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The potential future influence of sea level rise on leatherback turtle nests

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ABSTRACT

Climate change models predict sea level rise and increased intensity of storms and hurricanes in tropical sea turtle nesting areas. These factors could significantly increase beach inundation and erosion, thus affecting water content of sea turtle nesting beaches. Here, we conducted a field and laboratory study of how sand water content is related to embryonic development and hatching success of leatherback turtle nests. Moreover, we have experimentally incubated eggs of this species in beach sand under standardized conditions, but at different realistic levels of sand water content, varying from 1% to 12%. On the beaches, females nested from the intertidal zone to the lower part of the sand vegetation dunes, where nests were exposed to a wide range of sand water contents that ranged from 0.8% to 22%. However, both field and experimental studies revealed a strong negative correlation between sand water content and emergence success (field study: $r = -0.73$, $P < 0.0001$; experiment: $r = -0.84$, $P < 0.0001$). In the field, mean emergence success varied from 0% for the wettest nests to 64% for the driest ones. Nests in wet sand suffered higher mortality, primarily in the earlier developmental stages. Eggs incubated in the driest sand lost mass, but there were no significant effects on hatchling mass or run speed compared to eggs that gained water during incubation. However, hatchling straight carapace length (SCL) was greater in eggs from the driest treatment. The results of the present study inform management of change under future climate change sea level rise scenarios, suggesting that leatherback turtle nesting success should be expected to decrease.

1. Introduction

There is high confidence that the rate of observed sea level rise increased from the 19th to the 20th century due to global warming (Zhang et al., 2004). The total 20th century rise is estimated to have been 0.19 m (range 0.17 to 0.21 m; IPCC, 2013). The rate was faster from 1993 to 2010: about 3.2 mm per year (range 2.8 to 3.6 $mm \cdot yr^{-1}$) (IPCC, 2013). In addition, widespread increases in the frequency of heavy precipitation events have been observed, even in places where total rainfall has decreased. In the tropics, heavy storm and hurricane frequencies vary considerably from year to year, but evidence suggests substantial increases in intensity and duration since the 1990s (Baker et al., 2006; Goldenberg et al., 2001; Webster et al., 2005). The severe coastal erosion witnessed in the 20th century will be exacerbated in the 21st century under plausible global warming scenarios (Dickson et al., 2007). Thus, up to 32% of the total current Caribbean beach area could be lost with a 0.5 m rise in sea level, with lower, narrower beaches being the most vulnerable (Fish et al., 2005).

All of these environmental changes can increase average moisture levels, flooding and erosion of sea turtle nesting beaches (Fuentes and Abbs, 2010; Fuentes et al., 2010). The impact of global warming may affect nest survival, thus contributing to the decline of already threatened sea turtle populations (Fuentes et al., 2011; Hawkes et al., 2009; Katselidis et al., 2013, 2014; Witt et al., 2010). Embryonic development is influenced by the sand water content in most reptiles (Marco et al., 2004; Packard, 1999), including sea turtles (Ackerman, 1997). For example, in one study high levels of humidity were correlated with longer incubation durations in loggerhead turtles *Caretta caretta* (McGehee, 1990). Sea turtles also appear to exhibit variation in tolerance to nest humidity: while the eggs of the flatback turtle *Natator depressus* can apparently tolerate desiccation (Hewavisenthi and Parmenter, 2001, 2002), green turtle *Chelonia mydas* eggs have higher mortality in drier sands (Mortimer, 1990). Humidity may affect nest placement in some species, for instance the olive ridley sea turtle *Lepidochelys olivacea* tends to nest in drier zones (typically <1% water content), which produce high hatching success (Lopez-Castro et al., 2004) but other species may not use sand moisture as a cue for nest site selection (Wood and Bjorndal, 2000).

The leatherback turtle (*Dermochelys coriacea* Vandelli, 1761), which is listed by the World Conservation Union as 'vulnerable' http://www.iucnredlist.org/, nests on tropical beaches worldwide from 30°N to 30°S (Eckert, 2001; Spotila et al., 2000). Different human impacts on

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both the sea (James et al., 2005; Morreale et al., 1996) and nesting beaches (Spotila et al., 1996) are contributing to a dramatic decline in population numbers (Chan and Liew, 1996; Sarti et al., 2007; Spotila et al., 2000). In general, leatherback turtles have lower reproductive success per clutch compared with other marine turtle species with hatching success usually around 40–50% worldwide (Bell et al., 2004; Ralph et al., 2005; Wallace et al., 2004), compared with 80% or more for other species (Wallace et al., 2004). Decades of investigations concerning marine turtles have generated a great deal of knowledge regarding the problems facing these species. However, there remains much debate about how globally important changes are expected to influence their reproductive success (Fuentes et al., 2013; Katselidis et al., 2012; Patino-Martinez et al., 2012).

The International Panel on Climate Change (IPCC, 2013) gives modelled projections over the next 100 years of accelerated levels of sea level rise (Dickson et al., 2007). In order to understand the potential impact of this on the reproductive success of leatherback turtles, we have evaluated the effect of sand water content (moisture) on embryonic development, hatchling emergence success and hatchling characteristics in nests, both in situ and in laboratory conditions.

