Ghost crab (*Ocypode quadrata*) abundance and depredation on Loggerhead sea turtle (*Caretta caretta*) hatchlings on Onslow Beach, North Carolina

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Introduction

Sea turtles must overcome nest mortality and avoidance of predators following emergence from the nest (Fowler 1979, Miller 2003). Nest mortality can occur due to nest placement, erosion, development of beaches, temperature, and predators (Lutz & Musick 1997, McFarlane 1963). In some locations predators, (e.g., raccoons, foxes and crabs) are the main cause of nest mortality (Barton & Roth 2008, Engeman et al. 2003, Fowler 1979, Garmenstani 2005, Ratnaswany & Warren 1998) and may be the main cause of sea turtle hatchling mortality. Management of sea turtle nests has decreased the mortality of sea turtle nests and hatchlings by some predators in North Carolina (Cordes & Rikard 2005); however, the effect of the current predator management policy of removing raccoons is unknown, but this practice may be causing an increase in other predator populations, such as ghost crabs (*Ocypode quadrata*).

Little is known regarding the depredation rates of sea turtle hatchlings by ghost crabs; however, the abundance and distribution of ghost crabs along Onslow Beach varies dramatically between different areas of the beach (S. Fegley, pers. comm.), which may make sea turtle hatchlings at certain areas of the beach more susceptible to predation. Also, beach characteristics may be responsible for increased depredation. The longer the transit time from sea turtle hatchling emergence to entrance into the ocean, the greater risk of predation. Therefore, our objectives were to determine sea turtle hatchling transit time, depredation rates by ghost crabs, and relationships between nest mortality and abundance of ghost crabs to provide quantitative information on the potential role that ghost crabs may play in sea turtle hatchling survival.

Materials and Methods

Study Area

Onslow Beach, North Carolina is a barrier island which is completely contained within the Marine Corps Base Camp Lejeune. Onslow Beach is 12 km long and is used for recreational and military activities. Based on anthropogenic uses, Onslow Beach was divided into six zones including the impact zone, buffer zone, two recreational beaches, training zone, and an overwash area (Figure 1). The northernmost part of the beach included the impact and buffer zones that had restricted human access. To the south was a recreational beach that was open to military personnel and guests. The training zone was where full-scale military exercises occurred and the beach was disturbed by a range of terrestrial and amphibious vehicles including land craft air cushion vehicles, medium tactical vehicle replacement and high mobility multipurpose wheeled vehicles. Directly south of the training zone was another recreational beach, which was used by military personnel and guests and was used by off-road recreational vehicles (ORRV's) when training exercises were not occurring. For sea turtle conservation, ORRVs were not permitted on the beach at night between May and October but were allowed during the day. The southernmost point of Onslow Beach was the overwash area, where the high tides washed up to the dune line.

Potential predators of sea turtle nests and hatchlings on Onslow Beach included: ghost crabs, bobcats (*Lynx rufus)*, raccoons (*Procyon lotor*), opossums (*Didelphis virginiana*), gray fox (*Urocyon cinereoargenteus*), white-tailed deer (*Odocoileus virginianus*), feral cats (*Felis catus)*, and various gull species (*Larus sp.)*.

For the purpose of this study, Onslow beach was divided into four sites (Figure 1). Site 1 was located in the overwash area at the southernmost end of the beach. Nests in this area were frequently overwashed due to high tides. Site 2 was located between the overwash area and the training zone. Site 3 was located between the training zone and the buffer zone, and site 4 was located from the buffer zone north (Figure 1).

The Environmental Management Division (EMD) of Camp Lejeune was responsible for managing sea turtle nests throughout the nesting and hatching season. At approximately 0600 hours EMD biologists checked the beach for turtle tracks to locate nests. Sea turtle nests laid in the training zone or below the high tide line were excavated upon detection and relocated to the north end of the beach, usually into the buffer zone. All other nests were covered with a wire cage to prevent nest disturbance by predators (e.g., raccoons, foxes, and bobcats). At the south end of the beach, 55 days after a nest was laid a black tarp was placed behind the nests to prevent lights from Topsail Island (to the South) and other parts of the base from disorienting turtle hatchlings after emergence. Some nests were taped off and included a "runway" to the ocean, to prevent foot traffic, domestic animals, or ORRVs from disturbing the area in front of the nests. Most nest runways (with and without tape) were raked daily during the potential hatching phase (55 – 70 days after a nest was laid), to prevent hatchlings from getting stuck in tire tracks and footprints. All nests were excavated three days after the first hatchling emergence or after 70 days if no nest activity was observed. Hatchlings found alive in the nest by the EMD were released and monitored throughout their transit to the water.

