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Diving behaviour of black petrels (*Procellaria parkinsoni*) in New Zealand waters and its relevance to fisheries interaction

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Abstract The black petrel (*Procellaria parkinsoni*) is recognised as the seabird species at greatest risk from commercial fishing activity within New Zealand fisheries waters. Despite the fact that valuable mitigation information could be obtained from such data, little is known about the diving ability of this species. Diving data were obtained from electronic time–depth recorders from 22 black petrels breeding on Great Barrier Island (Aotea), Hauraki Gulf, New Zealand, during the early chick rearing period from January-February in both 2013 and 2014. This paper presents the first information on the diving ability of black petrels. The deepest dive recorded was 34.3 m, but maximum dive depths varied considerably among individuals (range 0.8-34.3 m). The majority (86.8%) of all dives were < 5 m and black petrels rarely dived to depths of >10 m. The majority (92.7%) of dives were during the day and time of day had no major effect on dive depth. Only males dived at night, between 2300 and 0200 hours. This information could be used to improve mitigation measures for black petrel and other seabird bycatch in longline fisheries particularly in relation to recommended depths for unprotected hooks and line sink rates. To achieve the recommended minimum 10 m depth for unprotected hooks it has been shown that hooks have to be deployed at 6 knots with a 0.3 m/second line sink rate when using 100 m streamer lines. Adoption of these measures should further reduce black petrel bycatch in longline fisheries.

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Keywords black petrel; *Procellaria parkinsoni*; time-depth recorder; dive depth; dive duration; bycatch; Great Barrier Island (Aotea); New Zealand

INTRODUCTION

Black petrels (*Procellaria parkinsoni*) are a medium-sized endemic seabird which is only known to breed on Little Barrier Island (Te Hauturu-o-Toi) and Great Barrier Island (Aotea), Hauraki Gulf, New Zealand (Heather & Robertson 2015). Black petrels are recognised as the seabird species at greatest risk from commercial fishing activity within New Zealand fisheries waters (Richard & Abraham 2013) and have been studied on Great Barrier Island since 1995 (Bell *et al.* 2011). During summer, breeding birds disperse widely from their colonies, foraging throughout northern New Zealand, into the Fiji Basin, towards Australia and to East Cape (Freeman *et al.* 2010). Black petrels are listed as vulnerable by the IUCN and Department of Conservation because of the size and range of the population, risk from fisheries and predicted rate of population decline (Birdlife International 2012; Robertson *et al.* 2013). Most reported bycatch of black petrels (96.2% of 78 birds caught between 2002 and 2013) comes from longline fisheries (Abraham *et al.* 2015). Therefore, it is important to understand black petrel diving capability to help reduce the risk of interaction with fishing

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Table 1. Summary of LOTEK™ Time-Depth-Recorder deployments on breeding black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea), 2013 and 2014.

Earliest deployment date	Final retrieval date	Number of birds carrying devices				Number of burrows	Number of foraging trips per deployment (range of days)
		Male	Female	Unknown sex	Total		
29 January 2013	26 February 2013	2	4	0	6	6	18 (2-7)
1 February 2013	10 February 2013	3	5	0	8	8	14 (1-4)
22 January 2014	30 January 2014	2	2	1	5	5	6 (1-2)
26 January 2014	3 February 2014	2	0	0	2	2	3 (1-2)
27 February 2014	28 February 2014	0	0	1	1	1	1 (1)
Total		9	11	2	22	22	42 (1-7)

vessels, particularly longline boats. Determining the extreme and mean maximum dive depths for black petrels could help develop better mitigation measures on longline vessels to protect baited hooks from the birds until they sink below known dive ranges. Currently, little is known about black petrel diving and foraging behaviour. They are known to be scavengers, are suspected to feed close to the surface and their diet suggests mainly nocturnal foraging behaviour (Imber 1976, 1987; Harper 1987; Warham 1996). Described as capable divers, black petrels have also been recorded feeding during the day in association with whales and dolphins in the eastern tropical Pacific and have been estimated to dive up to 10 m (Pitman & Balance 1992).

