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Article *in* Aquatic Conservation Marine and Freshwater Ecosystems · August 2017

DOI: 10.1002/aqc.2805

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Received: 8 November 2016 | Revised: 17 April 2017 | Accepted: 14 May 2017

DOI: 10.1002/aqc.2805

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RESEARCH ARTICLE

Assessing the importance of net colour as a seabird bycatch mitigation measure in gillnet fishing

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Funding information
Agreement on the Conservation of Albatrosses and Petrels (ACAP)

Abstract

1. Gillnets are used widely in fisheries throughout the world and known to cause the death of thousands of seabirds each year. Currently few practical or technical options are available to fishers for preventing seabird mortalities.
2. The ability of little penguins (*Eudyptula minor*) to differentiate between different coloured netting materials was tested under controlled conditions to ascertain if changes in gillnet colour could facilitate a potential mitigation measure by improving visibility of nets.
3. The study involved a repeated-measures design with penguins exposed to variously coloured mono-filament threads creating a gillnet mimic. The gillnet mimic was made up of gillnet material configured as a series of vertical lines 25 mm apart stretched tightly across a stainless steel frame that measured 1160 mm × 1540 mm and divided into two equal panel areas. The panels were placed in a large tank within an enclosure that housed 25 penguins. Penguins were able to readily access the tank and swim freely. The frame was always introduced into the tank with one panel containing a gillnet mimic, and the other panel left empty as a control.
4. Gillnet filament colours tested were clear, green and orange. Orange coloured monofilament lines resulted in lower collision rates (5.5%), while clear and green monofilament lines resulted in higher rates of collision (35.9% and 30.8%, respectively).
5. These results suggest that orange-coloured lines were more apparent to the birds. Constructing nets of orange-coloured material may be effective in reducing bycatch in gillnets set in shallow waters and high light levels where seabirds are able to identify fine colour differences.
6. Further testing under experimental conditions, accompanied with at-sea trials to verify effectiveness in varied light conditions is warranted, together with an assessment of the effect of gillnet colour on catch efficiency of target species.

KEYWORDS

bird, incidental mortality, new techniques, ocean, penguin, seabird, sensory perception

1 | INTRODUCTION

Gillnets are used widely in commercial, recreational and artisanal fisheries in all oceans and many inland waterways of the world (Lewison et al., 2014). A range of diving seabirds and other non-target organisms are susceptible to capture in this type of fishing method when it overlaps with their feeding grounds or transit routes to feeding grounds (Lewison et al., 2014; Žydelis, Small, & French, 2013). Fishers involved in using gillnets have few practical or technical options available to them for preventing seabird mortalities. Current measures that are practised in some gillnet fisheries include holding fish offal on board when nets are being shot away or hauled and thus removing an attractant for seabirds, staying with the net to remove any seabirds that are caught, minimizing soak time of the net, and only using nets in low seabird risk areas or at low risk times (Wiedenfeld, Crawford, & Pott, 2015).

Gillnet-related fisheries bycatch is now considered a major conservation issue (Waugh, Filippi, Blyth, & Filippi, 2011). Most net fisheries occurring in or near coastal regions, are small-scale industries and are inadequately scrutinized for their impact on target and non-target species; these factors make assessing bycatch statistics challenging (Žydelis et al., 2013). However, several studies have reported the importance of this issue while identifying hotspots and taxa-specific assessments (Dagys & Žydelis, 2002; Lewison et al., 2014; Lyle et al., 2014; Waugh et al., 2011; Žydelis et al., 2013). Seabirds and fisheries often compete for fish resources, so interactions are common. In total, 81 species of seabirds have been identified as being affected by gillnet fishing practices and many others are considered to be susceptible to this fishing method (Dagys & Žydelis, 2002). A global review conducted on gillnet bird bycatch estimated that at least 400 000 birds are likely to be killed each year in gillnets (Žydelis et al., 2013). This toll is higher than the total estimated mortality from longline fishing, which has been widely implicated in the decline of many albatrosses and petrel species (Baker, Gales, Hamilton, & Wilkinson, 2002). Species that have been affected significantly owing to gillnet mortality include Humboldt penguins (*Spheniscus humboldti*), yellow-eyed penguins (*Megadyptes antipodes*), magellanic penguins (*Spheniscus magellanicus*), little penguins (*Eudyptula minor*), long-tailed ducks (*Clangula hyemalis*), common guillemots (*Uria aalge*), thick-billed guillemots (*Uria lomvia*), greater scaups (*Aythya marila*) and red-throated loons (*Gavia stellata*) (Žydelis et al., 2013).

