# The Thermal Ecology of Basking Green Turtles *(Chelonia mydas)*

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*Grant 1765:* For a study of the thermal ecology of Hawaiian green turtles.

Although terrestrial basking is common among freshwater aquatic turtles (Boyer, 1965; Moll and Legler, 1971; Terpin et al., 1979), the only sea turtle that basks in the sun, on land, is the green turtle *(Chelonia mydas)*. Furthermore, only certain populations of green turtles have been reported to bask (Balazs, 1979). Among these, the Hawaiian population may be the most important in terms of numbers of turtles and the consistency of their basking behavior. Little is known about the biology of basking sea turtles. Balazs and Ross (1974) reported that six-month-old turtles kept in a tank at the Hawaii Institute of Marine Biology basked when given the opportunity, although animals of this age do not bask under natural conditions. In a later report, Balazs (1977) described the nocturnal basking behavior of green turtles at Necker Island in the northwestern Hawaiian Islands. Balazs (1979) reported that, at French Frigate Shoals, also in the northwestern Hawaiian Islands, the incidence of diurnal basking was highest during the breeding season of the turtles, when, presumably, the number of turtles present at French Frigate Shoals was highest. The purpose of the present investigation was to study the thermal aspects of basking in Hawaiian green turtles in the hope of discovering why the turtles bask.

## Methods

The site of the study was French Frigate Shoals, in the northwestern Hawaiian Islands. French Frigate Shoals is an atoll consisting of a crescent-shaped reef and approximately 12 small sand islands (Figure 1). Of these islands, Trig and Whale-Skate are favored for basking while East Island, which is the main site for nesting, is used particularly during the

[1] Co-investigator for this project was George H. Balazs, Hawaii Institute of Marine Biology, University of Hawaii, Honolulu, Hawaii.

egg-laying season. Most observations in the present investigation were made on Trig Island. Captive green turtles were studied at the Kewalo Marine Laboratory (University of Hawaii), the Hawaii Institute of Marine Biology (University of Hawaii), and Sea Life Park, an oceanarium on Oahu, Hawaii. On both Trig and Whale-Skate Islands, the procedure was to observe a single turtle and to keep a complete dossier of its movements, behavior, orientation with respect to that of the sun and wind, and its respiratory pattern, from the time of its emergence to the time of either its return to the ocean or when the observer left the island. Records were also kept of the temperature of a 15.2-cm black globe, the temperature of the sand surface, and the magnetic compass bearing of the sun and wind. Great care was taken to ensure that the turtle was not aware of the observer. This was usually achieved by lying prone behind vegetation. If the observer was seen by the turtle it appeared to remain alert, with its eyes open; but the profile of an observer standing close to a turtle would invariably provoke it to return to the sea.

The black globe (Casella & Co., London), painted with Nextel Black Velvet coating (Minnesota Mining Co.), was suspended 10 cm above the surface of the sand to approximate the midpoint of the turtle. The ratio-

