea turtle interactions in USA fisheries resulted in 71 000 mortalities annually (Finkbeiner *et al.* 2011). Since implementing mitigation measures, mortality has dropped by 94% (Finkbeiner *et al*. 2011). This reduction has largely been attributed to the use of Turtle Excluder Devices (TEDs) in the shrimp trawl fishery. TEDs were first used in 1987 but became truly effective after 2003 when the size of TED openings was regulated to ensure they were large enough to allow larger turtle species such Loggerheads (*Caretta caretta*) and Leatherbacks (*Dermochelys coriacea*) to escape (Finkbeiner *et al*. 2011).

A controversial measure to reduce bycatch is time-area closures, usually implemented to ensure fisheries avoid the greatest densities of vulnerable species (Wilcox & Donlan 2007; Finkelstein *et al.* 2008). Even the threat of closure has proven effective, including for reducing albatross mortality in trawl fisheries (Zador *et al.* 2008). Closure of fisheries over seasons has helped to reduce mortality of auks in the UK (Robins 1991), White-chinned Petrels (*Procellaria aequinoctialis*) around breeding islands (e.g. round South Georgia, Reid *et al.* 2004) and sea lions in New Zealand (Baird 1996). Many bycatch events are rare (dispersed over space and time), relative to catch of target species. Under these circumstances changes to fishing gear or the use of mitigation devices can be more effective than closure of fisheries (Finkelstein *et al.* 2008).

Seabird bycatch mitigation

Fishing vessels attract a diversity of seabird species by providing food in the form of discards of fish and fish processing waste, bait, and fish dislodged from nets (Melvin *et al.* 2010). Once in close proximity to fishing vessels, seabirds face the dangers associated with coming into contact with fishing equipment, such as nets, cables and hooks (Melvin *et al.* 2010) and may also collide with vessels, especially at night (Ryan 1991).

The mortality of seabirds caused by fisheries is a major threat to many seabirds around the world, particularly albatrosses, petrels and shearwaters (Tuck *et al.* 2011; Weimerskirch & Jouventin 1987; Gales 1993; Croxal *et al.* 1998; Melvin *et al.* 2010). Of the 22 albatross species, 17 are threatened with extinction, and the remaining five are near-threatened (IUCN 2012). The key threat to most albatrosses is incidental mortality due to fishing activity (Robertson & Gales 1998). Seven species of *Macronectes* and *Procellaria* petrels listed under the Agreement on the Conservation of Albatross and Petrels (ACAP) face similar threats from fisheries, as do several shearwater species (e.g. Anderson *et al.* 2011).

Some studies have extrapolated observations of mortality rates to estimate seabird mortalities across entire fisheries, and given the massive scope of some fisheries, the resultant estimates are staggering. Anderson *et al.* (2011) estimated that 160 000 - 320 000 seabirds are killed annually in longline fisheries globally. Watkins *et al.* (2008) estimated that 18 000 birds (8000- 31 000, 95% confidence intervals) were killed annually in South Africa's hake (*Merluccius* spp.) trawl fishery before mitigation measures were introduced. Sullivan *et al.* (2003) determined that over 1 500 seabird mortalities were caused by the finfish trawl fishery in Falkland's

waters in 2002/3, most of which were Black-browed Albatross (*Thalassarche melanophrys*), currently listed as Endangered (IUCN 2012).

Several international conservation instruments have been established in response to concerns over the number of seabirds threatened by fisheries (Tuck *et al.* 2011), such as the United Nations' Food and Agricultural Organisation's International Plan of Action (IPOA) for Reducing Incidental Catch of Seabirds in Longline Fisheries (FAO 1999) and the Agreement on the Conservation of Albatrosses and Petrels (Anderson *et al.* 2011). The UN Convention on the Law of the Sea also includes articles (such as the Convention of Biodiversity, the Convention on Migratory Species, and the UN Fish Stocks Agreement) which either encourage or require practices considered conducive to ecosystem-based fishery management, such as minimizing the impact of fisheries on non-target species (Tuck *et al.* 2011).

Seabird bycatch in longline fisheries

It was only in the early 1980s that the first records of incidental seabird mortality on longlines was reported from bird band recoveries (Anderson *et al*. 2011). In the late-1980s, the first attempt was made to extrapolate the relatively small numbers of seabirds caught on individual longline sets to the gargantuan scale of total longline fishing effort in the Japanese tuna fishery of the Southern Ocean (Brothers 1991). The resultant estimate of total annual bycatch precipitated an understanding that observed decreases in albatross populations could be causally linked to longline fishing effort (Croxall *et al.* 1990; Weimerskirch *et al.* 1997; Croxall *et al.* 1998; Weimerskirch & Jouventin 1998; Nel *et al.* 2002). Most fatal interactions between longline fishing gear and seabirds occur during setting, resulting mainly in the

mortality of larger, surface feeding groups such as albatrosses and petrels, which get caught and drowned while trying to snatch baited hooks (Anderson *et al*. 2011; Yokota *et al*. 2011).

Seabird bycatch in trawl fisheries

Initial concerns about seabird mortalities caused by trawlers centred on collisions with data transmission (netsonde) cables (Bartle 1991). The problem was eliminated in many fisheries by banning these cables (e.g. CCAMLR waters, New Zealand waters and several other fisheries in the Southern Hemisphere; Sullivan *et al.* 2006a; Løkkeborg 2011). Currently most trawl mortalities are caused by net entanglement and warp strikes (Sullivan *et al.* 2006a; Melvin *et al.* 2010). Trawl warps are the cables that pull the net. Net entanglement is primarily a problem in pelagic trawls, where the net stays on the sea surface for long periods and diving birds becoming trapped in the mesh of the net (Sullivan *et al*. 2006a). It can be problematic for some species in demersal fisheries (e.g. Cape Gannets *Morus capensis* in the hake trawl fishery off South Africa; Watkins *et al*. 2008). CCAMLR has worked on measures to reduce the likelihood of birds getting caught in the mesh of nets (Sullivan *et al. 2006a*).

Of particular interest to this study is the mortality of seabirds as a result of warp strikes. This phenomenon is prevalent in factory trawlers that attract large numbers of foraging birds as they discard factory waste (whole fish, heads and guts). Birds that feed on these discards are in danger of being struck by the warp, dragged under the water and drowned. Injuries also occur when flying birds collide with the aerial section of the warp, but this is relatively rare (Watkins *et al.* 2008). The main concern is when birds become entangled on the warp and dragged under by the force of the

water moving past the cable. They drown unless they are able to disentangle themselves (Sullivan *et al.* 2006b). Large-winged birds such as albatross and the larger species of petrels are particularly susceptible to this problem (Melvin *et al.* 2010). When startled, or competing aggressively, these birds often raise their wings, increasing the chance of the wings becoming entangled around the cable (Melvin *et al.* 2010).