Little penguins, a species found in temperate Australasian waters (Stahel & Gales, 1987), are regularly caught in gillnets (Martin & Crawford, 2015; Žydelis et al., 2013). Birds nest in colonies along coastal, inshore and offshore islands of southern Australia and New Zealand, and typically forage within 30 km of their colonies. The distribution of little penguins overlaps with gillnet fisheries targeting a range of pelagic fish, exposing them to potential net entanglement and drowning (Lyle et al., 2014; Stahel & Gales, 1987). Most bycatch species, including little penguins, appear to be captured in gillnets as the nets are not clearly visible to them (Martin & Crawford, 2015). Therefore, increasing the visibility of nets to seabirds may be an effective way of reducing incidental capture (Martin & Crawford, 2015). The characteristics of modern monofilament nylon gillnets have made them almost transparent to a range of species (Žydelis et al., 2013), thereby increasing interaction and bycatch (Waugh et al., 2011). Gillnets are available in several shades and colours, and the choice that fishermen often make in selecting colours and shades may be dependent on cost, availability and perceived effectiveness in catching target species. The size of mesh and setting depth varies depending upon the size and habitat of the target species, with net meshes typically ranging from 15 mm to more than 250 mm, and net length ranging up to several kilometres (Žydelis et al., 2013). Recent reports suggest that gillnets with mesh sizes greater than 60 mm have greater seabird bycatch rates as a typical trend (Dagys & Žydelis, 2002; Northridge, Coram, Kingston, & Crawford, 2017).

One way of improving visibility to seabirds may be to construct gillnets from different coloured material to those typically used. Initial work by Melvin, Parrish, and Conquest (1999) in USA coastal gillnet fisheries indicated that constructing the upper portion of a drift net using white material to provide a visual alert to seabirds reduced the catch of common guillemots by 40–45%, but also reduced the rate of target catch by more than half. Other mesh colours may also be visible to birds but, ideally, not to fish. A more recent experimental study to minimize right whale (*Eubalaena glacialis*) entanglements demonstrates promising results, with red and orange-coloured rope being perceived from significantly greater distances than green-coloured rope (Kraus, Fasick, Werner, & McFarron, 2014).

To ascertain whether changes in gillnet colour could facilitate a potential mitigation measure through improving visibility of nets, the ability (visual acuity) of little penguins to differentiate between different coloured netting materials was tested under controlled conditions. This is the first step in identifying net colours that are more visible to penguins, and potentially other seabirds.

2 | MATERIALS AND METHODS

The study was conducted at the little penguin enclosure at Melbourne Zoo, Australia. The enclosure houses 25 little penguins, most of which had been held in the enclosure for five years. All birds were individually marked with coloured-flipper tags applied to both flippers. The facility included a large tank (3 × 8 × 25 m), which contained three large observation windows fitted with one way glass for the public viewing of little penguins underwater. The facility contained 11 male and 14 female penguins at the time of the experiment, and all these animals were in good health and able to swim freely.

2.1 | Experimental design

The study involved a repeated-measures design with penguins being exposed to a number of experimental treatments (variously coloured mono-filament threads creating a *gillnet mimic*) and a control without the threads (*no gillnet mimic*). The *gillnet mimic* was made up of gillnet material (single-strand monofilament nylon of 0.5 mm diameter as per retail gillnets) configured as a series of vertical lines 25 mm apart stretched tightly across each panel (Figure 1). This configuration differed from the usual diamond meshed pattern typical of gillnets in order to minimize the risk of birds becoming entangled when they came in contact with a *gillnet mimic*. Having the lines tightly strung also enabled birds to be deflected should they come into contact with the *gillnet mimic* thereby minimizing any chance of entanglement and potential injury. Furthermore, there was a minimum of two people observing at all times the *gillnet mimic* was in the water to ensure the birds were safe.

