The Condor 99:530–534

THE EFFECT OF CARRYING DEVICES ON BREEDING ROYAL PENGUINS[1]

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Abstract. The impact of Time Depth Recorders (TDRs) and VHF transmitters, deployed on Royal Penguins *(Eudyptes schlegeli)* to examine foraging behavior, was assessed during all stages of the breeding season. Models of the devices were attached to penguins and compared to control birds with no devices. There were no impacts from transmitters on probability of return from a foraging trip, foraging trip duration, mass gained, water influx, or body composition, but substantial impacts from the TDRs. Attachment of TDRs (1) reduced the likelihood that penguins would continue the breeding attempt, (2) increased foraging trip duration, (3) increased water influx, and (4) decreased fat levels. The effects varied with sex and stage in the breeding season, which appeared to be related to the energetic demands of the stage in the breeding season. TDRs probably increased drag, affecting swimming speed and foraging success. The differential impact of the devices is most likely related to their cross-sectional area and streamlining, with TDRs being larger and less streamlined than transmitters.

Key words: Royal Penguins, Eudyptes schlegeli, *devices, transmitters, time-depth recorders, foraging behavior.*

Studies of the foraging ecology of penguins often use data loggers and/or transmitters to record aspects of their behavior. However, the behavioral, reproductive and energetic effects on penguins equipped with such devices recently have been scrutinized (Obrecht et al. 1988, Croll et al. 1991, Culik and Wilson 1991). Deleterious effects range from increased foraging trip durations, reduced swimming speed, reduced food intake, increased energy expenditure, and impaired movement (Wilson et al. 1986, Gales et al. 1990, Culik and Wilson 1991). Generally, different species of penguin compensate for devices in one of two ways: (1) reducing their speed, foraging range, and mass gain, or (2) increasing the duration of foraging trips (Culik and Wilson 1991), or a combination of the two.

As part of a study of the foraging ecology and breeding biology of Royal Penguins *Eudyptes schlegeli* on Macquarie Island, Time Depth Recorders (TDRs) and VHF radio transmitters were deployed on birds throughout the breeding cycle. In the current study the effects of carrying these devices were quantified by comparing return rates, foraging trip length, changes in mass, water influx, and body composition of instrumented birds to control birds without devices.

METHODS

Royal Penguins from the upper Sandy Bay colony, Macquarie Island (54° 30′ S, 158° 57′ E) were studied at four stages of the 1993–1994 and 1994–1995 breeding seasons. These stages were: male incubation (end of October), female incubation (mid-November), guard (mid-December), and early creche (early January). Departing adults were captured on the beach to reduce human disturbance in the colony (Hull and Wilson 1996) and to ensure that the birds were undertaking a foraging trip. Breeding adults were selected on the basis of plumage characteristics (Warham 1971) and by the presence of a brood patch. Birds were sexed using bill morphometrics (Hull, in press).

The penguins were allocated to one of three treatments (Table 1): (1) control (no device; $n = 45$), (2) transmitter ($n = 26$), or (3) TDR ($n = 38$). The transmitters were an exact model of two-stage VHF radio transmitters, packaged in black, hydrodynamic waterproof housings (Faunatech, Eltham Victoria). They measured 47 × 25 × 11 mm (frontal cross-sectional area: 0.36 cm^2, 0.24% cross-sectional area of a Royal Penguin), weighed 9 g, had a 20-cm flexible antenna, were neutrally buoyant, and streamlined to reduce drag. The antenna was a multistrand, nylon-coated stainless steel wire, 1.0 mm in diameter. The TDRs were clear, perspex models of the Mark V Wildlife Computers TDRs, 62 × 38 × 12 mm, weighing 50 g, with a frontal cross-sectional area of 4.6 cm^2 (2.3% cross-sectional area of a Royal Penguin), and no streamlining. Other than the allocation to different groups, all penguins were handled in the same manner. A temporary velcro band with an unique number was secured on the right flipper of all penguins to identify individuals.