Nest Selection

From July 15, 2009 through September 20, 2009, two to four observers monitored nests from approximately 2100 hours to 0530 hours. It was not possible to observe all nests; therefore, nests were selected based on estimated date of imminent hatching, spatial proximity to other nests, the number of observers available, and their presence outside militarily-restricted zones.

However, when possible more than one nest was watched per night, with one observer sitting at each nest. Due to these constraints, only nests in site 1 and site 3 were observed. Nests were watched until hatchlings emerged or wildlife biologists excavated the nest. Generally, excavation occurred three days after the first emergence or in response to natural conditions (i.e., impending tropical storms or hurricanes, hard-packed sand, or a probable dead nest). A flashlight with a red filter attached (Roscolux® medium red filter, wavelength range: 600-740) was used for illuminating nests during observations (Withering & Bjorndal 1991).

Loggerhead sea turtle nest observations

Nests were observed every minute using a filtered red flashlight. To obtain the time required for hatchlings to transit the beach, we created “start” and “finish” lines with wooden dowel rods and tape. When a nest hatched, one observer stayed next to the nest at the “start” line, while the other observer stood at the water line. We recorded the transit time of emergence out of the nest (at the “start” line) and into the water (past the “finish” line). Also, we recorded the number of hatchlings that emerged from the nest and the number of turtles that crossed the “finish” line and successfully made it into the water. We recorded active ghost crabs at time of hatching and documented all predation events. After all turtles entered the water successfully, we measured the distance between the nest and the water line.

Ghost Crab counts

We established three 10 m transects that extended from the toe of the dunes perpendicular to the water line. We placed one transect 50 m north of the nest, one at the nest site, and the last 50 m south of the nest. We conducted crab counts on a bi-hourly basis, beginning at approximately 2100 until approximately 0530 by walking each transect with a filtered red spotlight and counting the number of active ghost crabs within that transect. We visually classified crabs as small, medium, or large by walking along the transects with a filtered red flashlight. Carapace width less than 2.5 cm for small crabs, between 2.5 and 5.0 cm for medium crabs, and greater than 5.0 cm for large crabs.

Statistics

Site-specific and bi-hourly crab densities were calculated by dividing the total number of active crabs counted by the number of sampling days or hours at each nest. Nests were averaged across sites and were compared with a two-sample t-test. An analysis of variance (ANOVA) was used to determine differences in bi-hourly crab densities. Active ghost crab counts were used to determine whether ghost crabs were able to sense cues before, during, or after a nest hatched. Active ghost crab data versus pre-hatch, hatch, and post-hatch were analyzed in with an analysis of variance. To determine whether nest success rates (defined as the number of turtles that hatched out of their eggs) varied among our project sites, hatching data from all nests on Onslow Beach were analyzed using an ANOVA. Speed during transit from the nest to the water was determined by dividing total time on the beach by the distance traveled. All analyses were conducted with Microsoft Excel Version 2007 and Systat 13; alpha was set at $p < 0.05$.

Results

Abundance and distribution of Ghost Crabs

Our results indicate that site 4 (from the buffer zone to the north) had four to five times as many active crabs with an average of 0.14 +/- 0.02 active crabs/site/day compared to site 2 (between the overwash and training zones) with an average of 0.05 +/- 0.01 active crabs/site/day and were significantly different (t = -5.462, df = 4, P = 0.005) (Figure 2). Bi-hourly activity in ghost crabs was similar and ranged between 0.28 to 0.31 active crabs/bi-hour/day. Accompanying means and standard errors are presented in Table 1.

Crab Activity vs. Hatch Date

Hatchlings were observed emerging from seven individual nests and the number of active ghost crabs observed pre-hatch (average of 12.30 +/- 5.21), hatch (average of 6.29 +/- 1.58), and post-hatch (average of 6.58 +/- 3.27) were similar (F = 0.234, df = 2, 46, P = 0.792).