Detailed information on diving behaviour has been obtained from a range of petrels and shearwaters, including sooty shearwaters (*Puffinus griseus*), flesh-footed shearwaters (*Puffinus carneipes*), grey-faced petrels (*Pterodroma macroptera*), Westland petrels (*Procellaria westlandica*) and white-chinned petrels (*Procellaria aequinoctialis*) using capillary tubes and more recently, electronic time–depth recorders (Weimerskirch & Sagar 1996; Freeman *et al.* 1997; Taylor 2008; Rayner *et al.* 2011; Rollinson *et al.* 2014). This paper provides the first quantified information on the diving behaviour of breeding black petrels.

METHODS

Twenty-two Lotek™ LAT1900-8 Time-Depth Recorders (TDR) (Lotek Wireless, Ontario, Canada) were deployed on breeding adult black petrels on Great Barrier Island (Aotea) in January-February 2013 and 2014 (Table 1). Birds were chosen from burrows within the study area on Mount Hobson/Hirakimata that has been monitored as part of a long-term study on black petrels since 1995 (Bell *et al.* 2011). These TDRs were light (2 g) and small (8 mm x 15 mm x 7 mm) and were attached by 2 cable ties to the metal band already on the bird's leg. They were removed by cutting the cable ties with scissors. The total instrument load (percentage of bird's weight) was 0.3% (for a 700 g breeding bird; Imber 1987). Application of each TDR took no longer than 10 minutes (mean ± SEM = 4.5 ± 0.5 minutes; range 2.1-10.0 minutes) and removal of each TDR took no longer than 2 minutes (mean ± SEM = 0.65 ± 0.1 minutes; range 0.2-2.0 minutes). The TDRs were programmed using Lotek Tag Talk (Version 1.9.40.7) to record time, pressure and wet/dry state information and data was collected every second when the device was wet. All TDRs were set to record depth >0.5 m, and maximum dive depths and dive durations were recorded. The devices have an error of 1% (C. Milne, Sirtrack/Lotek Wireless, *pers. comm.*). Time of each day was set to a 24-hour clock (NZDT) with hours of darkness classified from sunset to sunrise as determined by the New Zealand Meteorological Service for Great Barrier Island during January and February.

Each bird was weighed (using Pesola™ scales) before and after deployment to obtain information on body condition and the impact of carrying the devices. Thirty control birds were also weighed between 29 January 2013 and 28 February 2014 to compare to the deployment birds.

TDRs were deployed on 14 black petrels (9 females, 5 males) during the early chick-rearing period between 29 January and 26 February 2013, and 8 black petrels (2 female, 4 males, 2 unknown sex) during the chick rearing period between 22 January and 28 February 2014 (Table 1). The birds came from 22 burrows (Table 1). Burrows were checked regularly until the bird returned and the device was retrieved.

Table 2. Total number of dives, time of day when diving and depth of dives from all the LOTEK™ Time-Depth Recorder deployments on breeding black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island), 2013 and 2014.

Sex	Hours at sea	Number of dives						Depth of dive (m)		
		Total	Day	Night	Shallow (< 5 m)	Medium (5 – 10 m)	Deep (> 10 m)	Maximum	Minimum	Mean ± SEM
Male	492.7	484	423 (87.4%)	61 (12.6%)	434 (89.7%)	30 (6.2%)	20 (4.1%)	27.4	0.8	2.2 ± 0.2
Female	1026.6	1189	1127 (94.8%)	62 (5.2%)	1016 (85.5%)	112 (9.4%)	61 (5.1%)	34.3	0.8	2.7 ± 0.1
Unknown	56.3	33	32 (96.7%)	1 (3.3%)	31 (93.9%)	2 (6.1%)	0	5.9	0.9	1.9 ± 0.2
All	1575.6	1706	1582 (92.7%)	124 (7.3%)	1481 (86.8%)	144 (8.4%)	81 (4.8%)	34.3	0.8	2.6 ± 0.1

Each device was downloaded using the Lotek Tag Talk programme and separated into dive trips (*i.e.*, time spent at sea) beginning when the device first recorded the bird in the water and ending either when the bird returned to the colony or when the device stopped recording dive activity (*i.e.*, when the device storage was full).

