

Offshore Migratory Activity of Hawksbill Turtle (*Eretmochelys imbricata*) Hatchlings, II. Swimming Gaits, Swimming Speed, and Morphological Comparisons

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ABSTRACT. – Previously, we showed that during their first six days of swimming hawksbill hatchlings are less active than the hatchlings of other marine turtle species. Here, we document that hawksbills also employ slower, drag-based swimming gaits during the brief periods when they do swim. These gaits may render the turtles less conspicuous to predators that detect prey on the basis of movement. Over the 6-day period of observations, predominantly drag-based locomotion (by “rear-flipper kicking” and “dogpaddling”) was gradually replaced by a larger proportion of “power stroking”, a more powerful and faster lift-based means of locomotion. Under natural conditions, this change probably occurs after the hatchlings have reached deep water where predator concentrations are lower. Hawksbill hatchlings are smaller than those produced by most other marine turtles, suggesting that their unique migratory strategy might be correlated with insufficient power to swim rapidly. However, a comparison among species of marine turtle hatchlings suggests that size is poorly correlated with swimming speed. We hypothesize instead that both hatchling size and swimming speed independently determine vulnerability to inshore fish predators. Thus, hawksbills may opt for “hiding by flotsam mimicry” because their size makes them vulnerable to so many fish predators. Therefore, their slower swimming speed may be a consequence, rather than a cause, of that strategy.

KEY WORDS. – Reptilia; Testudines; Cheloniidae; migration; activity; swimming behavior; hawksbill; *Eretmochelys imbricata*

In our previous paper (Chung et al. 2009; this volume), we document that Malaysian hawksbill hatchlings (the only population of this species studied to date) show no frenzy period and are relatively inactive during their offshore migration, compared to other species of marine turtles. We hypothesize that these differences arise because hawksbills use a different behavioral strategy to escape detection by shallow water predators, one based upon mimicry of inanimate objects (dead leaves and other flotsam) drifting on the water surface.

Our purpose in this paper was to determine whether gait use through time by hawksbill hatchlings also differed from other hatchling species; and if so, whether these temporal patterns were consistent with predictions based upon the “flotsam mimicry” hypothesis. For example, during the frenzy period, other species use their fastest and most efficient (lift-based) swimming gait (“power stroking”; Wyneken 1997), presumably to minimize their exposure time to shallow-water predators. If, for hawksbills, stealth is more important than speed, their use of gaits should be different. While negotiating shallow water near the nesting beach, hawksbills might couple inactivity with the use of less conspicuous, slower, drag-based swimming gaits (“rear-flipper kicking” and “dogpad-

dling”; Wyneken 1997). Several days later, having reached deeper water where there are fewer predators, hawksbills might increasingly use power stroking to more efficiently search for food, refugia, or favorable positions within oceanic currents (as shown by loggerheads; Lohmann and Lohmann 2003). We tested this prediction by quantifying hawksbill gait use in pools during the first six days of migratory activity.

Hawksbills produce small hatchlings that might swim more slowly than the other species. We measured hatchling swimming speed, mass, body and flipper dimensions, and flipper surface areas to determine 1) how these parameters differed among species, and 2) whether hatchling size was directly correlated with differences in swimming speed.

Our results indicate that hawksbill hatchlings emphasize the use of drag-based, slower gaits of locomotion early in migration but then gradually incorporate greater use of power stroking into their later migratory movements. Also, we confirm that Pacific hawksbills are on average smaller than the hatchlings of most marine turtles, but our comparisons also indicate that hatchling size is poorly correlated with swimming speed. We suggest as an alternative hypothesis that both hatchling size and

swimming speed are important variables affecting survival during offshore migration and that both may be independently altered to enhance particular offshore migratory strategies.

