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Basking Behavior of the Hawaiian Green Turtle (*Chelonia mydas*)[1]

G. C. WHITTOW[2] and G. H. BALAZS[3]

ABSTRACT: Observations were made on green turtles basking on the white sand beaches at French Frigate Shoals in the northwestern Hawaiian Islands. The highest rectal temperature recorded from the basking turtles was 31.3°C, but the surface temperature of the carapace attained values as great as 42.8°C. During basking, the turtles flipped sand onto their carapaces, but they did not appear to orientate their position in relation to the sun. The duration of basking was inversely related to the mean temperature of a black globe, and the basking beaches were relatively cool. The pattern of breathing during basking consisted of periods of breath-holding alternating with single breaths. The amount of time that the turtles basked varied from 0.3 to 7.5 percent of the total time they were under observation. The biological significance of basking and the advantages that might accrue to Hawaiian green turtles from their unique basking behavior are discussed.

TERRESTRIAL BASKING IS COMMON in freshwater aquatic turtles, and its biology has been described by several authors (Boyer 1965, Moll and Legler 1971, Terpin, Spotila, and Foley 1979). Among sea turtles, however, basking on land is comparatively rare. Only the green turtle (*Chelonia mydas*) has been reported to bask, and it does so only in certain parts of the world, notably in the northwestern Hawaiian Islands. One of eight breeding colonies that have been designated for high priority by the World Conference on Sea Turtle Conservation (1979) is located at French Frigate Shoals in the northwestern Hawaiian Islands.

Little is known about the basking behavior of Hawaiian green turtles. Balazs and Ross (1974) showed that 6-month-old turtles kept in a tank at the Hawaii Institute of Marine Biology basked when given the opportunity, although turtles of this age have not been observed to bask under natural conditions. At French Frigate Shoals the incidence of basking was highest during the breeding season, when, presumably, the number of turtles present was greatest. Balazs (1980) showed further that during the nesting season, the number of basking turtles declined as the egg-laying season progressed. However, there is not a month in the year when turtles have not been observed to bask. Both male and female turtles have been reported to bask (Balazs 1980). Turtles that formerly basked off the coast of Mexico and in the Galápagos Islands were predominantly female (Fritts 1981) and so also are the turtles that presently bask in Australia (Bustard 1973). In another report, Balazs (1977) described the nocturnal basking behavior of green turtles at Necker Island in the northwestern Hawaiian Islands. This latter behavior points to the possibility that the function of basking may not be that of acquiring heat by solar radiation, although this is believed to be one of the principal functions of basking in freshwater turtles (Boyer 1965).

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[2] University of Hawaii, John A. Burns School of Medicine, Department of Physiology, and Pacific Biomedical Research Center, Kewalo Marine Laboratory, Honolulu, Hawaii 96822.

[3] University of Hawaii, Hawaii Institute of Marine Biology, Kaneohe, Hawaii 96744.

