DO TRACKING TAGS IMPEDE BREEDING PERFORMANCE IN THE THREATENED GOULD'S PETREL *PTERODROMA LEUCOPTERA*?

YUNA KIM[1], DAVID PRIDDEL[2], NICHOLAS CARLILE[2], JOHN R. MERRICK[3] & ROBERT HARCOURT[1]

[1]*Department of Biological Sciences, Faculty of Science, Macquarie University, NSW 2109, Australia (yuna.kim@mq.edu.au)*
[2]*Office of Environment and Heritage, PO Box 1967, Hurstville, NSW 2220, Australia*
[3]*Department of Environment and Geography, Faculty of Science, Macquarie University, NSW 2109, Australia*

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SUMMARY

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Effects of tracking device deployment have been studied in large seabirds but less in small seabirds. Given the widespread use of tracking for distribution and foraging research, understanding whether attachment of such devices impedes breeding performance is critical. We examined the effects of both short- and long-term deployment of geolocators on Gould's Petrel *Pterodroma leucoptera* at Cabbage Tree Island, Australia, during the 2010/11 breeding season. We monitored breeding adults and their chicks over the 3 month period they carried geolocators. No significant effect on hatching success, fledging success or chick fledging mass was found. Body mass of adults carrying geolocators declined during the breeding season, but this was similar to birds without geolocators. No detectable negative impact was found for long-term (8–9 month) deployment during the non-breeding season on body mass or subsequent breeding performance. These findings suggest the use of small (1.5–2.0 g) geolocators does not inhibit foraging success and chick provisioning in Gould's Petrel. Similar verification in other small migratory seabirds fitted with geolocators is recommended.

Keywords: adult condition, fledgling mass, fledging success, hatching success, meal mass, tracking device impacts

INTRODUCTION

Over the last three decades, our understanding of the movements of wide-ranging marine predators has been revolutionized as a result of the development of tracking technologies (Croxall *et al*. 2005, Egevang *et al.* 2010). Progressive miniaturization of devices has made it feasible to extend investigations from a few large species to many smaller ones. Yet most platform terminal transmitters (PTT) and global positioning systems (GPS) are expensive and may require additional data fees. As well, until recently, packages were relatively heavy for small birds (PTT >9 g and GPS >20 g; Burger & Shaffer 2008). Compared with PTT or GPS tracking devices, geolocators, also known as loggers, can be comparatively small and lightweight (~2 g). They function by recording ambient light levels which, when integrated with an accurate clock, can be used to estimate longitude based on deriving local noon and comparing to GMT, and latitude based on determining day-length (Hill 1994, Afanasyev 2004). However, unlike PTT or GPS, geolocators yield only one or two locations per day and so have usually been used for long-term deployment only (Burger & Shaffer 2008). Moreover, the accuracy of geolocators (ca. 200 km; Phillips *et al*. 2004, Shaffer *et al*. 2005) precludes their application for studies involving species that travel over relatively short ranges.

Geolocators that log data must be retrieved to download the data, so they are ideal for use with philopatric species in which there is a high degree of certainty of recapturing the study animals (Fiedler 2009). Attaching devices of any kind to flying birds is likely to affect their aerodynamics, and repeated capture to download data may induce capture and handling stress. These impositions may interfere with the animal's normal behaviour, leading to the collection of biased data (Carey 2009). A device mass of >3% of bird body mass is generally accepted as a critical point above which normal behaviour is impaired (Phillips *et al.* 2003). However, some studies (e.g. Wanless *et al.* 1988, Paredes *et al.* 2005, Ackerman *et al.* 2009, Adams *et al.* 2009) have found that even lighter devices (0.7–3.0% of body mass) have caused reduction in adult body mass, offspring attendance, provisioning rates and/or frequency of foraging trips. All of these studies were undertaken on relatively large birds, whereas few have investigated the effects of geolocators on small seabirds (Rayner 2007, Quillfeldt *et al*. 2012, Rayner *et al*. 2012). In addition, none of the aforementioned studies clearly demonstrated whether the adverse effects resulted from capture and handling, or whether the device reduced foraging efficiency (Carey 2009).

