Monitoring *Caretta caretta* (Loggerhead) sea turtle hatchlings by using Turtle Sense to predict emergence

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INTRODUCTION

Caretta caretta (loggerhead) sea turtles frequently nest along the Cape Hatteras National Sea Shore. Loggerheads are protected under the endangered species act (FWS and NMFS 1978, 43 FR 32800) established in 1978 (*The Federal register* 1978). This poses an issue for the National Park Service (NPS). The NPS is in charge of protecting the Loggerheads by restricting local fisherman and tourists attempting to access the beach. Despite these protections in America, worldwide capture of adult turtles for eggs, meat, leather, tortoise shell, and accidental capture through fishing nets and shrimp trawls has decreased breeding populations. The anthropogenic pressure placed on sea turtles through the fault of humans is another problem for the conservation of their species (Jackson, 2001).

The fact that sea turtle populations have been declining for an assortment of reasons reiterates the importance of survivorship (Arendt *et al.* 2013). Like all species, survivorship and reproductive values are immensely crucial for population survival, but a lengthy maturation period presents an added challenge for Loggerhead sea turtles. One study in particular shows that the conservation of the Loggerhead species will be more effective by concentrating research efforts on the vastly unstudied juvenile population rather than the existing mature population (Van Houtan & Halley 2011).

To that end, Loggerhead nests are being studied to figure out what factors impact egg development. Currently, studies have been conducted to show a temperature dependency in the gender of an egg (Glen *et al.* 2006). Loggerhead female sea turtles make their journey on land to lay their nest, typically taking them up to one hour after digging and burying the nests. Approximately 50-90 days after a sea turtle lays her nest, the hatchlings will emerge from their nest. A study has shown that hatchlings remain underground for several days after they pip from their eggs, due to the fact that they collect just under the sand before emergence as to wait until the majority of the nest is ready to emerge (Salmon & Reising, 2014). Taken together, these studies indicate that sea turtle egg development varies with the environment in which it is located.

Under the current Endangered Species Act protocol used at the Seashore, approximately 55 days after the nest is laid, the placed nest enclosure is expanded all the way to the shoreline, as well as parallel to the shoreline to provide hatchlings an additional margin of safety upon emergence. Under this current system, emergence from successful nests might not occur until as much as 6 weeks after enclosure expansion. The nests are monitored daily for evidence of a small depression, indicating that the turtles have begun to pip, or hatch. At this point, emergence from the nest will happen within a few days, and a volunteer nest sitting team (tasked with ushering the hatchlings safely to the sea) will sit with the nest nightly waiting for hatchlings to emerge. These volunteer nest sisters will watch some, but not all nests, as volunteer resources cannot keep up with the sheer number of turtle nests— in 2015, 289 nests were laid at the National Seashore, and the 321 nests in 2016 have already surpassed the previous year’s total.

A National Research Council report concluded that advances in turtle population ecology will come primarily from improvements in human monitoring systems (National Academies Press, 2016). One such improvement is the Turtle Sense project, a highly collaborative nest monitoring system that seeks to both preserve the health of endangered sea turtle hatchlings, while lessening the impact of beach closures for people and freeing up valuable volunteer resources. Turtle Sense is an innovative, remote controlled, real time access sensor and communication system designed to monitor motion in sea turtle nests in order to better predict dates of emergence of the hatchlings onto the sand. We hope to use Turtle Sense to predict the turtle’s emergence within a +/- 1-day period.

Principal Approaches

Turtle Sense technology was developed by NerdsWithoutBorders.net, a non-profit organization which publishes hardware, software, and product designs on their website, available with an open-source license. Turtle Sense continuously records nest motion of any sort (indicating possible hatchling, emergence, predator activity, etc.). The 1” x 1” sensor circuit board contains a motion and temperature sensor, as well as a microprocessor (figure 1A). The sensor circuit board is sealed in a turtle-egg sized plastic sphere designed to keep moisture out (figures 1B and D). The system is relatively reliable, with the majority of the sensors that have been used for the past 2 seasons showing few failures. Collected data is sent to a researcher's server in the cloud using a microprocessor-controlled cell phone interface. The system's operational parameters can be monitored and adjusted remotely (Figures 1C and 1E).