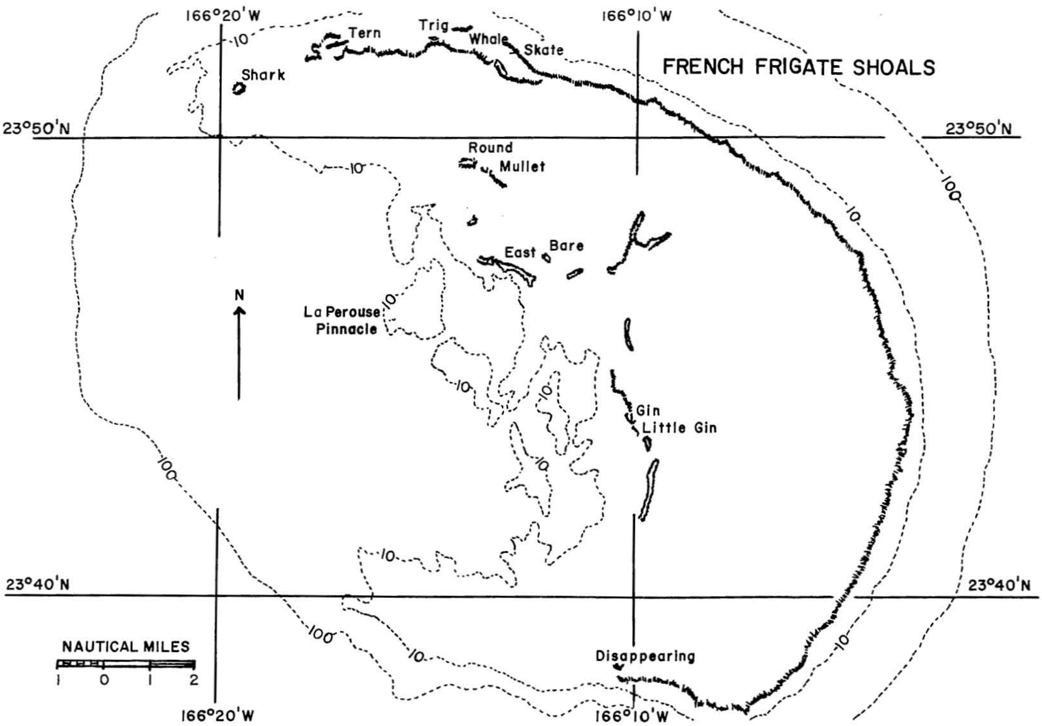

FIGURE 1. Map of French Frigate Shoals showing Trig, Whale-Skate, and East islands. Depths in fathoms.

The purpose of the study reported here was to obtain additional information on the basking behavior of Hawaiian green turtles, with special reference to their thermal ecology. It is apparent that the thermal environment during basking on land is considerably different from that in the ocean. A better understanding of the dimensions of this environment and of its impact on the turtles seems likely to provide valuable insights into the nature of basking.

PROCEDURES AND METHODS

Basking turtles were studied mainly on Trig Island at French Frigate Shoals, which consists of a crescent-shaped reef with approximately 12 small sand islands (Figure 1). Of these islands, Trig and Whale-Skate are favored for basking throughout the year, while East Island, which is the main site for nesting activity, is used particularly during the breeding season. Studies of captive green turtles were made at the Pacific Biomedical Research Center, 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 the sun and wind, and respiratory pattern, from the time of its emergence to the time of its return to the ocean, or until the observer left the island. Records were also kept of the temperature of a 15.2-cm-diameter black globe, the temperature of the sand surface, and the magnetic compass bearing of the sun and wind. Care was taken to ensure that the turtle being observed was not aware of the presence of the observer. If the observer was seen by the turtle, it appeared to remain alert, with its eyes open. The profile of an observer against the sky, or the proximity of an observer to a turtle would invariably provoke it to return to the sea.

Occasional measurements were made of the surface temperature of the carapace of the turtles, both at French Frigate Shoals and in the captive situation. The rectal temperature of some turtles at French Frigate Shoals was also measured.

Additional observations on basking behavior were made in the course of a separate study by the authors in which tracking telemetry transmitters were attached to the carapace of four male and four female adult turtles. The purpose of this study and the telemetric techniques used are described elsewhere (Dizon and Balazs 1982). The transmitters incorporated a thermistor, so that when the turtle emerged from the ocean the temperature increased as a result of exposure to the higher air temperature and solar radiation. Consequently, the basking behavior of a turtle could be detected by a rise in the temperature of the transmitter, together with the recording of a continuous signal from the transmitters; the signal from a submerged turtle could not be received. The receiving station was mounted on Tern Island and the range of the transmitters permitted the detection of basking on Trig, Whale-Skate, and East islands. Six of the eight turtles were monitored for a period of 20 days. Contact was lost with the other two turtles—both males—after 4 and 17 days, respectively. In several instances, confirmation of basking, presumed from telemetric recordings, was provided by visual observations. However, at night, telemetric recordings did not permit a distinction to be made between turtles that were ashore nesting and those that were basking. Therefore, the telemetric observations were mainly of value in the detection of basking during the day.

