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Tools and Technology Note

Effects of Satellite Transmitters Fitted to Breeding Cory's Shearwaters

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ABSTRACT We studied the effects of a new technique to fix satellite transmitters on the feeding behavior and chick body growth of the Cory's shearwater (*Calonectris diomedea*). Transmitters did not significantly affect the breeding bird's body mass or diving performance. However, on average, pairs with ≥1 adult equipped with a transmitter brought a lighter meal (54.8 ± 18.9 g) to nestlings than did control birds or the same pair with the transmitter removed (77.4 ± 8.3 g) leading to a decreased chick body growth. However at fledging, chicks in control and treatment groups had similar body mass whether parents were equipped with a PTT or not. Our method of transmitter attachment could therefore be an appropriate alternative for studying the ecology of procellariiforms weighing <1 kg given that birds are fitted with transmitters for <2 weeks and restricted to 1 parent only. © 2011 The Wildlife Society.

KEY WORDS body growth, calonectris diomedea, corsica, foraging, meal mass, satellite transmitter.

Petrels are subjects of conservation programs and satellite tracking, which is a powerful tool to gather data on their ecology at sea and has been used extensively on petrels and albatrosses in the southern ocean (BirdLife International 2004). Studies should, however, assess how marking affects individual's behavior (Murray and Fuller 2000). Flying birds may be particularly sensitive to permanent or temporary marking and several studies reported negative effects of monitoring devices on bird behavior (review in Murray and Fuller 2000; Phillips et al. 2003). For example, tubenose birds carrying platform transmitter terminals (PTTs) extended their forage trip durations ranging from 26% to 130% for albatrosses and from 44% to 128% for petrels as compared to non-equipped birds. Similarly, high rates of nest desertion were associated with birds carrying PTTs >3% of their adult mass in 7 out of 18 species of albatrosses and petrels (see Phillips et al. 2003). Preliminary trials with dummy PTTs to check whether birds displayed adverse effects of carrying transmitters are therefore highly recommended, especially with species weighing <1 kg (Klomp and Schultz 2000, Söhle 2003, Burger and Shaffer 2008).

The Cory's shearwater (*Calonectris diomedea*) breeds in the Mediterranean Sea and the subtropical East Atlantic (Thibault et al. 1997). With an average body mass ranging from 545 g to 738 g (Thibault et al. 1997), this small procellariiform can probably carry PTTs weighing ≤30 g without exceeding 5% of body mass, to limit negative effects of marking on bird's behavior (Murray and Fuller 2000: 39). Harness-like attachment techniques have been previously used to fit Cory's shearwater with PTTs (Mougin and Jouanin 1997, Ristow et al. 2000). This technique may be, however, problematic to use with small procellariiforms for both technical and biological reasons (Phillips et al. 2003). In many instances PTTs stopped sending a signal in <11 days because of bird mortality or harness loss (Mougin and Jouanin 1997). Harnesses are therefore unreliable for long-term monitoring of individuals. In addition, harnesses may affect bird's behavior, as harnessed Cory's shearwaters migrated later than unharnessed birds, likely resulting from a reduced foraging efficiency of birds carrying a PTT (Ristow et al. 2000).

More recently, alternative attachment techniques involving PTTs taped to the back feathers have been successfully deployed for petrels weighing >1 kg without detectable consequences for equipped birds (Weimerskirch et al. 1999, Berrow et al. 2000, Freeman et al. 2001). Similar attachment methods used on different shearwater species weighing <1 kg led to lower colony attendance for equipped than non-equipped birds. No negative effect was reported on mass or breeding success of tagged adults or on their chick mass at fledging (Klomp and Schultz 2000, Söhle et al. 2000, Freeman et al. 2001, Söhle 2003). Igual et al. (2005), however, found that data-loggers (approx. 1.5–2% of bird mass) fitted on Cory's shearwaters decreased adult body mass by 10% the year following device attachment. Overall, despite being less constraining for birds, empirical support for a lack of consequences of PTTs taped to the back feathers and applied to light procellariiforms remains inconclusive and understudied. The investigation of alternative methods is therefore needed.