2. Material and methods

2.1. Study site

The study was conducted at Playona beach, Colombia (total length 12 km), which is located in the south-western Caribbean on the border with Panama (8° 30′N, 77° 15′W; Fig. 1). This area hosts the fourth largest leatherback turtle nesting rookery in the world and one of the two most important leatherback nesting beaches in Colombia (Patino-Martinez et al., 2008). All work was carried out under permit from the local environmental authority in Colombia (CODECHOCO and Consejo Mayor de Comunidades Negras Acandí). Guidelines for animal experimentation using protected species were followed. During the study period, there were 18 days of rainfall in 2005 and 30 days in 2006 that coincided with incubation.

2.2. Instruments used

Hatchlings were checked for abnormalities, straight carapace width (SCW) and length (SCL) measured (using Cen-Tech Digital callipers; Harbor Freight Tools, Pittsburgh, PA, USA; accuracy ±0.01 mm) and weighed (using a microbalance PK401 Denver Instrument; accuracy ±0.1 g). Sand samples were taken, by means of acylindricalbore (drill) of PVC.

2.3. Measuring nesting beach water content

First, the natural range of sand water content at Playona beach was measured by obtaining 72 sand samples from (i) a 3-km stretch of the beach with high leatherback nesting density (>81 nests/km; n = 36 samples) and (ii) a 3-km stretch with low nesting density (<15 nests/km; n = 36 samples). Sand samples were taken at two different depths: 10 cm (to evaluate whether water content in the nest can be estimated from the surface); and 60 cm (corresponding to the average leatherback nest depth) (Quinones et al., 2007). Samples were collected on two dates during peak nesting (26th March and 3rd May 2005) from three different zones on the beach following a water content gradient from the sea inland: (i) the intertidal zone (below the high water mark); (ii) the mid-zone (between the high tide line and where dune vegetation began); and (iii) vegetated zone (above the dune vegetation line extending to the back of the beach). Three replicates were taken at each sampling location (Fig. 2.A), carefully avoiding mixing sand from different depths.

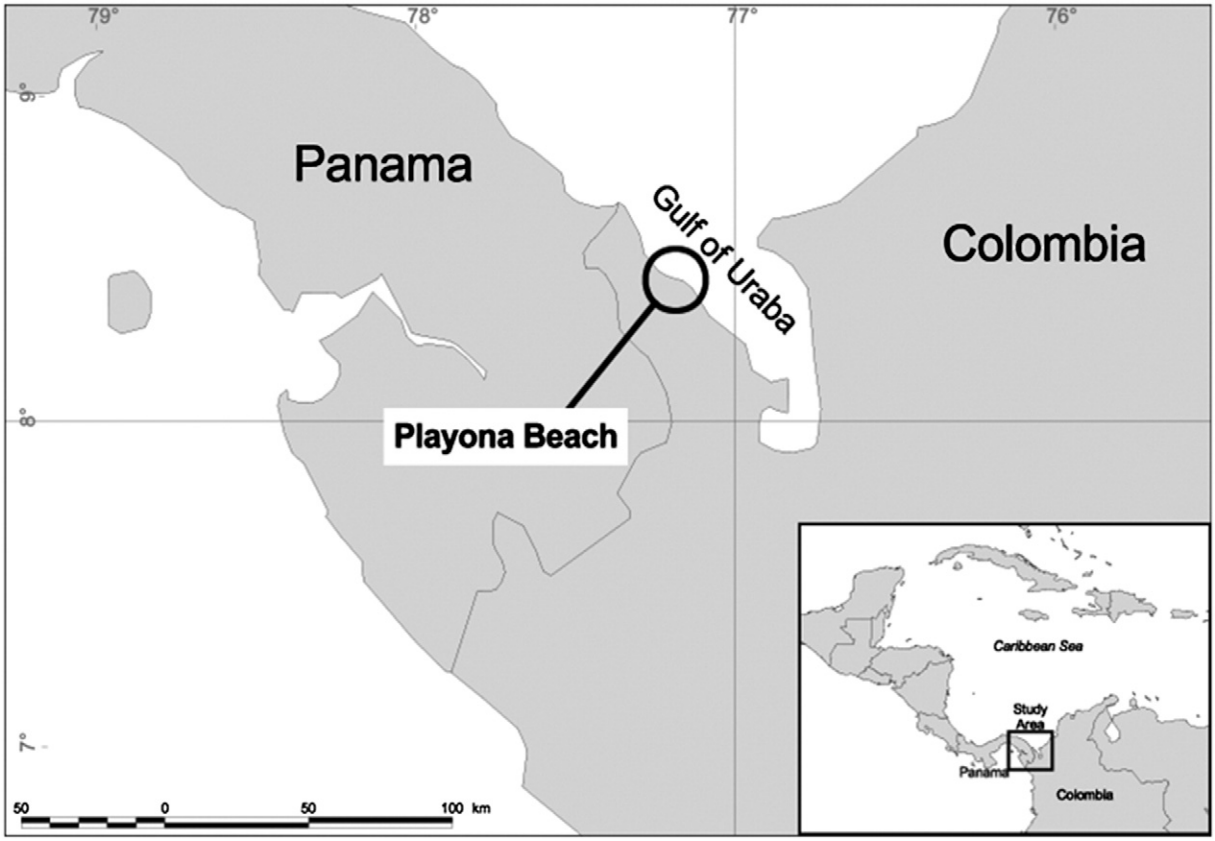

Fig. 1. Map of the study area location in Colombia. Playona (indicated in black circle) is one of the two most important leatherback nesting beaches along the Caribbean coast of Colombia.