

The Migratory Behavior of Hatchling Sea Turtles Beyond the Beach
Jeanette Wyneken
Department of Biological Sciences
Florida Atlantic University

ABSTRACT

Sea turtles are migratory specialists. As such, they possess suites of morphological, behavioral and physiological adaptations for migratory life. These include streamlining of the body, forelimbs that are modified into flippers for efficient locomotion, highly elastic lungs, and high aerobic capacity. Sea turtles migrate between nesting and nursery grounds, as well as between breeding and feeding grounds. For the purposes of this paper, I restrict my discussion to the biology of hatchlings and hatchling migrations from the shore to nursery areas. Hatchlings utilize a sequence of behavioral responses to intrinsic and extrinsic signals during this migration. Frenzy and postfrenzy swimming represents the drive to migrate. Wave and magnetic cues tell hatchlings where to go to locate appropriate niches.

Morphological, Behavioral and Physiological Adaptations

Morphology- Sea turtles possess morphological adaptations for long-distance migration. Among these are streamlining of the body and hypertrophy of the phalanges to form flippers. The body is tapered and has reduced head and limb pockets. These features reduce resistance through the water (drag) and hence reduce the costs of long-distance locomotion.

The flippers produce thrust during swimming. The primary form of swimming is called *powerstroking*, or "subaqueous flight." During powerstroking, thrust is produced by both the down and upward strokes (retraction and protraction); the forelimbs act like wings or propellers. There is no wasted movement, making this an efficient form of locomotion. There is also a division of labor between the forelimbs (producing thrust) and the hind limbs (which serve as rudders for steering).

Sea turtle swimming, when contrasted with that of freshwater turtles, is clearly adapted for movement over long distances, for long durations. In freshwater turtles (with the exception of *Carettochelys insculpta*) there is no division of labor between fore and hind limbs. Each limb acts as an oar. Thrust is produced only during retraction (backsweep of the limb) and each limb has a recovery stroke (protraction) during which no thrust is produced (Wyneken 1996; Wyneken in press).

Physiology- Sea turtles have several physiological and structural adaptations for life in and under the water. Their lungs are designed for rapid air exchange (Lutcavage and Lutz, 1996). Sea turtle lungs are highly elastic, have cartilaginous supports (secondary bronchi) that extend deep into the lung, and a large-bore trachea. These features allow for rapid evacuation of the lungs without collapse of the airways. High elasticity contributes to the large tidal volume that characterizes sea turtle breathing. During

swimming and diving marine turtles rely upon the lung (more so than the blood or muscle pigments) as a reservoir for air. These adaptations allow sea turtles to be efficient breath-holders, an important form of breathing for secondarily aquatic marine animals. Additionally turtles, including sea turtles, can deplete oxygen reserves to lower partial pressures than in other vertebrates. This allows them to remain submerged longer periods than other vertebrates that hold air in the lungs while submerged. Sea turtles differ from humans, and many other land-based vertebrates. We breathe while we exercise. Sea turtles do not. Instead they, as breath-holders, rely on the air stored in the lungs to supply the tissues. When blood O₂ levels drop to very low levels, the turtles come to the surface and breathe again (Lutcavage and Lutz 1996).

Hatchlings, during their early phases of migratory behavior, differ in species-specific ways in their aerobic scope (the maximum range of mass-specific oxygen consumption). *Chelonia* hatchlings can increase their O₂ consumption by 10-12 times of the resting level; hence they have the greatest aerobic scope. *Caretta* hatchlings have a higher resting metabolic rate and when swimming, increase their O₂ consumption by 4-6 times the resting level (i.e., less than in *Chelonia*). *Dermochelys* hatchlings are the most limited in the range of their aerobic activity. They have low resting oxygen consumption levels (similar to those of *Chelonia*), but can only increase their aerobic activity by 4-6 times while swimming actively, well below the levels seen in *Caretta* or *Chelonia*.

These differences in aerobic scope are correlated with differences among species in average swimming speed. *Chelonia mydas* hatchlings average 1.57 km/h, *Caretta caretta* hatchlings swim at 1.28 km/h, and *Dermochelys coriacea* hatchlings swim relatively slowly (averaging 0.91 km/h; Wyneken 1996). Comparable data are not available for the other marine turtle taxa.