The panels were made of 12 mm diameter polyvinyl chloride (PVC) electrical conduit pipe connected with elbow joints at each corner. These panels were presented to the birds in an 8 mm stainless steel frame (Figure 2). The stainless steel frame measured 1160 mm × 1540 mm and was divided into two equal panel areas. The frame was connected to a pulley system that was suspended over the tank. When submerged, the panel occupied 18% of the cross-sectional area of the water column, allowing sufficient space for the penguins to swim around the panels if they chose to do so. The frame was always introduced into the tank with one panel containing a *gillnet mimic*, and the other panel left empty as a control.

The gillnet filament colours used were green, clear and orange. Orange was chosen as other marine vertebrates (e.g. northern right whales, *Eubalaena glacialis*) are able to detect this colour at significantly greater distances than green coloured rope (Kraus et al., 2014). Green and clear materials were selected as they are widely used in gillnet fisheries globally. The three treatment colours were randomly selected for each trial and alternated between the top and bottom panels to account for any preference that the birds may have had in swimming depth or position within the tank. The orange and clear monofilament treatments were trialled eight times; four in the morning and four in the afternoon. The green monofilament treatment was trialled four times, twice in the morning and twice in the afternoon (Table 1). The trials ran for approximately one hour in the morning (0900–1000 hours) and in the afternoon (1430–1530 hours). The experiment ran for three weeks between 17 June and 31 July 2015.

2.2 | Behavioural observations and data analysis

The behaviour of the penguins during the trials was recorded using two GoPro video cameras, one attached to the top of the frame and positioned so as to capture bird interactions with the apparatus, and the other positioned outside the tank, looking through the underwater-viewing window (Figure 1b). Subsequently, recorded treatment