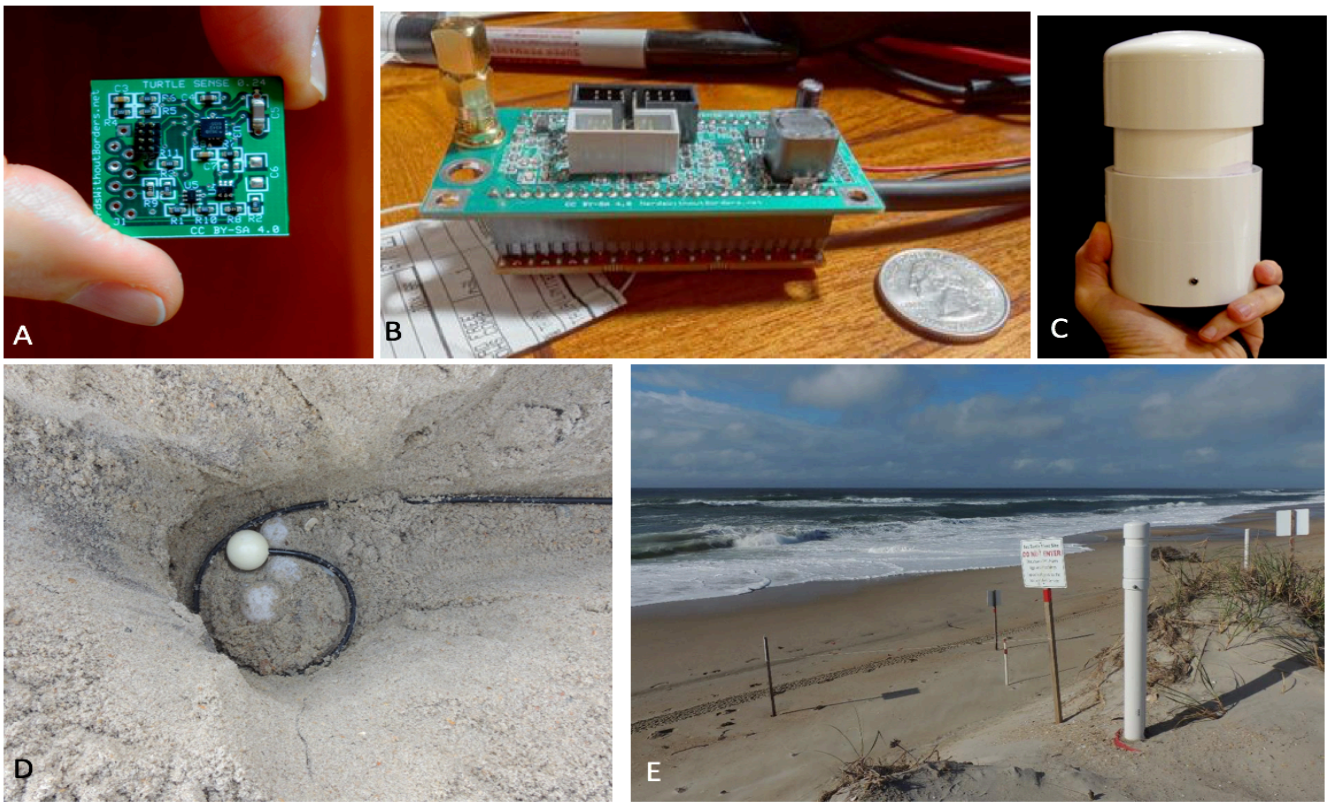


Figure 1. A schematic of the Turtle Sense system components (A) Sensor board (1" x 1") is sealed in a polyurethane ball designed to resemble a turtle egg. (B) Communications assembly is mounted in a 3" diameter PVC pipe (C) assembly (the quarter is for size reference). (D) The sensor ball is buried just above the sea turtle nest, with a buried cable leading to above ground communications assembly. (E) Turtle nest with functional Turtle Sense monitoring will remain in place until the hatchlings emerge and the nest is excavated by the NPS.

Our study used TurtleSense to specifically monitor loggerhead nests in a single section of the beach just south of the Cape Hatteras lighthouse, rather than placing sensors in nests that are convenient or in areas of high traffic, as was done in 2015. Every non-relocated loggerhead nest laid in this area (approximately 1/4th of the entire Cape Hatteras National Seashore's beaches) during early August this season was monitored with TurtleSense, in order to eliminate many confounding variables (variable species, traffic conditions, beach erosion, etc.) for a total of 11 nests. We used this controlled study to compare emergence predictions based solely on nest age and the presence of a depression vs. using TurtleSense specifically monitoring accelerometer readings, and we will use this to compare nest outcomes between nests with and without TurtleSense monitoring.

Our Turtle Sense emergence prediction method is empirically derived from field test experiences in 2014 and 2015. Our method divides the data gathered in the weeks leading up to emergence into four phases of activity. Phase A represents a quiet incubation period of roughly 50 days (figure 2). Phase B represents a transition period that usually has some big swings with a frequency of 2-4 swings/day (figure 2). This transition period lasts from 1-4 days, and often ends with a quiet (low) reading, often lower than anything in the preceding weeks.

