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SUMMARY

Petrels and shearwaters are known to have an extra-ordinary ability to dive while seeking food - shearwaters for example are capable of diving to the astonishing depth of over 65m. This project aims to document the diving and feeding behaviour of petrels and shearwaters in response to fishing baits to inform future development of methods of reducing seabird by-catch. As fishing baits can attract seabirds, there is a significant risk of fatal interactions between seabirds and commercial and recreational fishing activities. Black petrel *Procellaria parkinsoni* and flesh-footed shearwater *Ardenna carneipes* have been identified as being at high risk from commercial fisheries in New Zealand waters, particularly longline fisheries that target snapper and bluenose, in addition to interactions with other commercial fisheries and recreational fishers. This threat is most pronounced during their breeding season (ie. September-April) as these species migrate out of New Zealand waters during winter. Other species were also observed during this study, notably Buller's shearwater (*A. bulleri*) and fluttering shearwater (*Puffinus gavia*). We present distinctions in the bait preference and diving behaviour of black petrels and flesh-footed shearwaters towards baited experiments.

INTRODUCTION

Petrels and shearwaters have an extremely well-developed ability to find and investigate potential prey sources at sea. It is how they survive, find their food and raise their chicks. Foraging at sea is how species are sustained. Some petrel and shearwater species are attracted to fishing vessels, and within that group, some more than others.

Baits and the smell of fish are attractive to seabirds. These birds can dive in pursuit of prey and sinking baits on hooks on lines are just another potential food source. As a result, birds can become hooked, resulting in injury and or death. Some birds also get entangled in lines and drown.

The black petrel [1], has been identified as the 'most at risk' seabird in New Zealand from commercial fisheries in all three risk assessments undertaken since 2011 (Richard et al 2011; Richard and Abraham 2013). The flesh-footed shearwater [2] has ranged from 6th, to 3rd to 4th 'most at risk' in these three assessments. With both these species most fatalities occurred in bottom-longline fisheries targeting snapper and bluenose as well as some trawl and surface longline fisheries. These captures were during the breeding season, as both these species migrate out of New Zealand waters during winter; black petrels to the eastern Pacific and flesh-footed shearwaters to the North Pacific Ocean.

Abraham et al (2010) showed that interactions between recreational fishers and seabirds are commonplace, with nearly half of the fishers interviewed during the study having witnessed a seabird being hooked or tangled at some stage in the past. In many cases, fishers' comments indicate that birds were caught while chasing bait, e.g., "*bird chased bait as line going down*", "*dived after bait was cast & tangled in line*", "*line in water sinking down. Bird seemed to come out of nowhere and chased bait under water, getting caught in the process*". The species caught by recreational fishers included petrels, albatrosses, gannets, gulls, terns and shags. From personal observations (CG, JR) and this study flesh-footed shearwater, Buller's shearwater (*Ardenna bulleri*), sooty shearwater (*A. griseus*), short-tailed shearwater (*A. tenuirostris*) and fluttering shearwater (*Puffinus gavia*) can pursue baits aggressively while line-fishing from a boat in northern New Zealand waters.

Some seabirds have developed specialized sensory mechanisms that allow them to find productive areas, detect prey through the air-water boundary of the ocean surface, and then see amphibiously during extensive underwater foraging. For petrels, shearwaters and other Procellariiformes, locating foraging areas from distances likely incorporates olfactory cues (Nevitt et al. 1995, Nevitt 2000). Having large olfactory bulb to brain size ratios, many Procellariiformes also use smells to locate burrows, mates, and colonies (Bonadonna & Bretagnolle 2002; De León, Mínguez & Belliure 2003; Mardon & Bonadonna 2009). In addition to excellent olfactory sensing, seabirds that catch prey amphibiously have evolved highly specialized visual anatomy for locating and catching prey underwater. Albatross and penguin species have flattened cone cells that allow for a low absolute refraction and exhibit bill

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[1] Black petrel Nationally Vulnerable (NZTCS), Vulnerable (IUCN Red List)
[2] Flesh-footed shearwater Nationally Vulnerable (NZTCS), Least Concern (IUCN Red List)

positioning; allowing for perception and guidance underwater (Martin & Brooke 1991, Martin 1998, 1999). These traits are specific to amphibious foraging. In a comparative study of white-chinned petrels (*Procellaria aequinoctialis*, an amphibious foraging species), and Antarctic prions (*Pachyptila desolata*, a surface foraging species), it was found that white-chinned petrels have a visual system like that found in penguins and albatross while the Antarctic prion did not exhibit the visual adaptations for foraging underwater (Martin & Prince 2001). The colour spectrum visible to wedge-tailed shearwaters (*Ardenna pacifica*), and likely other seabird species, is also beneficial for seeing prey underwater (Hart 2004). These visual adaptations for amphibious foraging are also reflected in the ecology of many seabird species showing high catch rates during foraging bouts vs. plunge dives (Machovsky-Capuska et al. 2012), and lower activity of foraging at night in some species (Phalan et al. 2007). These specialized senses for locating prey make seabirds particularly vulnerable to interactions with fishing vessels and apparatuses.