RESULTS

All 22 devices were retrieved with devices being worn for between 5 and 318 days. Although one device was collected the following season (*i.e.*, deployed in January 2013 and retrieved in January 2014), data were only analysed for the January/February period of each deployment year (either 2013 or 2014) as the device had stopped recording once full. The birds showed no adverse effects from carrying the devices. The mean weight of TDR birds prior to deployment was 741.6 ± 17.3 g (range: 640-941 g) and the mean weight of control birds at the same time was 795.5 ± 13.7 g (range: 625-975 g); there was a significant difference between the weights of these 2 groups of birds (t_{50} = -2.47, P = 0.02). The mean weight of TDR birds on recovery was 752.1 ± 17.8 g (range: 566-885 g) and the mean weight of control birds at the same time was 732.1 ± 13.7 g (range: 575-874 g); this difference in weights was not significant (t_{50} = 0.91, P = 0.37).

Data from the 22 TDR devices showed a range of diving depths and dive behaviour; there were 42 different dive trips over 1575 hours of deployment resulting in 1706 dives (Tables 1 & 2). Data were recorded from 1189 dives by females and 484 dives by males, with females making significantly deeper dives than males (t_{1661} = -2.4, P = 0.008; Table 2). The mean maximum dive depth for females was 2.7 ± 0.1 m (range 0.8-34.3 m) and for males was 2.2 ± 0.2 m (range 0.8-27.4 m). The mean number of dives recorded per bird was 37.5 ± 8.4 dives (Table 3). Most dives (86.7%) occurred during daylight hours (*i.e.*, between sunrise and sunset) and over 80% of the dives were <5 m (Table 2, Fig. 1). This pattern was similar for both males and females with females having more overall daytime activity, although this was not significant (t_{38} = 0.44, P = 0.33; Tables 2 & 3, Fig. 2).

Ten of the 22 birds made dives >10 m deep. The deepest dive by a female was to 34.3 m at 0911 hours on 28 January 2014 and by a male diving to 27.4 m at 0548 hours on 2 February 2013. Overall, 95% of dives were shallower than 10 m (Table 2, Fig. 1). Time of day had an influence on the maximum dive depth with 92.6% of deepest dives (>10 m) occurring between 0600 and 2000 hours (Fig. 3). When foraging, most black petrel dive activity was between 10 am and 5 pm, with females more active during the day than males, although this was not significant (t_{38} = 1.17, P = 0.13; Fig. 3).

Although females made more dives than males, males had proportionally more dives that lasted over 40 seconds than females (Fig. 4). Mean dive duration for all birds was 6.8 ± 0.2 seconds (maximum = 78 seconds) with females (6.9 ± 0.3 seconds) having longer dives than males (6.6 ± 0.4 seconds) although this was not significant (t_{1669} = 0.58, P = 0.28; Table 4). Mean diving speed was faster on ascent (1.01 ± 0.01 m/second) than descent (0.92 ± 0.01 m/second; Table 4). The descent and ascent rates varied between males and females, with females making significantly faster descents (t_{1671} = -4.51, P < 0.001) and faster ascents (t_{1670} = -6.95, P < 0.001) than males (Table 4).

When using the full deployment time, the mean number of dives per hour for black petrels was 1.1 ± 0.3 (range: 0-10); however, using only the time when the birds are on the water during the deployment period, the mean number of dives per hour for black petrels was 73.3 ± 17.0 (range: 0-400; Table 5). Although females dived

Table 3. Mean deployment time in hours, mean number of dives by day or night and mean depth of dives from all the LOTEK™ Time-Depth Recorder deployments on breeding black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island), 2013 and 2014.

	Mean hours deployed ± SEM (range)	Mean number of dives ± SEM (range)					
		Total	Day	Night	Shallow (< 5 m)	Medium (5 – 10 m)	Deep (> 10 m)
Male	38.0 ± 13.6 (0.9-133.2)	38.6 ± 10.2 (0-79)	26.6 ± 8.4 (0-78)	12.0 ± 7.9 (0-56)	33.6 ± 9.5 (0-76)	2.9 ± 1.3 (0-12)	2.1 ± 1.5 (0-13)
Female	52.3 ± 14.3 (3.5-181.8)	40.0 ± 13.0 (1-169)	38.4 ± 12.3 (1-159)	1.6 ± 0.8 (0-10)	31.3 ± 10.6 (1-138)	5.6 ± 1.8 (0-26)	3.2 ± 1.3 (0-16)
Unknown	33.1 ± 10.8 (22.3-43.9)	13.0 ± 7.0 (6-20)	12.5 ± 6.5 (6-19)	0.5 ± 0.5 (0-1)	12.0 ± 6.0 (6-18)	1.0 ± 1.0 (0-2)	-
All	46.7 ± 9.6 (0.9-181.8)	37.5 ± 8.4 (0-169)	32.5 ± 7.8 (0-159)	5.0 ± 2.7 (0-56)	30.6 ± 7.0 (0-138)	4.3 ± 1.2 (0-26)	2.6 ± 0.9 (0-16)