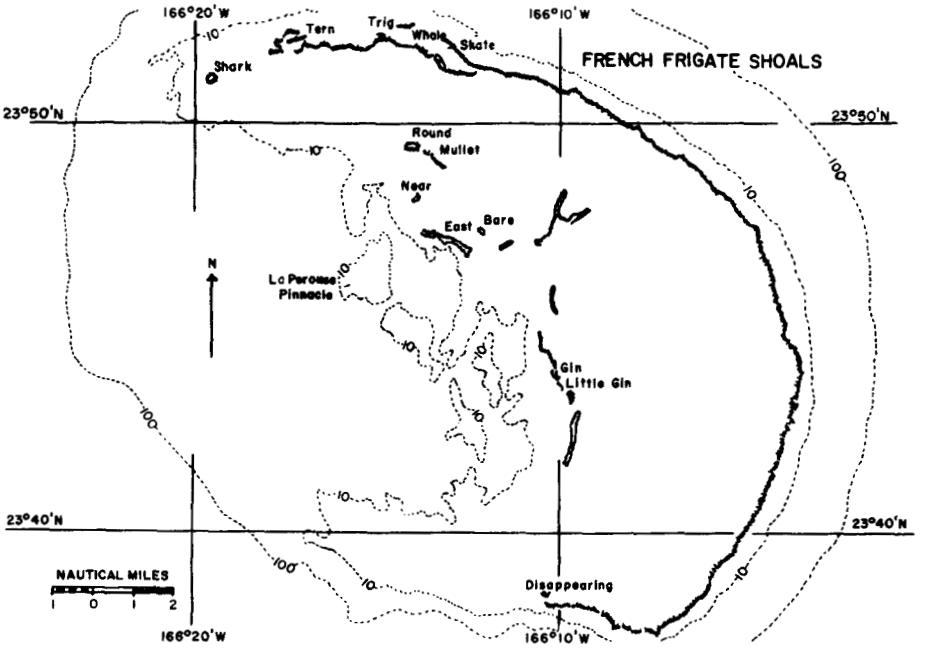


FIGURE 1. French Frigate Shoals showing Trig and Whale-Skate Islands.

nale for its use in field studies on the thermal ecology of basking turtles is similar to that for its use in field studies of basking seals (Whittow, 1978).

Sand surface temperatures, were measured with mercury thermometers; surface temperatures of carapace and plastron, with a Barnes Portable Infrared Thermometer (Model PRT-10-L), as described previously (Whittow, 1978).

The interval between breaths was measured with a stopwatch, using binoculars; most basking turtles raise their heads at each breath, which facilitates counting the number of breaths.

The orientation of the turtle was recorded with the aid of a sighting pocket compass. A compass was also used to measure the bearing of the sun and the direction of the wind, as described previously (Whittow, 1978).

## Results

*Thermal Profile of the Basking Beach.* On Trig Island, and also on Whale-Skate, the turtles prefer the side of the island facing the outer reef, and it is rare to see a basking turtle on the opposite side of the island. The basking beach also happened to be the beach facing the prevailing northeast trade winds. In Figure 2 the sand and black-globe temperatures are shown for both the basking beach and the beach not favored for basking. The data for the two sides of the island were obtained on the same day, so that they are directly comparable. It may be seen from Figure 2 that there was a striking difference between the thermal conditions on the basking beach and the opposite side of the island. This was true for both islands. Sand temperatures were lower, and black globe temperatures strikingly lower, on the beach favored by the turtles for basking. The basking beach faced the wind but, for the great part of the time, faced away from the sun—factors that probably contributed in large part to the cooler conditions on the basking beach. The slopes of the beaches, which may have a bearing on the amount of solar radiation incident on the turtles, were slightly different: 7° for the basking beach on both Trig and Whale-Skate, as opposed to 11.5° (Whale-Skate) and 9.3° (Trig) for the beaches where basking was rare.

*Basking Behavior.* The turtles began to come ashore to bask at midmorning and continued to do so during the afternoon. The duration of basking varied considerably. Some evidence was obtained that the duration of basking was greater, the lower the mean black-globe temperature while the turtle was basking (Figure 3). While the turtles were ashore they were extremely inactive. The only discernible movements were raising of the head each time that the turtle breathed, and sand flipping.

*Breathing Pattern.* The characteristic pattern of breathing in the basking turtles consisted of single respirations alternating with long periods of apnea (breath-holding). The mean duration of the breath-hold in the turtles at French Frigate Shoals was 219.2 sec, as shown below, but the range of values was considerable (50 to 635 sec). There did not appear

| | French Frigate Shoals | Kewalo Marine Laboratory | Sea Life Park |
|---|---|---|---|
| Mean (sec) | 219.2 | 227.8 | 217.4 |
| Standard deviation | 123.1 | 130.1 | 106.4 |
| No. of observations | 138 | 13 | 14 |