We proposed and tested an improved attachment system of PTTs on a small procellariiform (<1 kg), the Cory's shearwater, using humerals and strengthened rachis with a piece of fishing line. We first quantified the ability of the birds to retain the tags using the signal duration to assess efficiency of the proposed method. We then investigated whether our method could affect behavior of adult shearwaters by comparing body mass and maximum diving depths

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during foraging trips of birds with and without PTTs. Finally, we assessed the effects of adult birds carrying a PTT on meal mass and feeding rate of chicks, and the consequences on chicks' body growth patterns and body mass at fledgling. We predicted that use of PTTs would decrease meal mass brought to chicks (Phillips et al. 2003), lower parents' attendance to the nest (Söhle 2003), and thus decrease chicks' body growth before fledging.

STUDY AREA

We conducted our study during summer breeding seasons in 2003 and 2004, on a colony of 345–400 pairs of Cory's shearwater located at Lavezzi Island (41°20′N, 09°15′E), South Corsica in the Western Mediterranean (see Thibault 1993 for additional information).

METHODS

We attached PTTs to the 2 humeral feathers most proximal to the body on either side (Fig. 1) with 2 pieces of tape (Tesa®, 20 mm wide, Tesa SE, Germany; Wilson[Q1] and Wilson 1989, Proctor and Lynch 1993, Hickman 2008) and instant adhesive glue (Loctite 401®, Henkel AG & Co, Germany). To further strengthen the rachis, we added a short length of fishing line (80 mm long, 0.8 mm diam.) on a 35 mm × 10 mm piece of tape and glued it onto the feather with the fishing line against the rachis on 1 humeral on either side of the bird. We attached PTTs to 11 adult males and 8 adult females, with 3 of those individuals fitted twice. We used 6 PTTs with a soft pad on the base (Microwave Telemetry, Columbia, MD). Having few PTTs, we decided to equip more birds for a shorter time instead of fewer birds for a longer time, and planned to leave the device on the same bird for 10–12 days. Four devices weighed 22 g, representing 3.8% and 3.3% of average bird mass for females and males, respectively, and another 2 devices weighed 30 g, representing 4.6% of average male body mass.

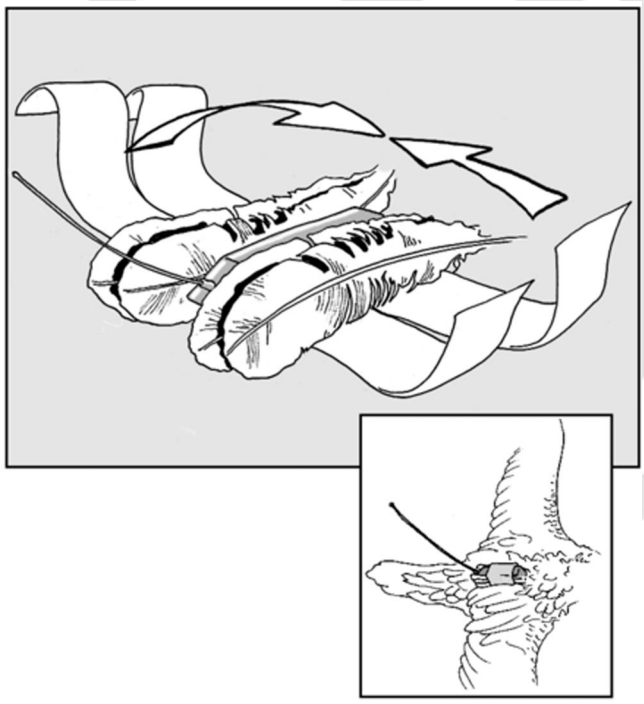

Figure 1. Visual description of how we attached PTTs to the 4 humerals of Cory's shearwaters, using tape and a piece of fishing line. We carried out this experiment on Lavezzi Island, south of Corsica in the Western Mediterranean, 2003–2004.