TDRs and transmitters were attached to the lower medial portion of an unanesthetized penguin's back using a cyanoacrylate adhesive (Loctite 401) which bonds quickly with the feathers of the bird. The loss of some devices from birds during the experiment resulted in unequal numbers of individuals in different stages of the breeding season. Transmitters were not deployed on male Royal Penguins during the incubation stage, and only on females during the guard stage as males do not undertake foraging trips at this time. Daylight observations were made from a hide on the beach so that birds could be recaptured when returning from a foraging trip. All devices and velcro bands were removed when penguins returned to the beach.

[1] Received 12 August 1996. Accepted 15 January 1997.

TABLE 1. The number of Royal Penguins used in each stage of the trials.

Stage	Device	No. deployed (returned)
Male incubation trip	control	15 (7)
	control 2*	15 (9)
	TDRs	12 (7)
	transmitters	not tested
Female incubation trip	control	10 (9)
	transmitters	10 (8)
	TDRs	10 (8)
Guard (females)	control	10 (4)
	transmitters	10 (6)
	TDRs	10 (2)
Creche (male)	control	5 (4)
	transmitters	3 (3)
	TDRs	3 (1)
Creche (female)	control	5 (2)
	transmitters	3 (1)
	TDRs	3 (0)
Total		122 (71)

* No tritiated water.

WATER INFLUX AND BODY COMPOSITION

Water influx and body composition were measured during the male and female incubation trips only. A 2-mL sample of blood was taken from the brachial vein (Samour and Jones 1983) in all birds to measure background levels of tritium. One mL (5 mCi/mL activity) of tritium, in physiological saline solution, was then injected intraperitoneally. The birds were left in an enclosure for 2 hr to allow the tritium to equilibrate with the body fluids (Green and Gales 1990). An additional 2 mL of blood was then taken and the bird released. When the penguins returned from a foraging trip they were reweighed, a 2-mL sample of blood taken, a second injection of tritium given, and then left for 2 hr to re-equilibrate. The birds were then bled again and released. This process was repeated on return from a foraging trip because of a greater than 10% change in mass, and consequently water pool sizes, during their time at sea (Green and Gales 1990).

Blood samples were frozen at −20°C until analysis back in Hobart, a few months later. Water was extracted from whole blood using vacuum distillation (Nagy 1983). Fifty μl of extracted water was added to 3 mL of PCS scintillation fluid, and counts of tritium made in a liquid scintillation counter (Beckman LS 5801). Water influx was measured from the decline in specific activity of the isotope between the initial equilibration and the recaptured equilibration, using equation four of Nagy and Costa (1980). Individuals whose isotope levels were less than four times the background levels (Gales 1989) following return from the foraging trip were deleted in analyses due to the inaccuracy of these flux estimates (Nagy 1980). Total body water was calculated from tritium dilution, and body composition (body fat content) was determined by comparing total body water, which is the inverse of body fat content (Groscolas et al. 1991), before and after a foraging trip.

An additional trial was carried out during the male incubation period to assess the effect of the tritium injection and handling time during the experiment. For this, 15 birds were banded with individually-marked velcro bands, weighed, then released. Their return rate, foraging trip duration, and mass change were recorded upon their return.

The likelihood of penguins returning to continue the breeding attempt was assessed using chi-square analysis. Mass changes, foraging trip duration, water influx, and body composition were analyzed using independent, two-tailed t-tests, two-way ANOVAs (stages and devices), and post-hoc Tukey tests. Mass change data were arcsine transformed. Data presented are mean ± SD.

RESULTS

There were no differences in return rate ($\chi^2_1 = 1.5$, $P > 0.05$), foraging trip duration ($t_{13} = 0.1$, $P > 0.05$), or mass gained ($t_{14} = 0.3$, $P > 0.05$) between birds with tritium and no device ($n = 7$), and birds with no tritium and no device ($n = 9$), indicating no adverse effect from the injection and handling. These two groups were subsequently combined to form the control group ($n = 16$) in further analyses.

Overall, 51 of the 122 (42%) penguins used during the experiment were not recaptured. Of these, 41 (76%) returned to the colony at some stage later in the season, but as failed breeders.