Large numbers of *Thalassarche* albatrosses, White-chinned Petrels and Cape Gannets attend demersal trawlers in southern African waters. Albatrosses and White-chinned Petrels are major bycatch species in longline fisheries in the South Atlantic Ocean (Tuck *et al.* 2011) and South Indian Ocean (Petersen *et al.* 2009). Thirteen of the sixteen albatross species found in southern Africa's waters are Vulnerable, Endangered or Critically Endangered according to IUCN criteria (BirdLife International, 2008). White-chinned Petrels and Cape Gannets are also listed as Vulnerable.

Much of the development and testing of mitigation devices for incidental seabird mortality has focused on longline fishing (Sullivan *et al*. 2006; Huang 2011). There are a few logical reasons why this should be so. First, seabird mortality induced by longline fisheries is more visible (as birds get hauled onboard), unlike trawl fisheries where carcasses are seldom retrieved (Watkins *et al*. 2008). This has led to prioritising the reduction of longline bycatch (Weimerskirch *et al*. 2000; Sullivan et al. 2006a; Tuck *et al.* 2011). Second, bycatch in longliners has economic implications, due to considerable bait-loss associated with seabirds foraging on longline sets, and the consequent loss of catch efficiency (Brothers *et al.* 1999).

The best solution to limit warp strikes is to eliminate the discharge of discards completely. A number of studies have shown that eliminating discharge significantly reduces seabird mortality (Sullivan *et al*. 2006a; Crofts 2006; Watkins *et al*. 2008; Abraham *et al*. 2009). However, this is not logistically possible for many vessels, and retrofitting fishmeal plants or storage tanks is prohibitively expensive (Sullivan *et al*. 2006a). Therefore, current approaches to mitigation measures are in the form of devices designed to prevent birds coming into contact with trawl warps. The three devices that have been proposed are *tori* lines, warp scarers and Brady Bafflers.

Tori lines

The first mitigation technology devised for longliners was the *tori* (Japanese for bird) line, a Japanese invention also referred to as a bird-scaring line, streamer line and bird scarer (Bull 2009; Yokota *et al*. 2011). *Tori* lines act as visual deterrents to keep birds away from baited lines (Snell *et al*. 2011) and have been used on longliners since the early 1990s (Sullivan *et al*. 2006a). *Tori* lines used during trawling are similar to those developed for longliners. The design varies, but they essentially consist of a main line (backbone) with a float (fishing buoy or road traffic cone) attached to create drag and keep the backbone taut (Bull 2009). Pairs of streamers are suspended along the length of the backbone, extending to the sea surface. The streamers are usually brightly coloured tubing that act as visual barriers, to keep birds clear from the area where the warp cables enter the water (Snell *et al.* 2011; Melvin *et al.* 2010). Typically two *tori* lines are flown, one outside each warp, mounted on the port and starboard sides of the vessel (Melvin *et al*. 2010, Figure 1). To avoid the risk of entanglement with the fishing gear, *tori* lines typically are deployed once the doors (structures attached to the warps that ensure the mouth of

the net is kept open horizontally) enter the water and are retrieved before hauling, so there are periods when the warp is unprotected (Bull 2009).

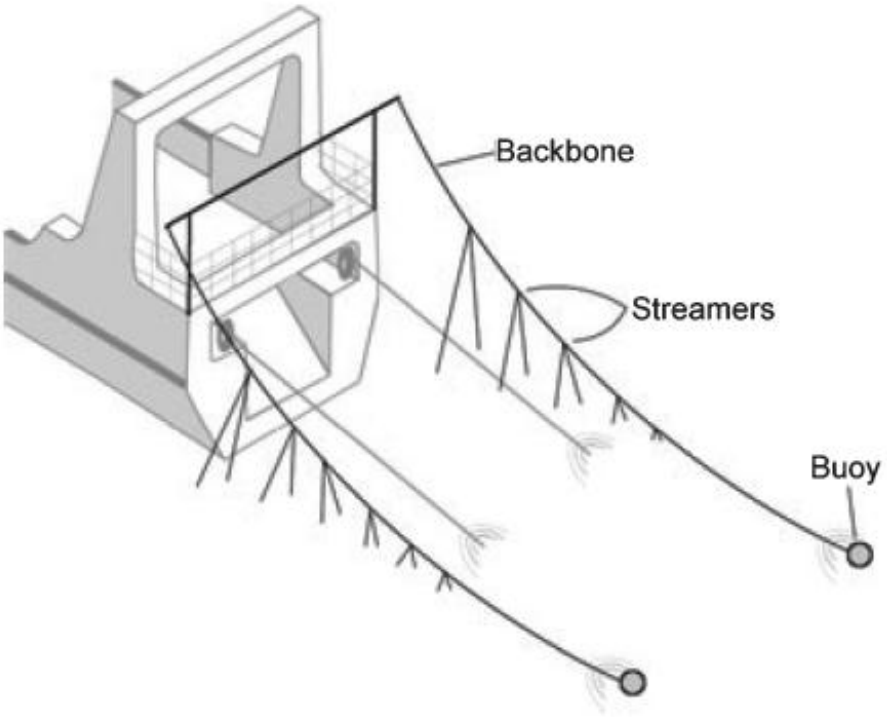

Figure 1. An example of *tori* lines used on a trawler (extracted from Bull 2009)

Warp scarers

Warp scarers (sometimes referred to as Falkland Island warp scarers) consist of a series of weighted rings attached to the warp with rollers that allow them to move freely up and down the warp (Bull 2009; Løkkeborg 2011) (Figure 2). The rings are joined by netting and the rings have ropes with reflective tape extending to the water (Sullivan *et al*. 2006a; Løkkeborg 2011). The device prevents birds from making contact with the warp and scares birds away from the warp as the vessels pitches and rolls (Sullivan *et al*. 2006a; Løkkeborg 2011).