The black globe (Casella & Co., London) was suspended 10 cm above the surface of the sand to approximate the midpoint of the turtle. It was painted with Nextel Black Velvet Coating (Minnesota Mining Co.). The rationale for its use in field studies on the thermal ecology of basking turtles is similar to that for basking seals (Whittow 1978). Sand surface temperatures were measured with mercury thermometers, and the surface temperature of the carapace was determined with a Barnes Portable Infrared Thermometer (Model PRT-10-L). Rectal temperatures were measured by means of a Yellow Springs Instrument Company Telethermometer (Model 46TUC) and thermistor probe (No. 401). The probe was inserted until its tip was estimated to lie within the rectum or colon. Care was taken to ensure that the tip of the probe was always proximal to the tip of the carapace, rather than in the tail. The interval between breaths was measured with a stop watch; it was easily observed using binoculars, since basking turtles raise their heads at each breath. The orientation of the turtle was recorded with the aid of a sighting pocket compass, which was used to measure the bearing of the sun and wind, as described previously (Whittow 1978).

RESULTS

Thermal Profile of the Basking Beach

On Trig Island, and also on Whale-Skate, the turtles basked on the side of the island facing the outer reef; it was rare to see a basking turtle on the opposite side of the island. The basking beach also faced the prevailing northeast tradewinds. In Figure 2 the temperatures of the sand and black globe are shown for both the basking beach and the beach not used in basking. The data for the two sides of the island were obtained on the same day, so they are directly comparable. It is apparent that there was a striking difference between the thermal conditions on the two beaches, both on Trig and on Whale-Skate. Sand temperatures were lower and black globe temperatures were strikingly lower 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 uncommon.

Basking Behavior

Three of the four female turtles and three of the four males with telemetry transmitters