We assessed potential effects of PTTs on adults 1) by comparing body mass before and after carrying a PTT and 2) by measuring diving depth and feeding frequency during foraging behavior. We used capillary tubes (Burger and Wilson 1988) to estimate maximum diving depth of birds equipped with a PTT ($n = 8$) and of controls ($n = 38$) in 2004. We calibrated capillary tubes at sea near the colony with capillary tubes attached to a string at every meter down to 14 m below sea surface. The result was a linear regression between depths we measured on the string and those estimated (x) from capillary tubes attached to birds (depth $= 0.798x + 0.385$, $r^2 = 0.99$, $n = 19$). We applied this equation to our data collected from adult birds to determine maximum diving depth. We also mapped foraging trips of birds equipped with a PTT using Geographic Information System. We followed trajectories taken by each foraging bird and, assuming the bird came back to its nest, drew a loop. In some instances, we confirmed this assumption in the field when we found foraging birds back at their burrow. We used those maps to determine duration of foraging trips in days. Assuming that males and females feed their chicks equally (Granadeiro et al. 1998), we divided this duration by 2 for the time elapsed between 2 feedings. We therefore obtained chick feeding rate (%) as the inverse of the elapsed time between 2 feeding events.

To test for the potential effect on breeding behavior of tagging adult birds with a PTT, we measured and compared the meal size of 4 treatment groups of chicks: 1) chicks weighed daily with ≥1 parent fitted with a PTT (PTT; $n = 5$ nests, 3 M, 3 F in 2003; $n = 13$ nests, 8 M, 5 F in 2004); 2) chicks of group 1, weighed daily, but for which we removed the PTT of their parents after 12 days (R-PTT; $n = 4$ nests in 2003; $n = 11$ nests in 2004); 3) chicks weighed daily with parents never fitted with PTTs (No-PTT; $n = 6$ nests in 2003; $n = 8$ nests in 2004); and 4) the control group, chicks never weighed with parents never fitted with a PTT (Control; $n = 41$ nests in 2003 and $n = 34$ nests in 2004). We obtained meal sizes by calculating the body mass increase of chicks weighed ≥3 times every night between 1900–2000 hr, 2300–0100 hr, and 0500–0600 hr on 34 days (20 Jul–23 Aug) in 2003 and 41 days (17 Jul–27 Aug) in 2004. We averaged meals of individual chicks per pair and then computed the overall average to compare meal mass between years and among chick groups. We performed all statistical tests using the software R Version 2.9.1 (http://www.r-cran.org/).

RESULTS

Of 22 trials, problems with birds carrying transmitters occurred only twice (9%). In 2003, 1 female fitted in May and later again in August had a feather shaft cut on each side of its body during the second trial and we removed the PTT after 6 days. In 2004, 1 female equipped (in spring and

summer) lost the PTT after 11 days during the second trial. In addition, 1 PTT was lost because the fitted male remained at sea for ≥48 days, at which time the signal was lost. During both seasons, adult birds were equipped 13 ± 3 days on average.

Mass of male shearwaters ($n = 11$) was not different before ($\bar{x} = 656$ g, SD = 48) and after they wore the PTT ($\bar{x} = 651$ g, SD = 56; paired t-test, $t_{10} = 0.23$, $P = 0.80$). Although females ($n = 7$) weighed slightly more before they wore the PTT than afterward ($\bar{x} = 578$ g, SD = 40 vs. $\bar{x} = 538$ g, SD = 45), the difference was not significant (paired t-test, $t_6 = 1.75$, $P = 0.11$). We found no relationship between mass loss and the amount of time birds carried a PTT ($F_{1,16} = 1.16$, $P = 0.30$, $n = 18$). Because average maximum diving depths for control males ($\bar{x} = 4.8$ m, SD = 2.5, $n = 20$) and females ($x = 4.2$ m, SD = 3.0, $n = 18$) did not differ ($F_{1,36} = 0.39$, $P = 0.49$), we combined both sexes in subsequent analyses. We detected no difference in the maximum depth of dives between controls ($\bar{x} = 4.5$ m, SD = 2.7, $n = 38$) and birds carrying a PTT ($\bar{x} = 4.9$ m, SD = 2.5, $n = 8$; $F_{1,44} = 0.120$, $P = 0.70$) for adults.