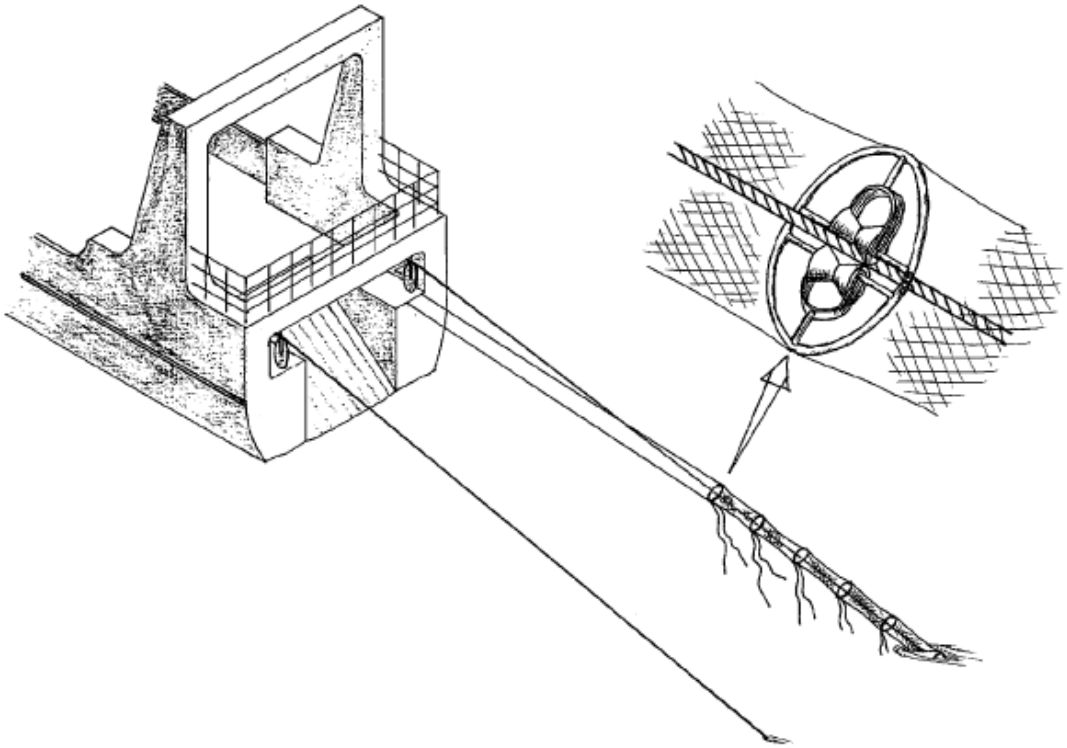

Figure 2. Warp scarer (extracted from Sullivan *et al*. 2006a).

Brady Bafflers

The Brady Baffler or warp boom (Melvin *et al.* 2010) was developed by Keith Brady (Sullivan *et al.* 2006a) to prevent birds congregating at the stern of the vessel while feeding on factory discards (Sullivan *et al*. 2006a). They consist of two booms on each side of the vessel; one boom extends backwards from the stern of the vessel and one boom extends out from the side of the vessel (Bull 2009; Figure 3). A series of ropes with a cone at the end of each rope hangs down from each of these booms (Sullivan *et al*. 2006a). As the vessel pitches and rolls the cones swing and prevent birds from gathering near them, subsequently keeping them away from the trawl warps (Sullivan *et al*. 2006a). The advantage of Brady Bafflers is that they can be deployed and remain in place throughout a fishing trip, except during extreme weather conditions (Sullivan *et al*. 2006a).

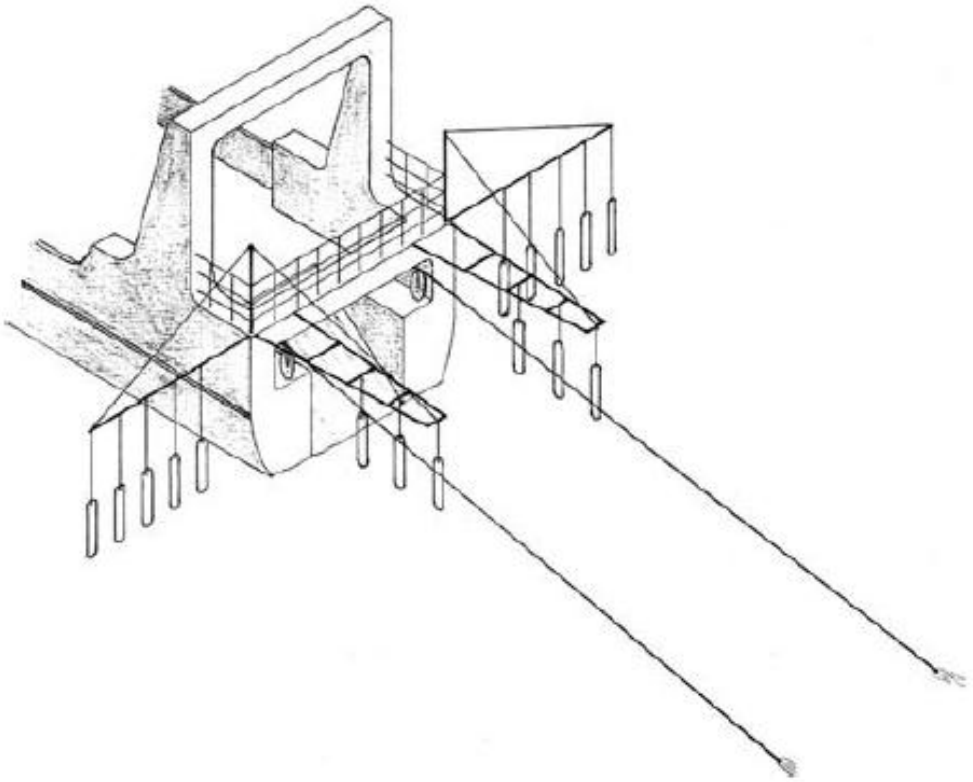

Figure 3. Brady bafflers (extracted from Sullivan *et al*. 2006a).

Effectiveness of mitigation measures

A study of these three mitigation devices (*tori* lines, warp scarers and Brady Bafflers) found *tori* lines to be the most effective device for reducing seabird collisions with warps (Sullivan *et al*. 2006a). Reid & Edwards (2005) determined that in the Falkland Islands' finfish trawl fleet, birds were 79% less likely to be killed during a trawl in 2004/5 when *tori* lines were used than in 2003/4 when *tori* lines were not used. *Tori* lines aren't without weaknesses. Using *tori* lines, there are periods when warps are exposed (Reid and Edwards 2005), and the streamers can become entangled with one another and with the fishing gear, especially in rough seas (pers. obs.).

Warp scarers reduced the rate of heavy interactions with trawl warps by 95% in the finfish trawl fishery of the Falkland Islands (Sullivan *et al.* 2006a) and reduced seabird mortality rates by around 63% in squid trawl fishery fleets in waters off New Zealand's South Island (Bull 2009). As with *tori* lines, warps scarers are deployed after shooting (deploying the net) and retrieved before hauling, resulting in periods when the warp is unprotected (Bull 2009; Sullivan *et al*. 2006a).

While testing the Brady Baffler, Sullivan *et al.* (2006a) found no significant difference between the warp strike rate when the Brady Baffler was used and the control. However, observers have noted that Brady Bafflers seem to reduce the number of birds landing adjacent to the trawl warp (Sullivan *et al*. 2006a) and Melvin *et al.* (2010) believe that they are likely to be effective if used in combination with *tori* lines.

