Relationship Between Basking and Fibropapillomatosis in Captive Green Turtles (Chelonia mydas)

Article *in* Chelonian Conservation and Biology · December 2006

DOI: 10.2744/1071-8443(2006)5[305:RBBAFI]2.0.CO;2

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Table 2. Observed natural hatching success and survival for *Chelonia mydas* on the Şeyhhızır section of Samandağ Beach.

	2001				2002			
	Nests	Total	%	X ± SD	Nests	Total	%	X ± SD
Total no. of eggs	14	1773	100	126.6 ± 33.5	82	10,021	100	122.0 ± 24.2
Unhatched eggs		256	14.4	18.3 ± 14.6		1974	19.7	24.1 ± 38.9
Infertile eggs		44	2.4	4.9 ± 7.4		594	5.9	8.1 ± 10.3
Abnormal eggs	Not determined					5	0.0	5
Lost or depredated eggs		212	11.9	16.3 ± 15.3		1375	13.7	19.9 ± 40.3
Total number of hatchlings	14	1517	85.5	108.4 ± 32.91	76	8047	80.3	106 ± 30.9
Dead hatchlings	Not determined					85	0.8	6.5 ± 9.7
Died in nest	Not determined					45	0.4	3.8 ± 4.4
Died on beach	Not determined					40	0.4	13.3 ± 16.7
Live hatchlings	Not determined					7962	79.5	104.8 ± 31.9

discussions. We also thank the Governor of Hatay and Türkiye Çevre Koruma Vakfı for supporting our 2002 studies, and Pesola for donation of scales and RACSPA and Monica Aureggi for technical support. Thanks also to Bektaş Sönmez, Hüseyin Dogru, Samim Kayıkçı, Murat Apiş, Şenay Korkmaz Munteha Sagaltıcı, Aynur Görün, Feryal Özkayalar, Semih Dalkılıç Cem Üllenoglu, Hasan Özgür, Zafer Keleş, Elif Enül, İsa Değirmenci, Onur Köse, Murat Apiş, Selçuk Yetkin, Evrim Yıldız, Merih Kara, and Ezgi Erken, students of the MKU Biology Department for their fieldwork assistance.

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Received: 20 April 2004
Revised and Accepted: 6 October 2005

Chelonian Conservation and Biology, 2006, 5(2): 305–309

Relationship Between Basking and Fibropapillomatosis in Captive Green Turtles (*Chelonia mydas*)

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ABSTRACT. – **This research was conducted to determine a potential relationship between fibropapillomatosis (FP) and basking behavior in green turtles (*Chelonia mydas)* in Hawaii. Only turtles with FP were observed basking, and basking resulted in increased body temperature of 2.9°C above ambient.**

The rare basking behavior exhibited by green sea turtles in various isolated locations around the world has drawn speculation regarding a potential physiological role for this behavior. It remains uncertain whether marine turtles derive similar benefits from basking as freshwater turtles, which include thermoregulation (Boyer 1965), synthesis of vitamin D (Pritchard and Greenhood 1968), improved digestion (Gatten 1974), and removal of algae and ectoparasites from the carapace (Boyer 1965). Previous attempts to explain basking in green sea turtles include enhanced egg maturation (Whittow and Balazs 1982; Snell and Fritts 1983), avoidance of courting males by females (Bustard 1974), predator avoidance (Whittow and Balazs 1982), and energy conservation (Balazs 1980). I initiated this study in order to determine if basking behavior could serve a role in disease, specifically if there is a link between the rare basking behavior of green turtles in Hawaii and their associated high rates of fibropapillomatosis (FP), and to speculate on potential immunological benefits associated with the behavior in a population threatened by disease.