METHODS

Observations and measurements were conducted between March and July 1999–2000, at Gulisaan Island (6°09'N, 118°03'E), one of three islands in the Turtle Island Park, 40 km north-northeast of the port city of Sandakan. Hawksbills came from either natural or hatchery nests and were collected as they emerged on their own at night or were removed from the nest in the late afternoon of the day they were scheduled to emerge. Turtles were temporarily stored in covered Styrofoam boxes at ambient (shaded) air temperatures until they were used for behavioral observations later that night.

Swimming Speed. — Swimming speeds were measured for 50 hatchlings (5 turtles per nest from 10 different nests). Observations were made on the night of scheduled hatchling emergence.

A 2.0-m length of light monofilament fishing line was tied around each hatchling's shell, just behind its front flippers. Tethered hatchlings were released on the beach ~ 1.0 m from the water's edge, allowed to crawl to the water, and then allowed to swim ~ 1.0 m away from shore (water depth, 30–40 cm). Turtles were held swimming in place at this location for one minute. Then, the tether was released such that each hatchling could swim an additional 2 m away from shore. A stopwatch was used to measure the time required to complete this movement. The hatchling was then slowly pulled by its tether back to the starting point and, after another minute of swimming in place, released for a second trial. This process was repeated until each hatchling completed five trials of straight-line swimming.

Unlike other hatchling species that use power stroking for locomotion in shallow water, hatchling hawksbills sometimes used different gaits during consecutive trials. Swimming speeds, determined for each turtle, were either the average of the speeds observed during two or more trials where the same gait was used or the observed speed shown for any gait that was used in only one trial. In a few trials, turtles switched gaits between the start and end of the 2-m swim. Those trials were not analyzed. All tests were conducted when there was no obvious current, little wind, and when waves were ≤ 10 cm in elevation.

Changes in Swimming Gait Use over Time. — Thirty-nine hatchlings were obtained from nests (five hatchlings from each of four hatchery and three natural nests; four hatchlings from one natural nest) as they emerged at night or were captured in the afternoon of the day they were scheduled to emerge. Turtles were measured and weighed as previously described, stored in individual Styrofoam® boxes, and then tethered that night in one of six seawater-filled fiberglass tanks (for tank dimensions, tethering, and

other procedures, see Chung et al. [2009]). Gait use was observed at night under the dim illumination provided by a small flashlight beam that passed through a red-colored plastic filter.

Two sets of swimming measurements were made. In the first, gait use during the first hour of swimming was measured. Durations (in seconds) of gait use were quantified with a stopwatch during 1-min observations, done at 5-min intervals (total of 12 observations/turtle on 30 turtles from 11 different hatchery nests). Gaits observed were power stroking, rear-flipper kicking, and dogpaddling. If turtles stopped swimming, the time spent inactive was noted. Breathing bouts were also quantified (bouts/min). Stroke rates used by the turtles during power stroking and rear-flipper kicking were the average of those observed during each observation.

A second set of swimming measurements was done to determine how gait use changed over six days. Observations were made on 20 hatchlings from hatchery nests with each turtle's behavior sampled every 3 h beginning at midnight (shortly after hatchlings were placed in their tank and tethered to the recording system). Observations lasted for 2 min or until each turtle had completed a single bout of swimming initiated within that time period. Turtles that were inactive did not contribute to the data set. The behavior of the active turtles was quantified by counting the total number of swimming strokes they performed using each gait. These data were then summed by gait for each day and plotted as the percentage of all swimming strokes for that day.

Morphological Measurements. — Immediately after collection, turtles were weighed (g) and measured (straight-line carapace length [SCL], straight-line carapace width [SCW], front-flipper length [distal humeral joint to the distal third phalanx], and front-flipper surface area). Five turtles from each of 10 hatchery nests were collected for these measurements. Front-flipper surface areas for each turtle were traced on graph paper by holding their surfaces flat with light finger pressure and tracing a peripheral outline on graph paper. Flipper surface areas were estimated by counting the enclosed 1-mm² blocks. Similar measurements were also done from outline tracings made from live hatchlings of other species, captured from nests in Florida. Surface areas for these turtles were calculated using Image J, version 1.37.