The Albatross Task Force and Responsible Fisheries Alliance

The Albatross Task Force (ATF) was formed by BirdLife International in 2006, to improve the conservation status of threatened seabirds by reducing seabird bycatch globally. The ATF works with fisheries to ensure that the adoption of bycatch mitigation measures is done according to best practice guidelines (Birdlife International Global Seabird Programme 2008). The Responsible Fisheries Alliance (RFA), a partnership between four of South Africa's leading fishing companies and the World Wide Fund for Nature South Africa (WWF-SA) has committed to adopting an Ecosystem Approach to Fisheries Management (EAF) (WWF 2012). The South African ATF works with the RFA to reduce seabird bycatch in the two fisheries that currently have the largest seabird bycatch problems, the pelagic longline fishery for tuna and Swordfish (*Xiphias gladius*) and the demersal trawl fishery for hake. In the

next chapter I test a mitigation devise developed for use in the demersal hake trawl fishery.

Chapter 2: The impact of RLs and fur seals on bird behaviour and warp strike rates

Introduction

Seabird bycatch in commercial fisheries is one of the major factors causing decreases in many seabird populations (Tuck *et al.* 2011; Yokota *et al.* 2011, Chapter 1). Seabirds caught on longline hooks often are hauled onboard fishing vessels, so their bycatch is more apparent and easier to record than seabird bycatch in trawl fisheries, where most mortalities are difficult to detect. In the South African hake trawl fishery, most seabird mortality result from collisions with warps (the cables used to tow the net, Chapter 1) although some occur through entanglement in trawl nets (Watkins *et al*. 2008). Birds killed through cable strikes are seldom retrieved when the net is hauled, and so dedicated observations are required to detect mortality in this fishery.

Watkins *et al*. (2008) reported that over 30 birds were killed by trawl warps in 190 hours of observation aboard hake trawlers operating in South African waters in 2004 and 2005, crudely extrapolating to approximately 18 000 birds killed per year. *Tori* lines have been used to decrease seabird mortality in some trawl fisheries by up to 90% (Reid & Edwards 2005). They are not, however, the panacea for bycatch in trawl fisheries because they cannot be used during setting and hauling of nets, leaving periods when the warp cable is unprotected (Bull 2009, Chapter 1). They also have a tendency to become entangled in fishing gear and are not as effective in rough seas. Thus, there is a need to develop additional or complementary measures to reduce seabird bycatch in trawl fisheries. Retrofitting factory vessels to manage

offal discards is an effective way to reduce seabird bycatch (Chapter 1), but it is expensive and is not feasible for at least some vessels operating in the South African hake fishery.

Currently, only one measure is required by South African government to reduce seabird mortality in the hake trawl fishery– use of *tori* lines above each warp. This measure came into force in mid-2006 (BirdLife International Global Seabird Programme, 2008). The Albatross Task Force (ATF) has conducted an assessment of the efficacy of this measure to reduce mortality, and preliminary results suggest a large reduction in albatross deaths, but little reduction of interaction rates across all species. This suggests that *tori* lines are less effective for smaller seabird species, creating the need to explore additional mitigation measures.

A key shortcoming of the *tori* line relates to the location of the trawlers' scuppers from which discards are released. In South Africa, scuppers exit from the side of a vessel towards the stern. When the factory is processing catch, this design creates a source point of discards, which in turn results in a plume of discards from the side of the ship, trailing towards the stern, into the danger area where the warps enter the water (typically 5-10 m astern). Foraging seabirds and fur seals gather at the scuppers, to compete for discards as soon as they are available (pers. obs.). Groups of birds gather around large discarded items. As the vessel moves forward, the group drifts back towards the danger area. Anecdotal observations from ATF instructors identified that because the seabirds are already on the water, and their attention is focused on competing for food, they are often oblivious to the *tori* line (which is primarily a visual deterrent to flying birds).

The ATF has helped to develop and test the Rory Line (hereafter, RL) which was designed by a South African hake trawl skipper, Roy Diedricks. The RL (Figure 4) is similar to the Brady Baffler (described in Chapter 1) but is designed to be used in conjunction with *tori* lines. It aims to reduce warp strikes by placing a physical barrier that scares seabirds that gather at the scuppers and breaks the stream of seabirds drifting aft towards the danger zone.

This study tests the efficacy of the RL by recording the behavioural responses of birds to the RL and its effect on the number of warp strikes.

Figure 4. The RL in the foreground on the portside of a trawl vessel, with the *tori* astern in the background.

Methods and study area

The South African deep water demersal trawl fishery for hake operates mainly along the edge of the continental shelf between the Orange River and Port Alfred (Watkins *et al.* 2008). Experimental trials with RLs took place on Irvin and Johnson (I&J), Sea Harvest and MarPro trawlers that departed from the ports of Saldanha Bay and Cape Town. Eighteen trips were conducted; eight aboard the *Harvest Nandi* (Sea Harvest), five on the *Foxglove* (I&J), four on the *Forest Lily* (I&J) and one on the *Maria Marine* (MarPro) between March 2010 and November 2011. Of these eighteen trips, eight were during summer (October to March) and ten were in winter (April to September).

Environmental parameters and bird counts

At the start of each trawl the following environmental parameters were recorded:

sea surface temperature (recorded by the vessel's instruments) and estimates of sea state (on the Beaufort scale), wave height (in metres) and wind and wave direction relative to the boat. Wind and wave direction were recorded in degrees, with 0^{o} being the direction the vessel was facing). Cloud cover was estimated in terms of how many eighths of the sky were covered in cloud, from 0 (cloudless) to 8 (overcast). The presence or absence of precipitation was recorded. The number of birds within a 50 m radius of the ship was counted for each trawl immediately after the net was set. An estimate was made of the proportion of individuals of each species that were flying, foraging and resting.

Warp observations

During each daylight trawl, interactions (any contact) between seabirds and the trawl warp were observed for 40 min (two 10 min periods with the RL and two control periods without the RL, with the order of treatments randomised). However, only three observation periods were conducted per trawl in 2010: two with the RL and one control. One trawl per day was recorded using a video camera (see details below). For trawls during which video footage was collected, the 10 min periods with or without the RL were coordinated to coincide with the 10 min periods captured on video. In the event of a warp interaction, the species and the outcome (not injured, injured, possibly injured or dead) were recorded. Presence/absence of offal discharged during each observation period was also recorded. I was able to use these discharge data in analyses of behavioural responses (described below) as the behavioural sampling coincided with the trawl observations. A variety of conditions meant that not all observation periods amounted to 10 minutes.