When we combined both seasons, we estimated foraging trips based on satellite tracks to be an average of 2.4 days (10 M, 9 F; $n = 225$ days), indicating that chicks would be fed on approximately 83% of nights. Using data obtained from chick mass (see below), we found that chicks with parents carrying a PTT were fed on 85% of nights ($n = 13 \times 146$, chick × night), similar to our estimation from the satellite data. In contrast, chicks from nests in which no parent carried a PTT were fed, on average, on 92% of nights ($n = 14 \times 461$, chick × night), which was more frequent than chicks from nests of PTT-fitted adults ($\chi^2 = 5.06$, df = 1, $P = 0.02$).

The weighing of chicks ($n = 11$ and 20) provided 321 and 746 measures of meal mass in 2003 and 2004, respectively. Of those 1,067 measures, we excluded 54 meal masses involving 1 dead chick and 1 male desertion yielding a sample size of 1,013 meal masses. We found that meal mass brought back by adults carrying a PTT was less than meal mass brought back by control birds, but the difference was dependent on year (Fig. 2, Table 1). In 2003, average meal mass delivered to a chick when only 1 parent was equipped with a PTT was 42 g (SD = 48, $n = 27$), but this dropped to 34 g (SD = 32, $n = 16$) when both parents carried a PTT. Meal mass brought to chicks by adults carrying a PTT in 2003 ($n = 41$) was 54% less than that brought by adults not carrying a PTT ($n = 95$). However in 2004, adults carrying a PTT brought a meal mass ($n = 125$) weighing only 21% less than that brought by adults not carrying a PTT ($n = 291$). Using a mixed model to account for repeated measures of body mass on the same bird (entering chick identity as a random factor, see[Q2] Pinheiro and Bates, 2000), we found that the effect of carrying a PTT was highly significant (Table 1), reducing the average meal size by approximately 23 ± 4 g on average, essentially equal to the mass of the 22-g tag.

We compared chick's growth among the 3 groups (PTT, R-PTT, and No-PTT), using a logistic growth curve:

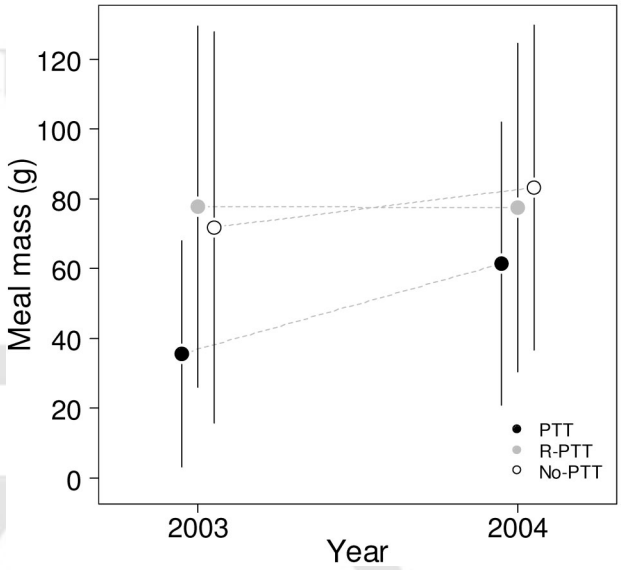

Figure 2. Effects of fitting breeding Cory's shearwater with a PTTs and year of study on the average meal mass (g) brought back by adult Cory's shearwaters to their chicks on nests on Lavezzi Island south of Corsica in the Western Mediterranean, 2003–2004. Comparisons are among: 1) PTT: birds carrying a satellite PTT, 2) R-PTT: birds with PTT removed after 12 days, and 3) No-PTT: birds that never carried a PTT.

Table 1. Modeling meal mass (g) brought by Cory's shearwater parents to their chicks on Lavezzi Island, South of Corsica, in the Western Mediterranean during the breeding seasons 2003–2004. Treatment included: birds carrying a platform telemetry transmitters (PTT); birds with PTT removed after 12 days (R-PTT), and birds never fitted with a PTT (No-PTT).

