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# A comparison of methods used to monitor groundwater inundation of sea turtle nests

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ABSTRACT

Sea turtle eggs are at risk of inundation and erosion throughout their incubation. Inundation reduces gas exchange necessary for proper embryonic development with prolonged exposure resulting in mortality. Management actions such as nest relocation may reduce this threat; however, they are often undertaken with incomplete information (e.g., tolerance of sea turtle embryos to inundation, and knowledge of the environmental differences between the original and final nest locations). Despite the need to understand the risk of sea turtle nest inundation, few studies measure inundation directly, and those that have, used PVC-based equipment with limited sampling resolution and measurement precision. To improve in situ inundation monitoring, we tested the use of electronic water level loggers (HOBO U20L-04) at loggerhead sea turtle nests, and compared costs, benefits, and limitations of this equipment to the PVC devices used in previous research. The HOBO loggers demonstrated > 90% correlation with the PVC inundation devices in inundation frequency for both experimental sites and incubating nests. PVC devices tended to overestimate inundation duration (24.7 ± 5.0 h SE) and underestimate inundation severity (14.6% ± 6.6% SE) compared to the HOBO loggers. The greater temporal resolution and measurement precision of the HOBO logger provided higher quality data pertaining to inundation stress in the nests during inundation events over the PVC devices. Small-scale studies of inundation tolerance and other physiological responses to inundation would benefit from this improved data quality; however, the cost of each unit and associated software and hardware may be prohibitive for some monitoring programs. The PVC devices are low cost and simple to mass-produce, lending their use for large-scale monitoring efforts to better inform relocation decisions and productivity assessments.

## 1. Introduction

Sea turtle eggs require a narrow range of incubating conditions for proper embryonic development and survivorship, including temperature, moisture content, and gas exchange (Ackerman, 1997; Mortimer, 1990; Wood and Bjorndal, 2000). Incubation conditions may be altered by sea level rise, coastal squeeze, and changes in cyclonic storm frequency and/or severity, causing particular concern for the long-term management of sea turtles as climate change progresses (Baker et al., 2006; Fish et al., 2005; Fuentes et al., 2010; Fuentes and Abbs, 2010; Mazaris et al., 2009). Inundation by groundwater reduces gas exchange necessary for proper sea turtle embryonic development and prolonged submersion results in increased mortality (Cheng et al., 2015; Foley et al., 2006; McGehee, 1990; Patino-Martinez et al., 2014). However, sea turtle species-specific tolerance to inundation and its variability relative to embryonic development is currently poorly understood (Caut et al., 2010; Foley et al., 2006; Pike et al., 2015). Considering that inundation is listed as a major threat to sea turtle nesting populations (Hawkes et al., 2009; National Marine Fisheries Service, 2008) and is a primary motivation for management actions such as nest relocation (McElroy et al., 2015; Pintus et al., 2009; Tuttle and Rostal, 2010), this represents a significant knowledge gap.

Most of the available information on inundation stress on sea turtle embryos in situ is derived from crude proxies for groundwater inundation, such as observations of waves washing over the sand surface of the nest (Caut et al., 2010; Margaritoulis and Rees, 2006; Vaughan and Wyneken, 2008). The only inundation study using a laboratory environment, by Pike et al. (2015), suggested that six hours of submersion represents a critical threshold for green sea turtles noting a 30% decline in embryonic viability after this duration with no difference in susceptibility based on developmental state. Using a series of PVC pipes to record inundation in situ (Fig. 1), Foley et al. (2006) found that loggerhead nest productivity in Ten Thousand Islands, Florida declined with increasing severity of inundation, where severity is defined as the proportion of the nest exposed during an inundation event. Hatching success from nests that were completely inundated was

