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Effects of transmitters on the reproductive success of Tufted Puffins

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ABSTRACT. Although radiotelemetry is useful for monitoring nest attendance and the foraging ranges and distribution of breeding birds, attachment of transmitters may affect reproductive behavior. In 2003, we captured 25 adult Tufted Puffins (*Fratercula cirrhata*) at two colonies in Chiniak Bay, Kodiak Island, Alaska, and fitted them with subcutaneously anchored radiotransmitters (<1.2% of body mass). We determined the presence of radio-marked birds at each study site using automated, remote radiotelemetry systems, and compared rates of nestling growth, fledging mass, and fledging success for chicks with and without (control group) a radio-marked parent. Although most radio-marked adults continued to attend nests after capture and attachment of transmitters, nestlings with a radio-marked parent had lower mean growth rates (6.9 g/d vs. 14.4 g/d) and fledging success (33% vs. 84%) than control chicks. These results suggest that colony attendance by adult puffins fitted with transmitters declined sharply or completely and this led to high nestling mortality. Given the negative effects of transmitters on Tufted Puffins in our study and in other studies of alcids, we suggest delaying the attachment of transmitters until well after the brooding period. In addition, we recommend pilot studies be undertaken to distinguish the possible effects of capture and handling from those of actually carrying the device.

SINOPSIS. **Efecto de radiotransmisores en el éxito reproductivo de *Fratercula cirrhata***

Aunque la radiotelemetría es útil para monitorear la atención de los nidos, los patrones de forrajeo y la distribución de aves que se reproducen, el colocar radiotransmisores en aves puede afectar la conducta reproductiva. En el 2003, capturamos 25 adultos de frailecillos (*Fratercula cirrhata)* en dos colonias de Chiniak Bay, Isla de Kodiak, Alaska, y les colocamos, subcutaneamente, radiotransmisores (<1.2% de la masa corporal). Determinamos la presencia de cada ave "marcada" en cada área de estudio, utilizando un sistema automatizado remoto de radiotelemetría y comparamos las tasas de crecimiento de los pichones, peso de los volantones y éxito de los volantones con padres con y sin radiotransmisor. Aunque la gran mayoría de los adultos con radiotransmisores continuaron atendiendo a los pichones, estos presentaron una taza promedio de crecimiento (6.9 g/dia vs. 14.4 g/dia) y un éxito de dejar el nido menor que las aves control (33 vs. 84%). Estos resultados sugieren que la atención a los nidos de parte de adultos de frailecillo, a los cuales se les ha colocado radiotransmisores, se detiene o se reduce drásticamente y da lugar a alta mortalidad de pichones. Dado el efecto negativo de los radiotransmisores en los frailecillos, documentado en nuestro estudio y otros similares, sugerimos el dilatar la instalación de radiotransmisores en estas aves, posterior al periodo de empollamiento ("brooding"). También recomendamos que se lleven a cabo estudios pilotos para poder distinguir los posibles efectos de la captura y manejo para colocar radiotransmisores en estas aves.

Key words: Alaska, chick growth, *Fratercula cirrhata,* puffin, seabird, telemetry, transmitter effect

An assumption in radiotelemetry studies and other remote-sensing studies is that individuals fitted with the remote sensor provide unbiased estimates of measured parameters. However, attaching radiotransmitters and other remote sensors to marine birds can alter reproductive behavior (Wanless et al. 1985, 1988, Wilson et al. 1986, Massey et al. 1988, Croll et al. 1991, Taylor and Leonard 2001, Ackerman et al. 2004, Hamel et al. 2004), sometimes resulting in abandonment of a breeding attempt (e.g., Ackerman et al. 2004).

Radiotransmitters and other implanted or externally attached remote sensors (e.g., time depth recorders and satellite transmitters) may affect drag and wing-loading (Croll et al. 1991, 1992), and increase the energy required for flying and diving. This is especially important for alcids such as Tufted Puffins (*Fratercula cirrhata*) and other diving seabirds that have high wing-loading and use energetically expensive continuous flapping flight. Radio-marked birds may also respond physiologically or behaviorally to the presence of the device through,

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for example, increased production of stress hormones (Suedkamp Wells et al. 2003), excessive attention to the affected area (Nenno and Healy 1979), or abandonment of a breeding effort (Massey et al. 1988).