TRANSMITTERS

Deployment of transmitters produced no discernible effects on any variables examined. Penguins with transmitters were equally likely to return from a foraging trip as control birds ($\chi^2_3 = 13.6$, $P > 0.05$) (Table 1). There also were no differences in foraging trip duration ($F_{1,33} = 0.4$, $P > 0.05$), mass gained ($F_{1,31} = 0.03$, $P > 0.05$), water influx ($F_{2,16} = 0.2$, $P > 0.05$), or body composition change (Tukey's post hoc test, $P > 0.05$) (Table 2).

TDRS

In contrast, penguins carrying TDRs were less likely to return from a foraging trip during any stage ($\chi^2_3 = 13.6$, $P < 0.003$), and had longer foraging trips during the incubation stage (males: 24.9 ± 2.5 days; females: 20.1 ± 4.3 days) than control birds (males: 22.9 ± 1.7 days; females: 15.9 ± 2.6 days; $F_{1,47} = 8.7$, $P < 0.005$). Significant differences also were found in water influx in males with TDRs (148.0 ± 19.8 mL kg^{-1} day^{-1}, or 191% greater water influx; $t_5 = 7.6$, $P < 0.001$) than controls (77.4 ± 7.0 mL kg^{-1} day^{-1}), but not in females ($F_{2,16} = 0.2$, $P > 0.05$). Females with TDRs gained less fat than did control birds following their incubation trip ($F_{2,16} = 15.0$, $P < 0.001$), but males with TDRs did not differ from controls ($t_8 = 1.2$, $P > 0.05$) (Table 2). Mass gain was not significantly different for birds carrying TDRs at any stage ($F_{1,47} = 0.7$, $P > 0.05$) (Table 2).

DISCUSSION

The attachment of devices to penguins has been previously found to cause an increase in drag, and an impact on foraging behavior and/or foraging success (Wilson et al. 1986, Culik and Wilson 1991). However, the effects of devices on Royal Penguins and other

TABLE 2. The mean ± standard deviation of variables assessing the effect of transmitters and TDRs on Royal Penguins.

Variable	Treatment	Stage 1 (male incubation)	n	Stage 2 (female incubation)	n	Stage 3 (guard/creche)	n
Foraging trip duration (days)	Control	22.9 ± 1.7	16	15.9 ± 2.6	9	3.9 ± 2.4	10
	Transmitters	—	—	15.5 ± 2.8	8	3.3 ± 1.8	10
	TDRs	24.9 ± 2.5*	7	20.1 ± 4.3*	8	5.0 ± 2.0	3
Mass gained (% of body weight)	Control	46.0 ± 9.1	15	33.3 ± 10.2	9	10.6 ± 5.2	10
	Transmitters	—	—	36.2 ± 8.0	8	8.0 ± 9.0	10
	TDRs	32.4 ± 11.9	7	31.9 ± 11.2	8	15.9 ± 3.2	3
Water influx (ml kg^{-1} day^{-1})	Control	77.4 ± 7.0	6	191.4 ± 45.4	7	—	—
	Transmitters	—	—	194.4 ± 16.7	5	—	—
	TDRs	148.0 ± 19.8*	5	201.1 ± 28.1	7	—	—
Body composition (% difference of water before and after foraging)	Control	4.5 ± 2.1	6	4.2 ± 3.8	7	—	—
	Transmitters	—	—	5.7 ± 3.6	5	—	—
	TDRs	2.9 ± 2.3	5	−4.9 ± 3.9*	7	—	—

* Significant compared to controls, $P < 0.05$.

closely related species was not known, although these or similar devices have been used in previous studies (Brown 1987). The long foraging trips undertaken by Royal Penguins also enabled the assessment of instrument effects over extended periods.

