JOURNAL OF FIELD ORNITHOLOGY

Published by
Association of Field Ornithologists

VOL. 67, NO. 1 | Winter 1996 | PAGES 1–204

J. Field Ornithol., 67(1):1–9

FORAGING BEHAVIOR AND REPRODUCTIVE SUCCESS IN CHINSTRAP PENGUINS: THE EFFECTS OF TRANSMITTER ATTACHMENT

DONALD A. CROLL[1], JOHN K. JANSEN, MICHAEL E. GOEBEL[1], PETER L. BOVENG, AND JOHN L. BENGTSON

National Marine Fisheries Service
Alaska Fisheries Science Center
National Marine Mammal Laboratory
7600 Sand Point Way NE, Bin C15700
Seattle, Washington 98115-0070 USA

Abstract.—The effects of radio transmitter attachment on foraging trip duration and reproductive success of breeding Chinstrap Penguins (*Pygoscelis antarctica*) were studied on Seal Island, South Shetland Islands, Antarctica. Attachment of transmitters having a cross-sectional area 0.9% that of the penguin had no significant effect on foraging trip duration, nest visit duration or the number of foraging trips per nest per day. Adults equipped with transmitters had significantly lower chick survival rates than control animals, however. This difference resulted from a higher nest failure rate of transmitter-equipped adults. Most of these failures occurred in the early part of the guard period. The average number of chicks raised to the creche stage in successful nests was similar for control and transmitter-equipped animals. Thus, chick mortality occurred as a result of failure of the entire nest (i.e., abandonment by the adults) rather than lowered chick survival in individual nests. Nests at which both members were equipped with transmitters failed at a higher rate than nests at which one member was equipped with a transmitter. The transmitters used in this study may be considered a maximum size to be used for foraging trip duration experiments of medium-sized penguins.

CONDUCTA DE FORRAJEO Y ÉXITO REPRODUCTIVO EN *PYGOSCELIS ANTARCTICA*: EFECTO DE RADIOTRANSMISORES

Sinopsis.—Se llevó a cabo un estudio del efecto de radiotransmisores en la duración de viajes de forrajeo y éxito reproductivo en el pingüino *Pygoscelis antarctica.* El trabajo se llevó a cabo en Seal Island, South Shetland. El radiotransmisor no tuvo efecto significativo en la duración de los viajes de forrajeo, la duración de las visitas a los nidos y el número de viajes/nido/día. Los adultos equipados con radiotransmisores tuvieron una tasa de sobrevivencia de polluelos menor que el grupo control. La diferencia fue el resultado de una tasa de fracasos mayor en los pingüinos equipados con transmisores. La mayoría de los fracasos de anidamiento ocurrieron temprano en el período de vigilancia. El número promedio de polluelos criados hasta el etapa de "creche", en nidos exitosos, fue similar para el grupo ex-

[1] *Current address: Institute of Marine Sciences, University of California, Santa Cruz, California 95064 USA.*

perimental y el control. La mortalidad de polluelos ocurrió como resultado del fracaso de nido per se (ej. abandono de este por parte de los adultos). Los nidos en donde ambos adultos tenían radiotransmisores tuvieron una tasa mayor de fracaso que aquellos nidos en donde tan sólo uno de los adultos tenía transmisor. El transmisor utilizado en este estudio pudiera considerarse del tamaño máximo (9% del área del ave) a ser utilizado en pingüinos de tamaño mediano, para experimentos sobre la duración de viajes de forrajeo.

Use of radio telemetry permits measuring behavior in a manner not previously possible, often eliminating the need for long hours of vigil. It has been demonstrated, however, that attaching such devices to marine animals may significantly alter their behavior, leading to biased parameter estimates (e.g., Croll et al. 1991; Wanless et al. 1988; Wilson et al. 1986, 1989). The attachment of devices may lead to changes in behavior of the study animal through increased drag (Wilson et al. 1986) or the discomfort of the presence of the attached instrument package (Wilson et al. 1990). Croll et al. (1991) reported that attaching radio transmitters led to a significant increase in the duration of foraging trips of Chinstrap Penguins (*Pygoscelis antarctica*). It is important to understand the possible biases that might result from the use of animal-borne devices to collect behavioral information. Unfortunately, in many instances (e.g., diving behavior), it is difficult to assess accurately the impact of the attached device because comparable data from non-instrumented animals are not available. Some parameters, however, such as foraging trip duration and reproductive success, can be measured for birds with and without attached devices to assess instrument effects.