Within the *Pterodroma leucoptera* species complex, *P. l. leucoptera* is the smaller of two subspecies (~205 g), breeding principally on Cabbage Tree Island (32°41′20″S, 152°13′29″E), 1.4 km off Port Stephens, New South Wales, Australia. This subspecies is currently listed as Endangered under the Australian Government's *Environment Protection and Biodiversity Conservation Act 1999.* Although conservation issues for this subspecies at the nesting sites are well studied, little is known about its at-sea movements or foraging ranges (DEC 2006). Knowledge of movement patterns at sea is critical for developing management and conservation strategies (Priddel & Carlile 2009). The opportunity to obtain such information is now feasible because of the recent availability of small, lightweight geolocators. However, because of the uncertainty and limitations previously explained, there is a need to identify any risks of attaching such devices.

Although previous research had found that handling adult Gould's Petrel over a 7–10 day period during the incubation stage did not affect chick growth rates or survival (O'Dwyer *et al.* 2006), there are four possible areas where negative effects might be important. First, long-term deployment of geolocators during the non-breeding season might have negative consequences on the birds' breeding success in the following year by influencing body condition before breeding. Second, the impost of carrying a geolocator may affect foraging performance, resulting in less frequent or smaller meals fed to chicks, thereby leading to a reduction in fledging success. Third, the additional stress from recapture and handling during and after the hatching period might also have adverse impacts on breeding performance. Finally, tag deployments could affect the rate of adults return to the colony, as a result of either tag-induced mortality or birds returning to a different location. Therefore, this study aimed to investigate potential impacts of attaching a geolocator, with multiple capturing and handling, on the foraging behaviour of breeding adult Gould's Petrel. We measured breeding parameters, as foraging performance is directly related to breeding performance (Rayner *et al.* 2008). We investigated whether changes in behaviour could be detected by comparing adult body mass and hatching success between adults with and without geolocators. We also compared the fledging body mass and fledging success of their chicks.

Fig. 1. A typical artificial nest box (left) used to trap adult birds at night. The gate on the entrance tunnel (top right and bottom) opens inward but not outward. Displacement of the stick (shown in the tunnel, top right) indicated the presence of an adult bird in the nest box.

METHODS

The study was carried out on Cabbage Tree Island, New South Wales, Australia, between March 2010 and April 2011. The principal breeding habitat of Gould's Petrel is concentrated within two steep gullies on the western side of the island (Priddel *et al*. 2006). Since 1989, natural nests (marked by numbered tags) and artificial nest boxes have been surveyed annually to estimate population size, breeding success and reproductive output (Priddel & Carlile 2009). A nest box and entrance tunnel is illustrated in Figure 1; detailed description of the artificial nest boxes can be found in Priddel and Carlile (1995).

Gould's Petrels are sexually monomorphic (O'Dwyer *et al.* 2006) and nocturnal on land, arriving after sunset and leaving before sunrise. Adults first return to Cabbage Tree Island to breed from mid- to late September (DEC 2006). Egg laying commences in early November and, on average, 49 days are needed for incubation. As with all Procellariiformes, a single egg is laid; if lost, the egg is not replaced in the same season (Warham 1990). Following hatching, a parent broods the chick for 2–3 days; thereafter, it is fed infrequently by the parents until it fledges in April or early May (Priddel & Carlile 1995).

The study was carried out in a sub-colony estimated to number approximately 1000 breeding pairs (Priddel *et al*. 2006). Many of the adult birds are identifiable by a metal band inscribed with a unique number, and chicks are banded in March each year (Priddel *et al*. 2006).

Deployment during the non-breeding season

During 22–25 March 2010, 42 geolocators were fitted to Gould's Petrel adults taken from 35 nests (7 pairs, 28 single birds). Adults were captured while returning to the nest to feed their chick. Twenty MK14 (British Antarctic Survey; 1.5 g) and 22 LAT2900 (Lotek; 1.9 g) geolocators were attached to the legs of adult birds using Darvic bands (Figure 2). Each MK14 (20 × 9 × 5.5 mm) was attached using a single cable tie and fast-drying cyanoacrylate adhesive (Supa glue; Figure 2a). Each LAT2900 (20 × 8 × 6.7 mm) was attached using two cable ties as well as the adhesive (Figure 2b). The resulting packages weighed 2.0 g (MK14) and 2.5 g (LAT2900),

