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The Influence of Weather and Tides on the Land Basking Behavior of Green Sea Turtles (*Chelonia mydas*) in the Galapagos Islands

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ABSTRACT. – We monitored green sea turtle (*Chelonia mydas*) land basking behavior on Fernandina Island in the Galapagos Islands to determine the potential influence of tide level and weather on the presence and abundance of turtles. Using generalized linear models, we found that both presence and abundance of turtles were related to lower tide levels but that abundance was further related to higher air temperatures, reduced cloud cover, and falling tides; additionally, we recorded more males than have been found in other studies (males = 41.5% of observations). We hypothesize that haul out during low tide reduces energy expenditure of activities such as coming to the surface to breathe; however, more turtles take advantage of this behavior when conditions such as air temperature and cloud cover are more conducive to physiological benefits such as thermoregulation or acceleration of digestion.

Land basking, or haul out onto land not associated with nesting, is a well-known behavior in many aquatic reptiles such as freshwater turtles, alligators, and crocodiles (McIlhenny 1935; Avery 1982; Seebacher 1999). There are many theories for this behavior including predator avoidance and aiding other physiological processes such as thermoregulation and vitamin D synthesis (Boyer 1965; Pritchard and Greenwood 1968). Land basking is uncommon in sea turtles, however. Despite their circumglobal distribution, this behavior has been observed in only one species, the green sea turtle (*Chelonia mydas*), and only on isolated islands including in the Hawaiian Islands, Tromelin Island (French Territory), Ascension Island

(British Territory), Revillagigedo and Socorro Islands (Mexico), Bountiful Island (Australia), and the Galapagos Islands (Ecuador) (Balazs 1976; Fritts 1981; Garnett et al. 1985). Basking behavior of green sea turtles has been recorded in the Galapagos Islands since as early as 1684 and has been recorded on at least half of the major islands in the archipelago (Green 1998). In one study, over 800 turtles were recorded over 24 mo of observation (Zárate et al. 2006), and both sexes have been observed basking, although the incidence of females greatly exceeds males (Fritts 1981; Snell and Fritts 1983; Zárate et al. 2006).

A number of hypotheses for this behavior have been reported. These include avoidance of aggressive male reproductive behavior, predator avoidance, acceleration of digestion, acceleration of egg maturation, synthesis of vitamin D, and thermoregulation (Boyer 1965; Pritchard and Greenwood 1968; Bustard 1974; Balazs 1976; Snell and Fritts 1983). The thermoregulatory hypothesis is the most commonly cited hypothesis, and it implies that environmental factors associated with thermoregulation affect when turtles haul out (Snell and Fritts 1983). A number of studies have described basking behavior in detail, particularly in relation to the thermoregulatory hypothesis, but none have attempted to statistically correlate environmental factors with basking behavior. The most thorough of these studies by Snell and Fritts (1983) recorded the range of several environmental factors simultaneously with single-day opportunistic basking observations at several locations in the Galapagos Islands but did not attempt to statistically correlate environmental factors with basking behavior. We aimed to build on the study by Snell and Fritts by recording emergences and related environmental variables over several weeks at a single location on Fernandina Island in the Galapagos Islands, allowing us to determine whether specific environmental factors, including those associated with tide and weather conditions, correlate with increased incidence of basking behavior. We hypothesize that air temperature, wind and cloud cover will be correlated significantly with basking behavior because these variables influence thermoregulation, the most prevalent theory for why turtles bask. Further, we hypothesize that low tide levels will influence emergence because animals may emerge from the water more easily during a low tide.

Methods. — Observations were performed between 14 and 27 October 2009 at Tortuga Beach, Cape Douglas, an approximately 1-km-long beach in the northwest quadrant of Fernandina Island in the Galapagos Archipelago (Fig. 1; 0.31°S, 91.67°W, datum WGS 84). Number and sex of basking turtles, percent cloud cover, absolute minutes to low tide (whether before or after the low tide), whether the tide was rising or falling, wind strength, and air temperature were recorded at 6 intervals throughout the day (0600, 0900, 1200, 1500, 1630, and 1800 hrs) when possible, with 2 opportunistic night observations (near 2400 hrs) on 20 and 26 October. Wind