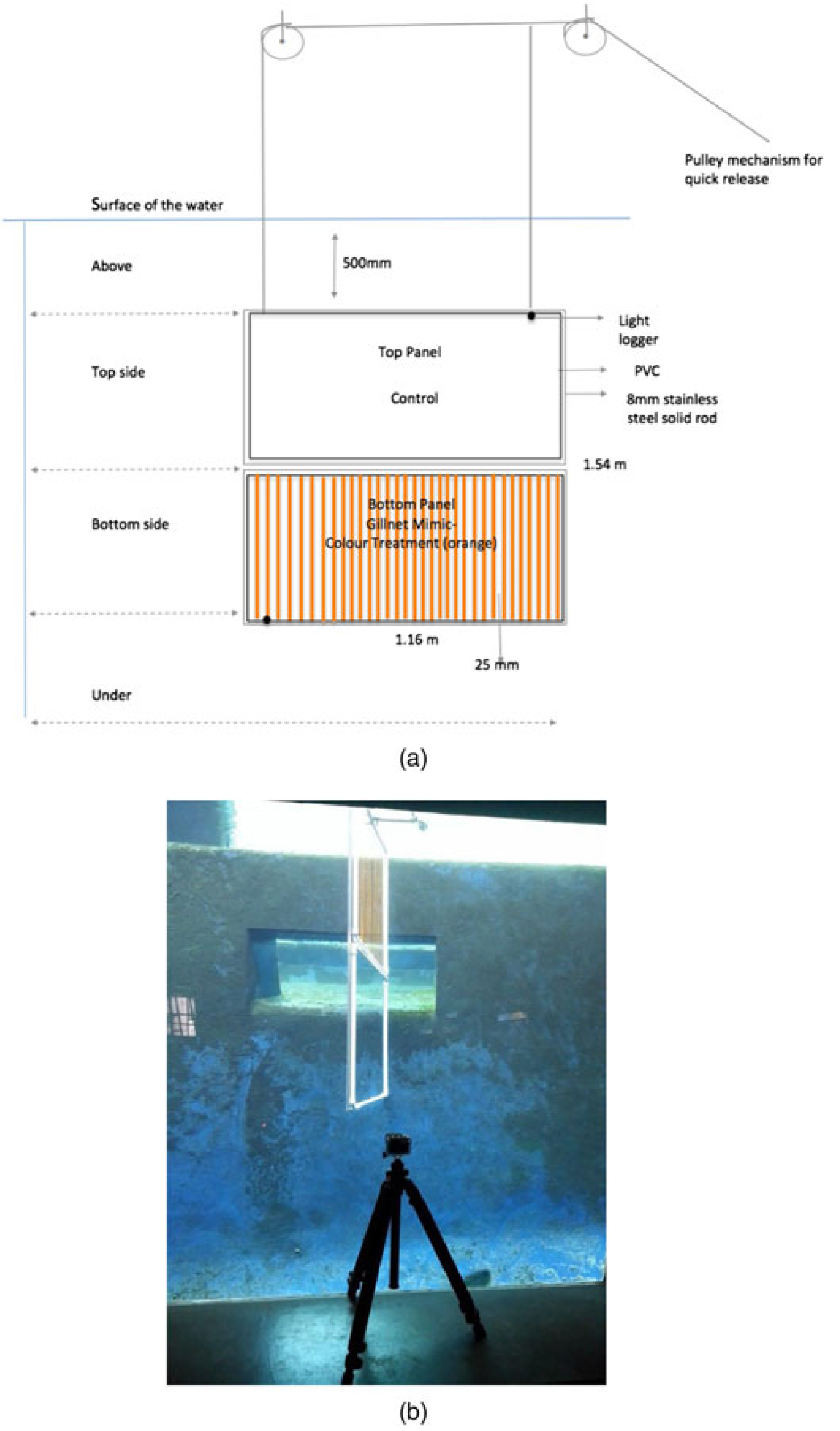

FIGURE 1 **(a)** Diagram of the steel frame holding the gillnet mimic with an orange coloured monofilament treatment in a vertical configuration and the classification of the water column into above, top side, bottom side and under. **(b)** Photo of the experimental frame and gillnet mimic suspended in the tank channel. Also shown is a tripod-mounted GoPro video camera positioned outside the tank, looking through the visitor-viewing window, and a second camera attached to the top of the frame. The top panel contains orange gillnet material, and the bottom panel has no material (control). (photo taken by Madeleine Curotte)