Alternatively, deleterious effects attributed to radiotransmitters may be a response to stressors associated with capture and handling. Burrow-nesting alcids are particularly sensitive to disturbance during the breeding season (Frazer 1975, Wehle 1976, Pierce and Simons 1986, Rodway et al. 1996), especially before hatching when parental investment is relatively low (Amaral 1977, Rodway et al. 1996). The sensitivity of incubating and provisioning alcids to capture and handling demonstrates a need for caution when attributing negative effects to radiotransmitters in correlational and nonexperimental studies.

Although the condition of parents naturally influences the condition of the offspring in altricial and semiprecocial species (Williams 1966), few investigators have focused on the effects on young of equipping parents with radiotransmitters and other remote sensors (Wanless et al. 1988, Söhle et al. 2000, Ackerman et al. 2004, Hamel et al. 2004). For long-lived, slow turnover, seabird species that favor self-preservation over reproduction and are difficult to monitor due to their pelagic and burrow-nesting habits, reproductive success represents a convenient means to identify the possible negative effects of transmitters on adults (Ackerman et al. 2004). As part of a study of the foraging ecology of Tufted Puffins, we captured and equipped one adult in each of 25 breeding pairs with a radiotransmitter. Our objective was to determine possible harmful effects on chicks provisioned by pairs with one radio-marked parent. Specifically, we compared growth rates, mass at fledging, and fledging success of nestlings with and without one radio-marked parent.

METHODS

Species and study site. Tufted Puffins are a long-lived, colonial species that breed from the coasts of California and Japan to the Chukchi Sea (Piatt and Kitaysky 2002). In the Gulf of Alaska, burrows are excavated on offshore islands and a single egg is laid between late May and early June. The mean incubation period is 45 d, hatching occurs from mid to late July, and chicks fledge from late August to early September. Both males and females incubate (Piatt and Kitaysky 2002). Rates of chick growth and fledging age vary with parental provisioning rates that depend on prey availability (Piatt and Kitaysky 2002) and, presumably, foraging experience.

We monitored nestling growth, fledging mass, and fledging success at three colonies in Chiniak Bay on Kodiak Island, Alaska (57°40′N, 152°20′W): Chiniak Island, Cliff Island, and Puffin Island (Fig. 1). Burrows monitored on Chiniak Island included treatment (one radio-marked parent) and control (no radio-marked parent) nests, whereas Cliff Island had only treatment burrows and Puffin Island had only control burrows. We assumed that puffins breeding on Cliff and Puffin islands experienced similar foraging conditions because these islands are only 2.7 km apart, and Tufted Puffins may forage as far as 100 km from their breeding colony (Piatt and Kitaysky 2002).

Capture and tagging. From 16 July to 1 August 2003, we captured, measured, and radio-marked (Model A2720; Advanced Telemetry Systems, Isanti, MN) 25 breeding adults on Chiniak ($N = 14$) and Cliff ($N = 11$) islands. All were captured in their burrows; four on eggs and 21 on chicks. Radios were attached using the subcutaneous anchor method (Newman et al. 1999, Parker et al. 2003) by inserting a sterilized anchor through a puncture in the skin made with an 18-gauge needle. Devices were positioned centrally on the back with the transmitter glued to feathers between the scapulae and the antenna facing backward. Total handling time was <20 min per individual. We used two transmitter designs: 7.5 g with a whip antenna 20 cm long and extending at a 45° angle from the back of the bird, and 9 g with a whip antenna of the same length but lying flat along the back. Transmitters weighed <1.2% of mean adult mass (774 ± 13.6 g), and had an expected life span of 11 weeks. At the time of capture, we determined nest status and measured the mass and wing chord of chicks, if present. Parents from control burrows were never captured.

Monitoring chicks and adults. We dug access holes for each burrow (25 treatment and 55 control) and placed either flat rocks or small plywood squares over the openings to facilitate access to nest chambers. We measured the mass and wing chord of chicks from treatment and control burrows every 4–9 d during the linear growth phase (day 10– 30) and every 4–5 d as