The use of radio transmitters has been accepted by the CCAMLR (Commission for the Conservation of Antarctic Marine Living Resources) Ecosystem Monitoring Program (CEMP) as a standard method with which to monitor foraging trip duration in penguins (Scientific Committee for the Conservation of Antarctic Marine Living Resources (SC-CEMP) 1991). In accepting this method, it was acknowledged that biases might potentially result from transmitter attachment, and that differences in foraging patterns might result from the attachment of transmitters to one or both members of a breeding pair. It was also noted that factors affecting variability in foraging trip duration should be examined to evaluate the utility of this method for monitoring ecosystem variability. This paper reports on: (1) the effects of radio transmitter attachment on nest attendance, foraging trip duration, nest failure and reproductive success in Chinstrap Penguins; (2) differences in these parameters when transmitters are applied to one or both members of a nest; and (3) variability in foraging patterns of penguins unencumbered by transmitters within the brood period. The present study extends our earlier work (Croll et al. 1991).

METHODS

Approximately 20,000 pairs of Chinstrap Penguins nest on Seal Island, South Shetland Islands, Antarctica (60°59′S, 55°23′W). This study was conducted from December 1990 to January 1991 in a discrete Chinstrap

Penguin colony composed of 666 nests (Seal Island CCAMLR study colony 25).

The methods used in this study were similar to those used by Croll et al. (1991). Transmitters were attached in the same manner as Croll et al. (1991), however the transmitters used in the present study were smaller (40% lower cross-sectional area) and tapered anteriorly to streamline the objects. Nests were individually identified by examining their relative location using Polaroid (reference to trade name does not imply endorsement by the National Marine Fisheries Service, NOAA) photographs. Attendance patterns of adult penguins at those nests were followed during three observation periods: early brooding (1800 hours, 31 Dec. 1990 to 2300 hours, 4 Jan. 1991), mid-brooding (2200, 13 Jan. 1991 to 2200, 15 Jan. 1991), and late brooding (2200, 25 Jan. 1991 to 2200, 27 Jan. 1991). Three experimental groups were examined during each period:

No instrument group (control).—A total of 102 nests that were active (eggs or chicks present) at the beginning of the observation period was used as a control group. No transmitters were attached to adults in this group. One member of each pair was marked on the breast with a spot of nyanzol-D dye (a black, waterproof dye) while the bird was incubating its egg(s). The birds remained on their nests during the approximately 15 s it took to mark them.

One adult with transmitter group.—One member of each pair at 20 nests brooding chicks was equipped with a radio transmitter and marked with picric dye (a yellow, waterproof dye).

Both adults with transmitter group.—Both members of each pair at 10 nests brooding chicks were equipped with a radio transmitter. One member was marked with yellow picric dye, the other with black nyanzol-D dye.

Radio transmitters (1.35-cm diameter × 6.8-cm length, 20 g weight, 1.4-cm^2 frontal cross-sectional area, 28.5-cm whip antenna) were attached to the contour feathers located on the middle of the animal's back using two cable ties and a small spot (approximately 3 g) of Devcon 5-min epoxy. The transmitter attachment and marking process took approximately 15 min from capture to release. The transmitters (Advanced Telemetry Systems, Model 2) were attached to the birds on 28–29 December.

A random sample of 50 nests was chosen from the 102 control nests prior to the first observation period to monitor nest attendance patterns. Nest attendance patterns for the control and treatment birds were recorded from an observation blind located within 50 m of all study nests. During each observation period, nests in all three groups were visually checked every hour, and the individual in attendance was identified and recorded. Whenever both members of a pair were present, the identity of the adult brooding the chick was recorded.

The survival of chicks and the failure of nests in the control group were followed from 29 Dec. 1990–30 Jan. 1991 (twelve nest-check dates) and in the treatment groups from 30 Dec. 1990–30 Jan. 1991 (eight nest-check dates). During each nest check, the number of eggs or chicks present in the nest was recorded. Nest failure dates were recorded as the first day that a nest was observed without chicks. A failure date of 13 January (the last date that a chick was observed to hatch in the control group) was ascribed to four control nests that were incubated but did not hatch eggs during the study. Chick survival was calculated for each of the three observation periods as the number of chicks present in nests on the last date of observations, divided by the number of chicks (and/or eggs) present in nests on the first date of observations. The number of chicks per active nest was calculated as the total number of chicks present divided by the number of nests in each group that contained chicks (i.e., nests that failed were excluded) for the beginning and conclusion of observations. Nest failure rate was calculated as the number of nests that had failed by the end of observations divided by the number of nests active at the start of observations.