The assumption that basking serves primarily a thermoregulatory function has been debated, whereby some authors contend that the term "basking" and its associated implication of serving an important thermoregulatory role is premature and inappropriate (Manning and Grigg 1997). In marine turtles, diurnal basking has been shown to increase body temperature (T_b) in *C. mydas* in the few locations where basking occurs, such as in the northwestern Hawaiian Islands (Whittow and Balazs 1982), and the Galápagos (Snell and Fritts 1983). However, basking and the resultant heat gain may also be the result of chance events, whereby turtles happened to remain in the sun long enough to become warm. In this scenario, heat gain incurred from basking may simply be a by-product of a behavior undertaken for some other benefit, such as retardation of algal or fungal skin infestations or attainment of a "behavioral fever" (Moll and Legler 1971; Monagas and Gatten 1983; Manning and Grigg 1997).

In Hawaii, the annual prevalence of FP has ranged from 42% to 65% of sampled populations (Aguirre 1998; Aguirre and Lutz 2004). Fibropapillomas are benign internal and/or external fibroepithelial tumors that primarily occur on the skin, eyes, and cloaca. Tumors in the mouth and on the eyes are most likely to disrupt vital functions such as swallowing, breathing, and acquiring food, and mortality for these turtles is assumed to be high (Balazs et al. 1997). Likely causes of FP include infectious agents such as herpesviruses (Herbst et al. 1995; Quackenbush et al. 1998) and retroviruses (Casey et al. 1997), as well as environmental factors such as toxins produced by algal blooms and human-induced pollution (e.g., benthic dinoflagellates that produce okadaic acid; Landsberg et al. 1999; Aguirre and Lutz 2004). Prevalence of FP is highest in green turtles as compared to other marine turtle species, and perhaps coincidentally green turtles are the only marine turtles known to bask on land.

Chelonia mydas populations in Hawaii have both a high prevalence of FP as well as an established colony of basking adults in the nesting grounds. In other locations where basking of *C. mydas* occurs (e.g., Galápagos Islands and Gulf of Carpenteria, Northern Australia), however, incidence of FP remains relatively low. In order to investigate a relationship between disease and basking, I conducted my research with green turtles from Hawaii.

Methods. — Between June and September 1994, I obtained 9 wild immature turtles from Kaneohe Bay (21°30′N, 157°50′W), island of Oahu, Hawaii. Turtles were captured by hand and transported to the Kewalo Research Facility of the NOAA-National Marine Fisheries Service in Honolulu. Of the 9 turtles brought into captivity, 5 had visible signs of FP and were placed in a separate tank with an independent water supply. Each 8-m-diameter tank had a constant supply of seawater (ranging from 23° to 27°C, mean = 25°C). Each turtle was fed 2 squid per day 6 days a week. Wooden ramps, with an incline of approximately 7°, led to a basking platform (1 by 2 m) in each tank. Basking ramps were exposed to full sunlight during all daylight hours.

The turtles with FP had a minimum of 6 and a maximum of 12 tumors measuring between 1 and 15 cm each. Visible tumors were located in the following locations: flippers, cloaca, eyes, mouth, jaw hinges, neck, and carapace. Turtles were evaluated for tumor severity based on an index described in Balazs (1991). Based on this index, tumor severity was moderate, with a tumor score ranging from 2 to 3 (mean: 2.5).

Straight carapace length (SCL) of all turtles was measured with calipers. Mean ($\pm$ SE) SCL for the FP-afflicted and apparently healthy turtles was 54 ± 1.8 cm and 48 ± 1.7 cm, and body mass was 21 and 15 kg, respectively. Two turtles (one with FP and one without) were identified as females, and 1 turtle with FP was identified as male using standard laparoscopic methods. Sexes for the remaining turtles were not identified.

I defined basking when at least one half of the body was on the ramp and out of the water. I measured basking behavior of captive turtles either through personal observation or by time-lapse photography. Turtle observations were made during 41 days between 10 October and 9 December 2004, for a total of 497 recorded hours. Observations were made in person (277 hours) by recording the number of turtles on the basking ramps, or by viewing photographs recorded with a Pentax WR-90 SLR 35 mm camera (220 hours) with an interval-timing mechanism set to photograph at every 30- or 60-min interval. At the time of initial data recording (10 October 2004), all turtles had been acclimated and had begun eating in captivity. Additionally, temperatures of air, substrate, and water were made for every observation day.