Effects	Estimate	SE	t value	Pr (>|t|)
PTT	41.268	7.568	5.453	<0.01
R-PTT	36.837	9.055	4.068	<0.01
No-PTT	30.802	8.432	3.653	<0.01
2004	18.980	8.721	2.176	<0.03
R-PTT × 2004	−19.834	10.433	−1.901	0.06
No-PTT × 2004	−7.854	9.897	−0.794	0.43

$p_i = \alpha/(1 + e^{\beta - \gamma t})$ fitted with a non-linear mixed model and entering chick identity as a random factor (Pinheiro[Q3] and Bates 1999). In the logistic curve, p_i is the chick mass measured at time t, α is the asymptotic body mass of chicks up to the age of 45 days, β is the initial instantaneous body growth rate, and γ is the rate at which the body growth rate decreases in time. In agreement with our predictions, we found that PTT chicks had a markedly different growth pattern than no-PTT and R-PTT (Fig. 3). Asymptotic body mass of PTT chicks was 20% lighter than the asymptotic body mass of both R-PTT and No-PTT chicks (Table 2). Similarly, the rate at which body growth decreased over time was 33% greater for PTT chicks than for No-PTT and R-PTT chicks (Table 2). However, R-PTT and no-PTT chicks had no distinguishable body growth patterns suggesting that removing PTTs from breeding birds after 15 consecutive days limited greatly the long-term consequences of a reduced feeding of chicks (Fig. 3).

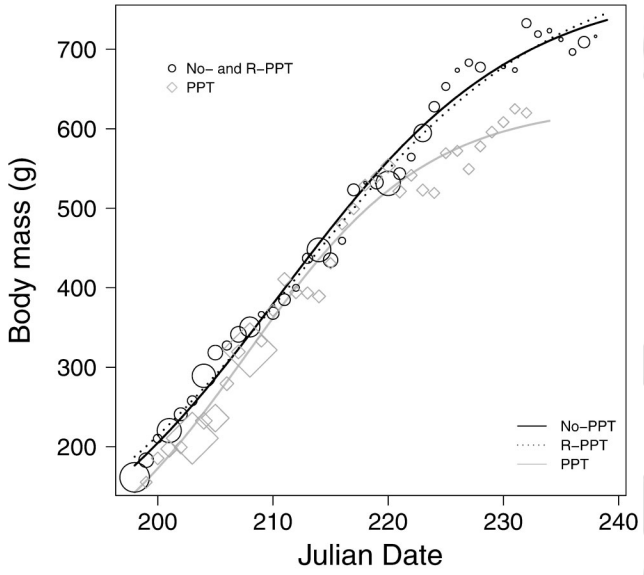

Figure 3. Effects of fitting breeding Cory's shearwater with a PTTs on chick's growth ($n = 1{,}069$) on Lavezzi Island, south of Corsica in the Western Mediterranean, 2003–2004 (PTT: birds carrying a satellite PTT; R-PTT: birds with PTT removed after 12 days; No-PTT: birds that never carried a PTT). Dot sizes correspond to the number of meal masses we measured on a given day (empty circles combined both groups: R-PTT and No-PTT because they have similar growth; empty diamonds represents the PTT group). Lines are the predictions from a logistic growth model fit to chick's body mass for R-PTT and No-PTT combined (in black) and PTT parents (in gray).

We then compared body mass of chicks at fledging (i.e., 29–30 Sep, chick age about 74–76 days) among the different treatment groups. After accounting for the year effect on body mass (782 ± 79 g in 2003 and 838 ± 78 g in 2004; $F_{1,99} = 11.8$, $P < 0.01$), fledglings with parents carrying a PTT (corrected body mass: $\bar{x} = 804$ g ± 91 g) did not differ in body mass from fledgings whose parents did not carry a PTT (corrected body mass: $\bar{x} = 830 \pm 82$ g; treatment effect: $F_{2,99} = 0.56$, $P = 0.57$). No interaction term between year and treatment could be detected either, meaning that the lack of treatment effect we observed holds for the 2 years of study (year × treatment first order interaction: $F_{2,97} = 1.07$, $P = 0.34$). Therefore, the marked difference in body mass we observed among the 3 groups (No-PPT and R-PPT vs. PTT) on 35-day-old chicks and consecutive to parents carrying a PTT was no longer detectable 1 month later at the time of fledging.

