Effects of Prolonged Retention in Hatcheries on Green Turtle (*Chelonia mydas*) Hatchling Swimming Speed and Survival

NICOLAS J. PILCHER[1] AND SIMON ENDERBY

Institute of Biodiversity and Environmental Conservation, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia

ABSTRACT.—Many sea turtle conservation projects include hatcheries where eggs are incubated and cared for, until hatchlings emerge and are released to the sea. Unfortunately, hatchlings are often retained for prolonged periods in hatchery enclosures after emerging from the sand. During this time they continuously crawl around, burning limited energy reserves, and missing valuable hours of darkness during which they would normally distance themselves from shore. We hypothesized that these forms of interference impair hatchling swimming behavior and, in turn, reduce survival rates during offshore migrations. We used hatchlings of *Chelonia mydas* in laboratory experiments to determine effects of retention in hatchery enclosures on hatchling swimming speed and behavior. Our results indicate that hatchery operations have a detrimental effect on hatchling behavior. Swimming speed decreased by over 12% with six hours of retention in the hatchery. Swimming style also varied with prolonged retention. Hatchlings frequently used a dog-paddle swimming style (rather than the more efficient powerstroke) after several hours of retention. This deviation in normal swimming style, coupled with decreased swimming speeds, likely hinders hatchling offshore migrations and reduces survival rates.

Conservation efforts that include hatcheries, by-catch reduction devices such as Trowler Exclusion Devices (TEDs), habitat protection, and a host of other strategies have been developed to halt the decline of sea turtles around the globe (Amarasooriya, 1998; Bjorndal, 1995; Crowder et al., 1995; Tucker et al., 1996). A disturbing trend among conservation practices is the use of manipulative programs, which have mostly met with little or no proven success (Seigel and Dodd, 2000). The efficacy of manipulative conservation techniques depends on many factors and have not been proven effective in maintaining or rebuilding sea turtle populations (Heppell et al., 1996). For example, sea turtle farms have not been shown to be directly beneficial to the conservation of wild populations (Ross, 1999). Headstarting of Kemp's ridley *Lepidochelys kempi* sea turtles in Galveston, Texas, has yielded no conclusive evidence of long-term success (Byles, 1993; S. A. Eckert, D. Crouse, L. B. Crowder, M. Maceina, and A. Shah, NMFS-OPR-3 Report, U.S. Department of Commerce, 1994). The decline of the leatherback turtle in Terengganu has been linked to hatchery operations, in which all offspring were female because of nest developmental temperatures (Chan and Liew, 1996). Mortimer (1999) suggests that hatcheries should only be used as a last resort only after other in situ programs have failed, as the hatcheries and their management

operations can have a net negative impact on wild turtle populations.

Many conservation programs, in developing countries in particular, have focused on the use of hatcheries aimed at ensuring egg survival and hatchling emergence. Little or nothing is known of the long-term success of these programs, as hatchery operations rarely track hatchlings once they leave the beach and thus have no measure of overall success. Pilcher (2000) cautioned that the hatcheries in Sabah, Malaysia, have not been proven to restock adult populations, and preliminary studies on hatchling survival as they migrate offshore have indicated that up to 50% of hatchlings may be lost in the first hour at sea (Pilcher et al., 2000). Sex-determination studies at these hatcheries (Tiwol and Cabanban, 2000), similarly concluded that the hatchery program was ineffective, by highlighting the negative effects of altering egg development temperatures through the removal of natural shading.

At the Turtle Islands Park (TIP) in Sabah, hatchery operations have been in existence since 1966 to protect eggs from human collection (Pilcher and Ali, 1999; Pilcher and Basintal, 2000). Eggs are gathered by park rangers during or immediately after oviposition and transported to a nearby hatchery, where each nest is individually placed within an enclosure. After incubation, hatchlings are supposed to be collected by park rangers and released close to the shoreline of one of two beaches. More often, however, hatchlings remain in their enclosures for up to six or seven hours. Hatchlings have