Statistical Analysis. — Correlation (Zar 1999) was used to determine whether the duration of gait use changed significantly over the first hour of swimming. A single-factor ANOVA (Zar 1999) was used to compare swimming speeds shown by turtles using different gaits. When differences were found, post hoc (Scheffe's matrix) tests were used to identify the sources.

RESULTS

Swimming Behavior and Speed. — The 50 turtles used to measure swimming speed most often swam by power

Table 1. (A) ANOVA analysis of swimming speeds by gait (measured in km/h). (B) Scheffe's matrix of pairwise comparison probabilities.

(A)					
Source	SS	MS	df	F	p
Gait	2.228	1.114	2	50.92	< 0.0001
Residual	1.554	0.022	71		
(B)					
	Mean diff.	Crit. diff.	p		
Power stroking, dogpaddle	0.276	0.101	< 0.001		
Power stroking, rear-flipper kicking	0.415	0.113	< 0.001		
Dogpaddle, rear-flipper kicking	0.139	0.125	0.026		

stroking ($n = 152$ trials, or 61 %), followed by rear-flipper kicking ($n = 43$, or 17%) and dogpaddling ($n = 40$, or 16%). In 15 trials (6 %), turtles used more than one gait; these trials were excluded from the analysis.

The majority of the hatchlings ($n = 29$) used only one gait during all of their (5) trials; whereas, a minority used two ($n = 18$) or three ($n = 3$) gaits. Thus, 21 of the 50 turtles contributed data that could be used to determine speeds for two or more gaits. Average swimming speeds (measured in m/min, then converted to km/h) were (mean \pm SD) as follows: power stroking, 0.76 ± 0.16 ($n = 38$ turtles); dogpaddling, 0.48 ± 0.14 ($n = 21$ turtles); and rear-flipper kicking, 0.35 ± 0.14 ($n = 15$ turtles). ANOVA analysis (Table 1A) revealed that these speeds differed significantly from one another. Post hoc (Scheffe's matrix) comparisons indicated each gait resulted in a statistically different speed (Table 1B).

Hawksbill swimming speeds while power stroking were lower than those estimated for loggerhead, green turtles, and leatherbacks in other studies (Table 2). Mean stroke rates during power stroking (2.62/s) were higher than stroke rates during rear flipper kicking (1.36/s; Fig. 1). Stroke rates did not change during the first hour of swimming (Fig. 1).

Changes in Gait Use and Activity over Time (First Hour). — Hawksbills were most active during the first 35 min of observations. Activity then declined (Fig. 2). Three gaits were used during swimming, but their proportional use changed over time. During the first 25 min, power stroking was the most common gait (40%–60% of each min); its frequency of use declined to about 20% of each min during the last 20 min of observations (Fig. 2).

Dogpaddling also declined from its highest usage (10%–30%) during the first 5 min of swimming to < 5% during the last 20 min of swimming observations. Rear-flipper kicking gradually increased in use from 10%–20% of all gaits used during the first 10 min of swimming to more than 40% of all gaits used during the last 30 min of observations (Fig. 2).

Correlation analyses were used to confirm trends in gait use. Over the first hour, power stroking ($r = -0.74$, $p < 0.05$) and dogpaddling ($r = -0.69$, $p < 0.05$) significantly declined; whereas, rear-flipper kicking ($r = 0.68$, $p < 0.05$) significantly increased.

Time spent inactive gradually increased during the first hour of swimming from $\sim 10\%$ of each minute during the first 35 min of swimming to $> 20\%$ of each minute during the last 10 min of swimming (Fig. 2).

Dogpaddling is used both to cover distance and to elevate the head above water during breathing. As the frequency of dogpaddling declined so also did the number of breathing bouts (Fig. 3). This decline was statistically significant ($r = -0.96$, $p < 0.01$).