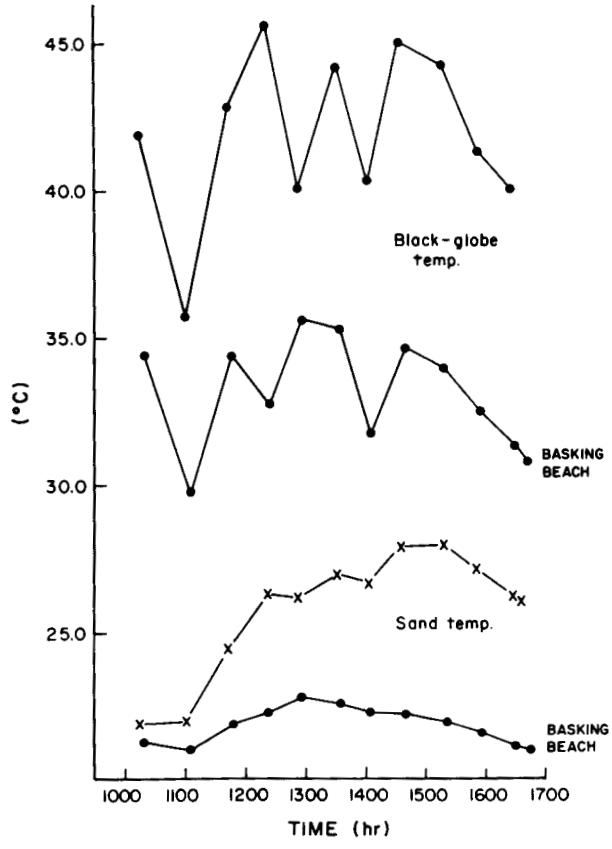


Figure 2. Sand and black-globe temperatures on the basking beach at Trig, and also on the beach not favored by basking turtles.

to be any trend in the respiratory pattern related to duration of basking. The breath-hold times recorded for captive animals at the Kewalo Marine Laboratory and Sea Life Park were within the range of those at French Frigate Shoals. So also were the times of voluntary submergence of the captive turtles in water, measured on seven occasions. On an eighth occasion, however, a captive turtle remained under water for 1032 sec. Most turtles raised their heads during a respiration, and many of them moved the head to one side. The turtles seemed more alert when taking a breath, and any small movements made by the turtles were executed immediately following a breath.

*Sand Flipping.* Many turtles flipped sand onto their carapaces with

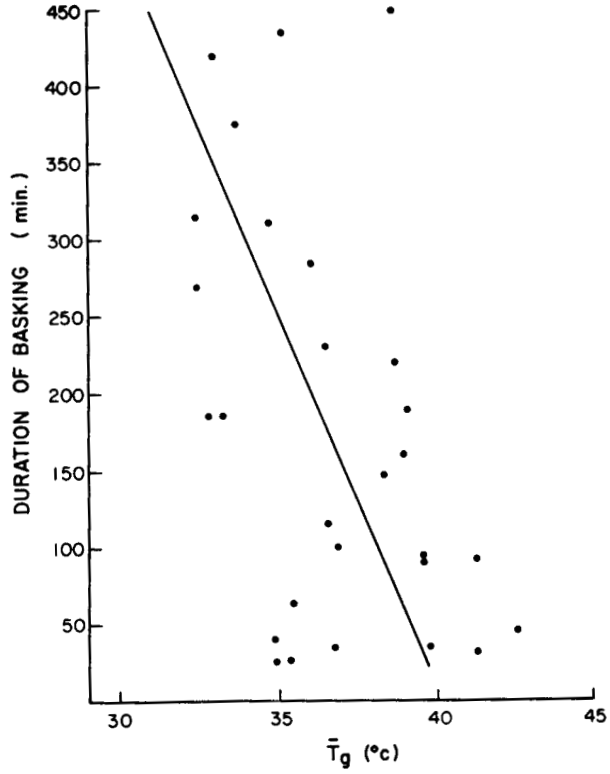


FIGURE 3. Relationship between the duration of basking and the mean black-globe temperature ($\bar{T}g$) during the basking period. Each point represents a separate turtle. The line is the fitted regression line ($y = 975{\cdot}96 - 21{\cdot}67\,x$).

their front flippers during basking. Because of the smooth surface and rounded contours of the carapace, little sand usually remained on the carapace, but it tended to accumulate on the edges. Continued vigorous sand flipping could cover as much as one third of the carapace with sand. Sand flipping did not occur until the carapace was dry, and it occurred more frequently on very hot days. On relatively cool, cloudy days, sand flipping was not seen. Simultaneous measurements of the temperature of the sand-covered carapace and of the uncovered carapace revealed that the latter could be 10°C warmer than the sand on the carapace. A variation of sand-flipping behavior was seen in the captive turtle at the Kewalo Marine Laboratory. This turtle was provided with a wooden basking ramp and it very often basked parallel to and close to the edge of the water in its tank. In this position, it was able to flip water over its carapace with one of its flippers.