Phase C represents hatching activity, typically 4 days long characterized by erratic, frequent (>4x/day) signal swings (figure 2). Phase D represents a quiet period indicating emergence is imminent (figure 2). The data is updated to the server approximately every 6 hours to include any updated motion in the nest; as the hatchlings approach the end of their incubation period, the timed data will be projected every hour to the server. Data is monitored to detect the beginning of Phase C; which is indicated by one full day of erratic swings. Once Phase C is detected, emergence is predicted to be 4 days later. Using this method, emergence dates can be predicted to within +/- 1 day.

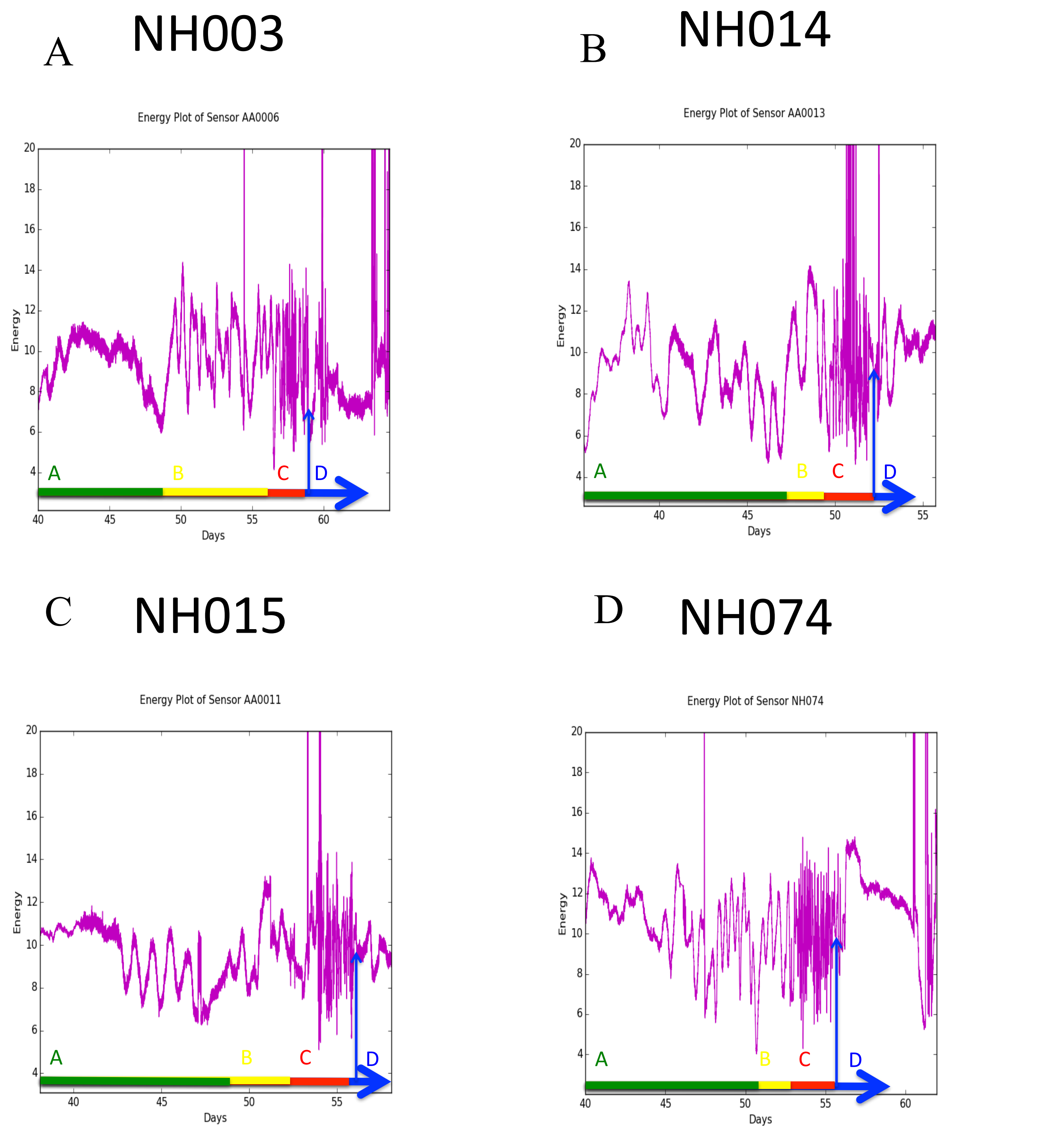


Figure 2: 2015 TurtleSense Data— Phase A is a quiet incubation period (roughly 50 days). Phase B is a transition period that usually has some big swings with a frequency of 2-4 swings/day. This transition period lasts from 1-4 days, and often ends with a quiet (low) reading, often lower than anything in the preceding weeks. Phase C is a Hatching activity, typically 4 days long characterized by erratic, frequent (>4x/day) signal swings. Phase D is a quiet period indicating emergence is imminent. Figure 2A represents a graph in which motion began on day 49-50 and emergence occurred on day 59. Figure 2B