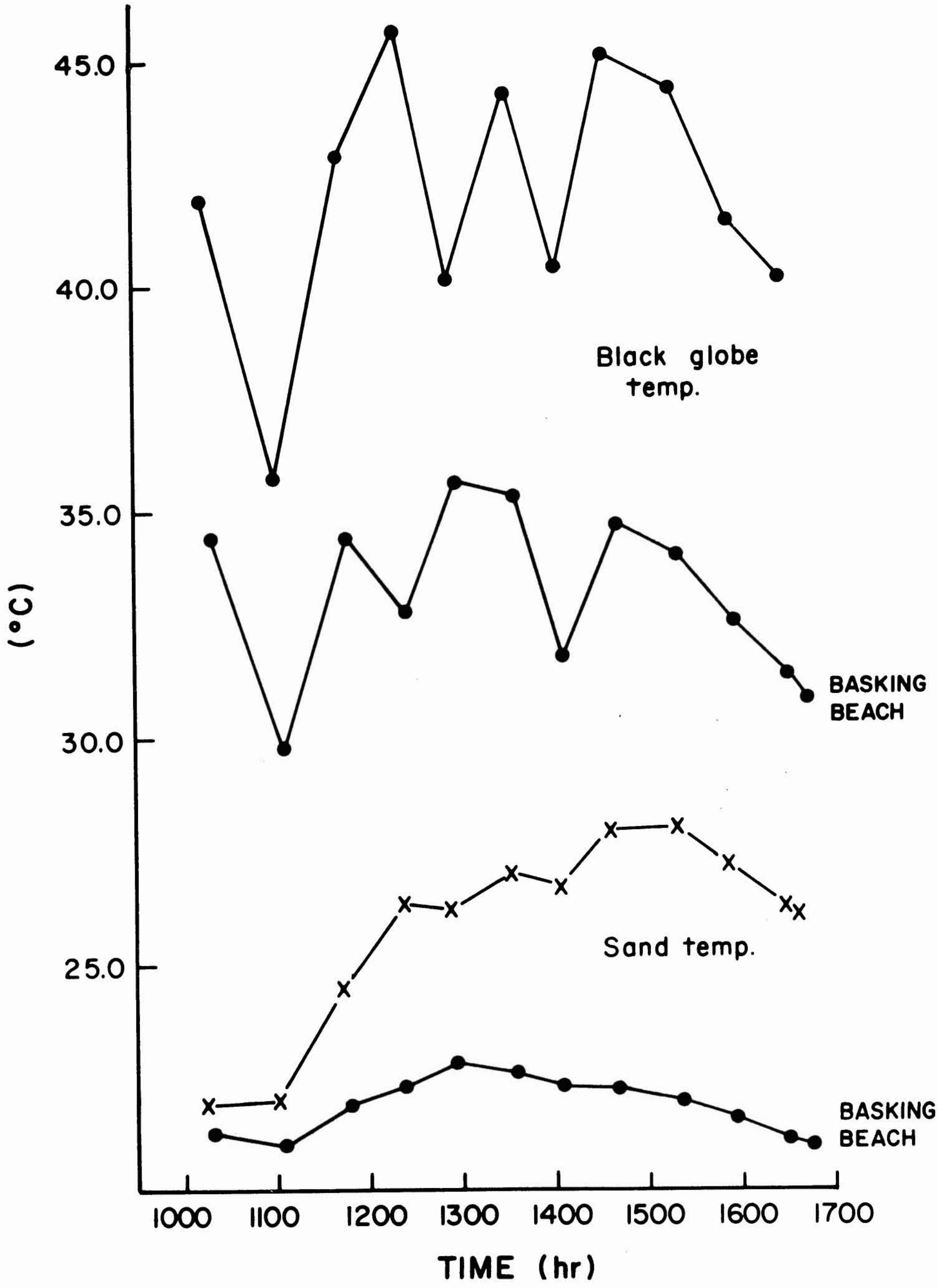

FIGURE 2. Sand temperatures (lower two graphs) and black globe temperatures (upper two graphs) on the basking beach at Trig and on the beach not used in basking.

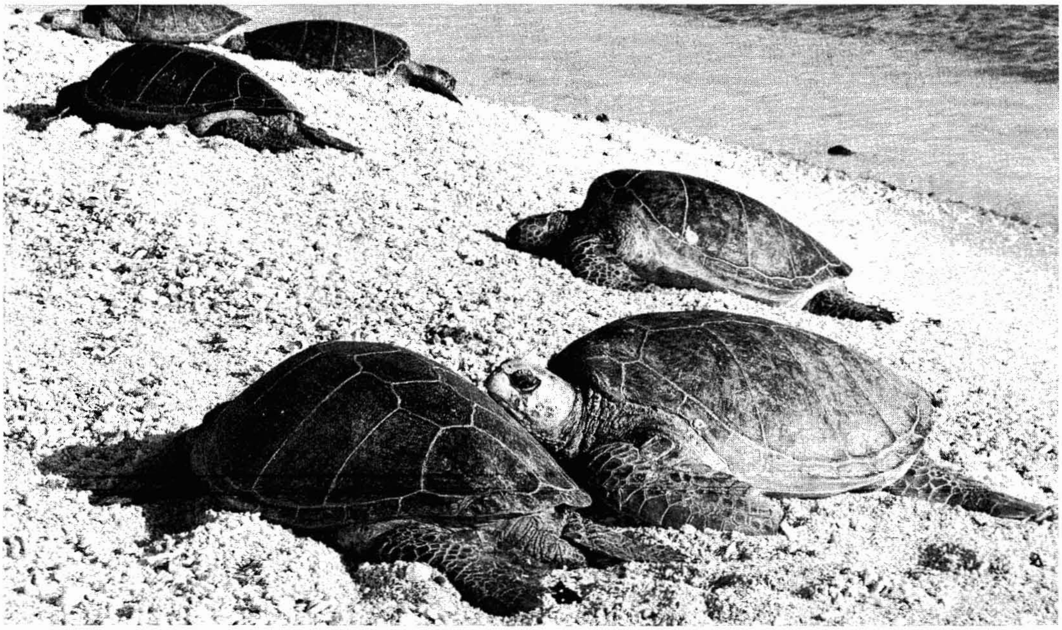

FIGURE 3. An aggregation of basking turtles on the beach at Whale-Skate.

attached basked. Mean basking time for the three female turtles was 2.8 percent of the time they were observed, with a range of 0.3–7.5 percent. The mean time that the males were basking was 4.6 percent of the total time telemetric recordings were made from them, with the range 2.9–7.3 percent. These values represent minimal durations of basking, because of our rejection of some data due to uncertainties. When the basking period included hours of darkness, only periods of basking that could clearly be differentiated from nesting activities were included in the data.

