



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.

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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·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 (Hewavisenithi 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 Bjørndal, 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.

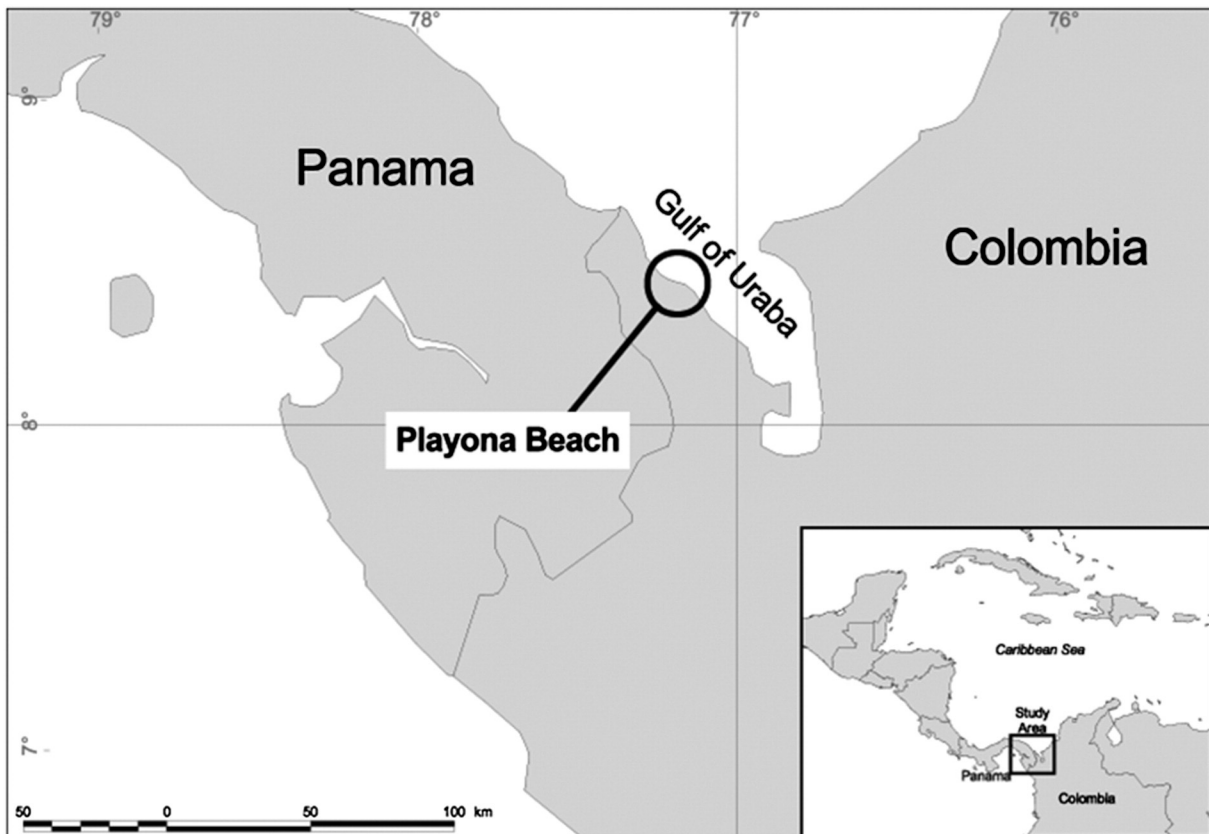


Fig. 1. Map of the study area location in Colombia. Playona (indicated in black circle) is one of the two most important leatherback nesting beaches along the Caribbean coast of Colombia.

2.4. Measuring the effect of sand water content on nests in-situ

To assess the influence of sand water content on incubation in-situ we conducted nocturnal surveys during the 2005 and 2006 nesting seasons (February–June) along a 3 km section of beach with the highest turtle nesting density. Sand samples were taken one-metre alongshore, from 39 nests as they were laid and after 45 days at two depths: (i) at nest depth and (ii) 10 cm below the beach surface. The 39 nests were protected in situ from predation throughout incubation using a cylindrical 1.5 m diameter plastic net and monitored until hatchling emergence. Each nest was assigned to one of the 3 incubation zones (Fig. 2.B). Eight of the 39 protected nests were illegally harvested and thus could not be used further in the present study.

2.5. Measuring the effect of sand water content on nests in a hatchery

To assess the influence of sand water content on incubation in hatchery conditions we translocated 30 leatherback nests to an open-beach hatchery using clean plastic bags. Nests were chosen for this part of the study if they were considered ‘doomed’, i.e. laid in an area with low survival probability. The eggs were transported by foot, with a maximum of 2 h between oviposition and reburial. Translocated nests were reburied at a depth of 60 cm and monitored throughout their incubation. The hatchery (10 × 6 m) was established on a portion of the beach where high tides and flooding are not generally observed. We therefore assumed that this part of the beach was relatively dry. We arranged nests in contiguous parcels of 1 m² for each nest, and sampled sand water content in three different locations of the hatchery at the typical nest depth.