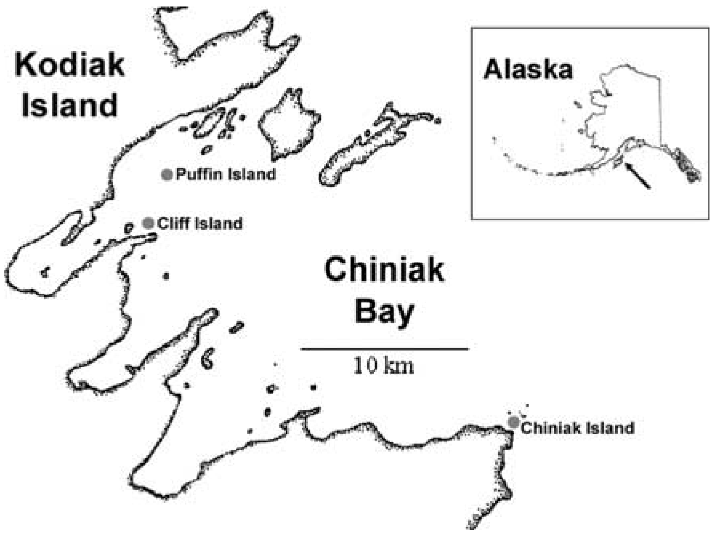

Fig. 1. Locations of three breeding colonies of Tufted Puffins within the Chiniak Bay study area on Kodiak Island, western Gulf of Alaska.

chicks approached fledging. The final nest check was on 14 September 2003. When hatch date was unknown, we used a wing chord versus age regression derived from known-age nestlings to estimate age (Gjerdrum 2001). We calculated growth rate as the slope of the linear regression equation relating mass and age during the near-linear portion of the growth curve (Gjerdrum 2001). We calculated fledging success as the number of chicks fledged per chick hatched; eggs that did not hatch were excluded from this analysis. Chicks were assumed to have fledged if their wing chord length was $\geq$130 mm (Gjerdrum et al. 2003) on the last day they were observed in the nest. We assumed that chicks that disappeared from burrows between successive visits and with wing chords $<$130 mm were dead.

We continuously monitored radio-marked adults at Chiniak and Cliff islands using R4000 receivers and D5041 data collection computers (Advanced Telemetry Systems, Isanti, Minnesota) at each colony. The receiving stations scanned through all 25 frequencies every 5 (Cliff Island) or 8.3 min (Chiniak Island). Detection ranges of the Cliff Island and Chiniak Island telemetry stations were 1 km and 2.5 km, respectively, and were determined using reference transmitters affixed to boats. The actual detection range for a radio-marked puffin was unknown and likely affected by activity (sitting vs. flying) and transmitter type. The detection range of birds equipped with antennas inclined at 45° was greater during aerial telemetry surveys (C.T.W., unpub. data). Although we did not detect any difference in colony attendance patterns for birds with the different transmitter designs, our small sample size precluded us from testing this directly. We considered a bird present at or near the colony if it was detected at least twice in 30 min. Before analyzing presence/absence data, we screened and excluded radio-frequency noise and other sources of poor data. The last day of detections was coincident with the last examination of burrows on 14 September 2003. We assumed that radio-marked adults had abandoned nests if last detected prior to nest failure or $>$7 d before fledging.

Statistical analyses. We performed all statistical analyses using SAS 9.1 (SAS Institute 2006), with the α-level set at 0.05. Because wing chord lengths (an index of age) on the day of the first nest visit were not normally distributed (Shapiro–Wilk test, $P < 0.05$), nonparametric tests (Mann-Whitney U tests) were used to compare wing chord lengths of control and treatment groups and to compare birds that fledged to those that did not. All other data met assumptions required for parametric analysis (Sokal and Rohlf 1981). Preliminary analyses revealed no significant colony differences within treatment groups for any reproductive parameter; colonies were therefore pooled for subsequent analyses. We compared growth rates, first wing chord measurements, and fledging masses of nestlings with and without one radio-marked parent using pooled t-tests. Although we excluded chicks that had not fledged by our last visit from analyses of fledging success and mass at fledge, we considered those chicks independently in the results and discussion. We compared fledging success of nestlings with and without one radio-marked parent using a continuity-adjusted chi-square test. Values are presented as means or proportions ± 1 SE. For significant differences, we estimated biological significance or effect size as the difference between means ± 1 SE.

RESULTS

Colony attendance. Twenty-three of 25 (92%) radio-marked adults were detected at the colony at least once after tagging and release. However, 48% of marked adults were not detected at the colony >15 d postcapture (Fig. 2). Of 18 radio-marked adults whose nests failed, six (33%) were detected for the last time after nest failure and nine (50%) prior to nest failure (we were unable to determine the order in the remaining three). Of seven radio-marked adults that fledged chicks, three (43%) were detected until or after fledging, three (43%) were detected for the last time >10 d before fledging, and one (14%) was detected for the last time six d before fledging.