The turtles began to come ashore and bask at midmorning and continued to do so during the afternoon (Figure 3). Duration of basking varied considerably. The longest basking period, recorded telemetrically, was 600 min; the greatest duration of basking recorded by direct observation was in excess of 450 min —from 1000 to 1730 hours. Some evidence was obtained that the duration of basking was greater, the lower the mean black globe temperature while the turtle was basking (Figure 4). On shore, the turtles were extremely inactive and the only discernible movements were (*a*) raising of the head each time the turtle breathed and (*b*) 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). Mean duration of apnea was 219.2 sec (Table 1), but the range of values was considerable (50–635 sec). There did not appear to be any trend in the respiratory pattern with duration of basking. The breath-hold times recorded in 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. However, on an eighth occasion, 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

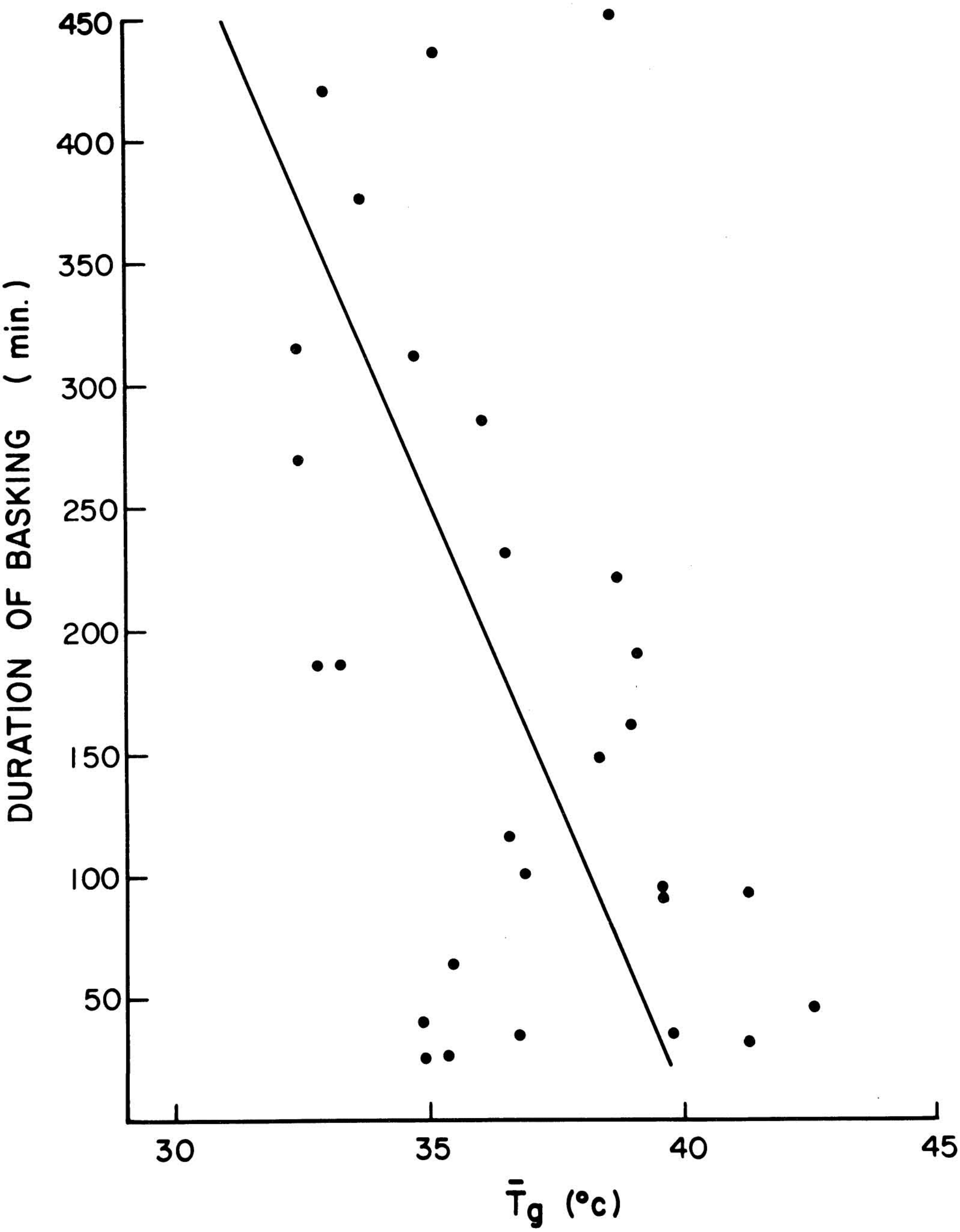

FIGURE 4. Relationship between the duration of basking and the mean black globe temperature ($\bar{T}_g$) during the basking period. Each point represents a separate turtle. The line is the fitted regression line ($y = 975.96 - 21.67x$).