Cloacal temperatures, and presumably T_b (Mrosovsky 1980), were determined by inserting a YSI thermistor probe (Yellow Springs Instrument Co, Inc, Yellow Springs, OH) to a depth of 15 cm in the cloaca. Body temperatures were recorded on all 41 observation days during the study period. The temperature probe was calibrated using a mercury thermometer to the nearest 0.02°C. I measured T_b of basking turtles ("postbasking") after they were basking a minimum of 1 hour. Body temperatures of turtles that I defined as "postwater" were from turtles that had been immersed in the water for a minimum of 2 hours prior to temperature determination. Water temperature (T_w) data were also recorded with the YSI thermistor numerous times on all 41 observation days. Air temperature measurements were obtained from the NOAA National Weather Service Honolulu station, which is located within 2 air miles of the study site and at the same elevation and has a similar topographical profile as Kewalo Research Facility. Statistical analyses were performed using SAS software (v. 6.08; SAS Institute, Inc, Cary, NC). Statistical significance was accepted at $p < 0.05$.

Results. — Body size (SCL) and mass, as well as a ratio of SCL and weight, of all turtles in this study were statistically similar ($p > 0.2$), thereby suggesting similar physical condition between groups. Only tumored turtles were observed basking, and at least 1 tumored turtle was observed basking on every observation day. All turtles with FP basked on a regular basis. In general, a circadian rhythm was apparent, whereby an average of 3 turtles basked throughout a 24-h period, yet basking was relatively rare between 0400 and 0800 hours. The number of turtles basking increased with increasing air temperatures from 22° to 29°C ($r = 0.301$; $p < 0.0001$), and then declined with increasing air temperature up to 32°C ($r = -0.501$; $p < 0.0001$), the highest temperature recorded during the study period. Basking resulted in a mean body temperature elevation of 2.9°C (SE ± 0.48; range: 27.8°–32.2°C) above T_w, which was significantly different than body temperatures of those same turtles postwater (Fig. 1; mean = 0.53°C above T_w, SE ± 0.065; range: 24.5°–26.3°C; $p = 0.0001$). Nontumored turtles were never observed on the basking ramp or platform. Following a minimum of 2 hours immersed in the water, body temperatures of both nontumored and tumored turtle groups were similar (mean = 0.49°C above T_w, SE ± 0.045; range: 23.3°–26.1°C; and mean = 0.53°C above T_w, SE ± 0.065; range: 24.5°–26.3°C; $p > 0.5$), respectively.

Discussion. — Measurements of basking green turtles in Hawaii have confirmed that the behavior results in elevated T_b both in the wild (Whittow and Balazs 1982), as well as in captivity. However, certain contrary behaviors, such as basking during relatively cool periods (e.g., during night), flipping reflective sand onto the carapace, and remaining partially submerged in water (Whittow and Balazs 1982; Snell and Fritts 1983; Swimmer et al. 1996), suggest that turtles do not bask solely to maximize heat gain. Rather, marine turtles appear

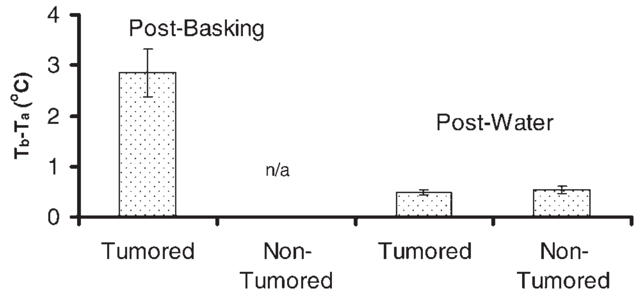

Figure 1. Difference between body temperature (T_b) and ambient water temperature (T_a) (± SE) for captive green turtles postbasking and postswimming. Range of T_b is between 23.3° and 26.1°C and 24.5° and 26.3°C for turtles with and without FP, respectively. Nontumored turtles in captivity never basked, and therefore no data are available for this group.