Gait Use over Six Days. — Gait use (as measured by the number of strokes performed using each gait) changed over 6 days (Fig. 4). Dogpaddling was rarely used during the first two days of swimming, as shown by its relatively low stroke count. However, those counts more than tripled over the last four days of observations. During days 1–3, stroke counts for rear-flipper kicking exceeded the counts for power stroking, but during days 5 and 6, this relationship reversed (Fig. 4).

Body Mass and Flipper Proportions. — Hawksbills from Gulisaan Island were smaller in mean mass (11.5 g)

Table 2. Comparisons among the power stroking swimming speeds of hawksbill hatchlings from Gulisaan Island, Malaysia, and green turtle, loggerhead, and leatherback hatchlings from Florida. Speeds are extrapolated from observations over shorter distances and durations and assume no change in gait or speed occurs over time.

Species	Sample size	Speed (km/h)	Reference
<i>Eretmochelys</i>	50	0.76	This study
<i>Dermochelys</i>	10	0.91	Wyneken, 1997
<i>Caretta</i>	3–30	1.26–1.28	Salmon and Wyneken, 1987; Witherington, 1991
<i>Chelonia</i>	10–30	1.56–1.57	Frick, 1976; Wyneken, 1997

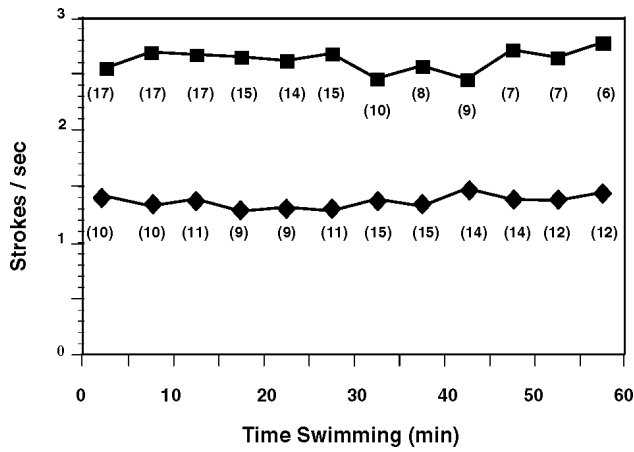


Figure 1. Mean stroke rates for 30 hawksbill hatchlings during their first hour of swimming. Above (squares), power stroking; below (diamonds), rear-flipper kicking. Values in parentheses indicate sample size at each observation time. Mean (\pm SD) for power stroking: 2.62 ± 0.10 ; for rear-flipper kicking: 1.39 ± 0.06 .

than loggerheads (19.1 g), green turtles (25.1 g), and leatherbacks (42.2 g) from Florida (Table 3). However, they fell within the range of mean values for hawksbill mass reported from several Pacific rookeries (9.4–14.6 g; Witzell, 1983).

Hawksbill hatchlings were smaller in SCL and SCW than Florida loggerheads, green turtles, and leatherbacks (Table 3). They also had front flippers that were shorter in length and smaller in surface area than those of the other species (Table 3).

DISCUSSION

The swimming behavior of hawksbill hatchlings during offshore migration shows some similarities to, but many differences from, other species of marine turtles. In other species, continuous swimming (the frenzy) is shown during the first night and the day that follows; during the

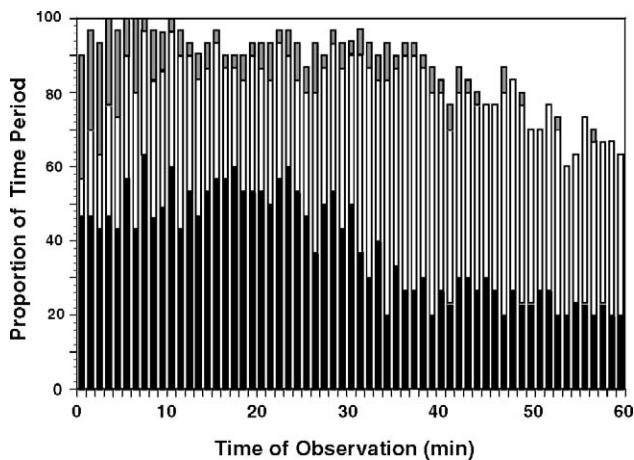


Figure 2. Average gait use by 30 hatchlings during the first hour of swimming. Grey bars, dogpaddling; clear bars, rear-flipper kicking; black bars, power stroking. Open area above each bar indicates the time that the turtles were inactive.