EFFECT OF TRITIATED WATER EXPERIMENTS

Injection of tritium alone did not influence return rate, foraging trip duration or mass gained in Royal Penguins, indicating that injected birds were representative of the behavior of Royal Penguins at this time of year. Previous studies have found a decrease in body mass when penguins were injected in the pectoralis muscle with isotopes (Culik and Wilson 1992, Nagy and Obst 1992), perhaps due to an effect on foraging behavior caused by obstruction of this muscle (Nagy et al. 1984). In the current study penguins were injected intraperitoneally using small quantities of physiological saline solution (Culik 1994), which probably reduced any negative impact.

Water influx, estimated by a decline in the specific activity of tritium during a trip to sea, measures water intake from food, drinking and metabolism (Green and Gales 1990). In free-living birds, the most effective way of ascertaining the contribution of metabolism is to use ^{22}Na and ^{18}O, the known sodium and water content of prey, and the assimilation efficiency of the penguin species, and then extract the contribution of food and drinking (Green and Gales 1990). Measurement of these factors was beyond the scope of this study. The intake of water from drinking usually is assumed to be minimal and less than 5% of water influx rates (Robertson et al. 1988). Hence, the water influx values described here represent the contributions from the three factors (but, primarily food and metabolic water) and not free-living energetics alone.

EFFECTS OF DEVICES

Previous studies have found that the effects of devices are minimized if they are small, neutrally buoyant, streamlined, and attached as far caudally as possible (Bannasch et al. 1994, Culik et al. 1994). They should be placed exactly on the midline to prevent a rudder effect which forces penguins to alter their swimming course to compensate (Culik and Wilson 1991). Despite using as many of these recommendations as possible when deploying the devices during this study, there were still effects from the attachment of TDRs.

The addition of TDRs resulted in increased foraging trip durations during the incubation period. The TDRs used had a relatively large cross-sectional area, which presumably resulted in an increase in drag (Bannasch et al. 1994), causing increased energy expenditure by the penguins (Culik and Wilson 1991). Even small devices that are approximately 2% of the cross-sectional area of a penguin decreased swimming speed measurably in flow tanks (Culik and Wilson 1991). Further, the TDRs in this study were not streamlined. The penguin body is particularly well streamlined and the addition of any device disrupts the flow geometry around the bird (Bannasch et al. 1994). The TDRs probably affected swimming speed and therefore foraging success. Incubation-period foraging trips are no doubt important for penguins to regain lost condition following the prolonged fast during the early part of the breeding season. The addition of a TDR, with its associated extra drag, may make it more difficult for penguins to regain condition, thereby increasing the duration of foraging trips.

Furthermore, the attachment of TDRs decreased the probability that penguins would continue the breeding attempt. This probably occurred as a result of the increased drag from the device on swimming speed and foraging success. This would reduce the penguins' ability to regain condition and/or obtain sufficient food for chicks, forcing an abandonment of the breeding attempt. The inability to regain condition after fasting causes the abandonment of a breeding attempt in Adélie Penguins *Pygoscelis adeliae* (Davis and Miller 1992).

The effects of TDRs on body composition and water influx varied with the stage in the breeding season and/or the sex of the penguin. Differences in fat accumulation, indicated by body composition, were found in females carrying TDRs, but not in males. The quantity of fat acquired by females with TDRs was substantially less than controls (7.8% less, see Table 2). Conversely, males exhibited a considerable increase in water influx (191%), whereas females only showed a small, nonsignificant increase. This may reflect a size or physiological difference between the sexes, an ecological difference as females provide the first meal for chicks when they return from this foraging trip, or different ingestion rates between the sexes. The effect on body composition and water influx rates most likely arose, again, because of reduced foraging success, resulting in either the inability to acquire as much condition, or an increase in energy expenditure to obtain a given quantity of food. Although not measured, the effect is likely to be similar or greater during guard and creche stages because of the dual requirements of chick and adult maintenance (Gales et al. 1990).