Seabirds are endothermic animals that are active in the air and on land, while being equally adept at foraging under the constraints of the ocean. Rapid changes in environmental forces indicate extreme adaptations for changes in pressure, oxygen availability, and metabolic rate (Boyd & Croxall 1996). The physiological ability of seabirds to forage while diving has been shown to be even greater than pinnipeds, when accounting for body size (Boyd & Croxall 1996). While studies have shown that seabirds are able to exceed modelled aerobic dive limits in a large percentage of foraging trips, the processes that allow for these foraging conditions remain unknown (Croll et al. 1992). A recent study comparing the diving effort of grey-faced petrels (*Pterodroma gouldi*), common diving petrels (*Pelecanoides urinatrix urinatrix*) and sooty shearwaters (*Puffinus griseus*), indicate that species that forage at greater depths (in this case, sooty shearwaters) have higher red blood cell and haematorcrit counts, showing evidence for key adaptations in amphibiously foraging in birds (Dunphy et al. 2015). Seabirds have evolved intricate sensory and physiological mechanisms for hunting prey underwater and the effectiveness of these traits is exemplified in their capacity for diving.

The diving capabilities of petrels and shearwaters, in particular the latter, have been well documented with shearwaters capable of diving to astonishing depths. Rayner *et al* (2011) showed that diving activity for flesh-footed shearwaters while on migration during non-breeding were shallower than those recorded during early stages of breeding (2.35 m vs 4.81 m). The maximum dive depth, recorded during the early breeding season, (66.5 m) was similar to that of other shearwaters including the sooty shearwater (breeding: 69.9 m, Shaffer et al. (2009); non-breeding: 68.2 m, Shaffer et al. (2006)), and wedge-tailed shearwater (breeding: 66.0 m, Schreiber & Burger (2001)), indicating a possible biological threshold for diving depth in shearwaters.

During the 2013/2014 breeding season Bell *et al* (2013) found that 80% of black petrel dives were shallow (<5 m) and this pattern was similar for males and females. In this study the deepest dive (-34.3 m) was by a female. In a previous study (Bell *et al* 2013) black petrels were found to dive mostly during the day (93.2%) and over 80% of the dives were shallow (<5 m) and this pattern was similar for males and females. The deepest dive in this earlier study was -27.4 m by a male.

Whether any of these recorded dives were during interactions with fisheries is not known, however black petrels and shearwaters are regularly seen foraging, feeding and diving for natural food (ie. no fishing activity present). This includes feeding in association with fish schools and following feeding cetaceans (e.g. with pseudo orca and bottle-nosed dolphins (RR, pers. obs.)).

Pierre and Goad (2013) note that the characteristics of surface longline gear that exacerbate the risk of seabird by-catch include relatively slow-sinking hooks, which remain within reach of seabirds for significant periods, the use of baits attractive to birds, long snoods, and the very long lengths of lines that are deployed with hooks attached. It should be noted that birds are also caught on the haul. Also, despite the existence of a number of measures to reduce by-catch in surface longline fisheries, on-going captures in these fisheries demonstrate that the available measures do not preclude the existence of significant by-catch risk (Richard et al. 2013, Pierre & Goad 2013).

For recreational boats anchored in no current, weighted baits will drop close to boats. However, for a drifting or anchored boat with a current flowing (ie. water flowing in relation to the stationary boat) baits will descend away from the vessel. Casting is a popular fishing method especially on a crowded back deck. Baits cast are visible to birds in the air before the reach the water and as they descend through the water column. All these situations have been considered for these experiments. Trolling baited lines or lures behind a moving boat is another category which we placed outside this study.

In the two trials undertaken 31 March and 4 April 2016 we showed that the use of a multi-frame camera apparatus and diver with camera is effective in better understanding the behaviour of petrels and shearwater in interactions with bait and fishing lines. Quantitative experiments were designed and conducted for the current study, based on the success of these initial trials.

PROJECT OBJECTIVES

Here, we combine the use of different bait types and bait depths to answer questions:
1) Are seabird species more attracted to certain types of bait?
2) Do seabird species have different abilities or tendencies to obtain prey at different depths?

METHODS

Sites

This study was carried out in the Hauraki Gulf, New Zealand from November 26, 2016 to March 6, 2017. Experiments were done aboard the *Waimania* on days when weather conditions were safe and visibility of experimental interactions would not be hindered. Sites included NW Reef, Horn Rock, and north of Little Barrier Island. Once at the site, salmon berley was used to attract birds in for participation in experimental treatments.

Experiments

Experimental treatments were used to quantify diving behaviour and propensity of species to dive to particular baits. Specifically, we combined types of bait (fish, squid, or control) at depths (2m, 5m, 10m, and casting bait). Alligator clips replaced hooks to secure baits to the lines. The combination of these treatments created a set of 12 possible experiments that were exposed to seabirds in the Hauraki Gulf (Table 1). Experiments lasted for 5 minute intervals and were randomly selected using numbers associated with each treatment in a bag. During each experiment a scientist recorded the animal behaviour, and success rate of seabird's interaction with the treatments. Additionally, an underwater camera rig using six GoPro Hero+ mounted and angled to record recorded approximately 180° horizontal and 120° vertical with overlap between the cameras. Video footage of the birds interacting with baits underwater to provide further insight into the foraging behaviour of seabirds and their interactions with baits. Experimental variables were analyzed using a nominal logistic regression (JMP 13.0.0, SAS Inst.)

Table 1. Randomly assigned experimental treatments.

Bait	Depth
Fish	2m
Fish	5m
Fish	10m
Fish	Cast
Squid	2m
Squid	5m
Squid	10m
Squid	Cast
Control	2m
Control	5m
Control	10m
Control	Cast

Table 2. Data recorded during each experiment.

