INTRODUCTION

Sea turtle hatchlings emerge from nests buried on oceanic beaches, crawl to the surf zone and swim rapidly offshore. The orientation of these movements depends upon the detection of certain external cues ('guideposts') that the turtles are primed to perceive during this stage of their development. The result is a kind of specialized behavior, characteristic of most animals during migration (Dingle 1996). That behavior makes hatchlings ideal subjects for studies of orientation and navigation, as well as of the way certain anthropogenic perturbations (such as artificial lighting) affect the fate of the hatchlings that depart from nests placed on those beaches.

In Florida, USA, we study these as well as other aspects of marine turtle behavior. Our subjects are usually the most abundant of the marine turtle hatchlings (loggerheads Caretta caretta) but the turtles are only available for a few weeks during the summer (mid-July through late August). Those seasonal constraints limit the amount of data that can be collected through experimentation each year. There are also diel constraints. In Florida, loggerhead hatchlings
emerge from nests most often between 22:00 and 02:00 h (Witherington et al. 1990). This leaves investigators with little time to capture their subjects, expose them to an experimental protocol and then return them to the beach for release within this presumed optimal time window.

For a number of years, we have dealt with these problems by removing a few hatchlings each day from several nests, generally in the afternoon prior to natural nocturnal emergences. We target nests that have been incubating long enough for the hatchlings to have left the confines of their eggs. We usually find the turtles resting as a group just above the mass of empty eggshells or, if they have commenced upward digging, within a few centimeters of the beach surface. We collect a few of these turtles, leaving the rest of the clutch undisturbed to emerge on their own that evening.

The turtles we take are stored in small coolers containing moist sand from the nest interior. The coolers are kept in a dark room at shaded temperatures. Under these conditions, the hatchlings remain inactive until we stimulate them through exposure to cooler (air-conditioned) laboratory temperatures. An analogous process activates the turtles within the nest as the hot beach sands that inhibit locomotion become cooler after sunset and the turtles begin to dig their way out of the nest (Mrosovsky 1968, Gyuris 1993, Moran et al. 1999, Glen et al. 2005). By inducing the captured turtles to become active earlier in the dark cycle, we have sufficient time to complete our experiments, return the turtles to the beach, and release them when many other hatchlings, emerging naturally, begin their migration.

These procedures appear to satisfy the requirements of scientists, and hatchlings collected in this way seem healthy and vigorous. There has, however, been concern expressed that hatchlings remaining in the nest might be adversely affected by the intrusion into their nest. The Florida Fish and Wildlife Conservation Commission (FWC) was specifically concerned that digging into the nest might in some way reduce nest productivity (the number of hatchlings that left the nest and were presumed to enter the sea). To determine if such an impact occurred, we undertook a comparison of nest productivity between nests from which a few hatchlings had been removed and nests that were left intact and undisturbed.

**MATERIALS AND METHODS**

Loggerhead nests were surveyed during the summer of 2010 along a 4.5 km long section of beach in Boca Raton (Palm Beach County), Florida (26° 22' N, 80° 07' W; Fig. 1). This nesting beach is managed by staff from the Gumbo Limbo Nature Center. Each day, nests deposited the previous night were marked with stakes and signage, numbered, and located by GPS coordinates. In a few areas, nests were screened to thwart predators (foxes, skunks and raccoons). The nests used in this study were a subset of those deposited on the beach between 5 May and 19 August.

To accommodate our experiments, some of these nests were assigned to our control (undisturbed) group and experimental (nests from which a few hatchlings were removed) group. The experiment
was designed in collaboration with Blair Witherington (FWC) who used power analyses of past records from loggerhead nests in Florida to estimate a statistically reliable sample size (minimum 62 experimental and 62 control nests) for the study.

Most of the nests were located in front of the city parks (Fig. 2), favored because of ample parking close to the beach and walkways between the parking lot and beach that allowed for convenient access to any nests targeted each day for inspection. All nests were located sufficiently far above mean high tide to minimize the risk of inundation or ‘wash-out’ by a storm-induced tide. None of the nests in our data set were relocated.