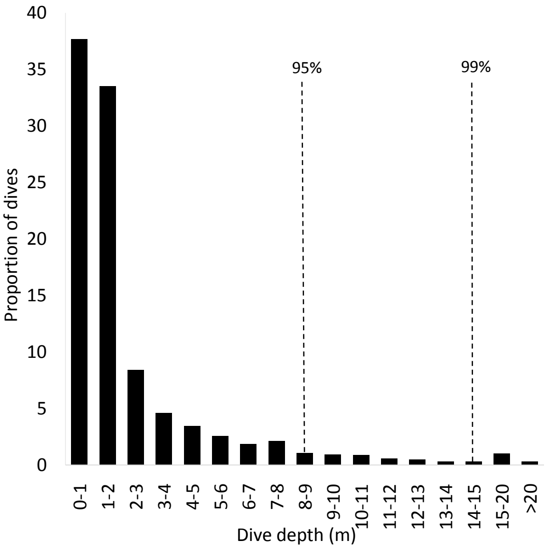

Fig. 1. Frequency of the maximum dive depths of black petrels (*Procellaria parkinsoni*) breeding on Great Barrier Island (Aotea Island), 2013 and 2014. Dashed lines show 95% and 99% dive depths.

more often than males both in total number of dives per deployment hour when in the water (t_{38} = 1.08, P = 0.14) and per hour of total deployment (t_{38} = -0.99, P = 0.17; Tables 2 and 5), neither was significant.

Over 60% of the total deployment time for both males and females was spent in daylight hours, but less than 20% of the total deployment time was spent in the water (Table 6). Males and females had similar activity levels for time spent on the water and time spent by day and at night during deployment, but males spent significantly more time on the water at night than females (t_{38} = -1.99, P = 0.03; Table 6).

DISCUSSION

Previously, little was known about the diving behaviour of the black petrel beyond anecdotal reports from bird watching expeditions, fishermen and fisheries observers (Marchant & Higgins 1990; Pitman & Balance 1992). Many reports provide only basic information and may be related to this species' habit of following boats to scavenge. However, the results of this study provide the first quantified information about diving depths and timing of diving of black petrels.

The foraging activity revealed by the TDRs suggests that black petrels may use 2 feeding strategies. The main foraging method occurs during daylight when targeting fish or other prey species that the birds observe from the air or from the surface (*i.e.,* dives >1 m). They could also be scavenging scraps or dead prey on or just below the surface, or possibly following fishing vessels during the day. It is likely that black petrels also forage on the surface during the day in association with dolphins and whales targeting surface scraps from these feeding events (Pitman & Balance 1992). The other strategy is night feeding when they probably capture bioluminescent squid on and just below the surface (Imber 1976). There is a suggestion that the level of squid in the diet of seabirds, particularly albatross and petrels, may be related to fisheries discards rather than these species being targeted by the birds, as many of the squid species dwell in deep water and are not within the diving range of most medium to large seabirds (Vaske 2011). Despite Imber (1976) reporting that their stomach contents indicated nocturnal feeding due to the level of bioluminescent cephalopods in their diet, it appears that black petrels forage more during the day than previously thought.

The maximum dive depth of black petrels (34 m) is more than double that of other *Procellaria* species that have been the subject of dive depth studies.