Figure 1. Green sea turtles (*Chelonia mydas*), Galapagos sea lions (*Zalophus wollebaeki*), and marine iguanas (*Amblyrhynchus cristatus*) basking on the shore of Tortuga Beach at Cape Douglas, Fernandina Island.

strength was approximately classified as either “none to low”, “moderate”, or “strong”: none to low winds occurred when wind was nearly undetectable; strong winds were capable of moving objects with mass greater than paper; and moderate winds were intermediate between these categories. We visually determined the sex of individuals by the relatively long tail length of males compared with females (Ross 1984) at a safe distance that did not disturb basking individuals. Tail length cannot be used to reliably determine sex in juveniles or the difference between adult females and large juveniles; thus, sex was classified as either male or “unknown” with the unknown classification including turtles where the tail was not visible, as well as females, juveniles, or adult males whose tails were not of a length easily classified as male. Air temperature was determined using an Mk9 archival dive recorder (Wildlife Computers, Redmond, WA) equipped with an internal temperature sensor ($\pm 0.1^\circ\text{C}$ accuracy; Simmons et al. 2009), resting in a shaded position on Tortuga Beach. Air temperature was recorded at 5-sec intervals, and temperatures coinciding with the time of turtle observations were extracted.

Using 2 separate parametric statistical models, we evaluated the relationship between environmental variables and 1) presence versus absence and 2) abundance of basking turtles. A generalized linear model (GLM) with a binomial distribution (logit link) was fit to the binary presence or absence of turtles on land to determine whether environmental variables correlated with turtle presence. To determine the relationship between environmental variables and the abundance of turtles, a GLM with a Poisson distribution (log link) was fit to turtle abundance

(count data). Independent variables were explored for collinearity; all variance inflation factors were less than 5, indicating a lack of collinearity (Zuur et al. 2007). All variables were included in the full models, and a backward-and-forward step-wise model-simplification function employing Akaike’s Information Criteria (AIC) (ΔAIC threshold = 3) was used to determine the most parsimonious model with the least number of independent variables. All analyses were performed using the R statistical package (Version 2.8.1, <http://cran.r-project.org/>).

Results. — Turtles were present in 33 of 59 (55.9%) observations (Fig. 2). We observed males in 41.5% of the 159 turtle observations ($n = 66$), with the remaining observations classified as unknown (female, juvenile, or unknown sex). Additionally, we observed a minimum of 5 turtles land basking during both of the observations near 2400 hrs. For daytime observations, air temperature ranged between 19.7°C and 46.9°C (mean = 30.7°C , $\text{SD} \pm 7.72^\circ\text{C}$). Cloud coverage ranged from no clouds to 100% coverage, with an average of 47% coverage. There was little to no wind at 38.9% of observations, medium strength wind at 44.1%, and strong wind at 16.9% of observations. Mean time to low tide was between 4 and 382 min (mean = 186.9, $\text{SD} \pm 104.8$ min) and the tide was “falling” in 32 of the 59 observations.

The presence/absence GLM indicated that the presence of basking turtles was related only to the time to low tide, with warmer air temperatures improving the model although air temperature was not significant (Table 1). Other variables were removed from the final presence/absence model. The turtle abundance model