Date	Date of trial
Site	Site name
Exp. #	Number of experiments at the site
Bait Type	Pilchard or squid
Depth	2 m or 5m or 10 m or Cast
Species	Seabird species 4 letter code
Dive behaviour	Flying dive, surface seizure, surface sighting, duck dive, short dive, prolonged dive, other
Success	Prey captured (if obvious)

RESULTS

Seabird species attracted to salmon berley included; white-faced storm petrels (*Pelagodroma marina*), NZ storm petrels (*Fregetta maoriana*), fairy prions (*Pachyptila turtur*), black petrels, fluttering shearwaters, flesh-footed shearwaters, Buller's shearwaters, and red-billed gulls (*Larus scopulinus*). Of these species, black petrels and flesh-footed shearwaters were primarily attracted to experimental baits (with very occasional interactions by Buller's shearwaters, fluttering shearwaters, fairy prions and red-billed gulls). Analysis of experiments focused on the two former species as being most likely to interact with fishing apparatus and with baits.

The results of a nominal logistic regression, using species as a y-intercept, show species-specific trends in how target species, black petrels and flesh-footed shearwaters, interact with both bait types (p<0.001), and behaviour (p<0.001), but not with the depth at which they would interact with baits (p=0.698, Table 3). In spite of depth being statistically insignificant factor in this study, further trials may show preferences for shallower depths based on our observed results (Fig. 3)

Table 3. Results of a nominal logistic regression testing the distinction of species, black petrel or flesh-footed shearwater, in determining the interaction with different bait types at different depths, and behaviours.

Attribute	N parm	DF	ChiSquare	Prob>Chisq
Bait Type	3	3	34.25	<0.001
Depth	3	3	1.43	0.698
Behaviour	6	6	26.6	<0.001

Flesh-footed shearwaters and black petrels indicated a divergence in their preference for experimental bait types. Black petrels interacted with treatments where squid baits were used more than fish, while flesh-footed shearwaters more commonly interacted with fish baits (Fig. 1). While individual birds could not be identified, patterns of bait preference are shown throughout the experimental trials indicating that preferences are not from one individual (Table 4). In spite of this result, a larger experimental sample size would indicate the substantiality of this trend over time and with a greater number of birds.

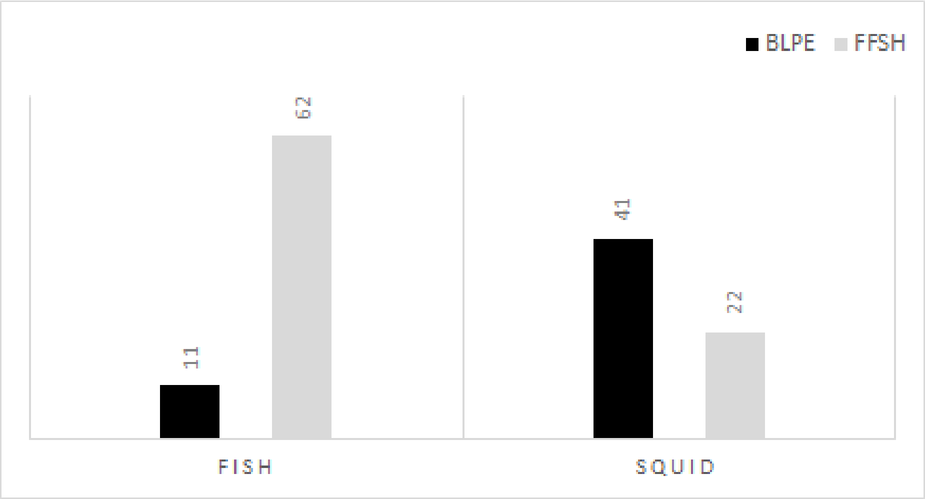
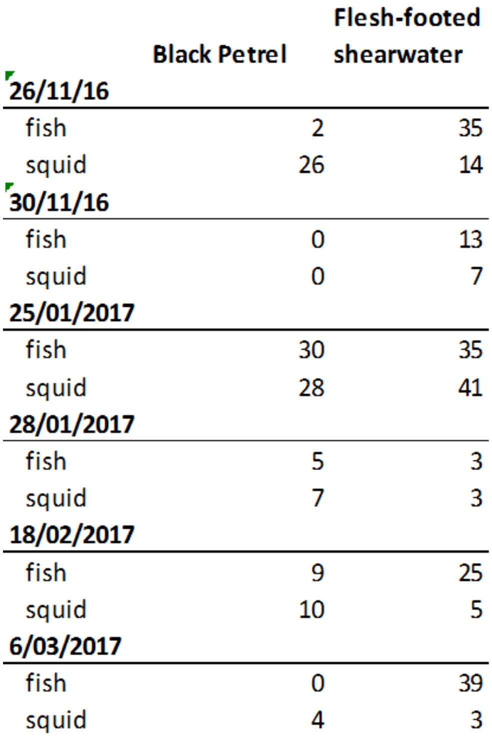


Figure 1. Black petrels (BLPE) more commonly interacted with baits on line that were squid, and flesh-footed shearwaters (FFSH), more commonly interacted with fish.

Table 4. Bait captures from line, cast, and thrown baits on successful experimental trial dates, indicating species-specific bait preference patterns.



	Black Petrel	Flesh-footed shearwater
26/11/16		
fish	2	35
squid	26	14
30/11/16		
fish	0	13
squid	0	7
25/01/2017		
fish	30	35
squid	28	41
28/01/2017		
fish	5	3
squid	7	3
18/02/2017		
fish	9	25
squid	10	5
6/03/2017		
fish	0	39
squid	4	3

Observed behaviour

Dive behaviour of seabirds has rarely been seen or investigated first hand. We found several prominent foraging behaviours, particularly as black petrels and flesh-footed shearwaters interacted with experiments of recreational fishing apparatus. The behaviours observed included; short dives, prolonged dives, fly dives, duck dives, and surface seizes (Fig. 2).