Nest/Hatchling Success Rate

Nest success rates were similar between different sites (number hatched versus site: F = 1.006, df = 3, 30, P = 0.404, average of 50.7 +/- 8.00), (number unhatched vs. site: F = 2.126, df = 3, 30, P = 0.118, average of 59.8 +/- 6.97).

Out of the ten nests we observed, six nests had at least one hatchling observed emerging from the nest. Out of those six nests, depredation was observed at 50 percent. Two out of the three (nest #11 and #13) nests were at site 4, and one (nest #25) was at site 2 (Table 2).

Transit Time

We recorded twenty-one hatchlings' transit time from three nests. All of the hatchlings traveled between 1.6 – 5 meters/minute, with an average time of 2.36 meters/minute (Table 3). Transit time was a positive, linear relationship between width of the beach and time traveled (adjusted R^2 = 0.545, S.E. = 0.861).

Discussion

Abundance and Distribution of Ghost Crabs

We observed active nocturnal ghost crabs between 2100 and 0530 with similar activity levels. Ghost crabs have the ability to travel distances of at least 750 m in one night (Vannini & Cannicci 1995, Linsenmair 1967, VanDusen pers. comm.); however during our study they generally traveled only 10-20 m. When resources are abundant and when human activity is minimal, ghost crabs may not need to travel far from their burrows. The Institute of Marine Science at the University of North Carolina detected higher abundances of ghost crab prey (e.g., *Emerita talpoida* and *Donax variabilis*) at site 4 (S. Fegley, pers. comm.) and combined with minimal human activity this may indicate a possible increase in ghost crab abundance in this area of the beach. Site 4, where the buffer and impact zones are located, has minimal human disturbance, abundant resources, and wider beaches; therefore it is likely that crabs do not travel far from burrows in these areas. The beach was approximately three times as wide at site 4 (90 m) compared to site 2 (30 m) during low tide. As a result, site 4 had higher active crab abundances which may result in higher hatchling depredation rates.

Crab Activity vs. Hatch Date

Sea turtles hatch out of their eggs before emerging from the nest (Miller 2003), which may provide tactile cues which are sensed by ghost crabs through Barth's myochordotonal organ (Popper et al 2001). Ghost crabs can sense vibrations from up to 10 m away and may sense turtles hatching only inches below the surface (Horch & Salmon 1972). Also, ghost crabs can sense pungent smells such as dead fish and feces buried under the sand (Wellins et al. 1989). However, it is unknown whether ghost crabs can smell sea turtles while buried under the sand or after an emergence occurs or how far away they can sense a smell. If the ghost crabs were able to smell the hatchlings within the nest we should have observed more active ghost crab burrows surrounding the nest before and after emergence. One nest had a 5% success rate due to inundation of water into the nest and was 2 hatchlings were found depredated by ghost crabs. It is possible the eggs had started decomposing and emitted a pungent smell that the ghost crabs were able to sense. Cronin (1986) noted that ghost crabs have poor eye sight at both long and short distances; so it is unlikely they can detect a sea turtle's nest.

To determine if visual cues are being used, future research should be conducted using uncaged nests as controls to compare depredations at caged vs. uncaged nests and to determine if ghost crabs or other predators have learned about cages through experience (Engeman 2006). Also, future research should focus on whether decomposing nests have greater depredation due to smells produced compared to non-decomposing nests.

Nest/Hatchling Success Rate

Egg hatching success rates from all nests were similar. However, these results only indicate whether or not hatchlings successfully hatched out of the eggs (while in the nest), not whether the hatchlings survived the transit to the sea. Ghost crabs are able to depredate hatchlings during transit to the water and have the ability to burrow into nests and depredate sea turtle eggs (Cordes & Rikard 2005, Strachan et al. 1999). However, depredation of hatchlings during transit was the primary cause of depredation of sea turtle hatchlings by ghost crabs on Onslow Beach. During our study we only observed crabs burrowing into a nest before hatchling emergence once.

Transit Time

The fastest turtle recorded was at nest 1, which had a steeper slope compared to other nests. The slope of the beach is related to the speed of the hatchlings, which helps explain an increase in predation on the turtles at the north end of the beach where the wide, low-slope beach allows predators more opportunities for depredation during transit from nest to water. The combination of high crab abundance and wider, low-sloping beaches increases the risk of predation by ghost crabs on sea turtle hatchlings.