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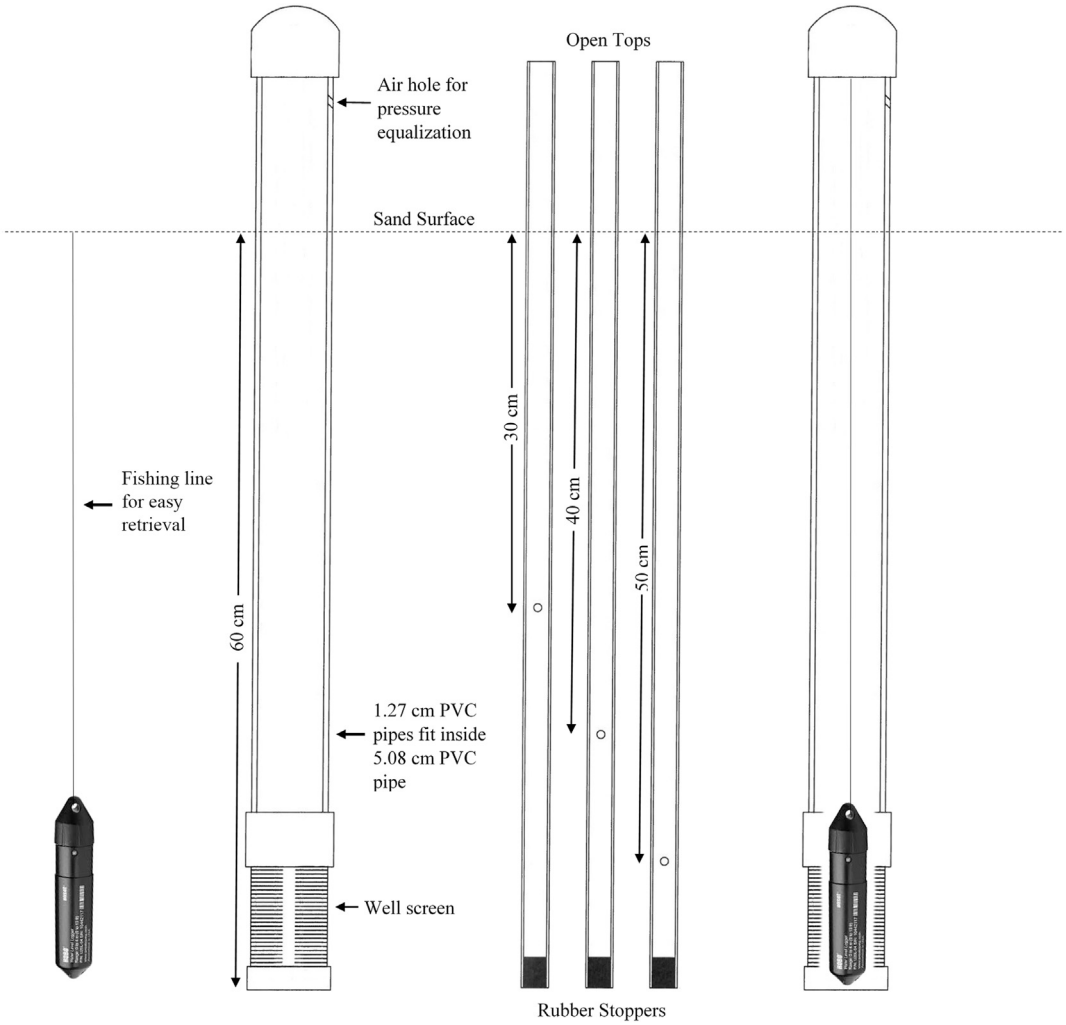


**Fig. 1.** Experimental site deployment configuration consisted of a HOBO U20L-04 water level logger buried directly in the sand, a PVC device used to record groundwater inundation in sea turtle nests in Foley et al. (2006), and a modified PVC device with a HOBO U20L-04 logger in place of the three interior tubes. All equipment was installed at 60 cm depth.

20.5%, a reduction of 76% relative to non-inundated nests. Similar results with comparable equipment to Foley et al. (2006) were found by Shaw (2013) on Keewaydin Island, Florida where hatching success declined to 9.6% after three inundations, an 89% reduction relative to non-inundated nests.

In situ data derived from the PVC device designed by Foley et al. (2006) are limited in both temporal and depth resolution. Though the PVC device construction is cheap and simple to mass produce, readings are limited based on sampling frequency (e.g., daily in the case of morning nesting surveys) and the number of sampling levels (e.g., bottom, middle, and top of the clutch, Fig. 1). Shaw (2013) solved the sampling level problem by replacing the interior PVC tubes with a wooden meter stick and ground cork, but was still limited in temporal resolution due to the need for manual readings. Electronic water level loggers have the potential to greatly improve inundation data acquisition by eliminating the need for frequent manual readings. User-defined sampling intervals and sub-centimeter depth resolution more precisely measure the depth of the water table relative to the nest and for how long that level was maintained. This improvement in duration and severity estimation is critical for relating observed hatching success with recorded inundation stress and consequently addressing some of the knowledge gaps pertaining to the impacts and risks on inundation to sea turtle reproductive success.

To improve future assessments of sea turtle embryonic inundation tolerance, we tested the use of HOBO water level loggers to assess inundation frequency, duration, and severity for in situ sea turtle nests. Further, we discuss costs of implementation, limitations, and benefits of this approach with that of PVC inundation devices used in previous research.

## 2. Methods

### 2.1. Experimental site deployments

Ten experimental sites were established in Fort Morgan, Alabama, a microtidal dissipative to intermediate beach (Fig. 2, GPS: 30.2262°N, 88.0279°W to 30.2307°N, 87.8009°W) from 2 May to 8 July 2017. Testing sites were established for one week and close enough to the high tide line (mean distance = 8.3 m ± 4.4 m SE) so that sites had a reasonable chance of being washed over by waves or inundated by groundwater during their deployment without being eroded away. At each experimental site, a HOBO U20L-04 water level logger (Onset Computer Corporation, Bourne, MA, USA), and a PVC inundation device (Foley et al., 2006) were deployed at 60 cm depth. These deployment methods were similar to methods already used in nest monitoring (e.g., Foley et al., 2006). HOBO loggers record ambient pressure and temperature during their deployment. Pressure values are converted to depth measurements in post-processing software with a resolution of 0.14 cm and an accuracy of ± 0.40 cm based on the density of the water and after removing atmospheric pressure changes. For this study, we