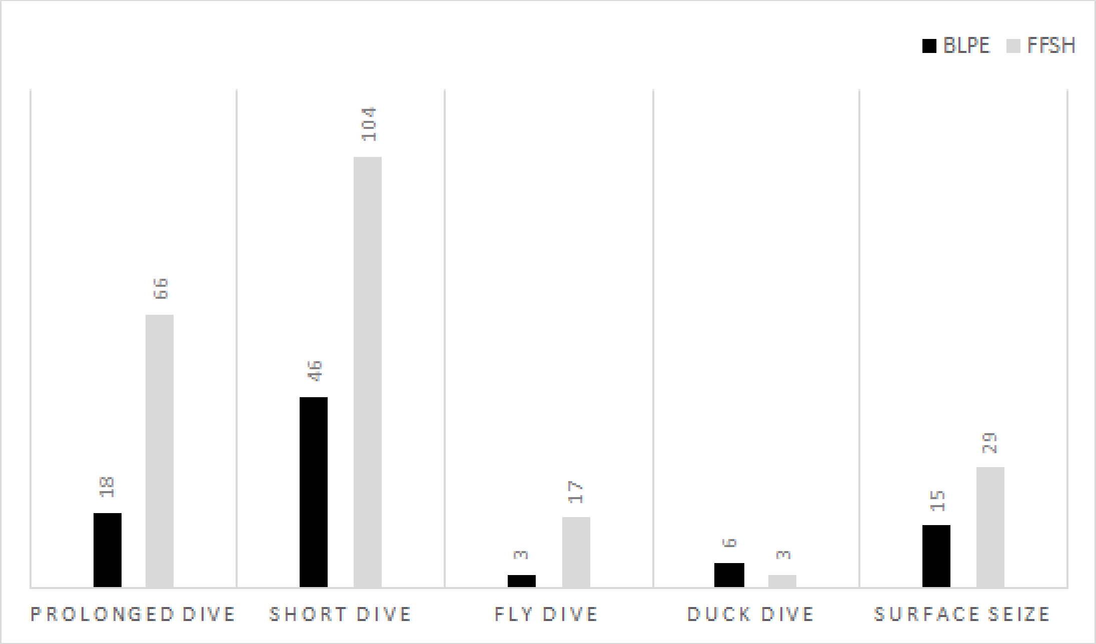


Figure 2. The observed foraging behaviour of black petrels (BLPE) and flesh-footed shearwaters (FFSH).

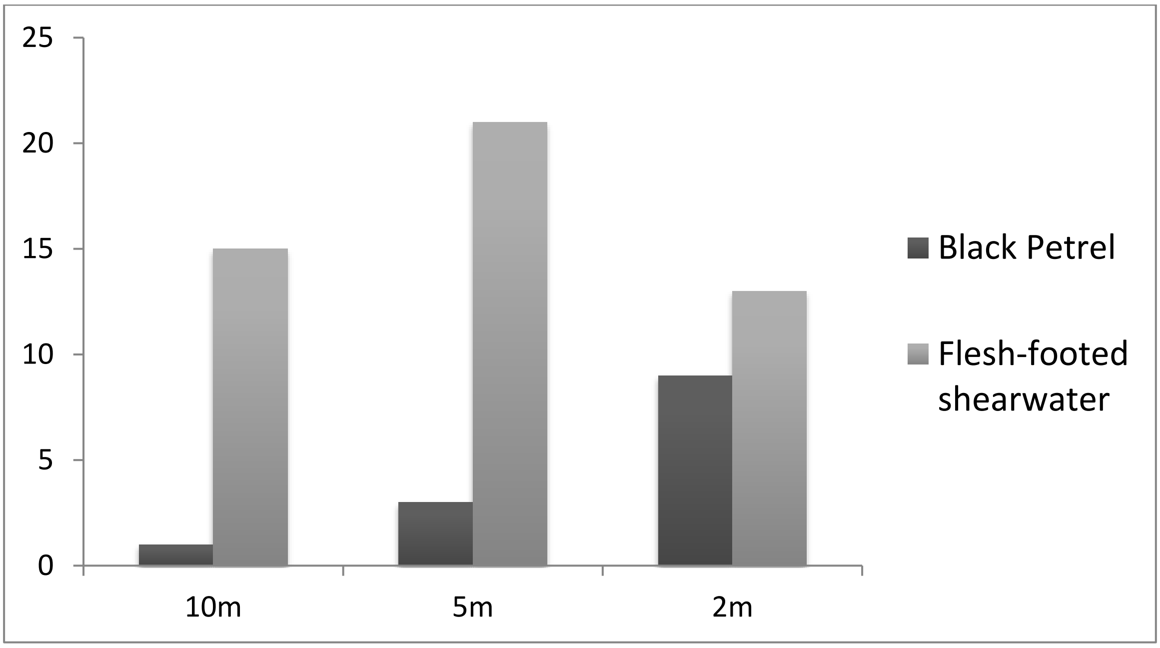
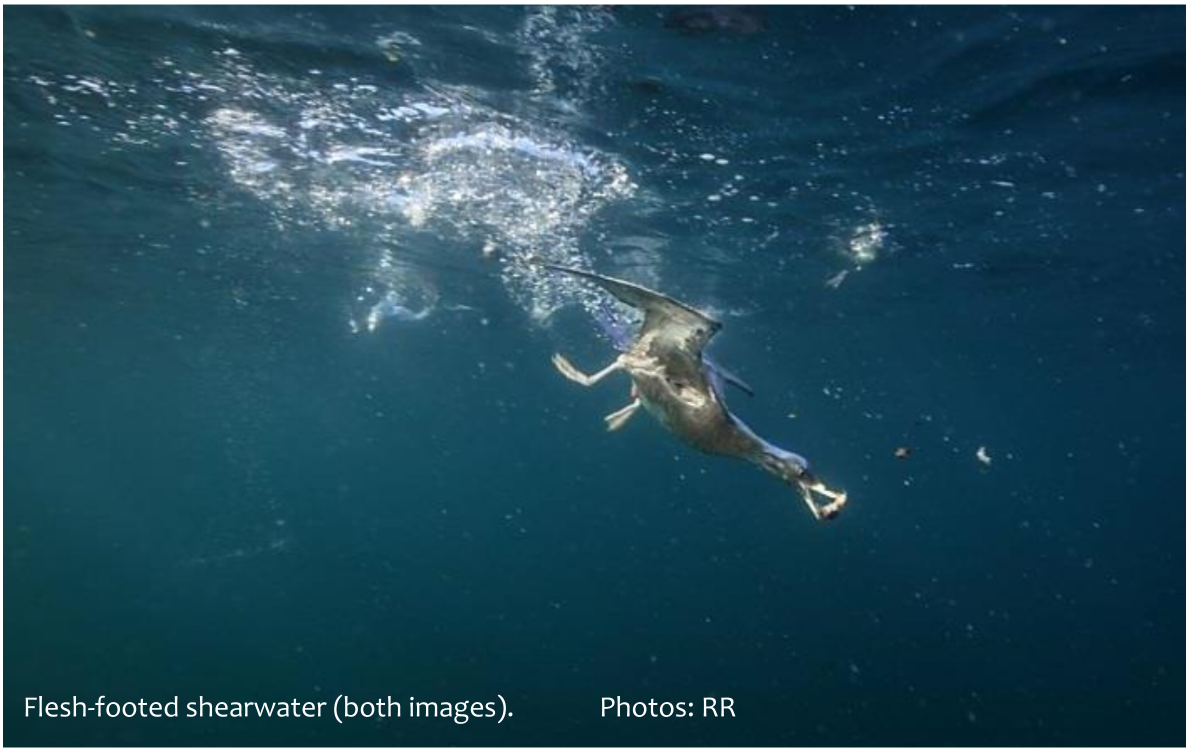