Behavioural responses

Behavioural observations were made to assess the factors affecting movements of bird feeding on discards away from the side of the vessel between the scupper and the stern, and to determine whether the RL reduced the number of birds entering the danger zone (i.e. at the stern of the vessel where birds are in danger of being struck by the trawl warp). A video camera was attached to the vessel's gunwale to record the behavioural responses of birds within 5 m of the RL. One 40 min period was recorded during trawling for each day at sea, consisting of two 10 min periods with the RL in place and two 10 min control periods without the RL. During analysis of the footage the responses of each bird within 5 m of the RL were recorded by species or

species-groups (to ensure adequate sample sizes). Two responses were recognized:

1. A response resulting in the bird moving >1 m away from the vessel
2. The bird moving into the danger zone by passing between the RL streamers (or past the point where the streamers would hang in the case of the control)

It was suspected that the presence of Cape Fur Seals may scare birds away from the vessel, so the number of fur seal porpoises (number of times a fur seal rises to the surface for a breath) occurring between the scupper and the RL was recorded for each 10 min period of video footage. As with the warp observations, not all behavioural response sampling periods (those recorded on video) amounted to 10 min.

Data analysis

Due to small sample sizes, all albatross species were grouped together for the analyses. This included Atlantic Yellow-nosed Albatrosses (*Thalassarche chlororhynchos*), Indian Yellow-nosed Albatrosses (*T. carteri*), Shy Albatrosses (*T. Cauta/steadi*) and Black-browed Albatrosses (*T. melanophrys*) Only White-chinned Petrels, Cape Gannets and albatrosses were sufficiently abundant to include in the behavioural analyses (analyses of the number of birds drifting into the danger zone, and the number of birds moving >1 m from the vessel).

Efficacy of RLs at reducing the number of birds entering the danger zone

Bootstrapping was used to calculate 95% confidence intervals for the mean rate of bird entering the danger zone for each species. Bootstrapping is a resampling

technique which can be used to estimate the sampling distribution of spatial point patterns (Solow 1989). This was necessary as there were many sampling periods with no interactions, resulting in non-normally distributed data (Sullivan *et al*. 2006a). An excel macro (Barreto & Howland 2005) was used to create 10 000 bootstrap replicates.

A generalized linear model (GLM), with a Poisson distribution, in the R statistical package (R Development Core Team 2008) was used to assess whether RLs affected the number birds drifting into the danger zone (Everitt & Hothorn 2006). Analyses were conducted for each species or species-group, as their behaviour differed. The dependent variable was the number of birds drifting into the danger zone relative to the number of birds within 50m of the vessel (number of birds that drifted into the danger zone per bird within 50m of the vessel). This value was capped at a maximum of one. Time watched was used as an offset term (Sullivan *et al*. 2006a). Explanatory variables included treatment, season, discards volume and the number of fur seal porpoises. It was possible to include environmental conditions in the GLM, but the random assignments of treatments to trawls resulted it little resolution in these data. It was necessary to use time as an offset term because sampling periods were not always exactly the same duration.

The “effect” term displayed in the GLMs in the results section is an estimate of the size of the effect of the variable on the dependent variable. It was calculated using the exponential of the estimate term produced by the model. The “effect” values for the number of fur seal porpoises is expressed as the size of the effect that 100 fur seal porpoises had on the dependent variable. This was obtained by raising the calculated estimate to the power of 100.

Variables affecting bird movements away from the vessel

A GLM was used to assess which variables (presence/absence of RL, season, amount of discards and number of fur seal porpoises) affected the movement of birds away from the vessel. The number of birds that moved >1 m was the dependent variable. Again this was expressed as the number of birds relative to the number of birds within 50m of the vessel and the value was capped at a maximum of one. Observation duration was used as an offset term. Step wise removal of terms was used to derive a model with the lowest Akaike's Information Criterion (AIC) value.

Warp observations

Tori lines were used during all trawls, resulting in too few mortalities during trawl observations to be able to determine the effect of RLs on mortality rates. Instead, warp interactions were used as a proxy for mortality risk, as the two variables are significantly correlated (Sullivan *et al*. 2006a). I analysed differences in trawl warp interaction rates between treatment (RLs) and controls, irrespective of the outcome of the interaction (i.e. how severely injured a bird was).

Bootstrapping was again used to calculate 95% confidence intervals for the mean interaction rate for each species. A negative binomial GLM (using the "glm.nb" function from the library "MASS" in R statistical package) was fitted to the data to determine differences in warp strike rates for treatment and season (Venables & Ripley 2002). Time was again used as an offset term due to varying sampling times.

Results

The mean numbers of birds that attended trawls was 1.7 times greater in winter than in summer (Table 1). The number of albatrosses was 1.4 times greater in winter, while Cape Gannets were an order of magnitude more abundant in winter (Table 1). By comparison, White-chinned Petrel numbers averaged 1.6 times greater in summer, and Great Shearwaters (*Puffinus gravis*) were more than 30 times more abundant in summer (Table 1).

Table 1. The total and mean number of birds attending trawls within 50 m of the vessel in summer (64 trawls) and winter (48 trawls).

	Summer		Winter	
	N	Mean	N	Mean
Albatrosses	7974	125	8887	185
White-chinned Petrel	8689	136	3976	83
Cape Gannet	617	10	6181	129
Great Shearwater	4486	70	138	3
All birds combined*	27485	429	35627	742

*All birds combined included all species counted during trawls

Behavioural response of birds to Rory Lines

In total, 110 video samples were analysed, amounting to 18.35 hours of footage. During this time, 2012 birds entered the danger zone, with the rate differing markedly between treatments (Table 2). The use of RLs significantly reduced the number of birds of all three species/groups drifting into the danger zone compared to the control treatment (Figure 5, Tables 2 and 3). Numbers of albatrosses, White-chinned Petrels and Cape Gannets that drifted into the danger zone decreased by 16%, 16% and 14%, respectively, when a RL was deployed. As suspected, fur seal presence also decreased significantly ($p<0.001$) the number of albatrosses, White-chinned Petrels

Table 2. The number and mean rate (per hour) at which birds entered the danger zone with RLs (n=62 observation periods totalling 10.29 h) and during control periods (n=48, 8.06 h), with bootstrapped 95% confidence intervals.

Species	Control (no RLs)		With RLs	
	N	Mean	N	Mean
Albatrosses	342	42.4 (15.4 - 17.5)	91	8.8 (6.9 - 13.7)
White-chinned Petrel	843	104.5 (72.8 - 121.8)	91	8.8 (6.9 - 11.6)
Cape Gannet	429	53.2 (35.5 - 45.9)	81	7.9 (5.7 - 8.4)
All birds combined*	1735	215.2 (116.9 - 361.1)	277	26.92 (12.3 - 45.3)

*All birds combined included not only the three species in the table but all birds entering the danger zone, including Great Shearwaters, Kelp Gulls (*Larus dominicanus*), giant petrels (*Macronectes giganteus/halli*) and Subantarctic Skuas (*Catharacta antarctica*)

and Cape Gannets drifting into the danger zone (Table 3). Every additional 100 fur seal porpoises during an observation period reduced the number of albatrosses, White-chinned Petrels and Cape Gannets by 4% (Table 3). Season had a highly significant effect ($p<0.001$), with the number of albatrosses drifting into the danger zone increasing in winter by 23% (Table 3).