to bask in ways that moderate surface heating, thereby prolonging basking duration, similar to findings in the freshwater turtle *Emydura signata* (Manning and Grigg 1997). However, given the frequency of the behavior as well as the finding that diurnal basking clearly elevates T_b by ca. 3°C above water temperatures, the behavior likely serves a thermoregulatory function.

In both endotherms and ectotherms, elevated body temperature results in increased metabolic activity and "cost", and therefore maintaining elevated T_b likely has adaptive value. One potential benefit of elevating T_b is to enhance an immune response. Selecting behaviors that increase body temperature, such as basking, have been observed in nearly all vertebrates in response to infection. Studies have shown that ectotherms that behaviorally attained a febrile state in response to infection had higher rates of survivorship via an enhanced immune system than when they were maintained at lower temperatures (Kluger 1978, 1991). This "behavioral fever" has been observed to occur in lizards (Vaughn et al. 1974), freshwater turtles (Monagas and Gatten 1983), teleost fish (Reynolds et al. 1976), frogs (Kluger 1977; Woodhams et al. 2003), and amphibian larvae (Casterlin and Reynolds 1977). I propose that turtles with FP may use basking as a means to achieve the immunological benefits of a febrile state. As observed with the green turtles in this study, those with FP basked on every observation day, and often remained basking for up to 20 hours a day. Due to the high specific heat of water, turtles would rapidly lose their attained heat once they returned into the water. However, even short periods of high body temperatures can have immunological benefits, such as eliminating a pathogen from its host, as has been observed in laboratory experiments with frogs induced with the chytid pathogen *Batrachochytrium dendrobatidis* (Woodhams et al. 2003). The lengthy life expectancy of green turtles (currently estimated at > 30 years) and a relatively poor understanding of marine turtles' immune responses, however, complicate interpretations of the effects of basking on their survival or immune function. Recent advances in the understanding of the immune response of marine turtles (e.g., Herbst and

Klein 1995; Herbst et al. 1998; Work et al. 2000), however, should improve efforts to link immunological factors with the health status of marine turtles.

A clear relationship between basking and disease is further confounded by the fact that in the population of green turtles from Hawaii, nearly all basking occurs on the breeding grounds in the northwestern Hawaiian Islands, where FP prevalence and severity is relatively low (12%; Balazs 1991). On the other hand, in the foraging grounds in the main Hawaiian Islands, disease prevalence is high (ca. 50%), and basking is rarely observed. While I speculate on the potential immunological benefits of elevated body temperature gained via basking, a study that investigates alterations in the host's resistance to disease would lend support to the suggestion that diseased turtles bask in an attempt to achieve a behavioral fever, which in turn helps fight disease. Determining the fate of diseased animals would be especially valuable for clarifying the impact of FP on green turtle population dynamics. Lastly, due to the observed potential biological benefits of basking, management efforts should be maintained to ensure access to basking beaches for the few remaining threatened or endangered populations of *C. mydas* known to bask.

Acknowledgments. — I would like to thank G. Balazs, R. Brill, T. Root, and G.C. Whittow for invaluable assistance throughout the course of this research as well as writing of the manuscript. I thank A. Southwood and M. Musyl for editorial comments. This research was supported in parts by the National Marine Fisheries Service, Sigma-Xi Grants-in-Aid of Research, Lerner Grey Fund for Marine Research (American Museum of Natural History), and the University of Michigan. Animal maintenance and experimental protocols were approved by the University of Michigan Institutional Animal Care and Use Committee. Collecting permits were obtained from the National Marine Fisheries Service, Southwest Fisheries Science Center Honolulu Laboratory.