Figure 3. The number of dive behaviour to a bait on a line at depths of 10m, 5m , and 2m by black petrels (black) and flesh-footed shearwaters (grey).

Feeding strategies for petrels and shearwaters observed during study

1 Flying dive

Bird sees bait below the surface from the air and either plunges smoothly through the water's surface with barely a splash or 'belly-flops' and continues 'flying' (ie. swimming) underwater to investigate the bait (ie. no alighting on the surface).



Flesh-footed shearwater (both images). Photos: RR

2 Surface seizing

Bird on surface snatching food from just underwater.

Black petrel. Photo: RR

3 Surface sighting

Bird on surface peering underwater while swimming, searching for food underwater

Fluttering shearwater. Photo: RR

Flesh-footed shearwater. Photo: RR

Black petrel. Photo: RR

4 Duck dive

Upended grab below the surface with bird head and shoulders underwater and wings part-opened.

Black petrel. Photo: RR

Flesh-footed shearwater. Photo: RR

5 Short dives

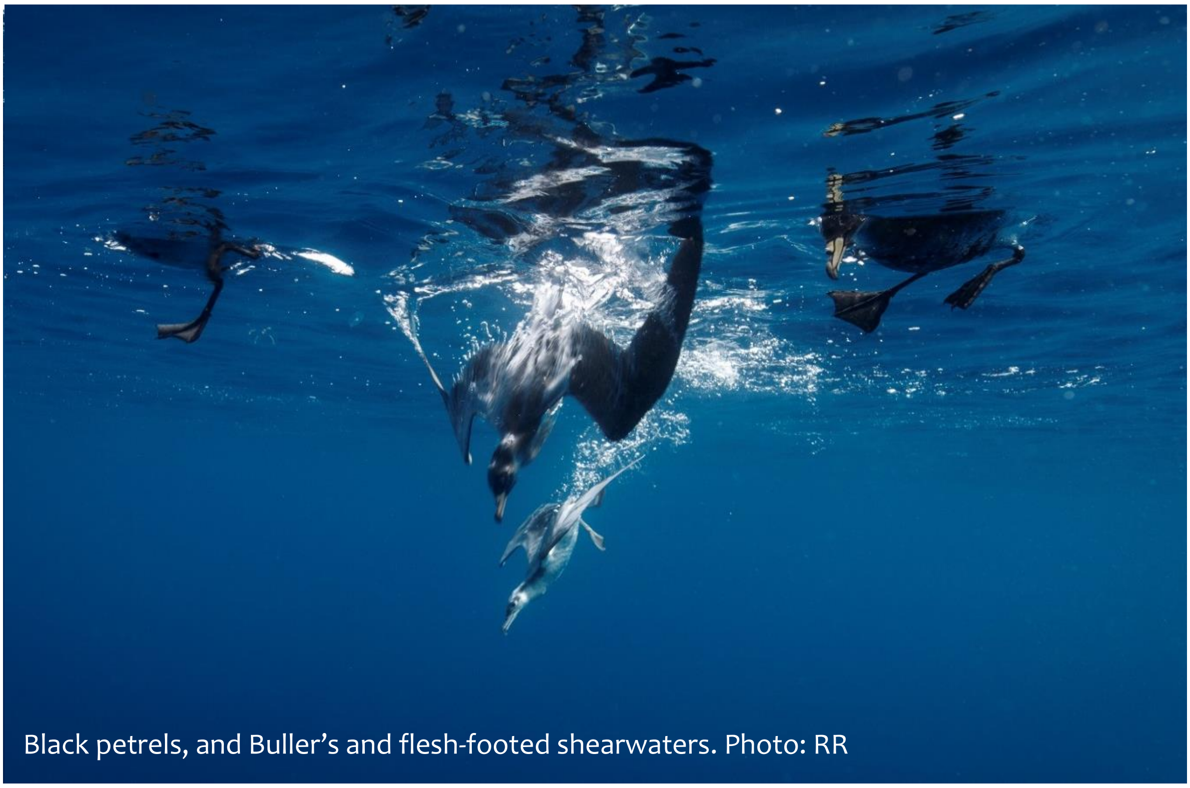
Whole body disappears briefly to retrieve food and return to surface with it, also in response to sighting bait underwater.