TABLE 1

DURATION OF BREATH-HOLDS IN BASKING GREEN TURTLES AT FRENCH FRIGATE SHOALS, AND IN CAPTIVE TURTLES ON OAHU, HAWAII

	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
Number of observations	138	13	14

FIGURE 5. Carapace of a basking turtle partially covered with sand as a result of sand flipping. Note that the left rear flipper is covered with sand. The sand on the carapace is moister than the sand on the surface of the beach.

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 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 (Figure 5). However, 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 with greater frequency on very hot days. On relatively cool days, with considerable cloud cover, 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 as much as 10°C warmer than the sand on the carapace. In those turtles in which carapace surface temperatures were measured (see below), sand flipping was evident only when the carapace surface temperature exceeded 35°C. Sand flipping was observed in a turtle with a rectal temperature (see below) as low as 28°C.

A variation of sand flipping behavior was seen in the captive turtle at the Kewalo Marine Laboratory. This turtle was provided with a

TABLE 2

CARAPACE SURFACE TEMPERATURES (T_{ca}) OF BASKING GREEN TURTLES AT FRENCH FRIGATE SHOALS, AND OF CAPTIVE TURTLES ON OAHU, HAWAII

LOCATION	NUMBER OF OBSERVATIONS	T_{ca} (°C) MEAN	STANDARD DEVIATION	RANGE
French Frigate Shoals	38	34.5	4.0	25.0–42.3
Kewalo Marine Laboratory	16	37.3	2.4	32.0–40.0
Sea Life Park	20	37.8	2.3	35.0–42.8

wooden basking ramp and it very often basked parallel, 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 the wind. The turtles very often remained in the same position—that is, the position adopted on first emerging from the ocean—for long periods of time.

Carapace Temperature

The carapace temperatures of basking turtles at French Frigate Shoals and of captive turtles are given in Table 2. The measurements were obtained under widely varying conditions, but they were all made when the carapace was dry and exposed to direct solar radiation. Mean carapace temperature was slightly higher in captive turtles, possibly reflecting the higher temperatures prevailing in their more southerly situation. In many ways, the range of values shown in Table 2 is more instructive than the mean. The lowest temperature (25°C) was obtained in the late afternoon when conditions on the beach were relatively cool. The highest temperatures (40.0–42.8°C) are sufficiently high to 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, the determination of rectal temperature involved interference with the animal. The measurements obtained are given in Table 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. It is conceivable that higher rectal temperatures would have been recorded if more measurements had been made.

Shade, Cloud, Rain

There is no shade on the beaches at French Frigate Shoals, and turtles clearly do not leave the ocean for shade. At Sea Life Park, part of the basking area was shaded by a tree, and on one particularly hot day with little breeze, two turtles were observed basking in the shade.

Turtles were never observed to bask when it was raining. In fact, two basking turtles that were under observation on Trig Island returned 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 inci-

TABLE 3

RECTAL TEMPERATURES (°C) OF BASKING GREEN TURTLES AT FRENCH FRIGATE SHOALS

NUMBER OF OBSERVATIONS	MEAN	STANDARD DEVIATION	RANGE
17	28.7	1.4	26.9–31.3

dence 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 weather, both at French Frigate Shoals and under captive conditions.

DISCUSSION

The observations made in this study suggest that basking green turtles may absorb a significant amount of solar radiation. Thus, the maximal values for carapace surface temperature are not compatible with a surface that is highly reflective to solar radiation. The maximal value for rectal temperature is also consistent with this belief. Thus, assuming that the mean body temperature of the turtle was equal to the rectal temperature (31.3°C), that the specific heat of the tissues is 0.83, and that the turtle's body temperature was close to that of the ocean when it emerged to bask, it may be calculated that the turtle stored 465 kcal of heat during basking. This calculation is 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). These calculations show that the quantity of heat stored by the turtle was more than 12 times the hourly metabolic rate of a turtle of the same size.