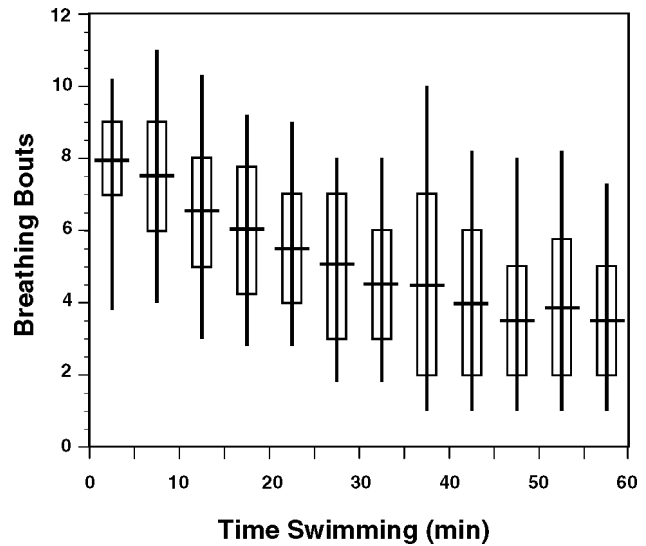


Figure 3. Average number of breathing bouts/min at 5-min intervals during the first hour of swimming by 30 hawksbill hatchlings. Vertical line, range; vertical box, SD; horizontal line, mean.

postfrenzy, swimming is largely confined to the light period. Hawksbills showed a similar pattern of gait use in relation to photocycle, but their swimming activity was lower during all days of observation. No frenzy period was evident (Chung et al. 2009).

Hawksbills also differ from other species in their greater use during migration of slower, drag-based swimming gaits (rear-flipper kicking, dogpaddling) instead of faster, primarily lift-based swimming gaits (power stroking; Figs. 2 and 4). These contrasts are most striking during the frenzy period when all other species use power stroking for rapid locomotion away from the nesting beach and toward deep water (Wyneken 1997). In contrast,

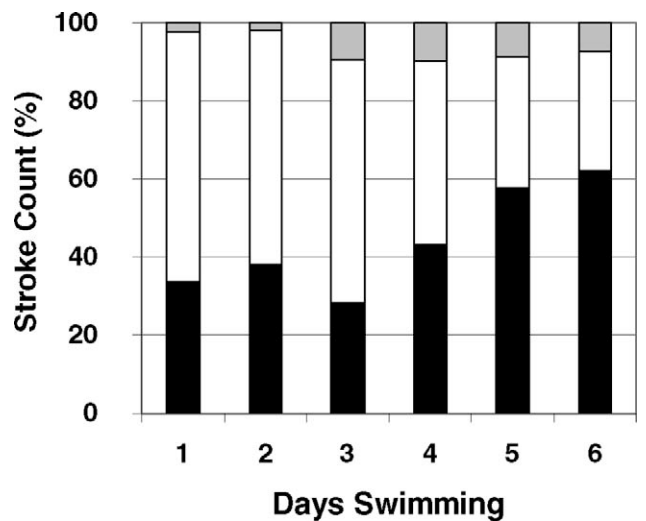


Figure 4. Gait use by 20 hatchlings over 6 days, totaled from measurements made at 3-h intervals. Data are based upon the number of flipper strokes performed using each gait during a single bout of swimming. Grey bars, dogpaddling; clear bars, rear-flipper kicking; black bars, power stroking. Total stroke counts each day ranged between 1154 (day 4) and 2305 (day 6).