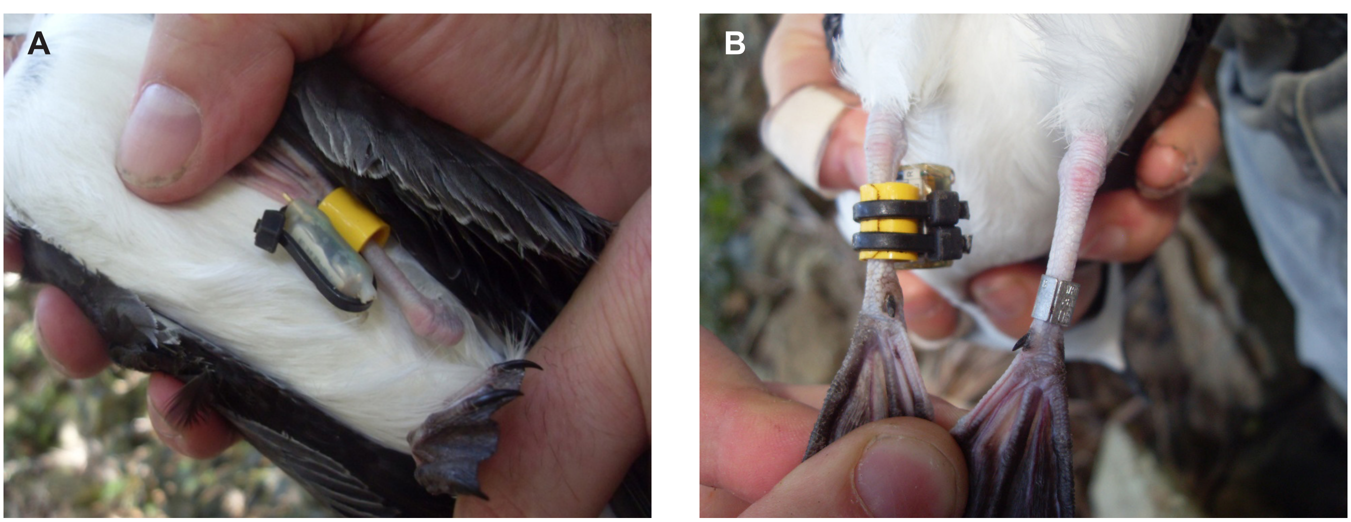

Fig. 2. Attachment of two types of geolocators: (a) MK14 with a Darvic ring and single cable tie; (b) LAT2900 with a Darvic ring and two cable ties.

equivalent to 1.0%–1.3% of average body mass. Logger attachment was completed within 15 min of capture.

Geolocators were retrieved in the following breeding season, between 23 November and 27 December 2010, and the mass of birds recorded to the nearest gram with a 300 g Pesola spring balance. This sample group is hereafter referred to as NBLOGGER. Twenty additional nests were selected randomly and the adult occupants (hereafter referred to as NBCONTROL) were weighed at the same time as NBLOGGER to test for differences in mass as a means of assessing the impact of geolocators deployed throughout the non-breeding season.

The nests of both instrumented and non-instrumented birds (NBLOGGER and NBCONTROL, respectively) were inspected during 23–25 November and 13–15 December 2010 to determine whether laying had occurred and during 7–10 March 2011 to assess chick survival. Very few chicks die late in the nestling period (Priddel & Carlile 1997), so advanced chicks present in March were assumed to fledge successfully.

Deployment during the breeding season

In late December 2010, we inspected all artificial nest boxes, except those housing birds used in the non-breeding study (NBLOGGER and NBCONTROL), to locate nests containing incubating adults. We then candled the eggs to assess whether they were viable. Twenty birds incubating viable eggs were selected for attachment of geolocators. If a selected bird changed incubation duties with its partner during the week-long sampling period, the second bird was also fitted with a geolocator. This sample group is hereafter referred to as LOGGER. Failed breeders leave the nesting grounds, so selecting viable eggs maximized the likelihood of the instrumented birds returning and thus increased the chance of retrieving the geolocators to download data. Another 20 pairs from artificial nests boxes with viable eggs were captured and weighed in the same manner as LOGGER, but were not fitted with geolocators; these are hereafter referred to as NOLOGGER. A third group of 20 adult pairs, from natural nests containing viable eggs, were neither fitted with geolocators nor captured; these are hereafter referred to as CONTROL. The purpose of the CONTROL was to provide a measure of incubation success, fledging success, fledging mass and approximate meal size against which to compare LOGGER and NOLOGGER. Adults in CONTROL nests were not handled, but the chicks were.