[1] Corresponding Author. E-mail: nick@dominomail.unimas.my
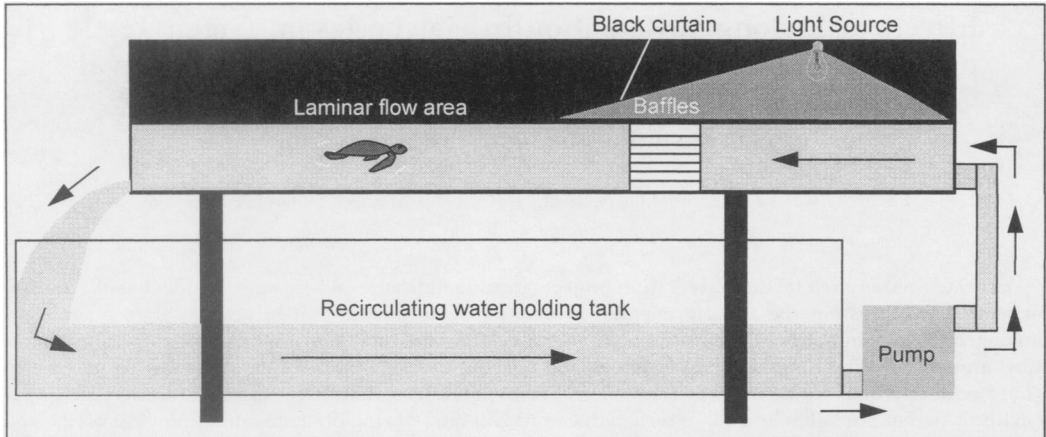
FIG. 1. Raceway system used for hatchling swimming trials (see text for construction and design details).

been observed to crawl continuously around and over each other during this time, after which they appear lethargic or inactive. It is likely that the perturbations to normal post-emergence behavior affect their chances of surviving as hatchlings, by depleting limited energy supplies and altering their programmed swimming behavior and timing after retention in the enclosures.

Under natural conditions, hatchlings crawl rapidly from the nest to the sea following emergence (Salmon and Wyneken, 1994). Hatchlings normally enter the sea at night and immediately begin a swimming frenzy that may last up to 24 h, during which they distance themselves from shore and shore-based predators (Wyneken and Salmon, 1992; J. Wyneken and M. Salmon, Broward Co. Bd. Comm., Dept. Nat. Res. Protect. Boca Raton, FL, 1994). In Sabah, most hatchlings do not display the normal vigorous crawling behavior after release from the hatchery enclosures, and by the time they enter the sea, they have presumably consumed valuable energy supplies needed for their swimming frenzy and offshore migration.

We hypothesize that hatchlings that expend energy while crawling for hours in hatchery enclosures swim slower and cover less distance in their first night at sea than if they are released immediately after emerging from the nest. If this is true, hatchlings should take longer to pass through nearshore waters, where depredation of hatchlings is high (Gyuris, 1994) and possibly face higher rates of predation. Additionally, the limited energy supply available to neonates that is partially consumed during their periods of detention should limit their ability to swim offshore. Finally, because hatchlings are deprived of valuable hours of darkness while retained in enclosures, survival should decrease

further as hatchlings will be in nearshore waters after daybreak, when predation rates likely increase. It was expected that the results of this study would be the basis for changes in current management practices at the Park, and an indication to other hatchery management bodies of the possible consequences of prolonged retention.

MATERIALS AND METHODS

To test for decreases in hatchling swim speeds and to identify changes in swimming behavior, a series of laboratory experiments that took into account known aspects of hatchling swimming and orientation were carried out with recently emerged green turtle *Chelonia mydas* hatchlings. The experimental setup was designed to account for the initial orientation acquired during the beach run, variable swimming speeds and styles, magnetic field influences, sound, light, and other visual cues such as silhouettes. Swimming trials were carried out on Selingan island ($6°10.5'$N, $118°03.5'$E) off Sabah, Malaysia, from November 1997 to April 1998. Swimming behavior was monitored in a custom-designed recirculating raceway system (Fig. 1).