Table 3. Morphometrics (mean \pm SD) for hatchling hawksbills from Gulisaan Island, Malaysia (this study), and for loggerheads, green turtles, and leatherbacks from Florida.^a

Species (no. nests)	<i>n</i>	Mass (g)	SCL ^b (mm)	SCW (mm)	FFL (mm)	FFA (mm ²)
<i>Eretmochelys</i> (10)	50	11.5 \pm 1.2	37.2 \pm 2.2	27.5 \pm 1.3	29.2 \pm 1.4	226.8 \pm 17.6
<i>Caretta</i> (6)	24	19.1 \pm 1.8	44.6 \pm 2.0	33.7 \pm 1.5	32.9 \pm 2.4	291.0 \pm 28.3
<i>Chelonia</i> (6)	23	25.1 \pm 1.3	51.8 \pm 1.6	39.1 \pm 1.6	41.1 \pm 1.5	497.5 \pm 38.9
<i>Dermochelys</i> (4)	12	42.2 \pm 4.0	58.6 \pm 2.2	39.6 \pm 1.3	55.7 \pm 1.9	823.1 \pm 61.2

^a Unpublished data from turtles studied by Wyneken and Salmon (1992).

^b SCL, straight-line carapace length; SCW, straight-line carapace width; FFL, front-flipper length; FFA, front-flipper surface area.

hawksbill use of power stroking (and their locomotor activity in general) actually declined during the first hour of swimming (Fig. 2), remained low over the next four days, and then showed a modest increase during days 5 and 6 (Fig. 4). These changes suggest that hawksbills employ different tactics for migration during the first three days than they do during days 5 and 6. Analogous shifts in swimming behavior occur in loggerheads. They change from mostly power stroking during the frenzy period to mostly rear-flipper kicking during the postfrenzy period (Witherington 1995; Wyneken 1997). But that shift in loggerheads begins earlier in time (day 2) and involves a change from a lift- to a drag-based mode of locomotion; in hawksbills, the shift is from mostly drag-based to increasing use of a lift-based mode of locomotion (Fig. 4).

Why Do Hatchlings Differ in Migratory Behavior?

Models of marine turtle life histories are based upon studies showing that adults have high probabilities of survival and few predators; whereas, hatchlings have low probabilities of survival and many predators (Richardson and Richardson 1982; Frazer 1983; Crouse et al. 1987, 1994; van Buskirk and Crowder 1994; Heppell et al. 2003). Hatchlings are especially vulnerable to predators because of their small size, relatively weak swimming and diving capabilities, and limited defenses. Marine turtle hatchlings are apparently unable to avoid being swallowed by fish predators, as reported for some freshwater turtle hatchlings (Britson and Gutzke 1993).

Hatchlings are especially at risk as they migrate offshore through shallow water where they are exposed to many near-shore, aquatic predators (Hendrickson 1958; Carr and Ogren 1960; Honegger 1967; Bustard 1979; Stancyk 1982; Gyuris 1994; Wyneken et al. 1997; Dobbs et al. 1999; Pilcher et al. 2000; Stewart and Wyneken 2004; Whelan and Wyneken 2007). Once hatchlings reach deeper water, encounters with predators may be less frequent and the turtles' probability of survival higher (Bolten 2003).

In our accompanying paper (Chung et al. 2009), we hypothesize that differences in activity shown by migrating green turtles and hawksbills represent alternative strategies for predator avoidance during offshore migration. According to this hypothesis, green turtles use a "sprinter" strategy to reduce their exposure time to

shallow water predators. Green turtle hatchlings are highly streamlined, relatively large, and are fast-swimming turtles (Table 1) with elongated, high-aspect ratio front flippers (Table 3) that are swept rapidly through the water (Wyneken 1997). They also couple high levels of activity with an appropriate physiology (broad aerobic scope) to sustain these movements over a 24-h frenzy period (Wyneken 1997). In contrast, hawksbills produce small hatchlings that swim slowly (Table 1) and have proportionally short front flippers (Table 3). They mimic (in body outline and in color) dead leaves blown into the water from land. Mimicry is an effective mechanism used by many animals to avoid predators (Edmunds 1974).