Behavior- Hatchling sea turtles have evolved unique activity patterns for rapid escape from the nesting beach, and migration toward oceanic nursery areas. Immediately upon leaving the nest they exhibit hyperactive crawling, then swimming. During seafinding (the crawl from the nest to the surf zone), hatchlings use a hierarchy of cues. They rely on horizon elevation (movement away from high silhouettes and toward lower ones). In the absence of reliable silhouette cues, they crawl toward brighter horizons (Salmon et al. 1993, 1995; Salmon and Wyneken 1994) to find the ocean.

Hatchlings leaving beaches along the east coast of Florida, USA, migrate offshore in an easterly direction. They soon encounter favorable oceanic currents (the Florida Current in the south and its northern continuation, the Gulf Stream) that entrain them into their nursery area (the North Atlantic Gyre). The initial part of the migration occurs in two phases. Upon entering the water, hatchlings undergo a period of hyperactive swimming, termed the *frenzy*. The frenzy functions to distance hatchlings from shore where risks of predation are high. In all species tested to date (*C. caretta*, *Ch. mydas*, and *D. coriacea*), the frenzy lasts about 24 hours (through their first night in the water, the next day, and into the next night; Wyneken and Salmon, 1992). Following the frenzy, hatchlings undergo a transition in behavior that establishes species-specific patterns of activity in relation to the photocycle; this transition is termed the *postfrenzy*. Postfrenzy swimming

conserves energy while the hatchlings complete their journeys to favorable currents and/or locate suitable niches in nursery areas. Postfrenzy swimming in turtles leaving Florida's east coast is primarily diurnal. By the end of their fifth day in the water, *Caretta* postfrenzy swimming behavior is characterized by diurnal swimming. In *Ch. mydas*, swimming is primarily diurnal but turtles also swim about 10% of the night. *Dermochelys* hatchlings swim diurnally and about 30% of each night. These different activity patterns probably reflect each species' foraging behavior and/or predator avoidance habits (Wyneken and Salmon 1992). *Caretta* hatchlings associate with floating debris at oceanic convergence zones. As hatchlings and posthatchlings they feed upon prey located on or in flotsam (surfaces). *Chelonia mydas* hatchlings hunt prey detected visually in the water column and are counter-shaded. Hence, they may not associate as closely with floating debris. Rather, they probably occupy open water near convergence zones, near the periphery of floating debris. *Dermochelys* avoid floating objects of any kind. They specialize on gelatinous prey, captured while diving. The distribution of this prey is patchy, and its caloric content is low. Hence their tendency toward slower, more continuous (both day and night) activity may reflect the need to search continuously to find sufficient food.

Hatchling Migration Depends on Intrinsic and Extrinsic Responses

The motivation that produces frenzy and postfrenzy swimming represent the intrinsic aspects of hatchling offshore migration. The behavior that results may be viewed as the "power source" that drives hatchling movements. But that energy needs to be directed toward appropriate environmental goals.

Offshore migration also involves responses to external (extrinsic) cues that direct the spatial component of migration. Extrinsic responses include orientation to wave and magnetic cues (Lohmann and Salmon 1989, Lohmann and Lohmann 1996a, 1996b, 1998; Lohmann et al. 1996). Orientation is defined as the capacity to move in a given direction (hold a course). In sea turtle hatchlings, different cues used to maintain directional movements are used sequentially. Visual cues are used on the beach to find the ocean; once turtles enter the surf zone, surface waves are used to guide swimming in the same direction, and toward deep water. Magnetic cues are the third guidepost used to maintain direction, and are used last in this sequence to reach offshore goals.

During their initial escape from shallow water, hatchlings show no magnetic directional preference. Rather, they learn one ("calibration") during the crawl and/or while they swim into waves (Goff et al. 1998). Specifically, the crawling and swimming direction in response to waves is transferred to a directional preference that is finally maintained using a magnetic compass.