represents a characteristic graph where motion began on days 46-48 and shows the typical 4-day cycle with emergence on day 53. Figure 2C represents a similar graph where motion began on day 46-48 and emergence occurred on day 55. In figure 2D, the motion began on days 51-52 and the emergence occurred on day 55.

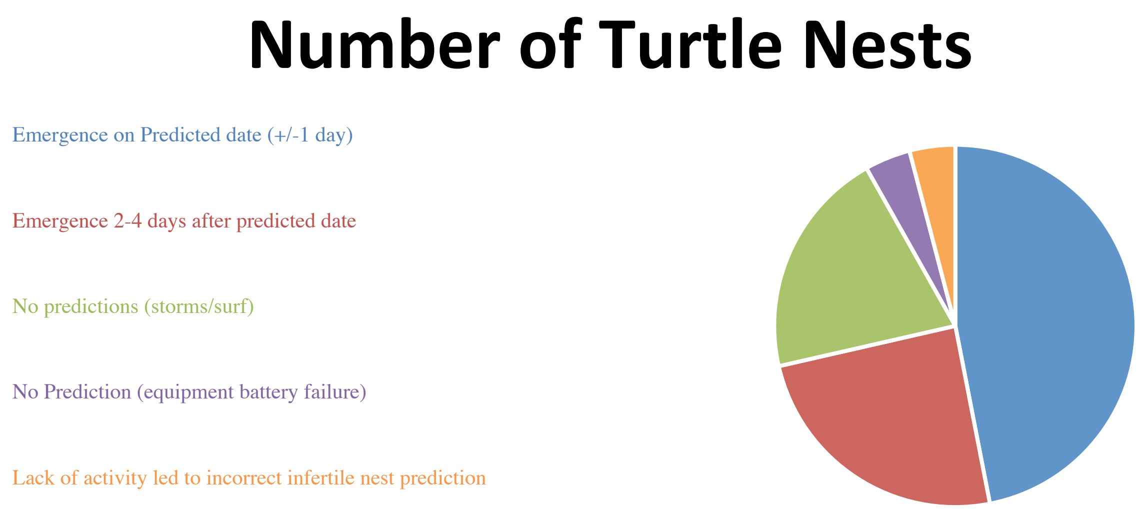
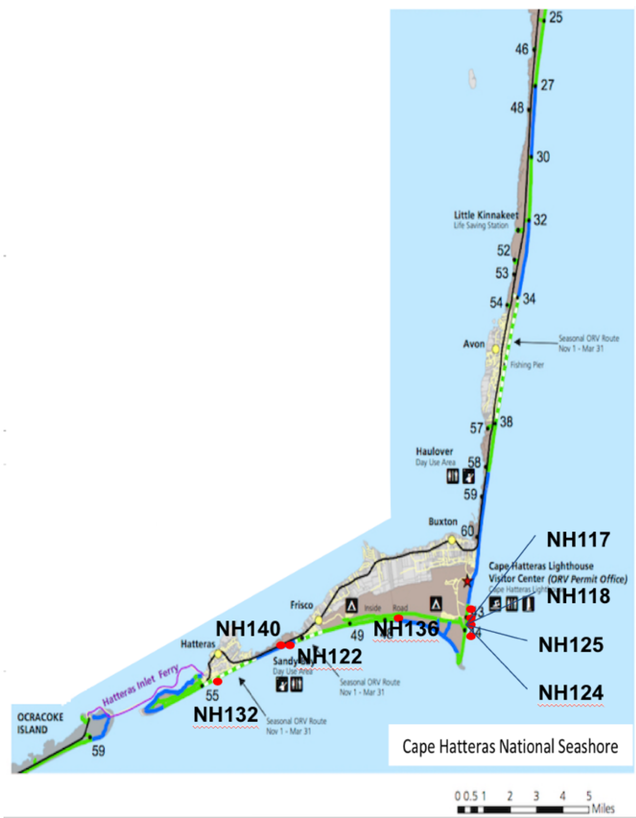


Table 1. Turtle Sense Data Summary of 2015 Field Test Predictions. Turtles first emerged on the predicted date (+/- 1 day) in 46% of the nests (n=12, blue). Turtles first emerged 2 to 4 days after the predicted date in 24% of the nests (n=6, red). No predictions were made because storms and surf destroyed the nests and even washed away some of the equipment in 20% of the nests (n=5, green). Lack of activity led to a prediction of an infertile nest (verified by NPS) in 4% of the nests (n=1, purple). Battery failure stopped measurements during incubation in 4% of the nests (n=1, orange). This pie chart will be updated to show 2016 data as it arrives throughout the end of this season.