To compare durations of feeding trips, attendance visits and overlap (both adults at the nest), the mean duration of each variable was calculated for each individual. The mean and variance among these individuals were then calculated and used in comparisons among treatments and time periods. This method eliminated possible bias resulting from overrepresentation of individuals that made a large number of short duration trips, visits or overlaps. The mean number of trips per day was calculated for each nest, using the total number of trips for both members of the nest. ANOVA and Chi-squared goodness of fit statistical tests were conducted using the SYSTAT statistical package (Wilkinson 1990). Times are given as hours in local time (Universal Time minus 3 h).

RESULTS

The average foraging trip and visit durations of each treatment group during each observation period are shown in Table 1. One-way analysis of variance demonstrated that neither the foraging trip durations nor visit durations of the treatment groups were significantly different from the control group in the same observation period. Comparison of the foraging trip duration and visit duration of the control group by period showed that both trip and visit durations were significantly different ($P < 0.01$) among the three periods. Multiple comparisons revealed that trip durations decreased significantly through the chick-brooding period, whereas visit durations during early brooding were significantly longer than those during mid- and late brooding, which in turn were not different. Comparison of the number of trips per nest per day between the three groups within each period revealed that there was no significant effect of transmitters (either on one or both members of the pair) (Fig. 1). The numbers of trips per nest per day in the control nests were significantly different among the three observation periods, however. Multiple comparisons (Tukey) showed that fewer trips were made during the early-brooding period than during both the mid- and late-brooding periods. There was no difference in the number of trips made during the mid- and late-brooding periods. The mean durations of overlap (Fig. 1)

TABLE 1. Mean foraging trip and visit durations (h), measured by visual observation during three periods, for nesting Chinstrap Penguins instrumented with radio transmitters on Seal Island, South Shetland Islands, Antarctica during the 1990–1991 breeding season. Values in parentheses indicate standard deviation and the number of penguins from which statistics were derived, respectively.

Period	Variable	Control	One member with transmitter		Both members with transmitters
			Bird with transmitter	Bird without transmitter	
Early brooding	Trip	13.4 (6.0, 99)	14.7 (4.7, 16)	14.6 (6.0, 16)	17.1 (9.6, 15)
	Visit	20.7 (7.2, 97)	20.8 (6.3, 16)	22.0 (6.6, 16)	17.5 (6.1, 15)
Mid-brooding	Trip	9.6 (2.7, 99)	11.5 (7.0, 10)	9.1 (2.7, 14)	11.1 (4.3, 12)
	Visit	13.6 (3.5, 99)	12.3 (4.5, 11)	17.0 (5.5, 13)	11.8 (4.1, 12)
Late brooding	Trip	7.8 (2.2, 89)	7.9 (1.7, 6)	7.6 (1.1, 5)	8.4 (2.0, 11)
	Visit	13.2 (5.6, 88)	9.3 (1.9, 5)	14.3 (5.7, 5)	10.6 (4.0, 11)

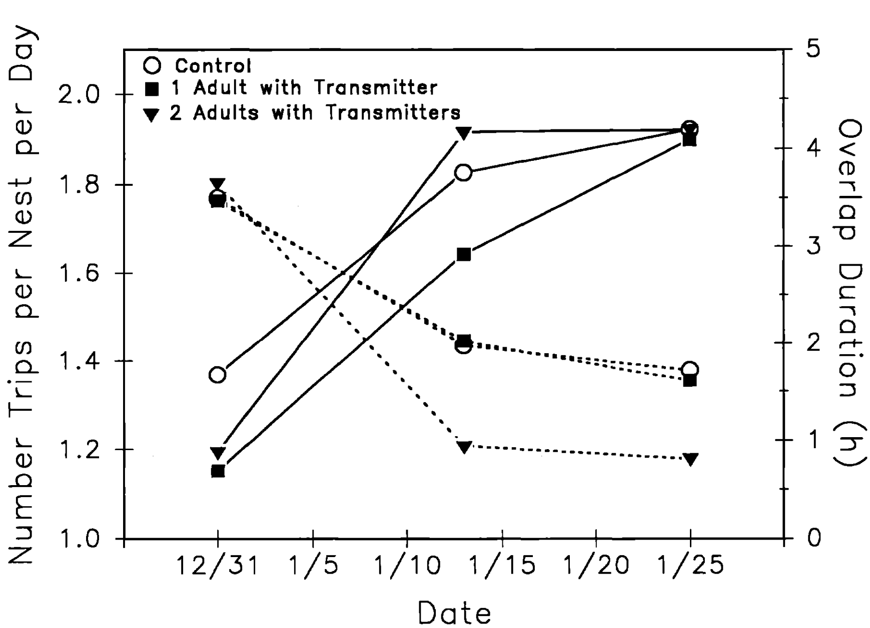

FIGURE 1. Mean number of trips per nest per day (solid lines) and overlap duration (h) (dotted lines) as measured by visual observations of Chinstrap Penguins nesting on Seal Island, South Shetland Islands, Antarctica, during the 1990–1991 breeding season.