Depredation Observations

When we located sea turtle carcasses on the beach, the only injury we observed was the removal of the hatchlings' eyes. Ghost crabs can depredate sea turtle eggs (Cordes & Rikard 2005); however, we never observed whole sea turtle eggs outside of the nest or depredated eggs inside the nest during excavations. Few studies have documented ghost crabs solely consuming sea turtle eyeballs and leaving the remainder of the sea turtle hatchling on the beach (Diamond 1976). We hypothesize the sea turtle hatchlings' leathery carapace and appendages prevent ghost crabs from breaking through the shell to consume the remainder of the turtle. If ghost crabs burrow into a nest with pipped (cut through the egg shell) hatchlings they can take advantage of the yolk still attached to the hatchling which would provide rich nutrients to the ghost crab.

Management Implications

Active crab abundance, transit time of hatchling turtles, and width and slope of the beach at the site 4 are all important factors for determining relocation of turtle nests. These factors suggest that turtle nests relocated to site 4 are at a higher risk of predation than nests elsewhere along the beach.

We recommend relocating nests to either site 2 or 3. Site 3 is the recreational beach, which has lower ghost crab abundances, and a narrower beach. Highly populated areas of other beaches may not be beneficial for relocation due to foot traffic and potential poachers, but because Onslow Beach is part of the USMC military base and stricter rules and management are in place, hatchlings may be at an advantage by having strict access to the beach. One disadvantage to relocating nests to site 3 is the lights on oceanfront buildings and use of white lights by fishermen throughout the night, despite the sea turtle conservation signs along the beach. Oceanfront buildings are equipped with red lights; however, some of the houses may not consistently close their blinds at night which can disorient sea turtle hatchlings. Implementing more “lights out for sea turtles” signs along the beach and inside oceanfront houses may help deter shining of white lights on the beach at night.

Site 2 had a high success rate of nests due to lower crab abundances and a high-sloped, narrow beach; however, due to the width of the beach nests were occasionally washed away due to off-shore storms creating high tides and eroding the beach. Due to the many factors that take part in nest success, relocation protocol can be changed; however it is important to determine the individual threats of each nest.

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Table 1. Means and standard errors of active crabs/bi-hour/day, Onslow Beach, 2009.

Time (Bi-hourly)	Mean	Standard Error
2000-2200	0.29	0.06
2201-2400	0.30	0.06
2401-200	0.31	0.07
201-400	0.30	0.06
401-600	0.30	0.07

Table 2. Loggerhead sea turtle hatchling predation events categorized by date and site, Onslow Beach, 2009.

Date	Site	Nest	Turtles Observed	Successful Turtles	Predation Events	Percent Successful	Percent Depredated
25-Jul	2	1	2	2	0	100%	0%
7-Aug	2	3	2	2	0	100%	0%
8-Aug	2	3	1	1	0	100%	0%
9-Aug	2	5	15	15	0	100%	0%
9-Aug	2	3	3	3	0	100%	0%
10-Aug	2	5	2	2	0	100%	0%
20-Aug	4	11	5	0	5	0%	100%
20-Aug	4	13	5	2	3	40%	60%
31-Aug	2	26	5	5	0	100%	0%
13-Sept	2	25	2	0	2	0%	100%

Table 3. Transit times of Loggerhead sea turtle hatchlings at Site 2 categorized by date and nest, Onslow Beach, 2009.

Date	Nest	Distance from nest to water (m)	Minutes from emergence to water	Time out of Nest	Time into Water	Speed (meters/min)
25-Jul	1	30	6	3:53	3:59	5
7-Aug	3	20	8	3:32	3:40	2.5
8-Aug	3	18	6	2:05	2:11	3
9-Aug	3	15	4	12:28	12:32	3.75
9-Aug	3	15	5	12:28	12:33	3
9-Aug	3	15	5	12:28	12:33	3
9-Aug	5	8	4	22:25	22:29	2
9-Aug	5	8	4	22:25	22:29	2
9-Aug	5	8	5	22:25	22:30	1.6
9-Aug	5	8	5	22:25	22:30	1.6
9-Aug	5	8	4	22:26	22:30	2
9-Aug	5	8	4	22:26	22:30	2
9-Aug	5	8	5	22:26	22:31	1.6
9-Aug	5	8	5	22:26	22:31	1.6
9-Aug	5	8	4	22:27	22:31	2
9-Aug	5	8	4	22:27	22:31	2
9-Aug	5	8	4	22:27	22:31	2
9-Aug	5	8	5	22:27	22:32	1.6
9-Aug	5	20	6	1:03	1:09	3.33
10-Aug	5	22	7	2:12	2:19	3.14
10-Aug	5	22	8	2:12	2:20	2.75

Figure Legend

Figure 1. Location of study site and military zones of Onslow Beach, Camp Lejeune, North Carolina, Onslow Beach, 2009.

