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BODY TEMPERATURE OF THE NESTING RED-FOOTED BOOBY (*SULA SULA*)

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The Red-footed Booby (*Sula sula*) nests in low bushes and trees in the Hawaiian Islands. The environmental conditions at the nesting site are extremely demanding (Howell and Bartholomew, Condor 64:6, 1962). There is no shade; the air temperature is quite high; there are both intense solar radiation and a great deal of radiant heat from the surroundings. Moreover, the air movement at the nest may be quite low and there is no fresh water available to replace water lost by evaporative cooling. In spite of this, an individual booby may sit on the nest from sunrise to sunset, conspicuously gular fluttering during the warmer parts of the day. Howell and Bartholomew (op. cit.) removed birds from the nest and quickly inserted a thermister probe into the stomach in order to measure their deep-body temperatures. Although the temperature recorded in this way was higher during the day than at night, the deep-body temperature did not exceed 42°C in any of the birds.

The purpose of the experiments described in this communication is to obtain continuous records of deep-body temperature in nesting boobies, using a telemetry technique which obviated the necessity to handle the birds, and in particular, to correlate changes in body temperature with behavior and indices of physiological thermoregulation such as gular fluttering.

MATERIALS AND METHODS

Two adult, female Red-footed Boobies were studied in the nesting colony established at Sea Life Park on the Island of Oahu. One of the birds was tested on two separate occasions. The deep-body temperature of the birds was recorded by feeding a "radio-pill" (Fox et al., J. Physiol. London 160:22, 1962) to the bird, in a fish. The radio pills were able to detect changes in temperature of 0.1°C, but the highest temperature that the pill was able to record varied in different pills. Its signal was detected by an antenna concealed near the nest, and a receiver (Rigel Instrument Co. Ltd.) approximately 25 ft away from the nest. Air temperature varied between a maximum of 30°C during the day and a minimum of 21.6°C at night. The amount of radiant heat impinging on the bird was estimated by means of black globe thermometer readings. Gular flutter rates were counted with the aid of a stopwatch.

RESULTS

Two separate experiments on one of the birds, a female, are illustrated in figure 1. On the first occasion, the telemetry capsule was fed to the bird while it was on the nest, at 10:15. Temperature readings were obtained until the bird left the nest at 19:45. The booby returned the next morning at 05:30, but the transmitter had been passed, presumably while the bird was feeding at sea. While the transmitter was in the bird, the booby was able to keep its body temperature below 40°C, although it was exposed to direct sunlight. During this time, the bird was observed to gular flutter at a rate of approximately 450/min. During the latter part of the afternoon, when the sun was obscured by cloud, the body temperature diminished and gular flutter did not occur at body temperatures below 39.3°C. The bird displayed a number of the behavioral thermoregulatory responses described by Bartholomew (Condor 68:523, 1966) for the Masked Booby during the course of the day. Its wings were held away from the body, the scapular feathers were elevated, and the bird tended to orientate its body so that the bill pointed away from the sun. In addition, the bird sometimes adopted a characteristic posture in which the body was tilted, head down, so that the entire head was in the shade of the bird's body. This was also observed in other boobies that were perched on adjoining branches of the tree or on rocks (fig. 2). In this posture, the bird appeared to be asleep and it did not gular flutter.

In the second test on the same booby, the radio pill was fed to the bird in the evening at 20:40, shortly after the female had returned to the nest after an absence of at least 12 hr. Unfortunately, the bird's temperature was beyond the range of the radio pill used on this occasion. Approximately 2 hr after the bird had returned to the nest, it was held gently and its rectal temperature taken by insertion of a mercury thermometer. The rectal temperature was 40°C. Forty-five minutes later, the bird's temperature could be detected by the radio pill (fig. 1). In spite of its relatively high deep-body temperatures, the booby did not display any indication that it was heat stressed. Gular flutter was absent and so also were the behavioral manifestations of heat stress observed in the previous test. The body temperature of the booby diminished while the bird was asleep (fig. 1). At 05:45, the booby awoke and exchanged positions on the nest with the male bird. It appeared to shiver at this time and the deep-body temperature increased (fig. 1). At the end of the test, shivering was again observed, but on this occasion it was prompted by the feeding of 10 cold fish (fig. 1). During the day, the body temperature of the bird increased to a maxi-