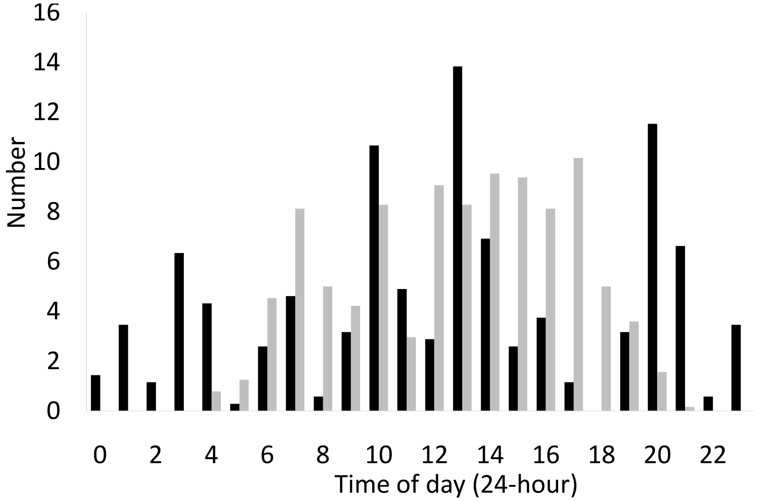

Fig. 2. Number of dives in relation to time of day for breeding black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island), 2013 and 2014. Black bars = males and grey bars = females.

Table 4. Length of dives and speed on descent and ascent from all the LOTEK™ Time-Depth Recorder deployments on breeding black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island), 2013 and 2014. Max = maximum, Min = minimum.

	Number of dives	Length of dive (seconds)			Speed of dive (metres/second)					
					Descent			Ascent		
		Max	Min	Mean ± SEM	Max	Min	Mean ± SEM	Max	Min	Mean ± SEM
Male	484	71	1	6.6 ± 0.4	2.15	0.22	0.85± 0.01	2.07	0.17	0.90 ± 0.01
Female	1189	78	1	6.9 ± 0.3	5.42	0.16	0.95 ± 0.01	8.51	0.17	1.06 ± 0.01
Unknown	33	20	2	6.7 ± 0.9	1.16	0.24	0.74 ± 0.05	1.21	0.31	0.84 ± 0.31
All	1706	78	1	6.8 ± 0.2	5.42	0.16	0.92 ± 0.01	8.51	0.17	1.01 ± 0.17

Rollinson *et al.* (2014) found that white-chinned petrels dived to 16 m and Freeman *et al.* (1997) recorded that Westland petrels dived to 7.6 m. Black petrels are predominately surface or shallow water feeders with 95% of all dives below 10 m and of short duration (<10 sec). Therefore the risk from fishing gear is close to the surface (generally less than 10 m). Many of the deeper dives showed apparent pursuit behaviour (*i.e.,* chasing prey underwater). Both white-chinned petrel and grey petrel (*Procellaria cinerea*) have been recorded deep pursuit plunging – a bird in flight plunges into the water, completely submerging and actively pursues prey underwater using wings or feet to propel themselves through the water (Harper 1987; Huin 1994). The data from this study suggests that black petrels have similar diving behaviour.

Although my study provides the first quantitative data on the diving behaviour of the black petrel, it is important to gather further information on diving behaviour during the different phases of the breeding season to determine if there are differences in dive patterns and timing that may put individuals at greater risk at certain times of the year. Taylor (2008), Rayner *et al.* (2011) and Rollinson *et al.* (2014) all suggested that the stage of breeding influenced diving behaviour with birds provisioning chicks diving deeper than those incubating eggs. The requirement for high quality food items or abundant food sources during incubation and chick rearing may also affect scavenging behaviour behind fishing vessels (Freeman 1998; Freeman & Wilson 2002; Taylor 2008).

Current mitigation measures for longline or trawl fisheries in New Zealand waters include weighted lines, night-setting (unless lines are weighted), restrictions on offal discharge while setting or hauling bottom longlines and the use of streamer lines (or bird baffler or warp deflectors) during setting and hauling (MPI 2010a, MPI 2010b, MPI2013, MPI 2014). These reports suggest that if lines sink to a depth of 5 m when protected by streamer lines this will prevent most seabirds from reaching the bait. However, given that this study showed that both male and female black petrels were capable of diving to depths exceeding 25 m, this target depth needs to be reassessed. Black petrels rarely dived over 10 m and I recommend