Swimming Trials.—Enclosures within the hatchery that contained large numbers of hatchlings after en masse emergence were identified early in the evening. From one of these, three hatchlings (designated E_0 representing Emergence at hour 0, or immediately after emergence) were selected at random and immediately moved in a sand-lined bucket to the raceway system. Hatchlings were not tethered in the raceway, rather, they were allowed to swim into an artificial current regulated to match their swimming speed. An E_0 hatchling was placed in the unit and allowed to acclimate for one mi-

nute with water recirculating through the system (the hatchling was expected to swim upon being placed in the unit). After acclimatization, swimming speed was recorded by measuring opposing water speeds using a Hydrological Services Pty. Ltd. OSS PC1 current meter linked to a CMC 200 counter ($\pm$ 0.02 m $\cdot$ sec^{-1}). An average of three 20-sec readings was used. Swimming speed was determined at 10-min intervals for one hour. Water speed was adjusted throughout the swimming period to maintain the hatchling's position within 30 cm ($\pm$) of a central reference point. Notes were also made on swimming behavior and deviations from normal swimming styles.

Hatchlings that did not swim ($N = 9$, each from a different nest) upon being placed in the unit were exchanged with others from the same subsample. After the first trial, the subsample was released and a second subsample (E_1, those that had been in captivity for one hour) was collected from the same nest. After monitoring the E_1 hatchlings, the process was repeated for subsamples of E_2, E_3, E_4, E_5, and E_6 hatchlings, representing up to six hours after emergence.

Raceway Design.—The system was designed to eliminate the effects of a number of environmental cues that affect hatchling behavior (reviewed by Wyneken, 1996). The marine plywood raceway measured 220 $\times$ 38 cm with a depth of 40 cm and an adjustable-height (0–4 cm) outflow area. The interior was matte black, and a dim light source was attached to the front edge, slightly above water line, toward which the hatchlings faced. The leading half of the tank was topped with black cover to reduce outside visual stimuli. The unit was in line with the hatchlings' normal offshore orientation, established by releasing 93 hatchlings of which 76 (81.7%) selected a 255° (magnetic) heading. Hatchlings were not found to continuously zigzag their way across the raceway during any of the trials, therefore we believed that the combination of point-source light and tank orientation helped keep the turtles swimming straight into the recirculating water and away from the sides of the unit.

Water depth averaged 15–20 cm, and flow speeds could be varied from 0–3.5 m $\cdot$ sec^{-1} with adjustable channel boards that narrowed or widened the water inflow. A series of baffles made from 8-cm lengths of half-inch PVC pipe glued in a honeycomb matrix were installed one-third down the length of the raceway to provide approximately laminar flow within the actual swimming area. Plastic mesh screens ensured that hatchlings swam in the laminar flow area. Water was maintained at normal sea temperatures by replacing water from the sump tank continuously during the trials.

Control Trials.—To test for possible variations in orientation and behavior resulting from transfer methods, 41 hatchlings were allowed to run down the beach before being introduced into the system to compare with those ($N = 67$) that were transported in the sand-lined bucket.

Statistical Treatment.—A one-way ANOVA was used to test for significant differences in average swim speeds between groups E_0 to E_6. Tukey's multiple comparison of means was used to determine real differences between each group E_n.

RESULTS

Swimming Speed.—Swimming speed decreased with retention time. Hatchlings swam over 12% faster if released immediately after emergence when compared with those that had been detained for six hours. A one-way ANOVA indicated significant differences (ANOVA: $F = 14.847$, $P < 0.0005$; Table 1) in swim speeds among groups E_0 to E_6, (Fig. 2) and among the 10-min intervals within each hourly group (Fig. 3). Pairwise comparisons among E_n means indicated that significant differences existed except between adjacent groups (Table 2). For example, differences between E_4 and E_2 were significant ($P = 0.002$), whereas those between E_4 and E_3 were not ($P = 0.628$). This suggests a gradual decrease, rather than any abrupt change in swimming performance.

Swim Style.—Swimming styles were as described by Wyneken (1996). Hatchlings in groups E_0 to E_3 adopted the powerstroke upon entering the water, usually within 10 sec of being placed in the raceway. The powerstroke was used almost exclusively except during surface intervals for breathing, where hatchlings used the dogpaddle motion. After four- to six-hour retention periods (groups E_4 to E_6), hatchlings used an erratic powerstroke toward the end of the hour's trial, which did not occur with hatchlings after shorter retention times. Hatchlings swam approximately 5–10 cm below the surface during trials and deviations from the swimming norm among all groups only occurred when hatchlings touched the side of the raceway, or more infrequently, the rear guard screen. When this occurred, they immediately pushed away from the side or rear, accelerated a little, and then continued normal swimming.