Black petrel. Photo: RR

Black petrel. Photo: RR

6 Prolonged foraging dive

Bird dives deep up to 15m sometimes going straight to bait or searching for baits, often changing direction, at times sharply. Bird may swallow bait underwater if small enough and continue foraging



Black petrels, and Buller’s and flesh-footed shearwaters. Photo: RR

Black petrel and flesh-footed shearwaters. Photo: RR

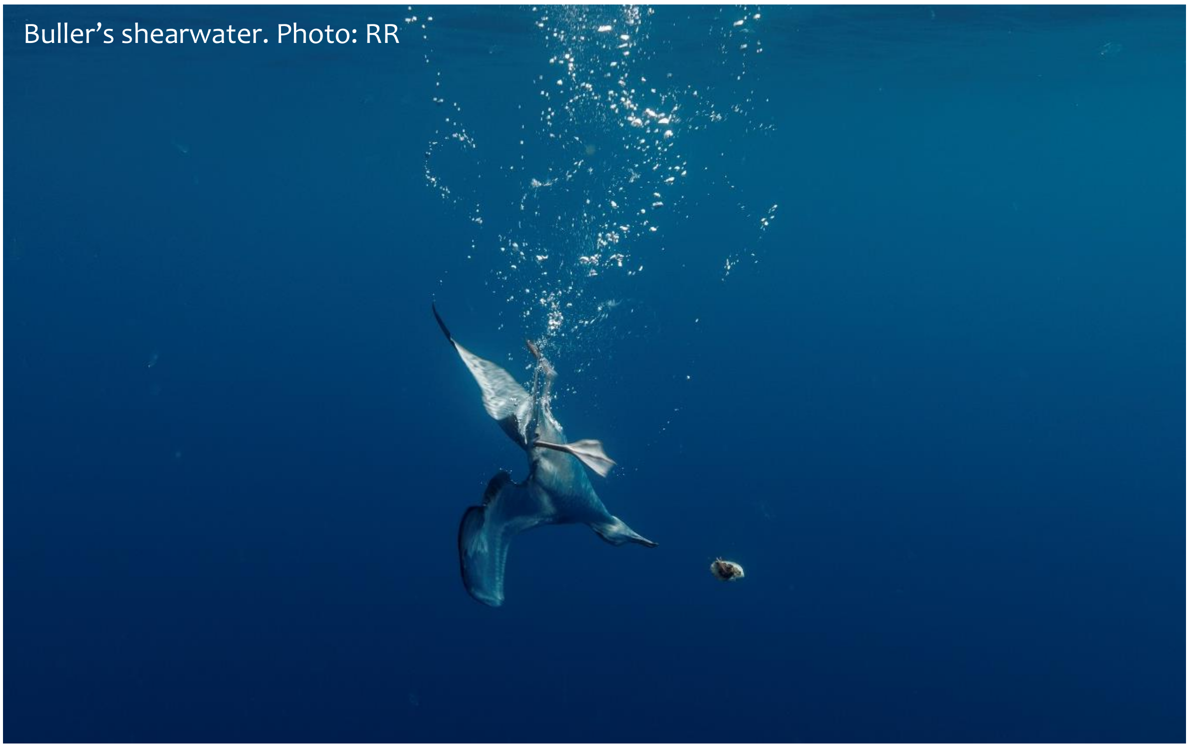
Buller’s and flesh-footed shearwaters. Photo: RR

Black petrel. Photo: RR

7 Manoeuvrability underwater

Underwater birds were seen to investigate baits and on a good number of occasions reject them. The behaviour was observed mostly with fluttering shearwaters. The impression gained was that flesh-footed shearwaters were very much grab first, then either reject or take to the surface to eat. In contrast to the fluttering shearwaters which appeared to be much more ‘discerning’. Birds were also highly manoeuvrable underwater and capable of changing direction with ease; but it was the extreme agility of the fluttering shearwaters which impressed most.

Flesh-footed shearwater. Photo: RR



Buller’s shearwater. Photo: RR

Fluttering shearwater. Photo: RR

Fluttering shearwater. Photo: RR

8 Anticipation and response

Birds on the water around the boat were observed to watch activity on the back deck very closely, anticipating actions such as throwing baits and cast lines, and, would, in response, move very quickly to where the bait landed and, if other birds were close by, very agressively.

Fluttering shearwater. Photo: Karen Baird

Black petrel. Photo: RR

9 Aggressive behaviour and competition

Birds competing over baits – above and below the surface.

Black petrels. Photo: RR

Includes competition with other taxa!