Trapping adults as they returned to the nest to feed their chick was only practicable for birds that nested in boxes. So LOGGER and NOLOGGER nests were selected from among occupied nest boxes. A shortage of additional occupied nest boxes meant that the CONTROL sample had to be selected from natural nests.

During 2–10 January, 8–15 February, 5–9 March and 10–22 April 2011, two people continuously monitored all LOGGER and NOLOGGER nests between 20h00 and 03h00. Whenever an adult was intercepted, it was weighed, and birds with geolocators had data downloaded. All chicks from all three groups were weighed at approximately 12h00 and 18h00 daily, and approximate meal size was determined from overnight weight increases. As we were interested in relative differences between groups rather than actual meal size, we ignored the possibility of underestimating meal sizes due to metabolic processes and defecation. Decreases in overnight masses were ignored, even if we knew the nest had been visited by a parent, as occasionally parents will visit the nest without delivering food to the chick (Hamer *et al*. 1999, Phillips & Hamer 2000).

LOGGER and NOLOGGER nest boxes were fitted with a removable one-way gate in the entrance tunnel, which could flip inwards from outside, but could not open outwards in response to pressure from inside. The gates were fixed in place at 18h00 each day. A small stick was placed across the tunnel entrance, displacement of which indicated that a bird had entered the nest. From 20h00 nests were monitored and the visits of individual parents logged. When the stick had been dislodged, we opened the lid of the nest box and checked the contents. If an adult was present, the time was noted and approximately 30 min allowed for the adult to feed the chick. Adult birds were then captured and weighed, and data downloaded from those carrying geolocators. Adults were then returned to the nest box and the gate removed so they could leave. Monitoring ceased at 03h00, when all remaining gates were removed. Adults arriving after the gates were removed, either after one parent had been captured or after 03h00, were not detected.

Data analyses

We conducted statistical analyses using IBM SPSS statistic 21. All tests were two-tailed and considered significant at $P < 0.05$. Comparison of adult body mass between NBLOGGER and NBCONTROL was tested using an independent *t*-test. The Mann-Whitney U test was used for comparisons of adult body mass among LOGGER, NOLGGER and CONTROL because the assumption of normality was violated and the data could not be transformed successfully. We compared hatching success, fledging success and breeding success between instrumented and non-instrumented birds using the chi-square test for goodness of fit. Kruskal-Wallis one-way analysis of variance by ranks was employed to compare fledging mass (due to small sample sizes) and mean meal size (due to non-normality).

RESULTS

Effects of deployment during the non-breeding season

Forty of the 42 geolocators deployed during the non-breeding season were retrieved; 33 tagged birds were weighed, 7 intercepted by associates were not. At the beginning of the 2010/11 breeding season, the body mass of adults that had carried geolocators throughout the non-breeding season did not differ from that of non-instrumented birds (Table 1). Fourteen percent of birds that carried geolocators failed to lay eggs, whereas 5% of non-instrumented birds failed to lay, a difference that was not significant (Table 1). Hatch rates were 60% for instrumented birds and 42% for non-instrumented birds, and again not significant (Table 1). All chicks that hatched (n = 26, Table 1) fledged successfully.

Effects of deployment during the breeding season

No incubating adult fitted with a geolocator abandoned its egg. Of the 60 eggs in study nests, 47 hatched (Table 2), and there was no difference in hatch rates among groups (LOGGER, NOLOGGER and CONTROL).

Fledging success was consistently high across all groups (Table 2). Of 15 chicks from the LOGGER group, one was found dead in the nest; all others fledged successfully. The nest containing the dead chick continued to be monitored to retrieve the geolocators from the parents. We found that the nest was attended by at least three adults, and disputes over nest ownership are likely to have contributed to the death of the chick. Similarly, in the CONTROL group all chicks except one fledged. The failed chick disappeared from the nest without a trace six days after hatching, presumably due to predation. All 16 chicks from the NOLOGGER group fledged.