Sensor #	Nest #	Nest Date	Depth to Eggs	Lat	Long	Comm Install Date	Comm Id	Predicted Date of Emergence
AA0006	NH117	7/19/16	44	35.23615	-75.52663	7/31/16	C-AA0007	9/12/16
AA0026	NH118	7/19/16	30.5	35.23784	-75.52644	7/31/16	C-AA00010	9/12/16
AA0011	NH122	7/21/16	20	35.22379	-75.6444	8/3/16	C-AA00014	9/14/16
AA0008	NH125	7/22/16	35	35.23135	-75.52746	7/31/16	C-AA00013	9/15/16
AA0012	NH124	7/22/16	24	35.23111	-75.61211	7/31/16	C-AA00015	9/15/16
AA0009	NH132	7/25/16	19	35.20705	-75.6956	8/3/16	C-AA00017	9/18/16
AA0015	NH136	7/26/16	42.3	35.23435	-75.57616	7/31/16	C-AA00012	9/19/16
AA0014	NH140	7/28/16	29	35.2211	-75.65436	8/3/16	C-AA000169	9/21/16
AA0018	NH143	7/29/16	35	35.2313	-75.6112			9/22/16
AA0017	NH144	7/29/16	26.5	35.23034	-75.61652			9/22/16
AA0020	NH145	7/30/16	35	35.22982	-75.6197			9/23/16

Table 2. Turtle Sense 2016 Data— The table is displaying various information about nest location, sensors being used, when the nest was found, depth of the nest, coordinates for each nest, what comm head is being used, and even a predicated date of emergence based on 55 days after initial finding.

Figure 3. Turtle Sense 2016 Nest Location with Sensors and Comm Heads— The Map represents the Cape Hatteras National Sea Shore. The red dots are displaying approximately the location of the nests with sensors and a comm head attached. The nest number is displayed in black bold text with arrows drawn to the dots.



DISCUSSION

In Loggerhead hatchlings, for example, the window of time to wait for emergence is reduced from a maximum of 6 weeks after incubation (days 50-90 after the eggs are laid) to a window of just a few days. Turtle Sense allows us to shorten the guessing period on when a nest might hatch to a predicted +/- 1 day. Predictions for the 2015 TurtleSense data were made by observing the phases of the graphs produced from the motion sensors in each night using a live time feed, and compared to data collected on site about when the hatchlings actually emerged. The graphs can be clearly divided into phases. During phase C a prediction can generally be made that emergence will be within +/- 1 day towards the end of the phase. The distinct sudden drop at the end of phase C marks the emergence is eminent in the nest.

As the popularity of the Seashore has grown, it has become increasingly difficult for the NPS to meet its obligations to both people and sea turtles, as the system of expanding enclosures limit recreational use of the Seashore. Despite the precautions taken, some successful nests don't ever develop a depression before hatchlings emerge, with some nests never producing any emerged hatchlings at all (due to infertility, ocean over-wash, temperature, and predation). The beach closures impact both vacationers and local fisherman, as several miles of the beach may be inaccessible for many weeks during the summer, with the locations of these closures constantly changing. Researchers of the company, Epson, in Japan have been conducting similar research from 2012, however no updated progress has been reported since that date ("Report of Loggerhead Sea Turtle Protection Project", 2012). The research being conducted in Hatteras, NC is vastly different because the data is actually being used to conduct real time predictions on when the sea turtles can emerge from the nests, potentially being applicable for use outside of simply sea turtles.

The use of the sensors can save time and resources for agency management, researchers who study events at emergence, and ecotourism. Sensors also offer better protection for sea turtles from many of the threats that typically impact their nesting period. The TurtleSense device is a robust module for studying hatchling behavior and biology. Through sensor modifications, TurtleSense could be applied to other environmental studies needing remote control/data flow. One of the main project objectives is to formally report the prediction success, so that TurtleSense technology can be spread through posters or presentations at international conferences and adopted for use in other biological systems.

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