Orientation and Navigation

Eventually, hatchlings reach the North Atlantic Gyre (Figure 1). Once there, it is essential that they know their position within the gyre so that they avoid being swept into cold waters outside the gyre, or back to shallow waters of the continental shelf. To know their position, hatchlings must possess an ability to navigate. Navigation requires a "map

sense”, or capacity to determine geographic position. When a hatchling senses displacement to unfavorable gyre locations, it must navigate toward a “better” (i.e., safer) area. Navigation, then, requires both a map sense as well as an ability to orient.

The key to understanding how navigation is accomplished is by understanding the elements of the map sense. Lohmann and Lohmann (1998) showed that for hatchling *C. caretta* the map is composed of information supplied by two coordinates; both are elements of the earth’s magnetic field. These are the magnetic inclination angle and magnetic field strength. The inclination angle (analogous to latitude) tells the animals if they are heading towards the either pole or the equator (Light et al. 1993). Magnetic field strength provides information roughly analogous to longitude, that tells the animal if it is heading roughly eastward or westward. How the hatchlings sense these components of the magnetic field is unknown. What we know at this time is that hatchlings detect each of these components, use them as maps to determine their gyre position, and on this basis swim in directions that correct for displacement to unfavorable gyre locations.

Conservation Implications of Hatchlings Sea Turtle Biology

The suite of morphological, physiological and behavioral adaptations described above can serve as guidelines for determining how we should best conserve and manage sea turtles. They remind us how sea turtles live, that they are migratory specialists, which spend the vast majority of their time in the water, away from nesting beaches. While major conservation and management are needed in some areas, it is critical that the biology of sea turtles not be left out when designing the practices. For example, hatchery use and/or headstarting are among the most commonly used management tools used throughout the world. Yet, they may “short-circuit” normal developmental events by depriving turtles of essential experiences at critical times in their development. Hatcheries, if not managed appropriately, also can increase hatchling mortality.

For example, turtles that are not released immediately after they emerge from hatchery nests continue their frenzy activity, burning valuable calories that should be used to migrate offshore. Their intrinsic motivation to swim runs like a clock, and that clock determines when they shift from the frenzy to the postfrenzy period. Hatchlings released hours or days after emergence may change their swimming rates before they have distanced themselves far enough from coastal waters, or have reached their nursery areas. Even if hatchlings are released “on time”, repeated entry into the surf zone at the same (hatchery) location can compromise their survival (Wyneken and Salmon, 1996, 1997; Wyneken et al., in press). Natural nests are spatially and temporally dispersed so that hatchlings emerge (and enter the ocean) from different sites, spread over time as well as space. It is tempting for hatchery managers to release thousands of turtles from the same, convenient location. But doing so concentrates a whole season’s production into a single or a few sites. Marine predators soon learn to wait for hatchlings at these locations. Hatcheries also, by their very nature, concentrate large numbers of nests (and hatchlings) making them vulnerable to storm events, bacterial attack (if the same sand is used repeatedly), or temperature conditions that can alter natural sex ratios.

Headstarting (captive-rearing) conditions can also affect the fitness of released turtles in ways that were unanticipated. Headstarted *Lepidochelys kempfi* were reared singly in small tanks to prevent injury (the turtles are aggressive to one another if reared together). But turtles in small tanks became inactive, and upon release had insufficient stamina and muscle development to swim and forage effectively (Stabenau *et al.* 1992).

Headstarting also interrupts the normal sequence of migration and by doing so, may affect the turtles' ability to navigate. Hatchlings learn a magnetic preference ("calibrate" their magnetic compass) while undergoing oriented crawling down the beach and/or swimming into waves. Insufficient exposure to the crawling and swimming experience could result in turtles that lack the ability to use their compasses, or to navigate appropriately, later in life. And while we know that hatchlings imprint to natal regions, and that imprinting involves a critical period in early development, we do not know the specifics of the process. Given that ignorance, interfering in any way with the normal course of developmental events and experiences hatchlings undergo is a risky management strategy and should be rethought. While some migratory birds have the ability to recalibrate their magnetic compass repeatedly throughout life, we do not know if sea turtles can do so (Lohmann and Lohmann 1998).

Our goal should be to insure that sea turtles hatchlings grow, thrive and mature as competent and productive adults. It is critically important to consider the biology of sea turtles when developing conservation and management plans.

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