Control Trials.—Allowing hatchlings to run down the beach had no effect on swimming speeds or styles. Average swim speeds (after the same retention times) of individuals that were transferred using a sand bucket and those that were allowed a short run down the beach were not significantly different (Z-test: $Z_{0.05} = 0.0728$).

TABLE 1. Summary data and one-way ANOVA between retention time groups (E_x) and mean hatchling swimming speeds.

Average first hour swim speeds (m·sec⁻¹)					
Group	Average	SD	Min	Max	N
E_0	0.625	0.0415	0.563	0.711	16
E_1	0.621	0.0393	0.554	0.719	16
E_2	0.608	0.0301	0.568	0.674	16
E_3	0.580	0.0313	0.505	0.624	16
E_4	0.561	0.0213	0.518	0.586	15
E_5	0.558	0.0258	0.510	0.598	14
E_6	0.549	0.0288	0.503	0.620	15

ANOVA					
Source of variation	SS	df	MS	F	P	F crit
Between groups	0.091621	6	0.01527	14.8472	<0.0001	2.18967
Within groups	0.103876	101	0.00103			
Total	0.195497	107				

DISCUSSION

Our experiments indicate that enforced captivity of turtle hatchlings in hatchery operations decreases swimming performance, irrespective of other environmental cues. The trials clearly show that prolonged captivity had a detrimental effect on hatchlings' swimming speeds, which dropped from 0.625–0.549 m · sec⁻¹ after six hours of captivity. Additionally, delayed-release hatchlings miss invaluable hours of darkness during which they would normally swim continuously (Wyneken and Salmon, 1992), distancing themselves from shore. Swim speeds were found to drop by over 12 % after a six hour retention period in a hatchery enclosure, and it is likely that these hatchlings would cover a shorter distance than hatchlings that begin their swimming frenzy shortly after emergence. The life history of sea turtle hatchlings is such that a hatchling's ability to navigate and swim rapidly away from its natal beach is a major requirement for survival (see Gyuris, 1994; Witherington and Salmon, 1992; Wyneken and Salmon, 1990; Wyneken and Salmon, 1992). Disturbances to the natural offshore migration, in particular the initial swimming frenzy period, likely results in decreased survival rates when turtles are unable to reach offshore currents and evade near-shore predators, after valuable hours
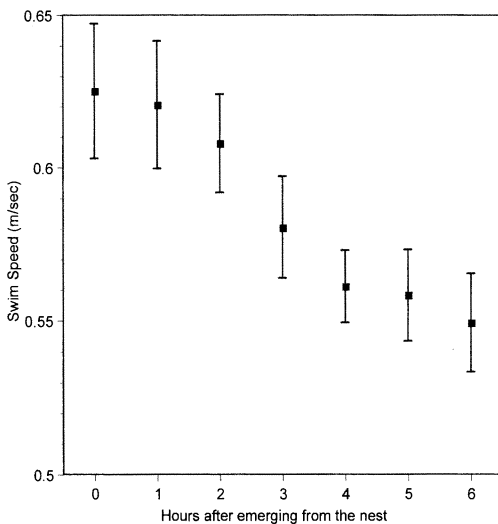

FIG. 2. Trend in average hourly speed during the first hour of swimming. Symbols represent mean speeds, outliers represent 95% confidence limits.
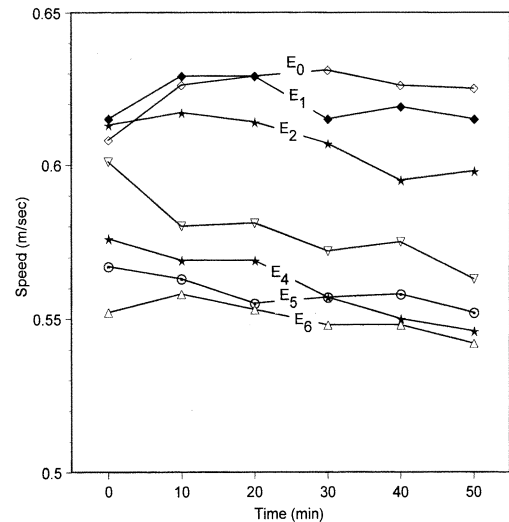

FIG. 3. Hatchling swimming performance. Average speeds during each 10-min segment of the first hour at different release times E_x.