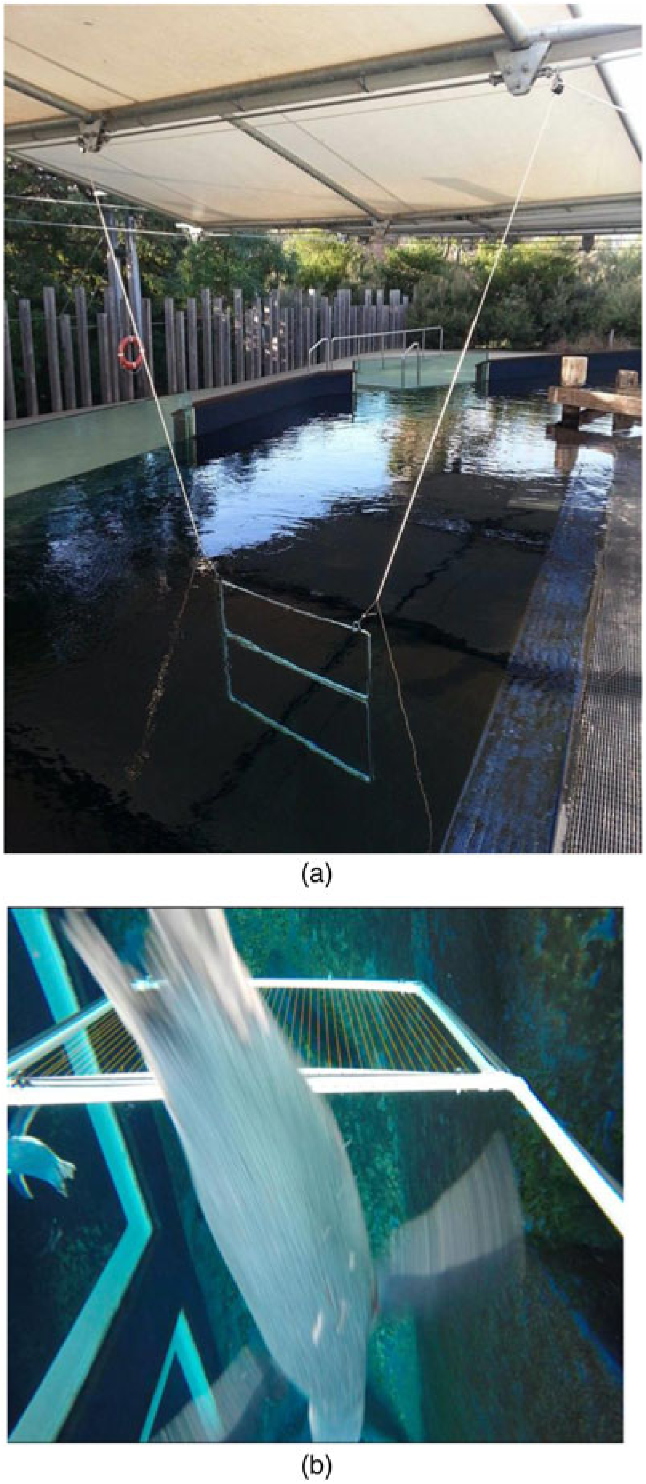

FIGURE 2 **(a)** View of the experimental stainless steel structure and conduit panels with gillnet mimic installed, taken from above and looking down into the water column. **(b)** View of a penguin passing through the empty top panel (control), with an orange treatment mimic fixed in the bottom panel (photo taken using a go-pro camera mounted on the top of the frame)

videos were watched by the same observer (RH) and all interactions with the panel apparatus were categorized and recorded. An interaction was defined as an instance where the bird swam through, around or up to within 30 cm of the apparatus. For each interaction it was recorded whether or not the penguin collided with the *gillnet mimic*. For each trial, the number of birds swimming in the area was recorded, as well as the number and type of interactions (collision or not) with the *gillnet mimic*, the colour in that trial (*colour*), the identity of the individual that collided (*id*), the position of the gillnet mimic in the frame (top or bottom: *position*) and the time of day (*tod*). These were the variables used in the subsequent analysis.

The data were analysed with generalized linear mixed effects models with a binomial family (Bates, Maechler, Bolker, & Walker, 2015), using the *glmer* function for the lme4 package in R (Bates et al., 2015). The binary response variable (the interaction was or was not a collision) and potential explanatory variables used were *colour*, *position*, *tod* and the interaction terms between them. To account for multiple interactions of individual birds within and between trials, individual (*id*) and each trial (*test*) were included as random terms. The analyses were restricted to birds that were in the water during the trials on at least 10 occasions.

All factors in the full model were assessed using the package *AICcmodavg* (Mazerolle, 2015) to assess their relative importance in the model. Factors were retained in the model based on multimodal inferences derived for model averaged parameter estimates along with unconditional errors using Akaike information criterion (AIC) (Pinheiro, Bates, DebRoy, Sarkar, & R Core Team, 2015). All analyses were conducted using R statistical software (R Core Team, 2014) and means reported as ± standard deviation.

3 | RESULTS

Of the 23 penguins which entered the pool during the gillnet trials, only 11 swam often enough (10 or more interactions with the experimental setup) during the three-week experiment period to be included in the analysis. The number of little penguins that swam each day during the treatment periods also varied and therefore, not all little penguins participated in all the treatments equally. There were 290 interactions recorded during the experiment, 54 (18%) of which were collisions. Collisions with the *gillnet mimic* occurred during 16 of the 20 trials (80%), with a mean collision rate per trial of 3.5 ± 4.1 (standard deviation).

Collision rates were much lower when the orange *gillnet mimic* was encountered (5 of 91 encounters, 5.5%) than when penguins encountered clear and green monofilament lines (33 of 92 encounters, 35.9%; and 16 of 52, 30.8%; respectively). These observations were confirmed by our modelling. The best model relating the number of collisions with the *gillnet mimic* and the explanatory variables included *colour* and *position* (Table 2). The orange coloured monofilament lines resulted in lower collision rates in both upper and lower treatment positions, while clear and green monofilament lines resulted in higher rates of collision (Figure 3). This pattern was consistent in both positions, but the number of collisions was lower in the top panel than the bottom panel.