Breeding success (the proportion of eggs that produced fledglings) was 70%–80% and was similar in all groups (Table 2). Fledging mass could be measured for only 11 chicks from LOGGER, seven from NOLOGGER and 10 from CONTROL, because fledging commenced before the final sampling period. Fledgling mass was similar across all groups (Table 2).

The overnight increase in body mass was regarded as approximating meal size. Meal sizes were highly variable (range 1–88 g) and not significantly different between groups (Table 2).

Instrumented birds (LOGGER) lost mass between attachment (December 2010 to January 2011) and when next intercepted (Feburary to April 2011) (Table 3; Kruskal-Wallis = 8.658, df = 3, $P = 0.034$, n = 68). However, body mass during February to April was no less for tagged birds than for non-tagged birds (Table 3).

DISCUSSION AND CONCLUSIONS

Conservation programs for many petrels, including those in Australia, have focused on breeding success at nesting sites, but it is now recognized that data on movements at sea are also critical for elucidating habitat use, migratory corridors and time-activity patterns (Baker *et al*. 2002, Shaffer *et al*. 2006, González-Solís *et al*. 2007, Priddel & Carlile 2009, Croxall *et al*. 2012, Madeiros *et al*. 2012). This recognition, together with the development of small economical geolocators, has facilitated research into the movements and migration patterns of many species. However, it is essential to verify that deployment of geolocators does not adversely impact the birds targeted, either by changing behaviour or by reducing breeding productivity. Such impacts could affect the quality of the data collected and therefore mislead broader ecological interpretations that may have proven effective in improving the conservation status of seabird populations.

In the present study, we did not detect any significant effect of geolocator deployment on the breeding performance of Gould's Petrels. While our findings were reassuring, sample sizes for some parameters (e.g. fledging success) were small, and significant effects may be discernible with larger samples. Additionally, this study was carried out at a site where artificial nest boxes have been used for many years, which might provide more benign habitat and positively affect breeding success (Madeiros *et al*. 2012). All birds were released back into the tunnel of the nest box and immediately settled back onto the egg, and no nest was abandoned after geolocator deployment. However, the possibility of nest desertions in natural nests following the deployment of tracking devices has been suggested by other researchers (e.g. Phillips *et al*. 2003).

TABLE 1
Effect of deployment of geolocators during the non-breeding season

Outcome	NBLOGGER	NBCONTROL	Test result	df	*P*
Adult body mass at the beginning of the breeding season, mean ± SD, g	209.2 ± 20.4 (n = 33)	213.2 ± 17.2 (n = 20)	$t = 7.4$	51	0.46
Egg-laying success, % (no./n)	86 (30/35)	95 (19/20)	$\chi^2 = 1.13$	1	0.29
Hatching success, % (no./n)	60 (18/30)	42 (8/19)	$\chi^2 = 1.50$	1	0.22
Fledging success, % (no./n)	100 (18/18)	100 (8/8)			

TABLE 2
Effect of deployment of geolocators during the breeding season

Outcome	LOGGER	NOLOGGER	CONTROL	Test result	df	*P*
Hatching success, % (no./n)	75 (15/20)	80 (16/20)	80 (16/20)	$\chi^2 = 1.96$	2	0.91
Fledging success, % (no./n)	93 (14/15)	100 (16/16)	94 (15/16)	$\chi^2 = 1.081$	2	0.58
Breeding success, % (no./n)	70 (14/20)	80 (16/20)	75 (15/20)	$\chi^2 = 0.53$	2	0.77
Fledging mass, mean ± SD, g (n)	177.5 ± 16.0 (11)	175.3 ± 15.4 (7)	181.8 ± 15.9 (10)	$\chi^2 = 1.00$	2	0.61
Meal size, mean ± SD, g (n)	20.4 ± 14.9 (72)	21.1 ± 14.1 (97)	16.9 ± 9.9 (108)	$\chi^2 = 4.3$	2	0.12

TABLE 3
Adult body mass change during the breeding season 2010/11

Date of record	Group, mean ± SD, g (n)		Test result (Mann–Whitney U)	Standard error	*P*
	LOGGER	NOLOGGER			
Dec–Jan attachment	198.9 ± 23.5 (15)	Not weighed			
Feb	179.2 ± 11.9 (28)	173.0 ± 13.1 (17)	163.5	42.6	0.08
Mar	182.3 ± 17.1 (19)	180.7 ± 22.2 (16)	134.5	30.1	0.57
April	176.2 ± 24.3 (6)	150.5 ± 3.5 (2)	0	3	0.71

All deployments on Gould's Petrels during the breeding season involved birds that were nesting in boxes. Due to a shortage of occupied nest boxes in the study area, data from these birds were compared with those from birds nesting in natural nest sites. No differences were detected, and there is no evidence that this confounding factor affected the outcome of this study.