TABLE 2. Chick survival, individual nest production and nest failure for Chinstrap Penguins instrumented with radio transmitters on Seal Island, South Shetland Island, Antarctica during the 1990–1991 breeding season.

	Control (no transmitter)	Treatment: One member with transmitter	Treatment: Both members with transmitters
Chick survival	76%	57%	47%
Chicks/nest:			
Start	1.74	1.4	1.70
End	1.43	1.23	1.33
% Change	−18%	−12%	−22%
Nest failure rate	12%	35%	40%

were also not significantly different among the three groups within each period. Comparison of the amount of overlap in the control group indicated significant differences ($P < 0.01$) among the early-, mid-, and late-brooding periods. Significantly more time was spent in overlap during the early-brooding period compared to the mid- and late-brooding periods (which were not different from each other).

Reproductive success of treatment and control groups is shown in Table 2. Significantly fewer chicks survived the study period in both groups in which transmitters were attached (to either one or both members of each pair) when compared with the control group ($P < 0.05$). Examination of the number of chicks per active nest and the nest failure rate revealed that although the decrease in number of chicks per active nest was not different between control and treatments (Table 2), there were significant differences among the control and treatment groups in the rate of nest failures ($P = 0.006$). Furthermore, a test for a gradient in proportions (Bartholomew 1959a,b; Fleiss 1981) indicated that there was a significant increase in the proportions of nest failures as the number of transmitters per nest increased, ($P < 0.005$).

Of the 12 nest failures in the control group, 50% occurred prior to 9 Jan.; in the treatment groups, 91% of the failures occurred prior to 10 Jan. Three of the 20 nests having one mate instrumented failed before the first nest check on 30 Dec. (the instrumented birds could not be located visually, although one was regularly detected on the radio-telemetry data logger).

DISCUSSION

Durations of foraging trips, visits and overlap.—In contrast to the study of Croll et al. (1991), the radio transmitters attached to Chinstrap Penguins in the present study had no significant effect on foraging trip duration. This contrast may have resulted from (1) differences in prey availability or environmental conditions that allowed the instrumented birds to forage more effectively in the present study than in the former study or (2) differences in the sizes of instruments used in the two studies.

Comparisons of chick growth rates, fledging weights and survival from hatching to creche (the point in the breeding period where chicks are left unattended by adults) on Seal Island indicated that overall conditions for rearing chicks during the brood period in 1990–1991 were similar to those during the 1989–1990 season (Croll et al., in press). As a result of this similarity, and the fact that the transmitters used in 1990–1991 were smaller than those used in 1989–1990, we favor the latter explanation.

The transmitters used in 1990–1991 had a frontal cross sectional area that was 40% of the frontal area used in 1989–1990 (1.43 cm^2 vs. 3.5 cm^2), and 0.9% of the frontal cross sectional area of the penguin (150 cm^2, Croll et al. 1991). As hydrodynamic drag is directly proportional to frontal area (Vogel 1981), the transmitters used in this study should have created much less drag in the water and therefore should have had less effect on swimming efficiency than the larger transmitters used previously. In addition, less epoxy was applied to the contour feathers when attaching the transmitters in 1990–1991, and the devices were tapered anteriorly to create a more streamlined object. Streamlining will significantly reduce the drag induced by the attached device (Vogel 1981).

The radio transmitters used in a study of Gentoo Penguins (*Pygoscelis papua*) (Williams and Rothery 1990) were similar in size to those used in the study by Croll et al. (1991) (18 mm diameter × 80 mm length, 35 g, and 20 mm diameter × 55 mm length, 25 g, respectively). It is possible that the increase in foraging trip duration observed by Williams and Rothery (1990) between brooding and creching may have been due to the chronic effect of transmitter attachment rather than changes in foraging patterns. We feel that the cross-sectional area of the transmitters used in the present study may serve as a maximum guideline for future studies of penguins of similar size because they did not produce the effects on foraging behavior observed for the larger transmitters by Croll et al. (1991).

Although neither the foraging trip durations nor the visit durations of either group equipped with transmitters were different from the control group, examination of Table 1 shows that foraging trips appeared to be slightly longer and visit durations slightly shorter for birds equipped with transmitters. This leads to the question of whether the failure to detect statistically significant differences was due to lack of an instrument effect or to high inter-individual variability of trip/visit durations and to small sample sizes.