Table 2. Parameters estimated (±SD) from the logistic growth model using non-linear mixed models[Q4] (Pinheiro et al. 2005) applied to the body mass of Cory's shearwater chicks for the 3 parent groups: birds carrying a PTT, birds with PTT removed after 12 days (R-PTT), and birds never fitted with a PTT (No-PTT). The study took place on Lavezzi Island, South of Corsica, in the Western Mediterranean during the breeding seasons 2003–2004. α is the asymptotic body mass of chicks up to the age of 45 days, β is the initial instantaneous body growth rate, and γ is the rate at which the body growth rate decreases in time; ε is the residual error.

Treatment	α	SE (α)	β	SE (β)	γ	SE (γ)	ε
PTT	631.38	20.97	26.41	2.59	0.12	0.01	66.1
R-PTT	782.60	17.90	20.62	1.18	0.08	0.005	79.5
No-PTT	812.97	21.23	18.63	1.02	0.08	0.005	67.4

DISCUSSION

The field test of our attachment method of PTTs suggests this technique is suitable for small procellariiforms <1 kg. Estimated loss rate of PTTs was low and attached PTTs had little effects on the foraging behavior or body mass of adult Cory's shearwaters. Our results emphasized, however, that breeding adults may lower their parental care as a consequence of carrying a PTT. Chicks of adult birds carrying a PTT indeed had slower body growth than chicks of PTT free adults, a difference that vanished once PTT were removed.

Transmitters taped to the back feathers of procellariiforms have operated with varying success. For larger petrels weighing ≥1 kg such as the westland (*Pterodroma westlandica*) or white-chinned petrel (*P. aequinoctialis*) this method has been generally successful (Weimerskirch et al. 1999, Berrow et al. 2000, Freeman et al. 2001), whereas for smaller species of <1 kg such as sooty (*Puffinus griseus*), short-tailed (*P. tenuirostris*), and pink-footed shearwaters (*P. creatopus*) PTTs are often quickly lost (Klomp and Schultz 2000, Sohle[Q5] et al. 2000, Guicking et al. 2001). For small species, weak back feathers may limit their ability to retain PTTs. Instead of attaching transmitters to back feathers, we used the more robust humerals and strengthened the rachis with a piece of fishing line. With a 91% PTT retention rate (20/22), we believe this technique is a viable alternative to previous attachment methods used for small procellariiforms for which measured retention rates were 66% (2/3) and 40% (2/5) in short-tailed shearwaters *P. tenuirostris* (587 g) and pink-footed shearwaters *P. creatopus* (709 g), respectively (Guicking et al. 2001). Our technique also uses fewer feathers than when using back feathers, resulting in lower risk of damage and wound to birds. Overall, our method performed well in terms of PTT loss and damage to birds themselves or to their feathers.

Biologists express increasing concerns that tagging could negatively impacts fitness or affect the behavior of marked individuals (see Murray and Fuller 2000, Phillips et al. 2003 for reviews), though little attention is paid to the potential effects of tagging. In agreement with previous studies on bird species of similar size (Klomp and Schultz 2000, Söhle et al. 2000, Freeman et al. 2001, Söhle 2003), we documented that Cory's shearwaters outfitted with PTTs did not lose mass and their average maximum diving depths were not affected. Cory's shearwaters we monitored actually dove deeper (4.9 m on average) than those reported by Mougin and Mougin (1998) in the Atlantic Ocean (2.7 m on average). Consequently, the direct and short-term impacts of attaching PTTs on feeding and foraging abilities of Cory's shearwaters seemed minor. Long-term consequences of PTTs on adult birds could be different and needs more investigations as, for instance, the only individual that carried a PTT for several weeks (i.e., 48 days) abandoned its nest. Although the consequences of carrying a PTT may

be limited on adult birds, there may be consequences for chicks of tagged adults.