Although we found no significant impacts of geolocator attachment on breeding performance, a comparative trip duration analysis may be a more sensitive indicator of the costs of carrying devices. Typically, foraging trips are prolonged following PTT attachments (~67% of studies reviewed in Phillips *et al.* 2003). For example, tagged Common Murres *Uria aalge* made fewer but longer trips away from the nest and provisioned their chicks significantly less frequently than their non-tagged partner (Hamel *et al*. 2004). Although we determined that there were no differences in approximate meal size and that nearly all chicks developed well enough to fledge, it is plausible that their parents expended more energy to perform similar provisioning effort compared with other non-tagged or non-handled birds. Comparatively, Carey (2011) questioned whether tagged adults could provision themselves, as well as their offspring, adequately.

Despite widespread acceptance of the "3% rule" suggested by Phillips *et al.* (2003), Barron *et al*. (2010) found little evidence that negative effects increased as devices became proportionally heavier. Rather, the method of device attachment was deemed to be more important. Harnesses and collars had more negative effects than the leg-band attachment used here. However, we found using glue can cause skin abrasion if not carefully applied (Figure 3). Excess adhesive can stick the Darvic ring to the bird's leg, causing superficial damage, so care must be taken when using this method. The time for glue to dry also varies with temperature, and this can affect handling time (Adams *et al*. 2009). We altered our attachment protocol and ceased using glue in subsequent deployments, replacing the Darvic band with Velcro and Tesa tape. However, this modification increased the mass of the attachment, causing abrasions at the base of the leg near the joint on long-term deployments (longer than 4 months). To avoid or minimize such negative impacts during long-term logger deployments, the mass of the equipment, frequency of handling and length of deployment should all be minimized, with the geolocators removed from the birds at the earliest possible time.

Fig. 3. Abrasion caused by accidental leakage of glue onto the leg resulting in the Darvic band adhering to the leg.

Data collected using new technologies are invaluable for understanding where seabirds forage and which parts of the ocean form critical habitat in their life cycle. However, to optimize the insights from such research, it is essential that we do so in a manner that does not interfere with breeding success or foraging habits of the study animals. We strongly recommend conducting similar experimental studies of logger impacts on any other species proposed for large-scale deployments. Relatively smaller procellariiform seabirds, such as Fork-tailed Storm-petrels *Oceanodroma furcata* (Boersma *et al*. 1980), Tristram's Storm-petrels *O. tristrami* (Marks & Leasure 1992) and Leach's Storm-petrel *O. leuchorhoa* (Blackmer *et al*. 2004), show negative impacts from short-term handling. Therefore, when tracking devices are small enough to be deployed on these species, it is recommended that researchers investigate possible attachment and handling effects before large-scale movement studies to ensure minimal detrimental impacts. The documentation of any disturbance effects caused by scientific research may be crucial for designing future research or conservation programs (Carey 2009).

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REFERENCES

ACKERMAN, J.T., ADAMS, J., TAKEKAWA, J.Y., CARTER, H.R., WHITWORTH, D.L., NEWMAN, S.H., GOLIGHTLY, R.T. & ORTHMEYER, D.L. 2009. Effects of radiotransmitters on the reproductive performance of Cassin's auklets. *Wildlife Society Bulletin* 32: 1229–1241.

ADAMS, J., SCOTT, D., MCKECHNIE, S., BLACKWELL, G., SHAFFER, S.A. & MOLLER, H. 2009. Effects of geolocation archival tags on reproduction and adult body mass of sooty shearwaters (*Puffinus griseus*). *New Zealand Journal of Zoology* 36: 355–366.