The thermoregulatory behavior (sand flipping) evinced by the turtles also conforms with the suggestion that the turtles had absorbed heat during basking and that they were mildly heat-stressed. The stimulus for sand flipping has not been elucidated in the present study, but, on the basis of the limited number of measurements of rectal and carapace temperatures, it seems likely that sand flipping is evoked by an increase in peripheral (carapace surface) rather than central (rectal) body temperatures. It is interesting that the turtles did not display any indication of thermal polypnea or open-mouthed panting. In this respect, green turtles differ from the slider turtle (*Pseudomys scripta*), which gapes when it basks (Moll and Legler 1971).

Sapsford and van der Riet (1979) came to a similar conclusion with regard to the absorption of solar radiation by a sea turtle (*Caretta caretta*) basking on the surface of the ocean. They suggested further that the pulmonary circulation may play an important part in the transfer of heat from the lungs, which are immediately below part of the carapace, to the rest of the body. McGinnis (1968) and Heath and McGinnis (1980) also reported a rapid increase in carapace temperatures in green turtles during simulated basking both on the surface of the ocean and ashore. However, they concluded that the transfer of heat from the carapace to other parts of the body was slow. Spotila, Standora, and Foley (1979) also observed a rapid rise in carapace temperature, and a slower increase in deep-body temperature in green turtles crawling on the beach in daylight.

Other observations made in the present study suggest that the impact of the heat absorbed by solar radiation is lessened by a number of factors such as the selection of a relatively cool beach and the complete inactivity of the turtles, apart from thermoregulatory behavior, while basking. These factors may enable the turtles to stay on the beach for a longer period of time than they would ordinarily.

Taken together, the observations made in this study, in conjunction with those made elsewhere, lead to the tentative conclusion that Hawaiian green turtles basking ashore do not primarily increase their body temperature. Indeed, increase in body temperature appears to limit the time they may stay ashore. The unique basking behavior of Hawaiian green turtles may have been made possible by the prevalence of the northeast tradewinds and the highly reflective, cool, white sand in 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). The absence of any clear orientation toward the sun is also in accord with the belief that the turtles were not maximally exposed to solar radiation. In contrast, in a freshwater turtle (*Pseudomys scripta*) there is some evidence that the turtles orientate with the sun (Boyer 1965, Moll and Legler 1971).

Freshwater turtles are believed to derive a number of benefits from basking, including synthesis of vitamin D, destruction of algae on the carapace, and improved digestion (Boyer 1965, Gatten 1974, Moll and Legler 1971). All these advantages derive from the increased body temperature of the basking turtle. A further benefit to the turtle may result from an increase in the temperature of the layer of fat immediately beneath the carapace. This may facilitate mobilization of the fat for metabolic purposes. This suggestion is given credibility by Heath and McGinnis (1980), who have shown that heat transfer through the carapace is rapid. The layer of fat may also be responsible for the relatively slow rise in deep-body temperature observed by both Spotila et al. (1979) and Heath and McGinnis (1980). The fat may act as an insulating layer, reducing the rate of heat transfer to underlying tissues. An additional advantage to the female turtles may be an accelerated rate of development of the eggs, with a corresponding reduction in the internesting interval. This might reduce the duration of the turtles' stay at French Frigate Shoals, with a commensurate decrease in the exposure of the turtles to an area with a high incidence of predatory tiger sharks.

Although the results of the telemetric study probably underestimate the total amount of time the turtles allocate to basking, it is clear that basking was not a major item in the time budgets of the eight turtles studied. It should be noted that the green turtles that feed in waters around the main Hawaiian Islands (when they are not breeding at French Frigate Shoals) have rarely been reported to bask (Balazs 1980). On a global scale, terrestrial basking is uncommon in sea turtles, although recent observations made in Western Australia suggest that basking may be more extensive in that area than had hitherto been supposed (R. E. Johannes, personal communication). In this perspective, it is appropriate to question the biological significance of land basking in sea turtles. Basking may well be a relict behavior. On the other hand, basking may be important when there are large aggregations of turtles (during breeding season) in a relatively small area that contains large numbers of tiger sharks, as at French Frigate Shoals. When the turtles are ashore, they are secure from the attacks of the tiger shark, their main predator (Balazs 1980). The effect of basking would then be to remove a significant number of turtles from the ocean at a time when they would not ordinarily be nesting ashore.

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