Chick growth and fledging. Based on mean wing chord lengths, the age of chicks from treatment (39.5 ± 3.7 mm, $N = 24$) and control (33.2 ± 1.4 mm, $N = 49$) burrows did not differ ($U = 246$, $P = 0.25$) on the first nest visit. Nestlings with one radio-marked parent had significantly lower growth rates ($t = 6.3$, $P < 0.0001$; $N = 11$ and 49, respectively) than control chicks (6.9 ± 1.3 g/d and 14.4 ± 0.5 g/d, respectively), whereas mean mass at fledging did not differ ($t = 1.37$, $P = 0.18$, $N = 7$ and 42, respectively) between treatment (504.6 ± 25.6 g) and control (535.6 ± 8.3 g) groups. The effect size for the difference in mean growth rates was 7.5 ± 1.2 g/d. With the exception of a single nestling that grew at a rate of 15.1 g/d, growth rates of all chicks with a radio-marked parent were more than one standard deviation below the mean growth rate of control chicks. Pairs with a radio-marked adult fledged significantly fewer young (mean = 0.33 ± 0.10 chicks per pair; $N = 21$) than control pairs (mean = 0.84 ± 0.05 chicks per pair, $N = 55$; $\chi^2 = 15.9$, $P < 0.0001$). Chicks with one radio-marked parent were typically older than

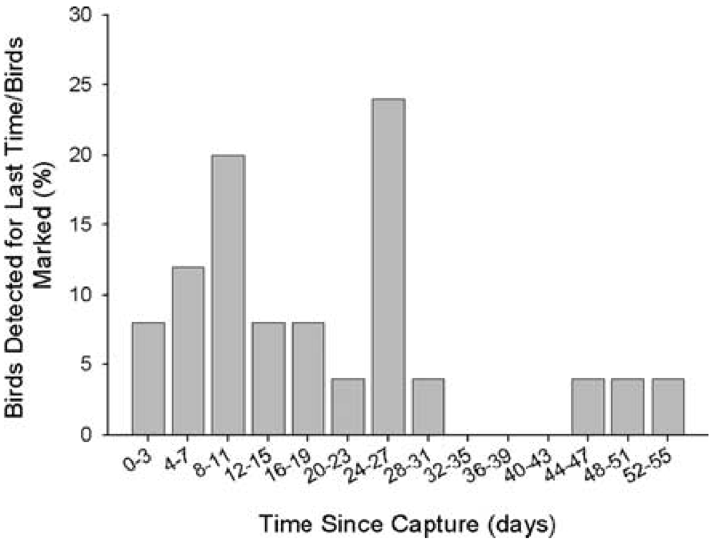

Fig. 2. Percentage of radio-marked Tufted Puffins ($N = 25$) detected at breeding colonies for the last time during each time period.

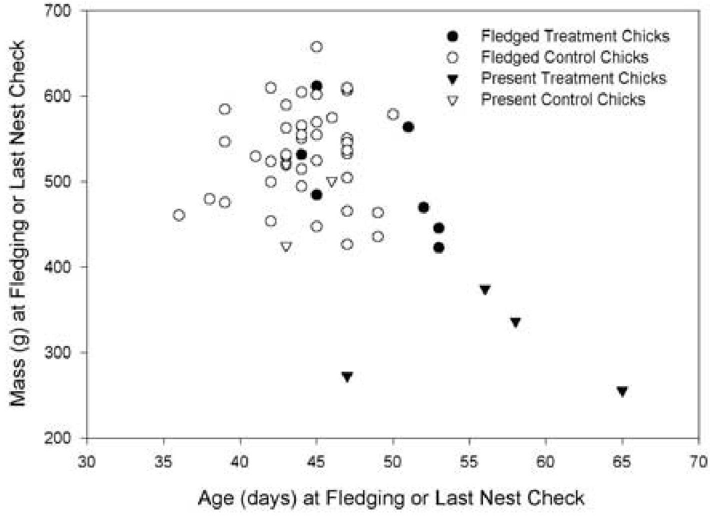

Fig. 3. Mass and age of treatment (one parent with a transmitter) and control (no parents with a transmitter) Tufted Puffin chicks that either fledged or were still in the nest burrow on our last nest visit.

control chicks at fledging (Fig. 3). Four chicks with one radio-marked parent that remained in nests at the last visit were smaller and older than four remaining control chicks (Fig. 3). Treatment chicks that fledged were significantly older ($\bar{x}_{wingchord} = 52.1 \pm 5.8$ mm, $N = 7$) when their parent was radio-marked than treatment chicks that did not fledge ($\bar{x}_{wingchord} = 33.4 \pm 4.7$ mm, $N = 13$; $U = 103.5$, $P < 0.02$). Treatment chicks that fledged were estimated to be 11.9 ± 1.8 d old when their parent was fitted with a radiotransmitter.