4 | DISCUSSION

This is the first study to experimentally assess, in a captive situation, the effect of net colour as a seabird bycatch mitigation measure in gillnet fishing. The results demonstrated that orange coloured

TABLE 1 Three coloured treatments conducted at different times of day with the number of replicates in the top and bottom treatment positions, with the number of birds in the water at the start of the trial

Treatment	Time of day	Treatment position Top	Treatment position Bottom	Control Position Top	Control Position Bottom	Total number of trials	Birds in the water	Birds included in analysis
Orange	AM	2	2	2	2	8	14	11
	PM	2	2	2	2			
Clear	AM	2	2	2	2	8	15	11
	PM	2	2	2	2			
Green	AM	1	1	1	1	4	14	11
	PM	1	1	1	1			

TABLE 2 Model ranking, based on AICs, of the models relating number of collisions to net colour, net position and time of day. Penguin id and trial were included as random terms

Model	Intercept (fixed term)	Df	Loglik	AICc	Delta AIC
colour + position	−0.041	6	−105.2	222.7	0
tod + colour + position	−0.059	7	−105.2	224.6	1.9
Colour	−0.741	5	−110.5	231.2	8.4
tod + colour	−0.694	6	−110.4	233.2	10.4
Position	−1.018	4	−114.6	237.5	14.8
tod + position	−0.934	5	−114.6	239.4	16.7
Null	−1.606	3	−117.0	240.1	17.4
Tod	−1.380	4	−116.7	241.7	18.9

Tod – time of day (AM or PM), position (top or bottom), colour (clear, green, orange or blank).

monofilament lines resulted in lower collision rates for little penguins compared with clear and green coloured monofilament lines, and suggests that orange-coloured lines were more apparent to the birds. The finding that orange coloured line appears more visible to little penguins was not unexpected, based on recent experimental work which demonstrated that northern right whales were able to perceive red and orange coloured rope mimics from significantly greater distances than green-coloured rope (Kraus et al., 2014).

Orange line was also clearly visible to all observers in both treatment positions (top and bottom), even under low light levels (Hanamseth, 2015). Theoretically, gillnets are visible to diving birds only at close ranges in most foraging conditions (Martin & Crawford, 2015). This study indicates that orange coloured gillnets may be detected from at least a few metres, and are certainly more likely to be seen than clear and green coloured monofilament gillnets. Collision rates were not only higher with the clear and green coloured monofilament lines, but also the little penguins persisted with attempts to swim through the clear and green monofilament lines after collision. These behaviours confirm patterns that for seabird species known to be affected by gillnets, there is a cognitive failure in identifying the danger of a hazard (Martin & Crawford, 2015), and provide some indication of the mechanism that leads to seabird entanglement in gillnets.

The top treatment position had a significantly lower interaction level than the bottom panel. This may be simply because the birds had a preference for swimming lower in the water column within the tank, but no inferences from this observation at this stage were drawn. In practical terms, gillnets vary in dimensions and depths according to the preferred habits of target fish species, and this observation is hard to interpret as to its relevance in mitigating bycatch. However, given light attenuation through the water column (see below), coloured netting material is likely to be more effective in shallow water fisheries than at greater depths. It is also important to consider the characteristic reflective colour of shallower waters in order to enhance the visual acuity and contrast provided by nets being used to seabird species.

Two potentially important factors were not assessed here owing to the limitations of working with the captive population in the experimental setup: (i) environmental conditions such as depth and season, and (ii) the impact of net colour on other marine organisms such as other seabirds, marine mammals, sharks and rays, and target species.

It is vital to understand that light levels in this experimental situation would be very different from the light levels experienced at sea or

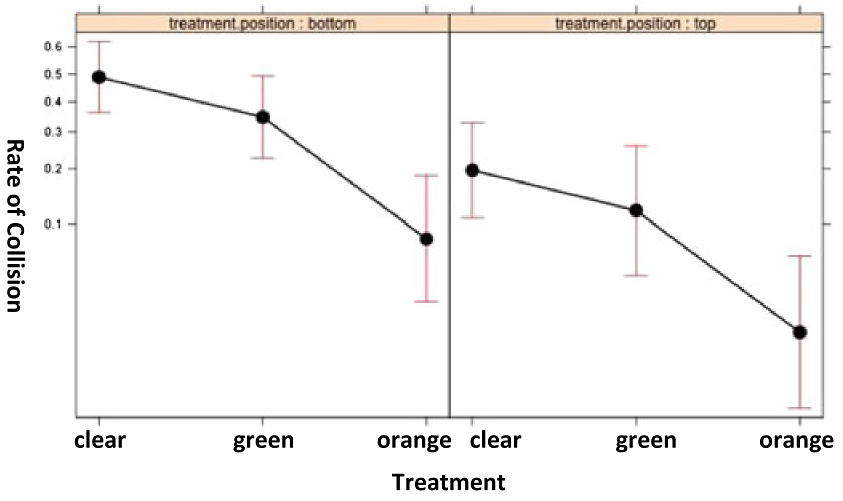

FIGURE 3 The probability of individual birds colliding with the three different coloured gillnet mimics in the bottom and top panel position of the water column. Orange coloured monofilament lines had the lowest collision rates in both treatment positions in the water column, while clear monofilament lines resulted in the highest rate of collision. The top position also had overall lower rates of collision. The red lines representing 0.95 confidence levels based on standard normal distribution