In both hawksbills and loggerheads, body coloration, shape, and texture simultaneously promote mimicry (in this case, resemblance to floating leaves) and crypsis (resemblance to background, such as flotsam; Feder and Lauder 1986; Hacker and Madin 1991). But hawksbills, unlike loggerheads, show behavior that suggests that mimicry, crypsis, and inactivity occur shortly after the turtles enter the ocean, rather than after a 24-h frenzy period.

It is tempting to speculate that hawksbill hatchlings differ behaviorally from the other hatchling species because small size constrains their ability to swim rapidly. But an alternative hypothesis is that the slower swimming shown by hawksbills is a consequence of their migratory strategy not their size. Relationships between body size and swimming speed cannot be used to distinguish between those hypotheses.

The comparative data (Tables 2 and 3) suggest that, among sea turtle hatchlings, body size is weakly correlated with swimming speed. For example, leatherback hatchlings are about 3.7 times larger in mass than hawksbills but swim only \sim 16% faster (0.91 km/h vs. 0.76 km/h). Loggerhead hatchlings differ much less in mass from hawksbills (\sim 1.7 times) but swim \sim 40% faster (1.27 km/h vs. 0.76 km/h). Yet, both loggerheads and leatherbacks opt for continuous swimming throughout their frenzy period in spite of large differences in both body size and swimming speed. Why?

One possibility is that both body size and swimming speed independently reduce the impact of predators, allowing hatchlings of different size (such as loggerheads, green turtles, and leatherbacks) to converge upon a similar migratory strategy. Larger body size in leatherback

hatchlings might impose gape limitations upon predators (Abrahams 2006), improving survival probabilities even at slower swimming speeds (that reduce the drag costs of locomotion). Smaller body size in loggerheads probably increases their vulnerability but reduces the cost of producing many offspring. Faster swimming speeds shown by loggerheads may reduce the time spent traversing shallow water, thus also improving survival probabilities.

Ecological variables may also be important. Loggerhead rookeries are located in subtropical or warm temperate habitats; although, scattered nesting also occurs in the tropics (Dodd 1988). Because coral reefs are either absent or less developed at those sites, predation pressures on hatchlings in shallow water may be reduced compared to those experienced by other species (Stewart and Wyneken 2004; Whelan and Wyneken 2007). But hawksbills nest predominantly in the tropics (Witzell 1983) where coral reefs can concentrate potential hatchling predators. For a small, vulnerable hatchling like the hawksbill, the adaptations shown may be the best option for escaping detection by near-shore predators.

How Hawksbills Migrate Offshore

In the absence of direct observations on how hawksbill hatchlings behave in the open ocean (Harewood and Horrocks [2008] describe behavior during the first 20 min of migration), we present a likely scenario describing how they might behave. These speculations are based upon the few observations that exist in the literature, as well as the behavior we observed in tanks with tethered hatchlings. Although the tank environment is in many respects artificial, in previous studies with loggerheads, the migratory activity observed in tanks (Wyneken and Salmon 1992) closely approximates the migratory activity of turtles tracked for several days as they migrate offshore (Witherington 1995).

Like the hatchlings of other species, hawksbills typically emerge from their nests at night and under most circumstances perform a vigorous crawl from the nest to the ocean (Carr et al. 1966; Kamel and Mrosovsky 2005). Deraniyagala (1930) reported that newly emerged hatchlings confined to a dry basin crawled steadily for hours but when placed in water, the turtles within a short time become inactive. Apparently in hawksbills, swimming for a short period of time actually inhibits further activity. No such inhibition occurs in green turtles, loggerheads, or leatherbacks.