DISCUSSION

The growth rates and survival of chicks with one parent equipped with a transmitter were lower than for control chicks, indicating that radio-marking adult Tufted Puffins during the breeding season may adversely affect their reproductive behavior. Based on colony attendance data, adult mortality did not contribute to the poor reproductive performance of radio-marked parents, with most radio-marked adults continuing to visit the colony for several weeks. However, 55% of radio-marked adults abandoned their offspring prior to either fledging or nest failure. Thus, radio-marked adult puffins put less effort into provisioning chicks and some eventually abandoned nests, resulting in slow chick growth and poor fledging success.

Our study and other studies of alcids (Family Alcidae), including Common Murre (*Uria aalge*; Wanless et al. 1985, 1988, Hamel et al. 2004), Razorbill (*Alca torda*; Wanless et al. 1988), and Cassin's Auklet (*Ptychoramphus aleuticus*; Ackerman et al. 2004), provide evidence that alcids may alter their breeding behavior when marked with transmitters. Hamel et al. (2004) found that mates compensated for reduced provisioning by radio-marked Common Murres so there was no significant difference in provisioning rates of treatment and control pairs. Our results suggest that adult Tufted Puffins were either unable or unwilling to compensate for reduced parental effort by their mate.

Ackerman et al. (2004) reported that Cassin's Auklet chicks with one radio-marked parent grew more slowly, were smaller at fledging, and were less likely to fledge than chicks with no radio-marked parent. Despite a greater than two-fold difference in growth rates, the mass of Tufted Puffin chicks at fledging in our study did not differ between groups. The few nestlings with a radio-marked parent that survived to fledge compensated for lower growth rates by staying in the nest longer, allowing these chicks to fledge at masses similar to those of control chicks. Alternatively, we may have failed to detect a difference between groups in mass at fledging because our sample size was small ($N = 7$ chicks with radio-marked parent) and the variance in fledging masses was relatively large.

We also found that treatment chicks that fledged were significantly older when their parent was radio-marked than treatment chicks that did not fledge. Tufted Puffin chicks require constant brooding for the first few days after hatching (Piatt and Kitaysky 2002) and may be more sensitive to changes in parental behavior during this time. Furthermore, energy stores of nestlings increase with age and older nestlings may be more resilient to intermittent parental provisioning. To minimize the effects of attaching external devices, we recommend that investigators avoid disturbing birds both during incubation when adults are most sensitive to the effects of disturbance (Amaral 1977, Pierce and Simons 1986, Rodway et al. 1996), and during the early nestling period. For nesting Tufted Puffins, as well as for nesting Horned (*F. corniculata*) and Atlantic (*F. arctica*) puffins, we suggest delaying attachment of remote sensors to adults until about 12 d after their eggs hatch. Although radio-marking adults with older nestlings may enhance fledging success, time-budgets and the foraging behavior of marked adults may still be affected.

Given the potential for biasing data and the harmful effects of radiotransmitters and other attached devices (i.e., remote sensors) on both adults and offspring, we recommend caution when planning studies involving radiotelemetry. Because we did not capture parents at control nests, we do not know if reduced fledging success and growth rates were due to radiotransmitter effects, stress associated with capture and handling, or both. Irrespective of how transmitters affect breeding behavior, it is likely that Tufted Puffins, a long-lived species with high future reproductive potential, will transfer costs of disturbance to offspring to maximize their own survival and future reproduction (Williams 1966). For future studies involving attachment of external devices to alcids and other long-lived seabirds, we recommend pilot studies involving small numbers of birds to determine the possible effects of tagging.

Our study and those of others (Ackerman et al. 2004, Hamel et al. 2004, Wanless et al. 1988) have clearly demonstrated that radio-marking alcids can alter their behavior and nesting success. However, additional study is needed to distinguish the possible effects on the birds of capture and handling from those of actually carrying the device. If capture and handling have a negative impact on the birds, then alternative methods, such as capturing birds outside their burrows or using anesthesia to reduce stress (Newman et al. 2005), may be needed. Alternatively, if transmitters or other devices are causing the negative impact, additional study is needed to determine if altering the size, shape, and placement of the device (Croll et al. 1991) will minimize that impact.

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