Table 3. GLMs for the number of birds drifting into the danger zone with treatment, season and the number of fur seal porpoises as explanatory variables. NSD = no significant difference.

	Treatment		Season		Seal porpoises	
	Control vs RL		Summer vs Winter		N vs N+100	
	P value	Effect	P value	Effect	P value	Effect
Albatrosses	0.001	0.843	<0.001	1.23	<0.001	0.962
White-chinned Petrel	<0.001	0.840	NSD	-	<0.001	0.957
Cape Gannet	0.028	0.860	NSD	-	<0.001	0.956

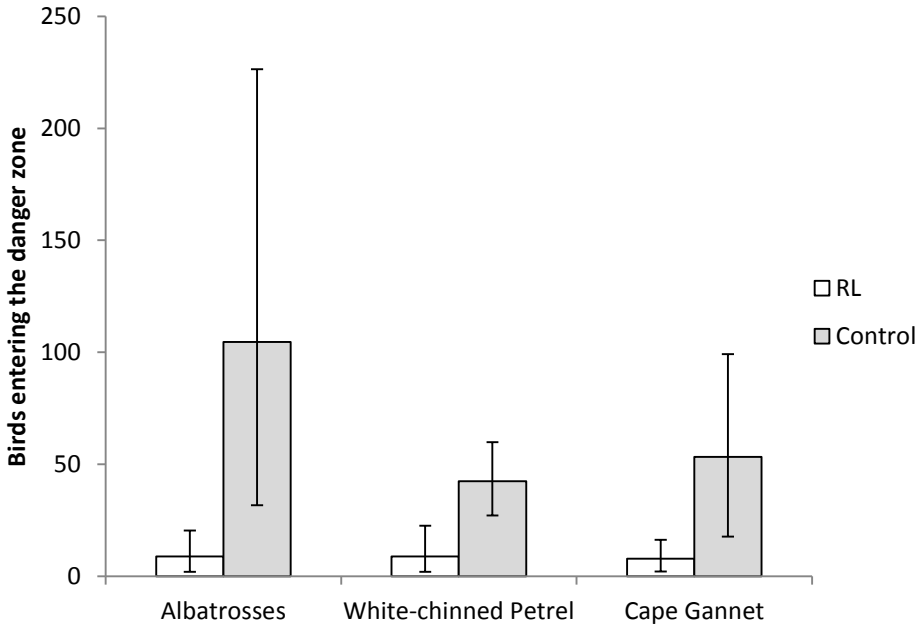

Figure 5. Rate (per hour) at which birds moved into the danger zone with (RL) and without (control) a Rory Line deployed, with bootstrapped 95% confidence intervals.

Variables affecting bird movements away from the vessel

Surprisingly, the presence of RLs had no effect on the movement of birds away from the vessel. Fur seals and season both had highly significant effects ($p<0.001$) on the numbers of albatrosses moving >1 m away from the vessel, but only fur seals affected the number of White-chinned Petrels and Cape Gannets moving >1 m away from the vessel (Table 4).

Table 4. GLMs for the explanatory variables affecting the number of birds moving >1 m from the side of the vessel. NSD = no significant difference

	Season Summer vs Winter		Seal porpoises N vs N+100	
	P value	Effect	P value	Effect
Albatrosses	<0.001	1.20	<0.001	0.960
White-chinned Petrel	NSD	-	<0.001	0.949
Cape Gannet	NSD	-	0.001	0.954

Warp interactions

Observations of cable interactions were conducted during 127 trawls, during 18 trips, with 423 10-min observation periods (Table 5). There was a slight decrease (16%) in the warp interaction rate for all species with the RL compared to the control (Tabe 5). This was not significant due to the large variance. However, when I examined the RL effect on species/groups, a significant reduction in collision rates was evident for White-chinned Petrels (68%) and Great Shearwaters (84%, Tables 5 and 6). There was a strong seasonal effect on the numbers of Cape Gannets and White-chinned Petrels hitting the warp, but Great Shearwaters were absent in winter so no test of seasonal effect was possible for this species (Table 6).

Table 5. Number and mean rate of warp interactions with the RL and the control, with 95% confidence intervals calculated using bootstrapping

Treatment	Observation periods	Trawl observation time (hours)	Warp interactions	Mean interaction rate (per hour)	95% CI
RL	242	40.28	313	7.77	4.22 - 11.89
control	181	30.16	279	9.25	6.00 – 13.00

Table 6. Negative binomial GLM for the number of warp interaction across treatment and season.

	Treatment Control vs RL		Season Summer vs winter	
	P value	Effect	P value	Effect
White-chinned Petrel	0.043	0.322	<0.001	0.0628
Cape Gannet	NSD	-	<0.001	0.0259
Great Shearwater	0.013	0.158	NSD	-

Discussion

The Rory Line proved highly effective at reducing the number of albatrosses, White-chinned Petrels and Cape Gannets that drifted alongside the vessel into the danger zone, where the trawl warp enter the water. This is in essence what it was designed to do. Just like a *tori* line, it acts as a barrier, discouraging birds from accessing the area at the stern of the vessel. This is not to say that the RL affected the number of birds entering the danger zone from other directions (astern, overhead or from the side). The fact that the RL was effective for these species/groups in particular is a promising result as they are all of conservation concern (Chapter 1).

RLs for reducing warp strikes

The number of warp interactions recorded during this study was generally low. All observations were conducted with *tori* lines deployed, so strikes rates were already low, even without RLs. Although the use of RLs failed to result in a statistically significant decrease in mean warp strike rates for all species combined, larger sample sizes may have demonstrated a significant effect. Watkins *et al.* (2008) reported difficulty detecting differences in seabird mortality because they are relatively rare events. The experiment would have been more powerful had it been conducted without *tori* lines, but this was not pursued for two reasons. First, removing *tori* lines would have increased seabird mortality, which would be difficult to justify from an ethical perspective. Second, the RL is designed to be used in conjunction with *tori* lines, not as a standalone device or replacement for *tori* lines.

When I investigated the effect of RLs on individual species, I found marked reductions in the numbers of warp strikes for both Great Shearwaters and White-

chinned Petrels (Table 6). RLs also decreased the numbers of Cape Gannets and albatrosses drifting into the danger zone (Table 3), but had no apparent effect on the number that were struck by the warp (Table 6).