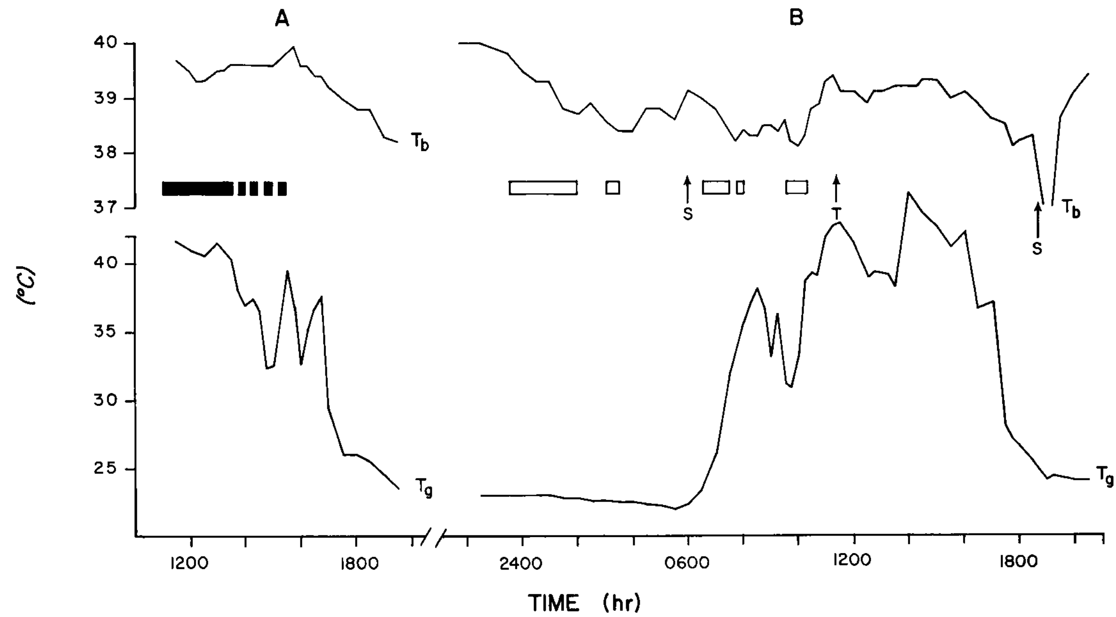

FIGURE 1. Deep-body temperature (T_b) of a mature, female, nesting Red-footed Booby recorded by telemetry on two separate occasions (A and B). T_g = black globe temperature; S = shivering; T = head-down posture; ■ = gular flutter; □ = sleep. The break in the body temperature record at approximately 1900 hr (B) represents cooling of the pill by fish fed to the bird.

mal value of 39.4°C. Although the repertoire of behavioral responses to heat observed during the first test was again evident, the booby did not display gular flutter. As may be seen in figure 1, the tilting of the body in a head-down posture seemed to be an effective means of reducing its body temperature.

The final experiment was performed on a second female shortly after she had returned to the nest, presumably after she had spent the night fishing at sea. Her initial deep-body temperature was high (41.8°C). The bird's temperature diminished during the day. Her behavior pattern during exposure to the sun was similar to that of the other bird. Gular flutter was observed and its occurrence was quite clearly related to the incidence of direct sunlight. The radio pill was recovered approximately 11 hr after it had been fed to the bird.

DISCUSSION

Several conclusions may be drawn from this study. In the first place, the range of body temperatures was similar to that determined by Howell and Bartholomew (op. cit.). It is noteworthy that the highest body temperatures were recorded immediately after the booby returned to the nest, presumably after flying continuously over the ocean. This conforms with the observation that flight of a few minutes duration by one of the birds, away from the nest, resulted in an increase in body temperature of 0.3°C. It is also in accord with the hyperthermic effects of flight activity in birds in general (Dawson and Hudson, p. 223. *In* Whittow [ed.] Comparative physiology of thermoregulation. Vol. 1. Academic Press, New York, 1970).

The pattern of thermoregulatory behavior in the Red-footed Booby was very similar to that described in the Masked Booby (Bartholomew, op. cit.). In addition, the head-down posture of the boobies observed in the present study seemed to be an effective behavioral response to heat.

Gular flutter was never observed when the deep-body temperature was lower than 39.3°C. On the other hand, gular flutter occurred at body temperatures in excess of this value only when the bird was exposed to direct sunlight. Gular flutter occurred within a few seconds of the emergence of the sun from behind a cloud. This observation would concur with that of Howell and Bartholomew (op. cit.). Clearly, the deep-body temperature has to exceed a certain value before gular flutter occurs and, equally clearly, when the body temperature exceeds this value, gular flutter occurs only in the presence of radiant heat, at least at the air temperatures encountered in the present study. The effectiveness of gular flutter is attested by the fact that the deep-body temperature of the bird while it was continuously engaged in gular flutter never exceeded 39.9°C (fig. 1).

It is interesting that shivering was observed when the birds awoke in the early morning hours. The air temperature at that time was approximately 22°C,

FIGURE 2. Characteristic posture of a Red-footed Booby during exposure to direct sunlight. The head is tilted down and the bird appears to be asleep.

while the deep-body temperature was 38.6°C (fig. 1). This probably reflects a lowering of the set-point for temperature regulation during sleep (Hammel et al., J. Applied Physiol. 18:1146, 1963). It would, however, be valuable to have some information on the lower critical temperature of tropical sea birds.