Reproductive success.—Although no significant effects on foraging patterns were observed, the transmitters did affect reproductive success, most likely through interference with the adults' ability to provide chicks with food. Gales et al. (1990) made similar observations in a study of the foraging behavior and instrument effects in the Little Penguin (*Eudyptula minor*). They found that although foraging trip duration was unaffected by instrument attachment, the efficiency of foraging, as measured using water turnover, was significantly decreased. It is unclear, however, whether the effect observed in Chinstrap Penguins derives from some chronic effect on energetics and/or behavior, or the handling and attachment process. The early loss of the nests of instrumented birds supports the hypothesis that failure was due to a handling effect. As penguins in the control group were not handled in the same manner as those in the instrumented groups, any chronic effect of carrying the transmitters would be confounded with any handling effects that may have occurred (e.g., Culik et al. 1990). Future studies should control for handling procedures.

The transmitters used in this study did not affect foraging trip duration, regardless if they were applied to one or both members of nesting pairs. Examination of Table 2, however, reveals that in all parameters of reproductive success that were measured, nests at which both members were instrumented fared worse than nests at which neither (control) or one member was instrumented. Several of the differences in those parameters were statistically significant. We recommend attaching instruments to only one member of each nesting pair in studies using radio transmitters to measure foraging trip duration in nesting seabirds.

ACKNOWLEDGMENTS

We thank Mr. Yoshihisa Mori for field assistance on Seal Island, and the officers and crews of the *NOAA R/V Surveyor* and the *M/V Society Explorer* for providing outstanding logistical support. The Asociacion de Biologos Ambulantes provided useful discussions of instrument effects. This research was supported by the National Oceanic and Atmospheric Administration (NOAA) as part of its Antarctic Marine Living Resources (AMLR) Program.

LITERATURE CITED

BARTHOLOMEW, D. J. 1959a. A test of homogeneity for ordered alternatives. Biometrika 46: 36–48.

———. 1959b. A test of homogeneity for ordered alternatives II. Biometrika 46:328–335.

CROLL, D. A., J. K. JANSEN, AND J. L. BENGTSON. In press. Reproductive performance of Chinstrap Penguins on Seal Island, South Shetland Islands, Antarctica. Antarctic J. U.S.

———, S. D. OSMEK, AND J. L. BENGTSON. 1991. An effect of instrument attachment on foraging trip duration in Chinstrap Penguins. Condor 93:777–779.

CULIK, B., D. ADELUNG, AND A. J. WOAKES. 1990. The effect of disturbance on the heart rate and behavior of Adélie penguins (*Pygoscelis adeliae*) during the breeding season. Pp. 177–182, *in* K. R. Kerry and G. Hempel, eds. Antarctic ecosystems. Ecological change and conservation. Springer-Verlag, Berlin, Germany.

FLEISS, J. L. 1981. Statistical methods for rates and proportions. John Wiley and Sons, New York, New York. 321 pp.

GALES, R., C. WILLIAMS, AND D. RITZ. 1990. Foraging behavior of the Little Penguin, *Eudyptula minor*: initial results and assessment of instrument effect. J. Zool. Lond. 220:61–85.

SCIENTIFIC COMMITTEE FOR THE CONSERVATION OF ANTARCTIC MARINE LIVING RESOURCES. 1991. CCAMLR Ecosystem Monitoring Program: standard methods for monitoring studies. CCAMLR, 25 Old Wharf Rd., Hobart, Tasmania, Australia. 131 pp.

VOGEL, S. 1981. Life in moving fluids: the physical biology of flow. Willard Grant, Boston, Massachusetts. 352 pp.

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

WILKINSON, L. 1990. SYSTAT: the system for statistics. Systat Inc. Evanston Illinois.

WILLIAMS, T. D., AND P. ROTHERY. 1990. Factors affecting variation in foraging and activity patterns of gentoo penguins (*Pygoscelis papua*) during the breeding season at Bird Island, South Georgia. J. Appl. Ecol. 27:1042–1054.

WILSON, R. P., W. S. GRANT, AND D. C. DUFFY. 1986. Recording devices on free-ranging marine animals: does measurement affect foraging performance? Ecology 67:1091–1093.

———, N. R. CORIA, H. J. SPAIRANI, D. ADELUNG, AND B. CULIK. 1989. Human-induced behavior in Adelie Penguins *Pygoscelis adeliae.* Polar Biol. 10:77–80.

———, H. J. SPAIRANI, N. R. CORIA, B. M. CULIK, AND D. ADELUNG. 1990. Packages for attachment to seabirds: what color do Adelie penguins dislike least? J. Wildl. Manage. 54:447–451.

Received 26 Oct. 1992; accepted 24 Nov. 1992.