TABLE 2. Tukey's pairwise comparison of means probabilities between E groups using 95% confidence intervals.

	E_0	E_1	E_2	E_3	E_4	E_5	E_6
E_0	1						
E_1	1	1					
E_2	0.735	0.921	1				
E_3	0.003	0.010	0.197	1			
E_4	0.000	0.000	0.002	0.628	1		
E_5	0.000	0.000	0.001	0.596	1	1	
E_6	0.000	0.000	0.000	0.062	0.872	0.891	1

of darkness are wasted and internal energy resources are depleted.

The swimming behavior of hatchlings under laboratory conditions using tethered subjects is similar to that found in the wild (Wyneken, 1996). The combination of system design and in particular the untethered protocol in these trials may have been even more representative of what may occur under calm natural conditions and, thus, more representative of what would happen in nature.

At the TIP, the rangers are often not available for hatchling releases for a number of reasons. Although the conservation efforts at the hatchery are well intentioned, these trials have shown that interference with hatchlings' natural emergence, beach crawl and offshore migration through prolonged retention results in decreased swimming speed and the distance they can cover during the initial phase of the swimming frenzy. Many hatcheries around the world employ similar strategies, with hatchlings emerging into small enclosures and being delayed prior to being released. These actions should be carefully reconsidered in light of these findings because they not only rob the hatching turtles of valuable hours of nighttime cover but also alter their swimming behavior and use much-needed energy reserves.

Releasing hatchlings offshore to compensate for retention effects might interfere with their natural ocean-finding mechanisms (as summarized by Lohmann et al., 1996), and well-intentioned management programs should respect the biological needs of hatchlings, in particular the need for a suitable beach crawl and lack of distracting orientation cues such as light. It is suggested that management programs that include the use of hatcheries should schedule the collection of hatchlings from enclosures frequently through the night and that hatchlings be released in individual groups at dark, distraction-free beaches.

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Origin of Loggerhead Turtles Stranded in the Northeastern United States as Determined by Mitochondrial DNA Analysis

KAREN RANKIN-BARANSKY,[1,2] CHARLENE J. WILLIAMS,[3] ANNA L. BASS,[4] BRIAN W. BOWEN,[4,5] AND JAMES R. SPOTILA[1]

[1]Department of Bioscience, Drexel University, Philadelphia, Pennsylvania 19104, USA
[3]Department of Medicine, Thomas Jefferson University, Philadelphia, Pennsylvania 19107, USA
[4]Department of Fisheries and Aquatic Sciences, University of Florida, Gainesville, Florida 32653, USA
[5]Archie Carr Center for Sea Turtle Research, Department of Zoology, University of Florida, Gainesville, Florida 32611, USA

ABSTRACT.—Loggerhead turtles (Caretta caretta) inhabit coastal waters of the Atlantic between Virginia and Massachusetts on a seasonal basis, but the nesting populations that rely upon this foraging habitat have not been determined. In this study, we examined mitochondrial DNA control region sequences to determine the origin of 82 stranded loggerheads, comparing their haplotypes to those observed among major nesting colonies of the Atlantic and Mediterranean. Our results indicated that the stranded animals originated from three demographically independent nesting areas: northeast Florida/North Carolina (25%), southern Florida (59%), an Quintana Roo, Mexico (16%). The data provide a demographic link between nesting populations and the Atlantic coast feeding ground aggregate and indicate that strandings in the northeastern United States remove individuals from these three nesting colonies, two of which show evidence of serious decline.

The loggerhead turtle (Caretta caretta) is distributed circumglobally in temperate and subtropical waters. Like most marine turtles, loggerheads undertake a series of migrations and use a variety of habitats at different stages of

[2] Corresponding Author. Present address: Department of Biological Sciences, University of Delaware, Newark, Delaware 19716, USA; E-mail: krb@udel.edu

their life cycle (Musick and Limpus, 1997). Because there are many difficulties involved in tracking turtles at sea, several aspects of loggerhead life history are unclear. In particular, information on migratory habits and distribution of juvenile and subadult turtles is limited, and our knowledge of movements of adults between nesting and feeding grounds is incomplete. These missing components of life history make