2.6. Lab analysis of sand water content

Water content was measured gravimetrically for all sand samples. The fresh samples (approximately 400 g) were weighed (to the nearest 0.1 g) using a portable digital scale, and then left to dry in high-sided containers in a sunny location (sand surface temperatures reaching up to 70 °C at noon). Samples were periodically reweighed until constant mass was attained (i.e. all water had been lost). The sand water content was calculated as water loss divided by total fresh (wet) weight, multiplied by 100.

2.7. An experiment on the effect of sand water content on nests

To experimentally assess the influence of sand water content on incubation, we incubated eggs in five controlled water content treatments. First, 210 eggs were collected from nests laid by five different females during the same night ($n = 42$ eggs per clutch). There were no significant differences in egg mass (ANOVA: $F_{1,8} = 0.01$, $P = 0.91$). Eggs were then cleaned with a soft brush, weighed and measured. Ten eggs (two per female) were then incubated at a depth of 60 cm in the hatchery in one of 21 plastic containers (0.32 m × 0.20 m × 0.21 m, 15 L) in which they were completely covered with sand. The upper part of the container had an air space to permit egg gas exchange during incubation (Bilinski et al., 2001). Each container was assigned to one of 5 different sand water content treatments: 1% = −10 kPa (5 replicates), 2% = −9 kPa (3 replicates), 6% = −6 kPa (5 replicates), 10% = −4.8 kPa (3 replicates) and 12% = −3.8 kPa (5 replicates). Substrate water potentials were measured using the filter paper method ASTM D 5298-94 (American Society for Testing and Materials, 1994). The

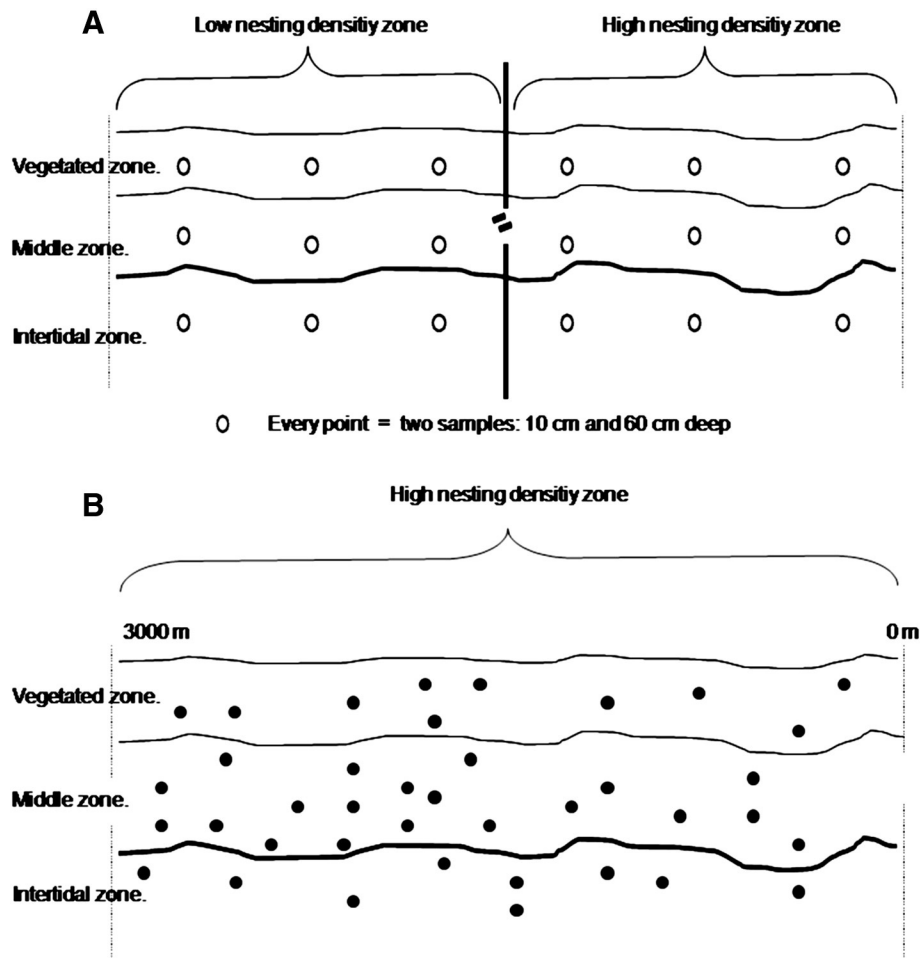


Fig. 2. Schematic diagrams showing A. Spatial sampling design to study sand water content. B. Location of leatherback nests where humidity and hatching success were studied.