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Received: 28 May 2004
Revised and Accepted: 17 February 2006

Chelonian Conservation and Biology, 2006, 5(2): 309–312

Nest-Site Selection in the Eastern Box Turtle, *Terrapene carolina carolina*, in Illinois

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ABSTRACT. – **We characterized the microhabitat features of nests constructed by eastern box turtles, *Terrapene carolina carolina*, in central Illinois. All nests were sited in open habitats; 87.5% of them were depredated within 72 hours of oviposition. Nest sites differed from random sites in vegetation height and composition, percentage ground and canopy cover, and light intensity. Land management practices that provide open areas suitable for box turtle nesting activity might make these areas more attractive to potential nest predators.**

Patterns of habitat selection are an important aspect of the natural history of an animal because of the potential impacts on individual fitness (e.g., offspring production and survivorship). Nest site selection is critical to oviparous taxa. Developing embryos at selected sites have a greater chance of survival than those at random sites (Wilson 1998); thus, natural selection should favor the evolution of nest-site selection (Schwarzkopf and Brooks 1987; Temple 1987; Kolbe and Janzen 2002). Research has shown that many turtle species actively select specific locations or microhabitats for their nests (e.g., *Malaclemys terrapin* [Burger and Montevecchi 1975], *Kinosternon baurii* [Wilson 1998], *Chelydra serpentina* [Kolbe and Janzen 2002]). The choice of a nest site is important because it will influence the likelihood of predation of both eggs and hatchlings as well as affect the temperature and moisture content at which the eggs develop (Bodie et al. 1996; Dodd 2001). The microhabitat (primarily soil moisture content and temperature) surrounding the nest site affects the developmental rate (Cagle et al. 1993), the sex of offspring (Wilhoft et al. 1983), and some fitness characteristics of the hatchlings such as size and growth rate (Burger 1976; Packard et al. 1985; Janzen 1993).

Terrapene carolina carolina (eastern box turtle) is a terrestrial turtle found predominantly in deciduous forests and woodlots throughout much of the eastern United States (Conant and Collins 1991). Here, we examined nest sites of *T. c. carolina* on a multipurpose tract of land in central Illinois to determine if nest sites differed in microhabitat variables compared to those of random sites.

Methods. — The study was conducted at the Rhodes–France Scout Camp (RFSC) in western Shelby County, Illinois. RFSC contains 200 ha of mainly oak–hickory forest, 40 ha of which are used by the scouts (primarily in June and July) and camp staff who have built permanent structures (buildings and pavilion support posts) and created various open areas within the forest for campsites. The camp is bordered on the north and west by agricultural fields (corn, soybean, alfalfa) and on the south and east by a grazed cattle pasture. We restricted our study to the eastern third of the camp (containing all RFSC camping sites).

Beginning in April 2001, female turtles ($n = 15$) with a carapace length of greater than 120 mm had a radio transmitter (Advanced Telemetry Systems model 7PN) glued to the right posterior of the carapace using rubber silicone sealant. Mean transmitter mass was 35 g, or 7.5 % of the subject mass (mean $\pm$ 1 SD = 468.3 $\pm$ 108.0 g). After affixing the transmitter, we released each turtle at its site of capture. We assumed that oviposition would take place from late May to early June (Ernst et al. 1994; Phillips et al. 1999). As such, all females carrying transmitters were located in the first week of May 2001 and radiographed to determine presence of shelled eggs. We recorded the clutch sizes of the gravid females (only 5 of the 15 originally outfitted with transmitters) and returned them to their capture sites.

The 5 subjects were located daily, at which time we recorded their position (using a Magellan Map410 geographic positioning system), activity, and mass ($\pm$ 0.1 g). Box turtles often nest in the evening hours (Legler 1960; Congello 1978; Dodd 2001) so we always located females between 1700 and 2100 hours to increase the chance of finding a turtle while it was nesting. We also searched both forested and cleared areas of RFSC for nesting activity by unmarked females (each of which,