By contrast, there was no effect on any of the variables tested for penguins carrying transmitters. This corresponds with previous work on Chinstrap Penguins *P. antarctica,* where effects were found only if devices were greater than 0.9% the cross-sectional area of the penguin (Croll et al. 1996). The transmitters used during the current study were streamlined with a very small cross-sectional area. The drag of an earlier, slightly larger model of this transmitter has been estimated at less than 17% for a 1 kg Little Penguin *Eudyptula minor* (Weavers 1992), with 70% of the drag attributable to the antenna. It is assumed that drag on Royal Penguins would be less than 17%, because of this penguins' larger size (approximately 5 kg). Although antennae have been previously found to increase drag and interfere with steering, causing serious behavioral disturbances when swimming (Fraser and Trivelpiece 1993), the lack of effect from the transmitters in this study suggests that the increase in drag is sufficiently small for these penguins to compensate.

The addition of devices did not affect mass, in contrast to previous studies (Wilson et al. 1986, Gales et al. 1990, Davis and Miller 1992). The effect was probably not found in the current study because Royal Penguins either compensated in other ways, or mass is not a sufficiently sensitive indicator of the impact of devices (Gales et al. 1990).

This study has found that the impact of devices is related to their design. Effects only were detected in the larger and nonstreamlined TDRs, confirming suggestions that device design should be made in relation to the animal's girth and frontal area, and be streamlined (Bannasch et al. 1994, Croll et al. 1996). The attachment of TDRs to penguins had several effects which differed with stage in the breeding season and sex, indicating that the impact of devices is complex. The increase in drag from TDRs probably affects swimming ability and foraging success, therefore, it can be assumed that return rates, the duration of foraging trips, water influx, and body composition of Royal Penguins equipped with TDRs will not be representative of natural behavior. Nor will studies in which these devices are used to measure swimming speed and foraging behavior, such as diving, be entirely representative of penguins under natural conditions. Satellite transmitters are now being deployed on penguins, and are generally larger than TDRs. Until the impact of these is measured empirically it can only be assumed that it is probably significant. Researchers should minimize the effects of devices by using appropriate device design until new technology is available.

This work was generously supported by the Antarctic Scientific Advisory Committee, and SeaWorld Research and Rescue Foundation grants. I would like to thank Mary-Anne Lea and Jane Wilson for assistance in the field, Keith Newgrain for analyzing the blood, and Mark Hindell, Leon Barmuta, Melissa Geise, Gerry Kooyman, and an anonymous referee for comments on the manuscript. Work was carried out under MI/34/94 and MI/3/95 Tasmanian National Parks and Wildlife permits.

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The Condor 99:534–538

A NEW APPLICATION FOR TRANSPONDERS IN POPULATION ECOLOGY OF THE COMMON TERN[1]

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Abstract. We injected transponders subcutaneously to mark single Common Tern (*Sterna hirundo*) adults and all chicks of a colony at Wilhelmshaven with the aim of establishing a completely marked colony. We present details on the equipment and methods and report preliminary results. Microtagged terns can be identified for life, not only at their nest when breeding, but also at resting places by fixed antennas at distances of < 11 cm. Thus, nonbreeders can be identified as well. We also weighed terns remotely to obtain information on their body condition. Body mass data as well as identification codes were electronically stored. Preliminary data indicated that adult survival was ≥ 87% and subadult survival until age two was ≥ 20%.

Key words: Common Tern, Sterna hirundo, *transponder, lifetime identification, marking technique, population biology, reproductive strategies.*

[1] Received 12 April 1996. Accepted 20 November 1996.

Long term studies of seabirds are costly and rare but essential to the understanding of their population ecology (Nisbet 1989). In small seabirds like terns, however, rates of survival, emigration, and immigration are not well known because of methodological problems. Individual color ringing has not proven successful. Rings are rarely visible at any distance and are not durable, and extensive trapping and retrapping of ringed adults can cause clutch desertion, trap-shyness, and unacceptable disturbance of the colonies (Nisbet 1978, Kania 1992). Furthermore, the removal of steel rings by African people on the terns' wintering grounds are a problem for population studies that use retrap or ring recovery analyses (Becker and Wendeln 1996). These obstacles also hinder the study of long-term aspects of population biology like lifetime reproductive success and fitness in relation to parental investment.

To investigate long-term aspects of Common Tern (*Sterna hirundo*) population ecology, we required a different method; marking birds with transponders