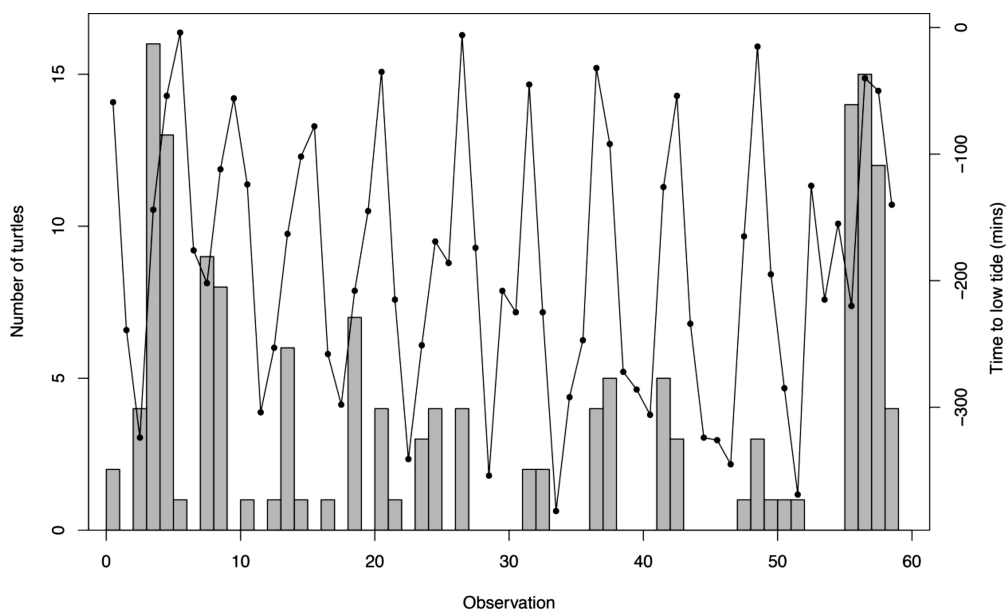


Figure 2. Number of turtles (grey bars) and tide level (black lines) across the 59 study observations. Tide level represents minutes since low tide (e.g., -200 min equates to 200 min since the low tide). Turtles are present in greater abundance during low tide. Note that observations are not evenly spaced in time (for details, see text).

indicated that the abundance of turtles was significantly correlated with lower tides, warmer air temperatures, and reduced cloud cover and negatively associated with rising tides (Table 1). Wind strength was removed from the final model.

Discussion. — We found that of our set of recorded variables, only tide level was correlated to the presence of one or more sea turtles land basking; however we found weather variables likely related to thermoregulation (cloud cover and air temperature) to be significantly correlated with the abundance of basking turtles. This suggests that larger number of turtles chose this behavior when warmer, sunnier conditions exist, thereby supporting the hypothesis that turtles bask to support physiological processes such as thermoregulation.

Other studies have shown conflicting results when looking at environmental variables in relation to thermoregulation. Manning and Grigg (1997) found basking did not elevate body temperature in the Brisbane River turtle (*Emydura signata*). Sapsford and van der Riet (1979) found loggerhead sea turtles' internal temperature was greater when basking at the water's surface during sunny weather, attributable to increased solar radiation. Additionally, Snell and Fritts (1983) suggested elevated cloacal temperatures in basking sea turtles in the Galapagos at air temperatures well below average temperatures found in this study (25.8° – 27.3° C, Snell and Fritts 1983; vs. 30.7° C, SD \pm 7.85, this study).

Solar radiation may be one of the driving factors behind thermoregulatory benefits, even for turtles basking at night. Although the relationship between cloud cover and solar radiation is complex (Li et al.

1995), some radiation does penetrate through clouds, and it may heat the sand enough to provide thermoregulatory benefits during the day and even at night if sand retains enough heat. Snell and Fritts (1983) additionally suggested both land basking and resting in shallow, warm waters of bays like that off Tortuga Beach results in elevated body temperatures despite the generally cool waters that sweep by the Galapagos. We were unable to determine water temperatures in Tortuga Bay, although we know that the coolest water temperatures occur during the garua, or dry, season (to 16° C or less) (Pak and Zaneveld 1973; Palacios 2004) when our study took place. Cool water temperatures may influence basking during the garua season, but other studies have shown that land basking occurs year round, including when both air and water temperatures are at their warmest (Zárate et al. 2006). High air temperatures in contrast to the cool water temperatures of the Galapagos, even in shallow warm bays, may be enough to maintain thermoregulatory and associated digestive benefits, as has been found in marine iguanas inhabiting this region (Wikelski et al. 1993).

It is possible that basking is at least in part an energy-saving behavior, as has been previously suggested for land basking green turtle populations in the Galapagos and off Australia and for water surface basking loggerhead sea turtles (*Caretta caretta*) in the Mediterranean (Garnett et al. 1985; Green 1998; Hochscheid et al. 2010). Given the absence of land predators on the Galapagos and other islands where basking occurs, turtles can safely rest on land while avoiding energy expenditure needed for activities such as readjusting position in currents and coming to the surface

Table 1. Mean, range, *p*-values, and *z*-values of environmental variables used to model effects on the presence and abundance of turtles; values given for the full and most reduced models. Akaike's Information Criteria (AIC) was used to determine the most parsimonious models.