SUMMARY

The deep-body temperature of two nesting Red-footed Boobies was measured by telemetry. The birds were able to keep their body temperatures below 40°C during exposure to direct sunlight by gular fluttering and behavioral adjustments. At night, the body temperature decreased to 38.1°C and the birds were observed to shiver in the early morning at an air temperature of 22°C. The highest body temperature was recorded after the birds returned to the nest, presumably after flying over the ocean for many hours.

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NEST-SITE SELECTION IN BLACK-CAPPED CHICKADEES

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The choice of a suitable nesting site is of prime importance to breeding birds. Any factor that so directly affects the survival of offspring must be under very strong selective pressures.

In many cases it is extremely difficult to determine which member of a pair takes the lead in deciding where the nest will be. This is made even more complicated in species such as the Black-capped Chickadee (*Parus atricapillus*), in which both members of a pair regularly explore and excavate several potential nest sites before a final decision is made. Yet Odum (Auk 58:518, 1941) wrote of the Black-capped Chickadee, ". . . the female apparently takes the lead in the selection of the site . . ." (p. 518), although he did not present his evidence for this conclusion. This paper gives evidence which suggests that, at least in some instances, the male may take considerable part in nest-site selection in this species.

The observations reported here were made during a 3-year study of color-banded chickadees in Wellesley, Massachusetts. Much of the study area, on Wellesley College campus, was covered with natural mixed woods, approximately 75% deciduous and 25% coniferous. Major deciduous species included red oak (*Quercus borealis*), white oak (*Q. alba*), and gray birch (*Betula populifolia*); most of the cavities used for nests by chickadees in this study were located in trees of these three species.

The observations for this paper center around male O/O, banded 12 November 1970. During the winter of 1970–71 he was the dominant bird in a flock of six and was frequently observed associating closely with Blue/O, a female banded 20 November 1970. These two birds paired the following spring. Their breeding territory, comprising almost all of the winter flock territory, was approximately 18 acres, of which an estimated 45%, or just over 8 acres, was covered with natural mixed woods. Although they excavated at least three natural nest sites in these woods, their final choice was in a black metal sign post in a parking lot, in an unwooded part of their territory. This post was 59 inches high and 2 inches in inner diameter and was completely open from above. The nest was supported by the lower of two screws attached to the sign; this screw was 13 inches from the top of the post. The only branch overhanging the post was the tip of a white oak branch, 27 ft above the nest entrance. Nevertheless, the nest in 1971 was successful, fledging at least four young.

O/O was once again the dominant bird of a six-bird flock in the winter of 1971–72. His mate Blue/O disappeared from this flock in late October 1971. After her disappearance, O/O associated closely with Y/Y, a female who had been part of his flock the previous winter, and who had mated with another male in 1971. However, Y/Y was found dead on 8 March 1972. O/O associated briefly with still a third color-banded female, from a flock some distance away, but she too disappeared in early May, and for the next 5 weeks O/O was alone in his territory. The boundaries of this territory were essentially the same as in the previous year. During this 5-week period, he vigorously defended his territory from the two neighboring pairs and sang far more frequently than the other territorial males, especially during the middle of the day. This unusual singing behavior stopped abruptly on 12 June 1972, with the appearance of

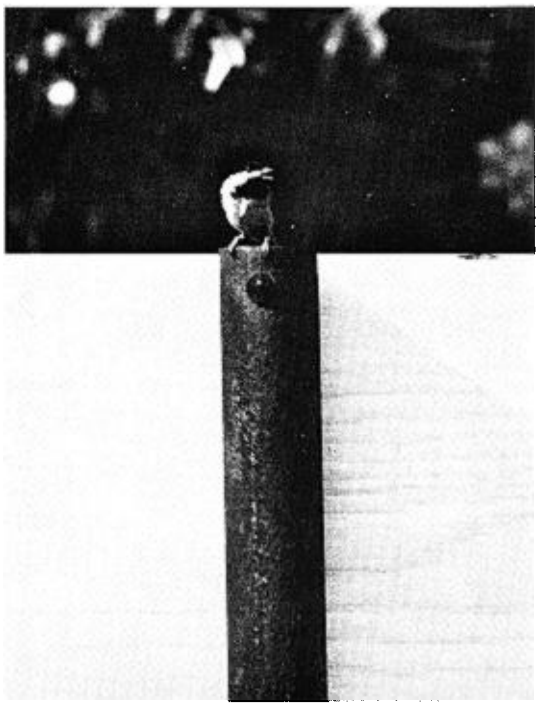

FIGURE 1. Female Black-capped Chickadee perched at the entrance to her nest in a sign post. Note the open bill and the sharp shadow caused by the afternoon sun.