Figure 2. Standardized mean abundance of active ghost crabs versus site location, Onslow Beach, 2009.

Figure 3. Time traveled from nest emergence to entrance into water by Loggerhead sea turtle hatchlings, Onslow Beach, 2009.

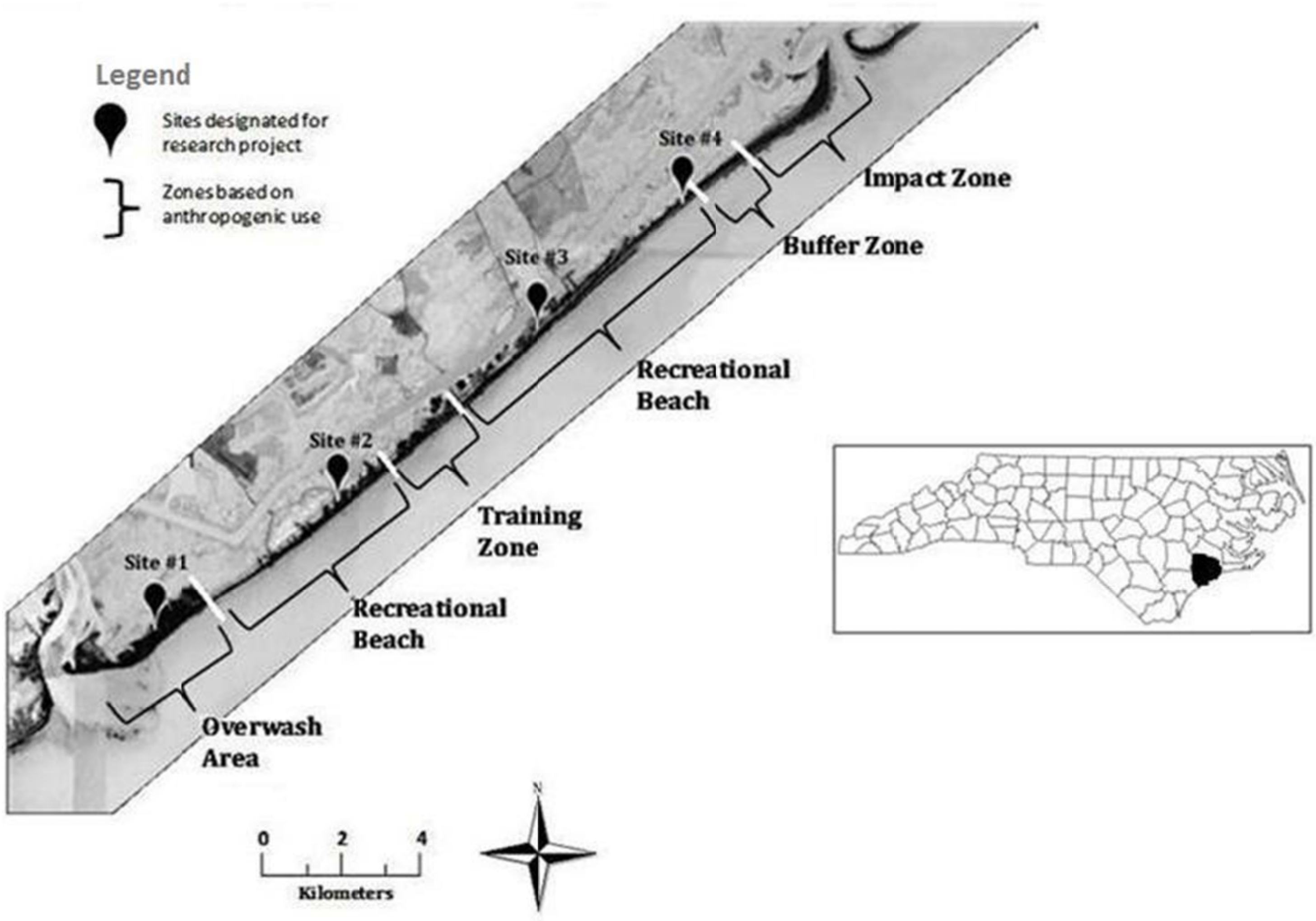

Figure 1. Location of study sites and military zones of Onslow Beach, Camp Lejeune, North Carolina, 2009.