Variable	Turtle presence				Turtle abundance					
	Full model		Reduced model		Full model		Reduced model			
	<i>p</i> -value	<i>z</i> -value	<i>p</i> -value	<i>z</i> -value	<i>p</i> -value	<i>z</i> -value	<i>p</i> -value	<i>z</i> -value		
Time to low tide (min)	186.9 (104.8)	4–382	0.023	-2.26	> 0.001	-2.83	> 0.001	-3.934	> 0.001	-6.56
Tide rising/falling	NA	NA	0.65	0.46	NA	NA	0.002	-3.170	> 0.001	-3.95
Air temperature (°C)	30.74 (7.72)	19.7–46.9	0.18	1.33	0.30	1.06	> 0.001	3.754	> 0.001	4.12
Wind (strong, medium, low)	NA	NA	0.31, 0.48, 0.23	1.00, 0.706, 1.18	NA	NA	0.27, 0.28, 0.12	1.10, 1.08, 1.55	NA	NA
Cloud cover (% coverage)	47	0–100	0.17	1.37	NA	NA	0.12	-1.563	> 0.001	-4.16
AIC value			46.68		39.19		123.18			119.75

to breath. Basking behavior may occur more prominently at lower, falling tide levels because the slope of the beach is reduced. This makes emergence from the water easier, also allowing turtles in the nearshore, shallow water to be passively stranded, with relatively easy re-entry into the water as the tide rises (Snell and Fritts 1983).

Results from our study potentially contradict hypotheses for sea turtle basking behavior. For example, we found a large incidence of males as well as females, suggesting that basking behavior is not primarily associated with egg maturation or avoidance of aggressive males, although it may also be indicative of males congregating at female aggregations. Previous studies were conducted largely during the nesting season (Snell and Fritts 1983; Zárate et al. 2006; Seminoff et al. 2008) or near nesting sites (Fritts 1981; Snell and Fritts 1983; Green 1998), possibly explaining the large incidence of females. Our study was conducted in October prior to the nesting season (which peaks December to March), and turtles are not known to nest on the study island. The lack of proximity to nesting beaches may additionally explain the abundance of male observations over females.

Predator avoidance may be another driving force behind basking behavior, especially given that both males and females have been shown to bask. Predator avoidance is not a factor that can be tested easily, although land basking in sea turtles tends to occur in areas where shark density is high (Whittow and Balazs 1982). Shark density in the Galapagos Islands is considerable (Edgar et al. 2004), but Tortuga Bay is a shallow, enclosed bay where sharks large enough to prey on sea turtles would have difficulty entering; sharks have never been observed in the bay by the authors some of whom have worked at the study site for decades. Additionally, reducing growth of fungi and algae or synthesis of vitamin D are possible explanations for basking behavior, but sea turtles are unlikely to need to bask even for short periods to absorb sufficient UV radiation, particularly in equatorial regions (Hochscheid et al. 2010).

Our study furthers our understanding of basking behavior in sea turtles. It is likely that this unusual behavior conveys a number of benefits to sea turtles and therefore cannot be easily linked to one. For example, reproductive benefits for females through faster egg development and avoidance of aggressive males may be heightened during the nesting season, whereas energetic benefits may be heightened for males in the nonbreeding season when they do not need to expend time and energy on mating. Given that male green turtles in most other populations never touch land following hatching and that females spend scarcely more time on land over their lifetime, it seems worthwhile to achieve a greater understanding of the factors influencing this rare behavior of an endangered species.