AFANASYEV, V. 2004. A miniature daylight level and activity data recorder for tracking animals over long periods. *Memoirs of National Institute of Polar Research Special Issue* 58: 227–233.

BAKER, G.B., GALES, R.G., HAMILTON, S. & WILKINSON, V. 2002. Albatross and petrels in Australia: a review of their conservation and management. *Emu* 102: 71–97.

BARRON, D.G., BRAWN, J.D. & WEATHERHEAD, P.J. 2010. Meta-analysis of transmitter effects on avian behaviour and ecology. *Methods in Ecology and Evolution* 1: 180–187.

BLACKMER A.L., ACKERMAN, J.T., NEVITT, G.A. 2004. Effects of investigator disturbance on hatching success and nest-site fidelity in a long-lived seabird, Leach's storm-petrel. *Biological Conservation* 116: 141–148.

BOERSMA, P.D., WHEELWRIGHT, T., NERINI, M.K. & WHEELWRIGHT, E.S. 1980. The breeding biology of the fork-tailed storm-petrel (*Oceanodroma furcate*). *Auk* 97: 268–282.

BURGER, A.E. & SHAFFER, S.A. 2008. Application of tracking and data-logging technology in research and conservation of seabirds. *Auk* 125: 253–264.

CAREY, M.J. 2009. The effects of investigator disturbance on procellariiform seabirds: a review. *New Zealand Journal of Zoology* 36: 367–377.

CAREY, M. 2011. Leg-mounted data-loggers do not affect the reproductive performance of short-tailed shearwaters (*Puffinus tenuirostris*). *Wildlife Research* 38: 740–746.

CROXALL, J.P., SILK, J.R.D., PHILLIPS, R.A., AFANASYEV, V. & BRIGGS, D.R. 2005. Global circumnavigations: Tracking year-round ranges of nonbreeding albatrosses. *Science* 307: 249–250.

CROXALL, J.P., BUTCHART, S.H.M., LASCELLES, B., STATTERSFIELD, A.J., SULLIVAN, B., SYMES, A. & TAYLOR, P. 2012. Seabird conservation status, threats and priority actions: a global assessment. *Bird Conservation International* 22: 1–34.

DEPARTMENT OF ENVIRONMENT & CONSERVATION (DEC). 2006. Gould's Petrel (*Pterodroma leucoptera leucoptera*) Recovery Plan. Hurstville, NSW: Department of Environment and Conservation (NSW).

EGEVANG, C., STENHOUSE, I.J., PHILLIPS, R.A., PETERSEN, A., FOX, J.W. & SILK, J.R.D. 2010. Tracking of Arctic terns *Sterna paradisaea* reveals longest animal migration. *Proceedings of the National Academy of Sciences USA* 107: 2078–2081.

FIEDLER, W. 2009. New technologies for monitoring bird migration and behaviour. *Ringing & Migration* 24: 175–179.

GONZÁLEZ-SOLÍS, J., CROXALL, J.P., ORO, D. & RUIZ, X. 2007. Trans-equatorial migration and mixing in the wintering areas of a pelagic seabird. *Frontiers in Ecology and the Environment* 5: 297–301.

HAMEL, K.C., HILL, J.K. & SCOTT, I. 1999. Chick provisioning and parental attendance in Cory's Shearwaters: implications for nestling obesity. *Journal of Avian Biology* 30: 309–315.

HAMER, N., PARRISH, J.K. & CONQUEST, L.L. 2004. Effects of tagging on behaviour, provisioning, and reproduction in the Common Murre (*Uria aalge*), a diving seabird. *Auk* 121: 1161–1171.

Hill, R.D. 1994. Theory of geolocation by light levels. In: Le Boeuf, B.J. & Laws, R.M. (Eds.). Elephant seals, population, ecology, behaviour and physiology. Berkeley: University of California Press. pp. 227–236.

MADEIROS, J., CARLILE, N. & PRIDDEL, D. 2012. Breeding biology and population increase of the Endangered Bermuda Petrel *Pterodroma cahow. Bird Conservation International* 22: 35–45.

MARKS, J.S. & LEASURE, S.M. 1992. Breeding biology of Tristram's storm-petrel on Laysan Island. *Wilson Bulletin* 105: 93–102.