This last result may be linked to the gannets' foraging behaviour. Gannets are plunge-divers, and do not compete aggressively with wings stretched open while on the surface, unlike albatross and petrels. Gannet warp strikes tend to be from them flying into the danger zone from directly above the warp (pers. obs.). Therefore, reducing the rate at which they drift to the stern of the vessel has little effect on their interaction rates.

Effect of fur seals on the number of birds entering the danger zone

Surprisingly, the impact that fur seals have on the behaviour of birds foraging on factory discards seems not to have been documented. I found that the presence of fur seals significantly reduced the number of albatrosses, White-chinned Petrels and Cape Gannets that drifted into the danger zone. Birds tended to avoid fur seals, moving away rapidly if one porpoised close to them. Fur seals are predators of seabirds (e.g. Makhado *et al*. 2006), but there are few records of them predating on albatrosses (Ryan & Barnes 2012). Given the lack of observations of fur seals attacking seabirds around trawlers off the Cape or elsewhere in the Southern Ocean, fear of predation doesn't seem likely given the abundance of factory discards. The size of this effect may seem small (e.g. a 4% decrease in the number of albatrosses drifting into the danger zone for every 100 fur seal porpoises) but if one considers that as many as 1000 fur seal porpoises were recorded during 10 min sampling periods, there is the potential for them to greatly influence the foraging dynamics and behaviour of birds attending factory trawlers.

Variables affecting movement away from the vessel

Although there was a strong effect of fur seals on the numbers of birds that entered the danger zone (Table 3), there was, counterintuitively, a significant decrease in the number of birds moving >1 m away from the vessel with an increase in fur seal numbers (Table 4). My personal observations suggest that fur seals scared birds away from the vessel while birds were still in the air, preventing them from landing close to the scuppers. This would explain why fewer birds entered into the danger zone and why fewer birds moved away from the vessel when fur seals were abundant. With high fur seal abundance, the birds wouldn't have landed next the scupper to begin with, so wouldn't have been recorded moving away from the vessel.

Seasonal variation in abundance, behavioural responses and warp interaction rates

There were significant seasonal differences in the relative number of Albatrosses entering the danger zone (Table 3) and moving >1 m away from the vessel (Table 4), yet there was no significant seasonal difference in the number of Albatross interactions with the warps. This suggests that Albatrosses' feeding behaviour alongside the vessel differs between seasons but there is evidence that these changes in feeding behaviour impact the probability of them coming into contact with the warps. There were no significant season differences in the recorded behavioural responses of White-chinned Petrels and Gannets (Tables 3 and 4). Both these species exhibited significant seasonal differences in the number of warp interactions (Table 6).

Conclusions

Preliminary results from a study of *tori* line impacts on seabird mortality in the hake trawl fishery suggest that *tori* lines are effective at reducing warp strikes with albatrosses, but not for smaller birds (Albatross Task Force, unpublished data). Here I show that RLs reduced the warp strike rates for some smaller species, specifically Great Shearwaters and White-chinned Petrels. The failure to show a significant result for albatrosses is due to the low power of the study for this group – a direct result of the effectiveness of *tori* lines for albatrosses. However, the efficacy of RLs at reducing the numbers of albatrosses drifting back towards the danger zone was similar to that achieved for White-chinned Petrels, and suggests that the net effect, while small, will still be a reduction in albatross mortality. I conclude that RLs are effective at doing what *tori* lines are failing to achieve, and effectively close an access route to the danger area for seabird species that are otherwise at elevated risk. As a complementary device to *tori* lines, RLs fulfil the role they were intended to. In the next chapter I discuss some of the valuable results that this study yielded and offer suggestions for modifications to make the RL more effective at reducing seabird bycatch.

Chapter 3:

Synthesis and future recommendations

I believe there is merit in continuing this study and adding to the existing data. Løkkeborg (2011) highlighted the lack of accurate information on the numbers of seabirds killed by fisheries, partly due to mortalities being rare events and partly because data from seabird mitigation studies only date back a few decades at most. Almost all the papers dealing with seabird bycatch that were reviewed for this study were published from 2004 onwards. Many of the estimated bycatch rates reviewed are based on small sample sizes. Løkkeborg (2011) refers to a specific example; the Brothers (1991) study that estimated 44 000 albatross were killed annually in the Southern Ocean by Japanese longline tuna fisheries alone. This estimate is widely cited even though it is an extrapolation based on the mortality of only 45 birds (Løkkeborg 2011). Long-term data on seabird bycatch in South Africa's hake trawl fishery is thus valuable and can be used in comparative studies on mitigation devices.

This study produced results that are valuable for future development and testing of similar mitigation devices. I divided these into three broad categories:

1. Improvements to the RL

   The RL reduced the number of birds drifting towards the stern of the vessel , although it is arguable that this effect is too localized to reduce warp strikes. During some trawls the warps enter the water several metres astern the vessel. As a result, the gap between the RL and the danger zone is large enough for birds to move around the RL and back into the stern of the vessel in time to contact a warp cable. Considering demersal trawlers move slowly

(less than 4 knots) while trawling it isn't surprising that birds are capable of cutting in behind the RL before they are astern the warps. If one wished to optimize the current design of the RL it would require moving the RL aft, closer to the danger zone. The RL was positioned as far astern as possible in this study. One could, however, pivot the boom of the RL sternward so the streamers hung closer to the warp (Figure 6). Testing of the RL at any angle other than 90^{o} to the gunwale has yet to be carried out, but I am confident that this will prove to be even more effective at reducing warp strikes. The RLs on the *Harvest Nandi* are designed to allow adjustment of the angle at which they protrude from the vessel so no modification to the current design will be necessary. Alternatively, the length of the boom could be extended to protrude farther from the side of the vessel, but this option may be more logistically and operationally complicated. Currently the RLs are deployed and retrieved manually, and require two members of the crew to lift. The additional weight associated with extending the RLs would make them more difficult to manoeuvre and may increase the likelihood of them breaking in bad weather.

A number of RLs, protruding from the vessel at different angles, could be used simultaneously, in a similar fashion to the Brady Baffler (Figure 7). An additional line running between the port and starboard booms has been used (Bull 2009). This mitigation device has been coined the "burka baffler" (Bull 2009). The burka baffler, as the name suggests, fully encompasses the danger zone by creating an enclosed area around the warps (Bull 2009). However, this is more suited to mid-water trawls where the warps enter the water very close to the stern of the vessel, at a steep angle. In the South

African deep water hake fishery, the distance astern is usually >4 m, and in rough seas the effect of swells causes that distance to change rapidly. As a result, I believe a burka baffler will be difficult to deploy effectively in this fishery.