*Orientation.* No evidence was obtained that the turtles changed their orientation with respect to either the sun or wind. The turtles very often remained in the same position for long periods of time; this was usually the position that they had adopted on first emerging from the ocean.

*Carapace Temperature.* The carapace temperatures of basking turtles at French Frigate Shoals, and of captive turtles, are given below:

| | N | $\bar{x}$ | S.D. | RANGE |
|---|---|---|---|---|
| French Frigate Shoals | 38 | 34.5 | 4.0 | 25.0-42.3 |
| Kewalo Marine Laboratory, Honolulu | 16 | 37.3 | 2.4 | 32.0-40.0 |
| Sea Life Park, Oahu | 20 | 37.8 | 2.3 | 35.0-42.8 |

The measurements were obtained under widely varying conditions but they were all made when the carapace was dry and exposed to direct solar radiation. The mean carapace temperature was slightly higher in the captive turtles, possibly reflecting the hotter conditions prevailing in their more southerly situation. In many ways, the ranges of values shown above are more instructive than the means of the values. The lowest temperature (25°C) was obtained in the late afternoon when conditions on the beach were relatively cool. The highest temperatures (40.0 to 42.8°C) suggest that the turtles may be absorbing a significant amount of solar radiation.

*Rectal Temperature.* The number of measurements of rectal temperature was limited by the consideration that, unlike other observations and

measurements in this study, it involved interference with the animal. Results on 17 animals were:

| N | $\bar{x}$ | S.D. | RANGE |
|---|---|---|---|
| 17 | 28.7 | 1.4 | 26.9-31.3 |

As in the case of the carapace temperature measurements, the values were obtained under a variety of conditions and the mean value is probably less informative than the highest reading (31.3°C). This value was 5°C higher than the ocean temperature. Higher rectal temperatures might have been recorded if more measurements had been made. Assuming that the mean body temperature of the turtle was 31.3°C, that the specific heat of the tissues was 0.83, and that the turtle's body temperature was close to that of the ocean when it emerged to bask, it was calculated that the turtle had stored 465 kcal of heat during basking. This calculation was based on an estimated body weight of 112 kg, derived from measurements of the turtle's linear dimensions. The estimated weight of the turtle was also used to obtain a value for the resting metabolic rate of the turtle (Prange, 1976). It transpired from these calculations that the quantity of heat stored by the turtle was more than 12 times the hourly metabolic rate of a turtle of these dimensions.

*Shade, Cloud, Rain.* There is no shade on the beaches at French Frigate Shoals, and turtles clearly do not leave the ocean in order to seek shade. At Sea Life Park, part of the basking area was shaded by a tree, and it is interesting that on one particularly hot, still day, two turtles were observed to bask in the shade.

Turtles were never observed to bask when it was raining. In fact, on Trig Island two basking turtles were observed to return to the ocean during a brief, heavy rain. Captive turtles did not bask during prolonged heavy rain, either. In both captive turtles and the turtles at French Frigate Shoals, the incidence of basking was high on the first sunny day following stormy, rainy weather. Turtles that had emerged from the ocean to bask during sunny weather remained ashore with the advent of cloudy conditions. On occasion, turtles—both captive animals and those at French Frigate Shoals—were seen to bask in cloudy weather.

## CONCLUSIONS

The observations made in this study suggest that basking green turtles may absorb a significant amount of solar radiation. However, the effect of any absorbed heat is lessened by the selection of a relatively cool beach and by the complete inactivity of the turtles, apart from thermoreg-

ulatory behavior. These factors may enable the turtles to stay on the beach for a longer period of time than they would ordinarily. Freshwater aquatic turtles are believed to derive a number of benefits from basking, including synthesis of vitamin D, destruction of algae, and improvement of digestion (Boyer, 1965; Moll and Legler, 1971; Gatten, 1974). To these might be added, for Hawaiian green turtles, evasion of predatory tiger sharks. The basking behavior of Hawaiian green turtles may in fact be made possible by the prevalence of the northeast trade winds and the highly reflective, cool, white sand of the northwestern Hawaiian Islands. A similar conclusion was made with regard to the thermoregulatory behavior of the Hawaiian monk seal, which shares the basking beaches with the turtles (Whittow, 1978).

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