Gumbo Limbo staff excavated each nest within 3 d after an emergence (as determined by hatchling tracks leading from the nest to the ocean) or by Day 70 post deposition (if no tracks were seen). Excavations were done to determine clutch size (the number of unhatched eggs plus the number of broken egg shells) and the number of hatchlings (alive or dead) that remained within the nest after the competent hatchlings departed. The number of broken egg shells, minus the number of hatchlings remaining in the nest, yields the number of hatchlings that departed from the nest (nest productivity). At the time of inventory, staff did not know which nests were in the control group and which were in the experimental group.

The number of incubation days from other nearby nests was used to estimate the expected emergence date for experimental nests. Hatchlings were collected from experimental nests in the late afternoon 1 d in advance of the expected emergence date. To assure uniformity only one of us (M.S.) dug into the nests. In the past, we typically collected 10 hatchlings from each nest, and we followed the same procedure in this study. If fewer than 10 hatchlings were present in either an experimental or control nest, that nest was not included in the analysis.

Control and experimental nests were compared with respect to 3 variables: clutch size, nest productivity, and incubation days before an emergence. Distributions for clutch size and nest productivity were either normal or nearly so, and showed similar variances. These comparisons were made using $t$-tests. Incubation duration, however, was skewed and so comparisons between experimental and control nests were made using a Mann-Whitney 2-sample $U$-test. All differences were considered statistically significant when $p \leq 0.05$.

**RESULTS AND DISCUSSION**

By the end of the field season our data set consisted of 67 experimental and 95 control nests, none of which were attacked by predators. The majority of the nests were located within a 2 km section of continuous beach in Red Reef and South Beach parks (Fig. 2A). The temporal distribution of these nests reflected the usual seasonal pattern of loggerhead nesting in southeast Florida (nesting reaches a peak during the months of June and July; Fig. 2B). Hatchlings in the experimental nests were most often found well below (up to ~30 cm) the beach surface, and on top of empty egg shells and unhatched eggs.

There were no statistical differences in clutch size or in nest productivity between the control and experimental nests (Table 1). However, incubation duration was shorter by about 1 d (mode of 48 d) in the
Table 1. Caretta caretta. Clutch size (no. of unhatched eggs plus no. of broken egg shells) and emerged hatchlings were compared for the experimental and control nests using t-tests: data are presented as mean ± SD and range (in parentheses) for each group. Data for incubation duration were not normally distributed and are given as mode and range (in parentheses). Statistical comparisons were made using non-parametric (Mann-Whitney U-test) statistics.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Experimental</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clutch size</td>
<td>99.8 ± 21.7</td>
<td>96.2 ± 26.7</td>
</tr>
<tr>
<td></td>
<td>(57–182)</td>
<td>(10–117)</td>
</tr>
<tr>
<td>t = 0.95, p = 0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emerged hatchlings</td>
<td>53.4 ± 22.3</td>
<td>54.1 ± 26.9</td>
</tr>
<tr>
<td></td>
<td>(10–102)</td>
<td>(11–117)</td>
</tr>
<tr>
<td>t = 0.16, p = 0.8</td>
<td></td>
<td></td>
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<tr>
<td>Incubation duration (d)</td>
<td>48</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>(46–53)</td>
<td>(44–53)</td>
</tr>
<tr>
<td>z = 2.6, p &lt; 0.01</td>
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</table>

In summary, the removal of a small number of loggerhead hatchlings from natural nests may be a useful procedure when scientists need more time to obtain measurements or to complete experiments. Doing so also allows scientists to complete their task and then release the hatchlings during what appears to be an optimal time window for the turtles. While we show here that the take of pre-emergent hatchlings has no apparent effect on nest productivity, it is nevertheless an intrusive procedure that must be executed with care. Only a few hatchlings should be taken, leaving the bulk of the clutch in place to socially facilitate one another’s digging toward the beach surface (see review by Lohmann et al. 1997). It is especially important to minimize disturbing the hatchlings that are left behind so that they remain quiescent. Early hatchling removal is best performed where nests are marked and monitored on a daily basis, where natural predation rates are low, and where the predators that remain are unlikely to be attracted to disturbed sites by visual or odor cues (Stancyk 1982). We emphasize that even if early hatchling removal is advantageous for research, scientists and their students must learn where, when and how that removal should be done.

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LITERATURE CITED


Glen F, Broderick AC, Godley BJ, Hays GC (2005) Patterns in the emergence of green (Chelonia mydas) and loggerhead (Caretta caretta) turtle hatchlings from their nests. Mar Biol 146:1039–1049

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