Hatchlings tethered in our pools also at first swam vigorously (Fig. 2). Their behavior was consistent with the hypothesis that hatchlings use power stroking to quickly distance themselves from the surf zone, perhaps responding initially to wave surge undertow for assistance (Carr 1987; Wang et al. 1998). Shortly thereafter, they probably orient offshore using surface waves (Salmon and Lohmann 1989). After 30 min of swimming, they may be displaced

far enough from shore to avoid being swept back to the beach, and both their swimming activity (Fig. 2) and surface-breathing rates (Fig. 3) start a decline. The turtles also shift gaits from power stroking and rear-flipper kicking in almost equal proportions to rear-flipper kicking as the dominant gait (Fig. 2). The typical posture for a rear-flipper kicking turtle is one in which the front flippers are flexed across the carapace, and the body outline viewed from below shows little evidence of appendages. At this point in their migration, the turtles remain in shallow water where they are probably exposed to an array of reef-dwelling predators.

We estimate that one hour after hatchlings enter the water turtles are no more than 500 m from the nesting beach. This estimate is based upon the following assumptions: 1) they orient directly offshore; 2) neither wind-induced nor tidal-induced currents displace the turtles to deeper water (although they may cause lateral displacement); and 3) the turtles swim at speeds that are the average (0.62 km/h) of their power stroking (0.76 km/h) and rear-flipper kicking (0.48 km/h) gaits.

Over the next six days, the turtles swim about 5–7 h per day and float inactively during other times (Chung et al. 2009). When active, rear-flipper kicking is used more often than power stroking during the first four days, but beginning on days 5 and 6, power stroking gradually becomes the preferred gait (Fig. 4). This change in behavior might occur because the turtles at this point in time have reached deep water and can search for food, shelter, or favorable currents using a more conspicuous, but now less risky, swimming gait.

Obviously, other scenarios might apply. Tidal currents near land and wind-induced surface currents once turtles reach open water probably assist in dispersal. Even inactive turtles can drift considerable distances under the influence of those forces. In the Atlantic Ocean, the North Atlantic gyre is probably used by both hawksbills and loggerheads for transport from Caribbean and western Atlantic rookery sites to eastern Atlantic nursery areas (Carr 1986; Bolten et al. 1994, 1998).

Deraniyagala (1930) observed that, when hawksbill hatchlings became inactive, they also became positively thigmotactic; this tendency in tanks containing several hatchlings resulted in the formation of a turtle “raft”. In our tanks, hawksbills almost immediately swam toward and grasped any floating objects (typically, dead leaves) blown into the tanks by occasional storms. Many then assumed a “tuck” posture (front flippers laid flat over the carapace and hind limbs overlapping one another covering the tail; Wyneken 1997). The cessation of locomotion after encountering floating mats of *Sargassum* was also reported for Honduran hawksbill hatchlings within 2 h after they entered the sea (Hasbún 2002). Hiding in flotsam also occurs in loggerheads (Mellgren et al. 2003) but much later in time (Witherington 1995). Juvenile hawksbills, green turtles, and loggerheads have been found hiding on or in mats of *Sargassum* and other flotsam that accumulate

at windrows and oceanic convergence zones (Carr 1986, 1987; Witherington 2002; Witherington and Hiram 2006).

In conclusion, Malaysian hawksbill turtle hatchlings show differences from the hatchlings of other marine turtle species in how they migrate offshore. Instead of swimming rapidly and continuously toward deep water, hawksbills swim intermittently, pausing often to “rest”. They also use slower (drag-based) gaits for locomotion during the early stages of migration; whereas, the other species during the same period use their fastest (lift-based) “power stroking” gait. These behavioral contrasts lead us to hypothesize that hawksbills depend upon dead-leaf mimicry and reduced movement to escape detection from predators; whereas, the other species swim rapidly to minimize their time in predator-rich waters. A comparison between species in morphology and swimming behavior suggests that each antipredator strategy is correlated with differences in hatchling body size, swimming speed, or both variables.

The obvious next step is to test the validity of these hypotheses through appropriate laboratory and field experiments.

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