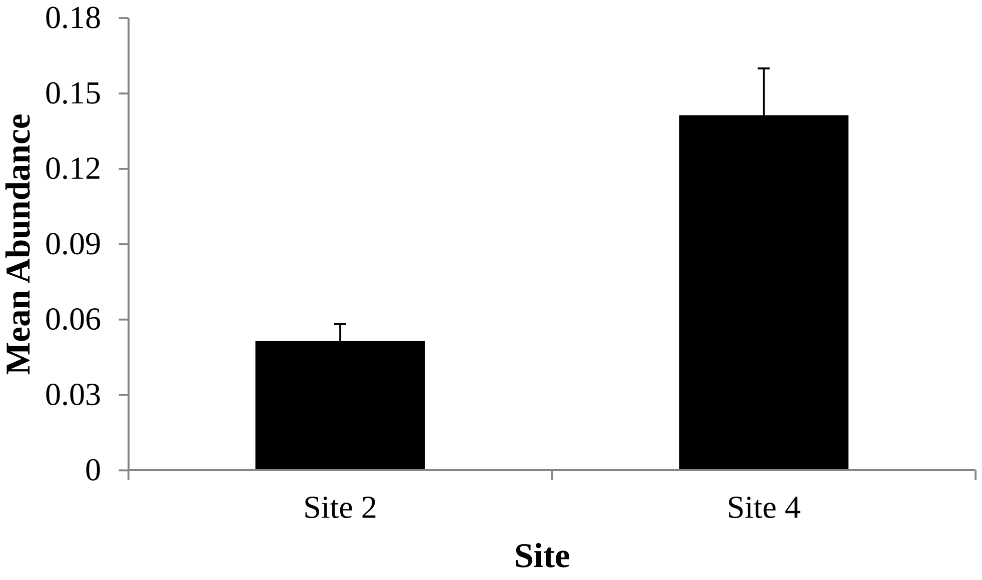

Figure 2. Standardized mean abundance of active ghost crabs versus site location, Onslow Beach, 2009.

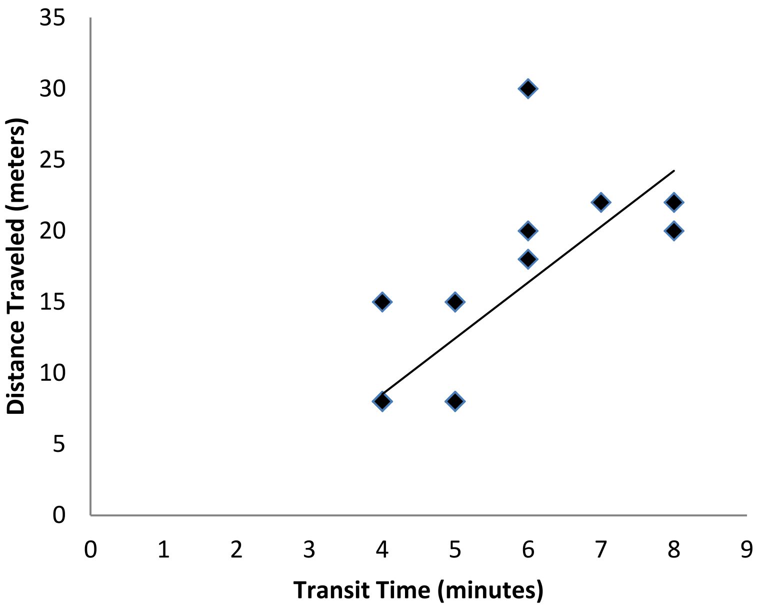

Figure 3. Time traveled from nest emergence to entrance into water by Loggerhead sea turtle hatchlings, Onslow Beach, 2009.