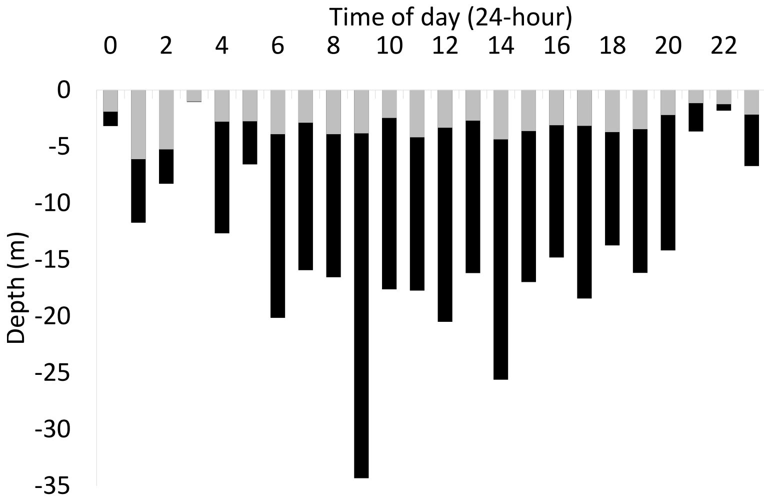

Fig. 3. Maximum dive depth (black bars) and mean dive depth (grey bars) in relation to time of day for breeding black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island), 2013 and 2014.

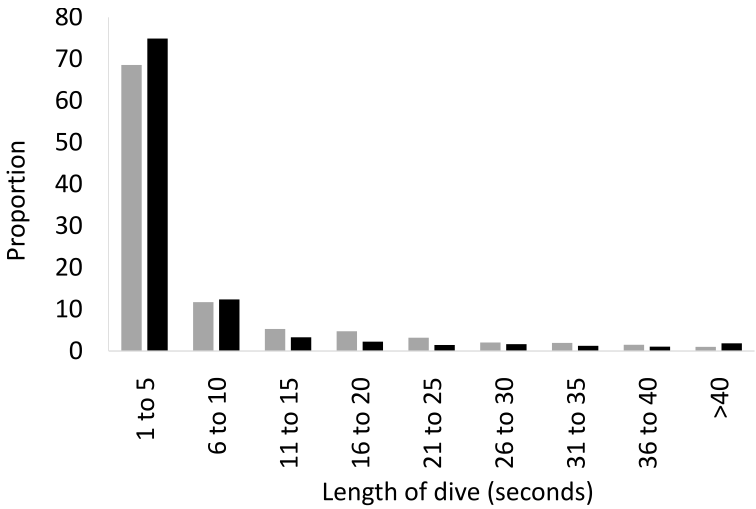

Fig. 4. Proportion of length of dives (in seconds) for breeding black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island), 2013 and 2014. Black bars = males, grey bars = females.

that this should be adopted as the minimum depth for unprotected hooks. Pierre *et al.* (2013) showed that some inshore bottom longline vessels only achieved the 10 m depth at over 200 m from the back of the vessel which was well outside the range of the streamer lines. Worse still, on bottom longline vessels targeting snapper (*Centroberyx affinis*), the fishing method with the highest overlap with black petrel, the lines are rarely at a depth greater than 5 m at the end of the streamer lines (Pierre *et al.* 2013). To achieve 97% of hooks below 10 m, Wanless & Waugh (2010) calculated that vessels would need to set lines at a speed of 6 knots for a line sink rate of 0.3 m/second while being protected by a 100 m streamer lines. Additional line weighting has also been shown to increase the sink rate and prevent bait access to seabirds (Smith 2001; Robertson *et al.* 2006; Pierre *et al.* 2013). This research confirms the importance of this 0.3 m/second sink rate to achieve the recommended minimum 10 m depth for unprotected hooks if black petrel bycatch is to be minimised.

The data reported here could not be separated into dives behind fishing vessels or those targeting natural prey away from vessels. It is possible that mean and maximum diving depths may differ depending on whether black petrels are foraging behind fishing vessels or not. For this reason, further research into comparing black petrel foraging behaviour both behind and away from fishing vessels would be useful to further refine industry regulations regarding seabird mitigation. On-going research into improving mitigation tools to reduce seabird interaction with fishing vessels needs to take into account of this and any new information on dive depth and foraging behaviour of black petrels.