in inland waterways. Light rapidly attenuates with water depth (Lythgoe, 1979). The transmission of light is determined by two physical processes, (i) absorption (the transfer of light energy to matter), and (ii) scatter (the deflection of light from its initial trajectory without any loss of energy), and these processes determine the quality of vision (Lythgoe, 1979). Water is a complex light environment because of suspended particles that scatter light (Lythgoe, 1979). The way in which an object may appear is not only affected by depth, time of day and water quality (e.g. chlorophyll content) but is influenced by its viewing angle (Cocking, Double, Milburn, & Brando, 2008; Johnsen, 2002, 2003; Johnsen & Sosik, 2003). The highest intensity of visible light energy in polar waters is green (500–560 nm) compared with the blue of tropical waters (475 nm) (Dehnhardt, 2002). This affects the perceptive capabilities of freshwater and marine species at any given time, as they not only move between media (air and water) but some species also travel rapidly to depths (Martin & Crawford, 2015) and across the latitudes, especially for several migratory species. Species such as sea turtles and pinnipeds increase the refractive power of their eyes upon entering the aquatic environment. The increase in refractive power leads to consequences such as formation of a brighter image, broader fields and short-sighted vision (causing distant objects to be blurred) (Martin & Crawford, 2015). Therefore, extending the findings of this study to depths below, say 20 m, should be done with extreme caution.

For a mitigation technique to be successful, not only should there be a significant reduction in bycatch but the catch efficiency for target species should not be reduced. While many mitigation and technical measures suggested for reducing bird bycatch have been tested, to date there are no established best practice guidelines for reducing bycatch in gillnet fishing while maintaining target catch and few studies on this topic. An experimental study conducted in a coastal salmon drift gillnet fishery demonstrated varying levels of reduction in bycatch of rhinoceros auklets (*Cerorhinca monocerata*) and common guillemots, depending on the approach being assessed, but the target catch also declined drastically (Melvin et al., 1999). Uptake of measures that reduce target catch are unlikely to be adopted by the fishing industry.

The colour preference experiments have shown that in shallow waters in high light levels, seabirds are able to identify fine colour differences. Martin and Crawford (2015) comment that in high light levels gillnet bycatch bird species are able to make fine colour discriminations throughout the visible spectrum between 400 nm and 650 nm. Therefore, further testing of these colours under experimental conditions is recommended, together with testing of black and white patterned panels (Martin & Crawford, 2015), accompanied with at-sea trials to verify effectiveness in varied light conditions. In addition, further studies should also assess the effect of gillnet colour on catch efficiency on target species within an active working fishing industry (Melvin et al., 1999).

ACKNOWLEDGEMENTS

This project was supported by a grant from the Agreement on the Conservation of Albatrosses and Petrels (ACAP), facilitated through the Australian Antarctic Division. This project was approved by the University of Tasmania Animals Ethics Committee (permit number: A14802) and the Zoos Victoria Animal Ethics Committee (Permit Number: ZV15007). We thank Zoo's Victoria for access to their facilities and the constant support provided by their staff; David Faloon at IMAS, University of Tasmania for assisting in the experiment design, the School of Chemistry, University of Tasmania, for use of their laboratory, and to two referees for providing comments that improved the manuscript. Special thanks to all the volunteers that assisted in the fieldwork, and to John Baxter for managing the editorial process.

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How to cite this article: Hanamseth R, Barry Baker G, Sherwen S, Hindell M, Lea M-A. Assessing the importance of net colour as a seabird bycatch mitigation measure in gillnet fishing. *Aquatic Conserv: Mar Freshw Ecosyst*. 2017;1-7. https://doi.org/10.1002/aqc.2805