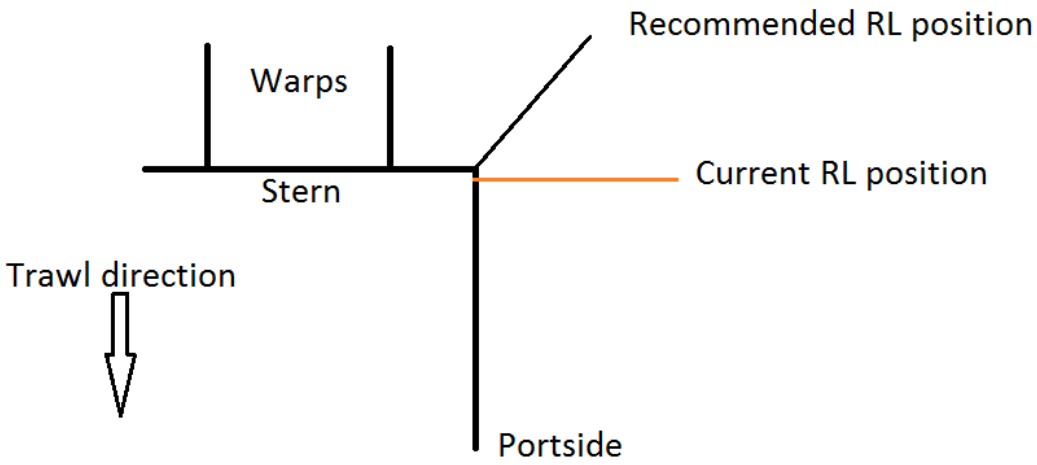

Figure 6. Possible adjustment to the current position of the RL for further testing.

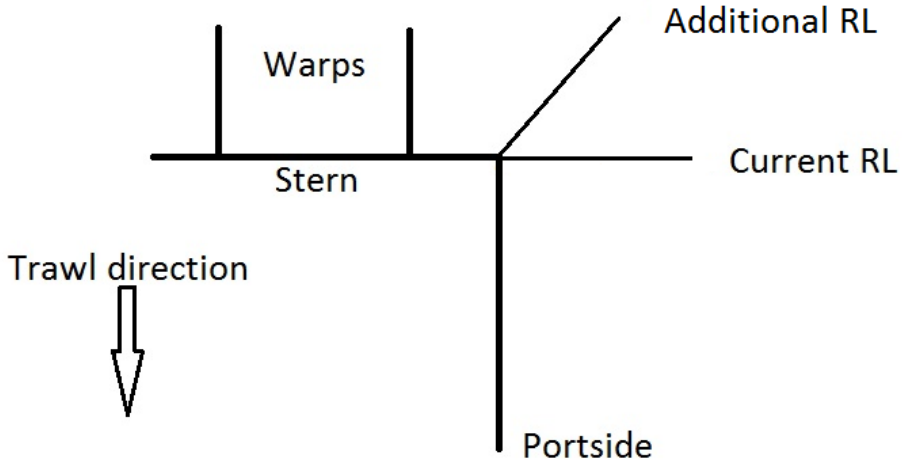

Figure 7. Possible addition of another RL for further testing.

2. Study design

Although this fishery kills large numbers of seabirds, mortalities from warp strike are nonetheless relatively rare events. In this study I recorded events which are theoretically more frequent (warp strikes and behavioural responses). Yet even here, with two years' data, sample sizes were insufficient to detect differences in mean warp strike or in behavioural response rates for some species. One should not underestimate the sample size required for these studies. The highly zero-inflated distribution and residual variance of these count data also reduce the ability to detect significant differences between subsets of data.

Testing mitigation devices used in combination with one another further compounds this issue, as events (e.g. warp strikes/mortalities) become even less frequent. As complimentary mitigation devices, such as RLs improve, differences between there efficacy will become more difficult to detect and sampling effort will have to increase to compensate for these difficulties.

3. Variables to consider

Of the explanatory variables I measured, the presence of fur seals had the most profound effect on the behaviour of birds. It is surprising that the effect of fur seals on the behaviour of birds around factory trawlers has not been documented. Densities of fur seals and seabirds are generally high around vessels that are discarding offal. Testing of any device that is intended to affect seabird behaviour should record the presence of fur seals as an explanatory variable.

Seasonal differences in behavioural responses and interaction rates also varied between species. These differences resulted from seasonal differences in the number of birds attending fishing vessels, and interactions between birds. This suggests that results could be biased if studies took place during only one season. One needs to ensure that mitigation studies have large sample sizes, as well as samples collected over a sufficient seasonal range.

Developing other mitigation measures

If a cheaper, less cumbersome mitigation device could be devised, this would be preferable over the RL and likely easier to implement within a fishery. I carried out a few observations using an inflatable orange buoy in place of the RL to see if it would deter the flow of birds sternward as the RL does. The buoy was tied to the gunwale with a rope so that the buoy floated in line with the where the RL streamers would have hung. Birds did seem to respond to the buoy by moving away from the vessel. However, there was insufficient drag (mostly because the vessel didn't move fast enough during trawling and as the vessel pitched and rolled, waves coming off the side of the vessel pushed the buoy away from the ideal site, allowing birds to drift under the rope alongside the vessel. I think the use of buoys could be explored further. Partly filling the buoy with water would cause it to sit deeper in the water and improve its drag coefficient. I also suggest experimenting with tying a series of buoys together.

Although costly if applied to existing vessels, the most effective method for reducing seabird bycatch in trawl fisheries must surely be better offal management (Abraham *et al*. 2009). This is a long-term and sustainable solution that obviates the

need for upkeep and replacement of large, cumbersome devices such as RLs and *tori* lines. A relatively simple offal management plan is to only dump offal between trawls when the warp cables are not in the water. The need for storage tanks and the space to house them currently prevents many vessels in the SA hake fishery from using this approach (B. Rose pers. comm.). The factory vessels I boarded do, however, already have the pumping and conveying technology to make this feasible. If some of the national fleet used discard management, it would result in a significant reduction in seabird deaths in this fishery. Another form of offal management is converting waste into fishmeal. Abraham *et al.* (2009) found that converting waste to fishmeal and only discarding sump water reduced the numbers of *Thalassarche* albatrosses and some of the smaller petrels attending trawlers in New Zealand waters by approximately 95%. Unless converting waste to fishmeal proves to be economically beneficial, it is unlikely that fisheries will commit to this level of offal management. I think that we should be investing more research into offal management in South Africa's trawl fisheries.

The development of the RL is a good example of the importance of working with fishers and fisheries while developing seabird bycatch mitigation measures. Roy Diedricks clearly understood the dynamics behind seabird foraging behaviour and the root of the warp collision problem when he developed the RL. The local knowledge of fishers and the amount of time they spend at sea are priceless tools for developing and improving mitigation measures. The ATF and RFA have great potential to act as platforms for scientists, fisheries managers and fishers to collate their skills and knowledge to develop improved and novel mitigation measures.

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