Table 5. Mean deployment time on the water per day or night in hours and mean number of dives by day or night per deployment hour from all the LOTEK™ Time-Depth Recorder deployments on breeding black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island), 2013 and 2014.

	Mean hour deployed ± SEM (range)					Mean number of dives/hour ± SEM (range)			
	On water	In day	In night	On water during day	On water during night	Total deployment	On water deployment	During daytime deployment	During night deployment
Male	4.0 ± 0.8 (0.01-7.8)	21.3 ± 5.8 (5.2-80.1)	13.9 ± 3.8 (0-54.0)	3.1 ± 0.7 (0.01-7.2)	0.9 ± 0.4 (0-5.4)	1.5 ± 0.7 (0.05-10.2)	50.8 ± 22.5 (0-248)	56.4 ± 25.7 (0-289)	15.5 ± 9.0 (0-100)
Female	2.8 ± 0.6 (0.01-8.3)	25.0 ± 5.3 (2.3-111.7)	14.5 ± 3.4 (0-70.1)	2.5 ± 0.5 (0.01-8.1)	0.3 ± 0.1 (0-2.6)	0.9 ± 0.2 (0-5.6)	90.9 ± 24.3 (0-400)	97.4 ± 27.9 (0-550)	106.7 ± 33.8 (0-400)
All	3.4 ± 0.5 (0.01-8.3)	23.3 ± 3.8 (2.3-111.7)	14.2 ± 2.4 (0-70.1)	2.8 ± 0.4 (0.01-8.1)	0.6 ± 0.2 (0-5.4)	1.1 ± 0.3 (0-10)	73.3 ± 17.0 (0-400)	79.3 ± 19.5 (0-550)	64.3 ± 20.3 (0-400)

Table 6. Mean percentage deployment time (± SEM, range in parentheses) on the water by day or night from all the LOTEK™ Time-Depth Recorder deployments on breeding black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island), 2013 and 2014.

	In day	In night	On water	On water during day	On water during night
Male	62.2 ± 3.4 (46.2-100)	37.8 ± 3.4 (0-53.8)	18.8 ± 3.5 (0.05-36.3)	83.8 ± 5.9 (22.1-100)	23.8 ± 8.3 (0-100)
Female	69.0 ± 3.6 (25.9-100)	31.0 ± 3.6 (0-74.1)	13.1 ± 3.1 (0.1-48.9)	90.5 ± 2.9 (50-100)	9.5 ± 2.8 (0-50)
All	66.2 ± 2.5 (25.9-100)	33.8 ± 2.5 (0-74.1)	15.5 ± 2.3 (0.05-48.9)	87.7 ± 2.7 (22.1-100)	14.9 ± 3.4 (0-100)

Black petrels are recognised as the seabird species that is at greatest risk from commercial fishing activity within New Zealand fisheries waters (Richard & Abraham 2013), but there is a high level of uncertainty around total bycatch estimates within New Zealand fisheries. High-resolution GPS tracking of black petrels during the breeding season showed that their distribution had the highest overlap with snapper bottom longline, big-eye tuna (*Thunnus obesus*) surface longline and inshore trawl vessels in New Zealand waters throughout the breeding season (E.A. Bell, *unpubl. data*; Freeman *et al.* 2010; Richard & Abraham 2013, Abraham *et al*. 2015). There have been 78 captures of black petrels on observed commercial fishing vessels in New Zealand waters between 1996 and 2013 and all these observed captures were consistent with the highest fisheries overlap periods over the incubation and chick-rearing stages (Conservation Services Programme 2008; Thompson 2010a, 2010b, 2010c; Abraham & Thompson 2012; Abraham *et al*. 2015). The timing of their capture suggests that most black petrels may have been breeding adults which indicates that their deaths would reduce overall productivity and recruitment (as one adult cannot incubate an egg or raise a chick). The level of bycatch for black petrels outside New Zealand waters is unknown, and may impact on the population dynamics of the species. If breeding adults continue to be caught by commercial fishing operations in New Zealand and overseas, this species could be adversely affected even by a small change in adult survival, especially as black petrels have delayed maturity, low reproduction rates and high adult survival (Murray *et al.* 1993). Continued bycatch of breeding adults in New Zealand and overseas fisheries has the potential to seriously affect the species.

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