Flesh-footed shearwater and mako shark. Photo: RR

10 Kleptoparasitic interactions

Intraspecific competition (flesh-footed shearwater on flesh-footed shearwater) or interspecific competition (flesh-footed shearwater on black petrel, occasionally black petrel on flesh-footed shearwater, also black-backed gull and Arctic skua on flesh-footed, Buller's and fluttering shearwaters).

11 Responding to olfactory and visual cues

Black petrels and flesh-footed shearwaters were attracted to berley rapidly even when not in the human line of sight of the boat. This behaviour is indicative of their highly specialized olfactory foraging capabilities and their rapid and powerful flying ability. The visual acuity, both long-distance and in close vicinity, is seemingly very good, but more research is required for these species.

DISCUSSION

Foraging behaviour of seabirds - Sensory

Seabirds have evolved specialized sensory modes that enable them to forage on the seemingly featureless open ocean. These adaptations, including smell for broad-scale foraging and highly specialized visual morphology, mean that seabirds are also able to identify areas of fishing rapidly and with ease. Our experiments show that birds are highly attracted to the odour cue of berley from vessels. Additionally, black petrels and flesh-footed shearwaters are able to identify baits at depth and choose to take baits from a line given bait preferences.

The physiology of Procellariiformes enables them to dive to great depths (Dunphy et al. 2015). In spite of these capabilities, our results show that both black petrels and flesh-footed shearwaters were similar in their willingness to dive to a depth of 10m. This result is aligned with research showing that black petrels tend to participate in shallow dives (Bell et al. 2013; Rayner *et al.* 2011). To maximise the efficacy of seabird mitigation it is therefore important that baited hooks are protected from seabird access to a depth of at least 10m after setting. Additionally, our results show that black petrels are significantly more inclined to forage using the 'duck dive' behaviour where the entire body is not submerged under the surface of the water (although the sample size for this behaviour was relatively small).

Our understanding of both the sensory mechanisms and physiology involved in seabird foraging is still scant, these experiments regarding black petrel and flesh-footed shearwater behaviour around baits indicate their ability to locate baits and the range in which they will readily choose to dive for baits. Further research in foraging sensory cues, physiology, and intra- and inter taxa communication around foraging hot-spots and fishing vessels would greatly improve our ability to mitigate against interactions with fisheries.

Our experiments show a bait preference that black petrels have for squid and flesh-footed shearwaters for fish, although further testing is recommended. This exciting result could inform mitigation practices to reduce interest of species to baits, were it shown to hold true. Any preference for squid bait by black petrels also raises further questions about their foraging patterns and their interest in baits at night (when squid are available naturally). Further experimentation with a larger number of trials using different bait types, and at night, would provide important information regarding night-setting and the foraging ecology of black petrels. A caveat on this preference for squid bait, is that black petrels are highly attracted to feeding cetaceans. This behaviour has been observed with mixed pods of false killer whales (*Pseudorca crassidens*), bottlenose dolphins (*Tursiops trunchatus*) and long-finned pilot whales (*Globicephala meias*). Black petrels dominate this feeding association with large groups of sometimes 100+ birds following pods (especially mixed pods of false killer whales and bottlenose dolphins). The birds will feed aggressively on fish scraps brought to or close to the surface by the whales' feeding. However, the deeper diving pilot whales bring pieces of squid to the surface which can be then scavenged by seabirds (Gaskin et al 2017).

While the experiments done here show relevance for recreational fishing (e.g. casting baits from a stationary or drifting boat), the behaviours observed are applicable to both commercial and recreational fishing. However, further questions arise from commercial vessels that have not been investigated. For example, how species respond to longline setting from different areas of the boat, using different baits, and species-specific behaviours around commercial fishing apparatus. Quantitatively testing the behaviour of Procellariiformes around commercial vessels is an essential next step towards improving mitigation measures for black petrels and flesh-footed shearwaters from fishing activity.