O'DWYER, T.W., BUTTERMER, W.A. & PRIDDEL, D.M. 2006. Investigator disturbance does not influence chick growth or survivorship in the threatened Gould's Petrel *Pterodroma leucoptera. Ibis* 148: 368–372.

PAREDES, R., JONES, I.L. & BONESS, D.J. 2005. Reduced parental care, compensatory behaviour and reproductive costs of thick-billed murres equipped with data loggers. *Animal Behaviour* 69: 197-208.

PHILLIPS, R.A. & HAMER, K.C. 2000. Periodic weighing and the assessment of meal mass and feeding frequency in seabirds. *Journal of Avian Biology* 31: 75–80.

PHILLIPS, R.A., SILK, J.R.D., CROXALL, J.P., AFANASYEV, V. & BRIGGS, D.R. 2004. Accuracy of geolocation estimates for flying seabirds. *Marine Ecology Progress Series* 266: 265–272.

PHILLIPS, R.A., XAVIER, J.C. & CROXALL, J.P. 2003. Effects of satellite transmitters on albatrosses and petrels. *Auk* 120: 1082–1090.

PRIDDEL, D. & CARLILE, N. 1995. An artificial nest box for burrow-nesting seabirds. *Emu* 95: 290–294.

PRIDDEL, D. & CARLILE, N. 1997. Conservation of the endangered Gould's petrel *Pterodroma leucoptera leucoptera*. *Pacific Conservation Biology* 3: 322–329.

PRIDDEL, D. & CARLILE, N. 2009. Key elements in achieving a successful recovery programme: A discussion illustrated by the Gould's Petrel case study. *Ecological Management and Restoration* 10 (S1): S97–S102.

PRIDDEL, D., CARLILE, N. & WHEELER, R. 2006. Establishment of a new breeding colony of Gould's Petrel (*Pterodroma leucoptera leucoptera*) through the creation of artificial nesting habitat and the translocation of nestlings. *Biological Conservation* 128: 553–563.

QUILLFELDT, P., MCGILL, R.A.R., FURNESS, R.W., MÖSTL, E. & LUDYNIA, K. 2012. Impact of miniature geolocation loggers on a small petrel, the thin-billed prion *Pachyptila belcheri*. *Marine Biology* 159: 1809–1816.

RAYNER, M. 2007. Effects of Dummy Global Location Sensors on foraging behaviour of Cook's Petrel (*Pterodroma cookii*). *Wilson Journal of Ornithology* 119: 107–109.

RAYNER, M.J., HAUBER, M.E., CLOUT, M.N., SELDON, D.S., VANDIJKEN, S., BURRY, S. & PHILLIPS, R.A. 2008. Foraging ecology of the Cook's petrel *Pterodroma cookii* during the austral breeding season: a comparison of its two populations. *Marine Ecology Progress Series* 370: 271–284.

RAYNER, M.J., TAYLOR, G.A., GUMMER, H.D., PHILLIPS, R.A., SAGAR, P.M., SHAFFER, S.A. & THOMPSON, D.R. 2012. The breeding cycle, year-round distribution and activity patterns of the endangered Chatham Petrel (*Pterodroma axillaris*). *Emu* 112: 107–116.

SHAFFER, S.A., TREMBLAY, Y., WEIMERSKIRCH, H., SCOTT, D., THOMPSON, D.R., SAGAR, P.M., MOLLER, H., TAYLOR, G.A., FOLEY, D.G., BLOCK, B.A. & COSTA, D.P. 2006. Migratory shearwaters integrate oceanic resources across the Pacific Ocean in an endless summer. *Proceedings of the National Academy of Sciences USA* 103: 12799–12802.

SHAFFER, S.A., TREMBLAY, Y., AWKERMAN, J.A., HENRY, R.W., TEO, S.L.H., ANDERSON, D.J., CROLL, D.A., BLOCK, B.A. & COSTA, D.P. 2005. Comparison of light- and SST-based geolocation with satellite telemetry in free-ranging albatrosses. *Marine Biology* 147: 833–843.

WANLESS, S., HARRIS, M.P. & MORRIS, J.A. 1988. The effect of radio transmitters on the behavior of Common Murres and Razorbills during chick rearing. *Condor* 90: 816–823.

WARHAM, J. 1990. The petrels: their ecology and breeding systems. London: Academic Press.