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LITERATURE CITED

- EVERY, R.A. 1982. Field studies of body temperatures and thermoregulation. In: Gans, C. and Pough, F.H. (Eds.). *Biology of the Reptilia*. London: Academic Press, pp. 93–166.
- BALAZS, G. 1976. Green turtle migrations in the Hawaiian Archipelago. *Biological Conservation* 9:125–140.
- BOYER, D.R. 1965. Ecology of the basking habit in turtles. *Ecology* 46:99–118.
- BUSTARD, H.R. 1974. *Sea Turtles: Natural History and Conservation*. London: Collins, 220 pp.
- EDGAR, G.J., BUSTAMANTE, R.H., FARINA, J.M., CALVOPINA, M., MARTINEZ, C., AND TORAL-GRANDA, M.V. 2004. Bias in evaluating the effects of marine protected areas: the importance of baseline data for the Galapagos Marine Reserve. *Environmental Conservation* 31:212–218.
- FRITTS, T.H. 1981. Marine turtles of the Galapagos Islands and adjacent areas of the eastern Pacific on the basis of observations made by J. R. Slevin 1905–1906. *Journal of Herpetology* 15:293–301.
- GARNETT, S.T., CROWLEY, G.M., AND GOUDBERG, N. 1985. Observations of non-nesting emergence by green turtles in the Gulf of Carpentaria. *Copeia* 1985:262–264.
- GREEN, D. 1998. Basking in Galapagos green turtles. In: Epperly, S.P. and Braun, J. (Eds.). *Proceedings of the Seventeenth Annual Symposium on Sea Turtle Biology and Conservation*. NOAA Tech. Memor. NMFS-SEFSC-415, pp. 63–65.
- HOCHSCHEID, S., BENTIVEGNA, F., AND HAYS, G. 2010. When surfacers do not dive: multiple significance of extended surface times in marine turtles. *Journal of Experimental Biology* 213:1328–1337.
- LI, Z.Q., BARKER, H.W., AND MOREAU, L. 1995. The variable effect of clouds on atmospheric absorption of solar-radiation. *Nature* 376:486–490.
- MANNING, B. AND GRIGG, G.C. 1997. Basking is not of thermoregulatory significance in the “basking” freshwater turtle *Emydura signata*. *Copeia* 1997:579–584.
- MCILHENNY, E.A. 1935. *The Alligator's Life History*. Boston: Christopher Publishing House, 134 pp.
- PAK, H. AND ZANEVELD, J.R.V. 1973. The Cromwell Current on the east side of the Galapagos Islands. *Journal of Geophysical Research* 78:7845–7859.
- PALACIOS, D.M. 2004. Seasonal patterns of sea-surface temperature and ocean color around the Galapagos: regional and local influences. *Deep-Sea Research Part II—Topical Studies in Oceanography* 51:43–57.
- PRITCHARD, P.C.H. AND GREENWOOD, W.F. 1968. The sun and the turtle. *International Turtle and Tortoise Society Journal* 2:20–25.
- ROSS, J.P. 1984. Adult sex-ratio in the green sea turtle. *Copeia* 1984:774–776.
- SAPSFORD, C.W. AND VAN DER RIET, M. 1979. Uptake of solar radiation by the sea turtle, *Caretta caretta*, during voluntary surface basking. *Comparative Biochemistry and Physiology A* 63:471–474.
- SEEBACHER, F. 1999. Behavioural postures and the rate of body temperature change in wild freshwater crocodiles, *Crocodylus johnstoni*. *Physiological and Biochemical Zoology* 72:57–63.
- SEMINOFF, J., ZÁRATE, P., COYNE, M., FOLEY, D., PARKER, D., LYON, B., AND DUTTON, P. 2008. Post-nesting migrations of Galápagos green turtles *Chelonia mydas* in relation to oceanographic conditions: integrating satellite telemetry with remotely sensed ocean data. *Endangered Species Research* 4: 57–72.
- SIMMONS, S.E., TREMBLAY, Y., AND COSTA, D.P. 2009. Pinnipeds as ocean-temperature samplers: calibrations, validations, and data quality. *Limnology and Oceanography: Methods* 7:648–656.
- SNELL, H.L. AND FRITTS, T.H. 1983. The significance of diurnal terrestrial emergence of green turtles (*Chelonia mydas*) in the Galapagos Archipelago. *Biotropica* 15:285–291.
- WHITTOW, G.C. AND BALAZS, G.H. 1982. Basking behavior of the Hawaiian green turtle (*Chelonia mydas*). *Pacific Science* 36: 129–139.
- WIKELSKI, M., GALL, B., AND TRILLMICH, F. 1993. Ontogenetic changes in food intake and digestion rate of the herbivorous marine iguana (*Amblyrhynchus cristatus*, Bell). *Oecologia* 94: 373–379.
- ZÁRATE, P.M., CAHOON, S.S., CONTATO, M.C.D., DUTTON, P.H., AND SEMINOFF, J.A. 2006. Basking behavior of green turtles in the Galapagos Islands. In: Frick, M., Panagopoulou, A., Rees, A.F., and Williams, K. (Eds.). *Proceedings of the Twenty Sixth Annual Symposium on Sea Turtle Biology and Conservation*, International Sea Turtle Society, Greece, p. 118.
- ZUUR, A., IENO, E., AND SMITH, G. 2007. *Analysing Ecological Data*. New York: Springer, 672 pp.

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