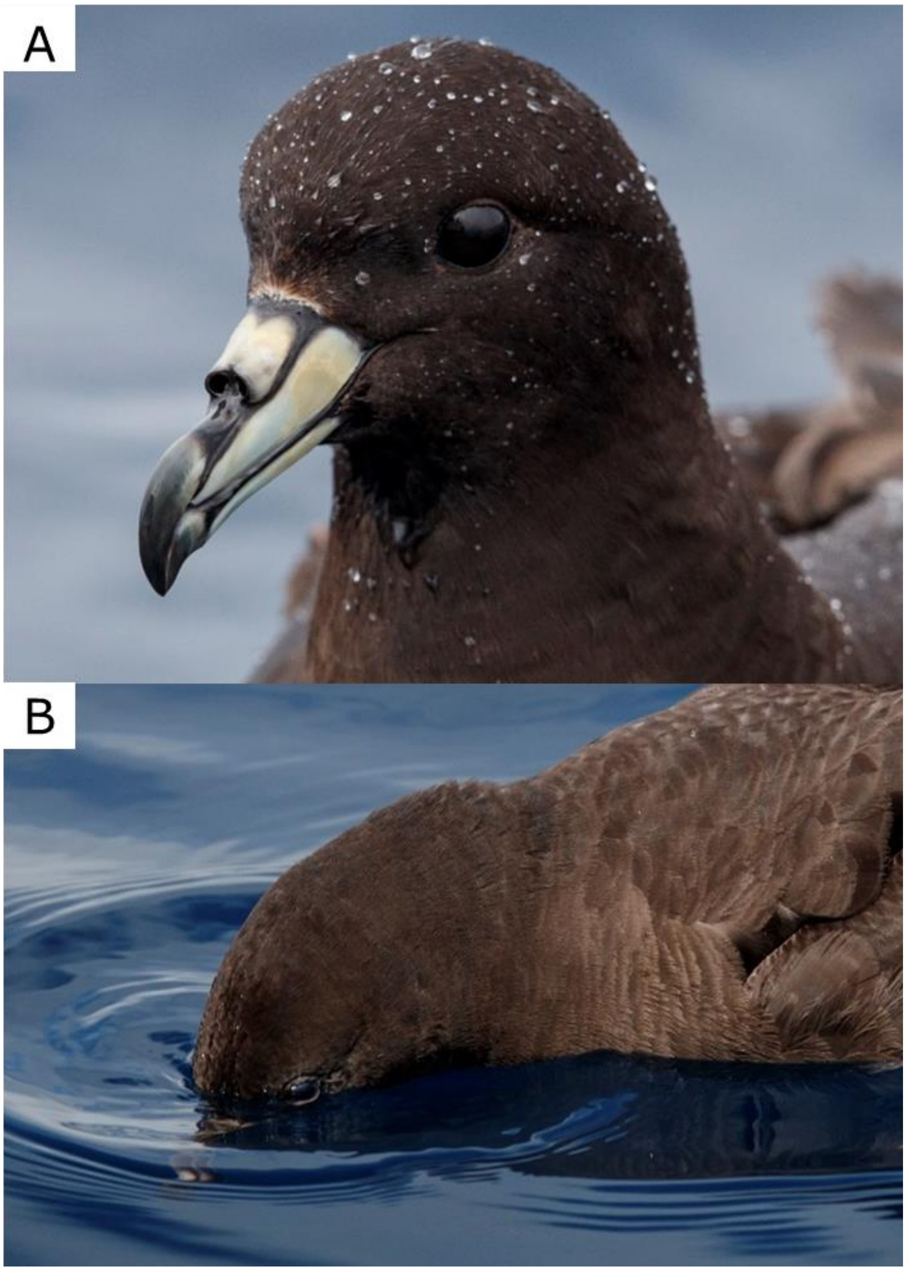


Figure 3. Our experiments show evidence for Procellariiformes being attracted to vessels through smell to berley (broad-scale location), and seizing baits under water through evolved visual systems.

Observed behaviour, primarily through the videos and RR's underwater photographs, highlight these birds' remarkable manoeuvrability underwater and the need to improve our understanding of their diving physiology. For example, their use of wings to 'fly' through the water, use of their large webbed feet in addition to their wings for propulsion are avenues of seabird diving biology that require further research. Additionally, the role the oiled feathers play in creating a layer over the body under water and the extent of compression on their plumage and bodies as they dive deeper are further avenues of diving physiology that could be investigated.

In addition to research of the physiology and sensory mechanisms that enable Procellariiformes to locate prey and forage underwater, the issue of seabird bycatch continues to be a hallmark of current marine conservation biology. Our experiments this year highlighted areas where the sensory adaptations and mitigation techniques can be further tested. Some areas of fishing practice require further, quantitative, experimentation to be broadly recommended. For example, experiments testing the use of barbless hooks could greatly facilitate the release of hooked seabirds and minimise handling and stress. We observed in birds around fishing vessel a shyness towards fishing lines and indicates highly adaptive visual acuity that could be exploited by experimenting with highly visible lines. This may also assist with preventing birds hitting and becoming entangled in lines.

The perception and attractiveness of baits under water is another area that requires experimentation. Our results showing that black petrels preferentially choose bait types indicates the ability to use baits that they may be less inclined to take. For example, whether seabirds would be attracted to soft baits needs to be tested. The large-scale use of artificial baits over natural baits may, however, have other conservation implications regarding plastic pollution and consumption

CONSERVATION RECOMMENDATIONS

1) Baits should be weighted. Floating or slow-sinking baits are easily taken up by seabirds and could result in hooking or tangling of the bird.

2) Baits should be rapidly sunk, and be protected from seabirds by adequate mitigation measures, to a depth of at least 10m.

3) Baits should be lowered into the water close to fishing vessels. Seabirds rarely forage under or very close to the stern of a boat especially where there is wave action.

4) Baits should never be cast when seabirds are in the vicinity even with weights.

5) Seabirds are attracted to berley or fish discards at or near the surface of the water from fishing vessels. The ability of seabirds to detect potential food sources through smell over long-distances has been well-documented. Seabirds clearly recognise boats as a potential source of food and as such the risks to seabirds from interactions with recreational fishing are real and continuous. Any discharge from vessels whilst fishing gear is being set or in the water should be eliminated or minimized to reduce the number of birds being attracted and put at risk of bycatch.

6) Where large numbers of seabirds are present, aggression and competition for baits within and between species may make *any* fishing un-safe for birds. In such instances the best course of action is to move.

7) Baits should be retrieved as quickly as possible.

8) Throwing bait scraps or 'used' baits over-board for disposal only serves to encourage the birds to chase them, which when there are numbers around, do so aggressively.

Conclusion

The results of this study quantitatively show bait preferences for flesh-footed shearwaters and black petrels, and diving behaviour, for seizing baits attached to lines. Additionally, we provide further evidence to the specialization of Procellariiformes (particularly) for locating vessels using smell (from berley) and highly adapted underwater sight (enabling bait choice at depth). From these experiments, we have outlined nine conservation recommendations related to our results, and video observations of the behaviour of seabirds around baits and vessels. We propose further research to clarify these preferences in baits and diving depths, and exhibit the behaviour of seabirds around commercial fishing vessels and their unique sensory and physiology mechanisms that enable them to readily locate fishing boats and baits, for improved mitigation measures.

Acknowledgements

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