A potential side-effect of fitting adult birds with PTTs could be altered feeding behavior of their chicks because of the additional weight imposed by PTTs (e.g., Klomp and Schultz 2000, Söhle et al. 2000, Freeman et al. 2001, Phillips et al. 2003, Söhle 2003). A lower level of parental care may jeopardize chick survival to fledging or may decrease body mass of fledgings and ultimately decrease breeding success of tagged birds. As expected, we found that breeding birds carrying a PTT decreased the amount of food brought back to their chicks (see also Phillips et al. 2003). The decrease of 23 g in the amount of food brought on each trip we report was roughly equal to the transmitter mass (22 g). This similarity between the decrease in meal mass brought by a parent carrying a PTT and the mass of the PTT was also reported for black-browed albatross (*Thalassarche melanophris*, Phillips et al. 2003). Moreover, Cory's shearwater chicks with 1 parent tagged were fed 7% less often than chicks of untagged parents. This reduction in the amount of food received by chicks as soon as 1 parent is tagged accumulates over time and explains the different body growth patterns we observed among the treatment groups of chicks (Fig. 3). Body growth rate of PTT chicks ($\geq$1 parent fitted with PTT >15 days) slows down after 2 weeks, as compared to R-PTT (PTT removed from parents after 15 days) or No-PTT (parent without PTT, Fig. 3). At the end of the daily monitoring of chick breeding, PTT chicks weighed 20% less than R-PTT and No-PTT chicks. Such undesirable consequences of PTT tagging on chick body growth were also documented for Cassin's auklet (*Ptychoramphus aleuticus*) and tufted puffin (*Fratercula cirrhata*; Ackerman et al. 2004, Whidden[Q6] et al. 2007) both of which weigh <1 kg. Nonetheless, long-term consequences of reduced feeding on chick body mass were limited in our study, as fledgings were of similar body mass in all chick groups (PTT, R-PTT, and No-PTT). A likely reason for such a lack of long-term effects on fledgings is that adult birds were equipped with a PTT on average 13 days in our study, which is shorter than the critical 15 days (Fig. 3). After we removed a PTT from a breeding adult, chicks were indeed fed another 45 $\pm$ 6 days in 2003 and 52 $\pm$ 9 days in 2004 before we weighed them again on 29–30 September• During that period, adults could have compensated for the negative effects of carrying a PTT by bringing more food more frequently to their offspring so that body mass of chicks of the PTT group at fledging was similar to both No-PTT and R-PTT groups. Such compensatory growth may also explain why previous work on small procellariiforms reported no difference in breeding success or on chick body mass at fledging between tagged and untagged adult birds (Klomp and Schultz 2000, Söhle et al. 2000, Freeman et al. 2001, Söhle 2003).

Overall, despite our small sample size of monitored birds by PTT, observed differences in traits were large enough to indicate biologically important implications of carrying a PTT as compared to birds for which we removed the equipment and to control birds. Most importantly, chick's decrease in body growth was evident after a couple of weeks only, but long-term effects could have been limited in our study because we limited the time of PTT attachment. Our study highlights that a few particular behaviors and traits may be altered by tags such as PTTs and that chicks of marked adult birds may be particularly affected.

MANAGEMENT IMPLICATIONS

Using humerals for PTT attachment on shearwater species <1 kg appears to be a promising alternative to attaching PTTs to back feathers. Based on transmitters weighing 3.3–4.6% of the bird's mass and attached to humerals, we found that adults could compensate for the added mass and successfully fledge chicks as long as PTTs were not attached for >2 weeks. Beyond 2 weeks, growth rate of chicks of tagged parents slowed compared to control birds. Of course, this 2-week attachment period could probably be extended by using lighter transmitters (1–2% of bird mass, but should be tested), which might reduce torque on humerals and decrease the average meal mass brought by equipped bird less dramatically. To avoid losing the PTT, the same individual should not be equipped more than once in a breeding season or be tagged using another method than the 1 we present in this study. Finally, to avoid too large of a decrease of body growth of chicks, parents should not both be simultaneously equipped with PTTs.

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