used filter paper was Whatman no. 42 (Fisherbrand 9-780A), treatments were selected as they covered the range of water contents observed in natural leatherback nests (Patino-Martinez, 2010). Experimental sand water contents were obtained by adding 1%, 2%, 6%, 10%, and 12% water (local rainwater) by mass to the dry sand before interring the eggs. The containers were then closed to prevent water loss and not opened again until hatching, with the exception of two replicates from the 1%, 6% and 12% water content treatments, which opened on days 1, 2, 6, 12, 29 and 50 of incubation to assess egg development. Eggs of these containers were cleaned, measured and weighed on each of the six days. From day 55 of incubation the containers were checked for signs of hatching.

2.8. Measuring hatchling size and vigour

Hatchlings ($n = 10$ per nest) were collected immediately after emergence from each nest in-situ, in the hatchery and in the laboratory. For each hatchling, the straight carapace length and weight was measured and recorded. Hatchling vigour was measured by timing how long each hatchling took to “run” across 50 cm of sand. These trials were conducted in an open-air location on dry sand at night and were repeated three times per individual and then averaged. After assessing their physical condition, the hatchlings were immediately released into the sea.

Nests were excavated 48 h after the last observed hatchling emergence, and all eggs dissected to determine the presence and developmental stage of dead embryos using the criteria proposed by Bilinski et al. (2001). Emergence success was calculated as the proportion of eggs that produced live hatchlings that emerged from the nest at the sand surface. Development success was calculated as the proportion of eggs that produced hatchlings or embryos that developed past stage by the end of incubation. Incubation temperatures were recorded in nine natural, six hatchery and two experimental nests using dataloggers (Hobo Stow Away Tidbit v2 Onset, www.onsetcomp.com, ± 0.2 °C accuracy, measuring 3.0 cm $\times$ 1.7 cm). The dataloggers were programmed to record temperature every 30 min. In addition, the sand temperature of the beach (without eggs; ‘control’) was recorded at a depth of 60 cm in two different locations on the nesting beach.

2.9. Statistical analyses

We arcsine-transformed the percentages of emergence success and sand water content data. We used Statistica (version 6) (StatSoft I,

2001) to carry out ANOVA and Pearson product-moment correlation tests, after testing all dependant variables for heteroscedasticity and normality. Alpha was set at 0.05.

3. Results

3.1. Field study

Natural sand water content on the nesting beach at Playona varied from 0.8 to 21.7% (mean 9.7 ± 5.7 s.d., $n = 36$). The water content of the sand at nesting depth was highly variable (range 2.3–21.4, mean 11.7 ± 5.9 s.d., $n = 36$) but mean values decreased from the sea to the vegetated zone (ANOVA: $F_{6,7} = 11.54$, $P < 0.01$; Fig. 3). There was no significant difference in sand water content between beaches with high and low nesting densities (ANOVA: $F_{4,18} = 0.99$, $P = 0.44$, Fig. 3).

3.2. The effect of water content on nests in-situ and in the hatchery

Emergence success differed among zones (ANOVA: $F_{3,27} = 31.90$, $P < 0.001$) ranging from 0% to 64% (mean 37.8 ± 34.7 s.d.) and was significantly lower in the wettest beach zone (Fig. 4). Nests in the wettest sand suffered the highest mortality, while nests in the driest sand had the highest emergence success (Pearson product moment correlation: $r = -0.73$, $P < 0.0001$, Fig. 5A). Nests incubated in the hatchery had intermediate values of both emergence success and sand water content (Fig. 4). Surface sand water content was not correlated with emergence success ($P = 0.16$). There was no influence of beach zone type on mean values of hatchling size (ANOVA: mass $F_{2,31} = 0.97$, $P = 0.38$, length $F_{2,34} = 1.28$, $P = 0.28$) or run speed ($F_{2,19} = 0.89$, $P = 0.42$).

3.3. The effect of water content on experimental nests

Hatching success significantly decreased with increasing water content, from mean 64% (± 23.3 s.d., range 30 to 90%) in the driest treatment to complete failure to hatch at 12% water content ($r = -0.84$, $F_{1,19} = 45.59$, $P < 0.0001$; Fig. 5B). Embryonic mortality in the wettest treatments (10%–12% water content) occurred earlier than in dryer treatments (ANOVA: $F_{4,16} = 10.60$, $P < 0.001$). While 90% or 100% of eggs experienced early embryonic mortality in 10% and 12% sand water content respectively, only 22% or 20% of eggs died early in 1% and 2% water content treatments respectively (Fig. 6). Indeed, under dry incubation conditions embryos died at a variety of developmental stages (Fig. 6).

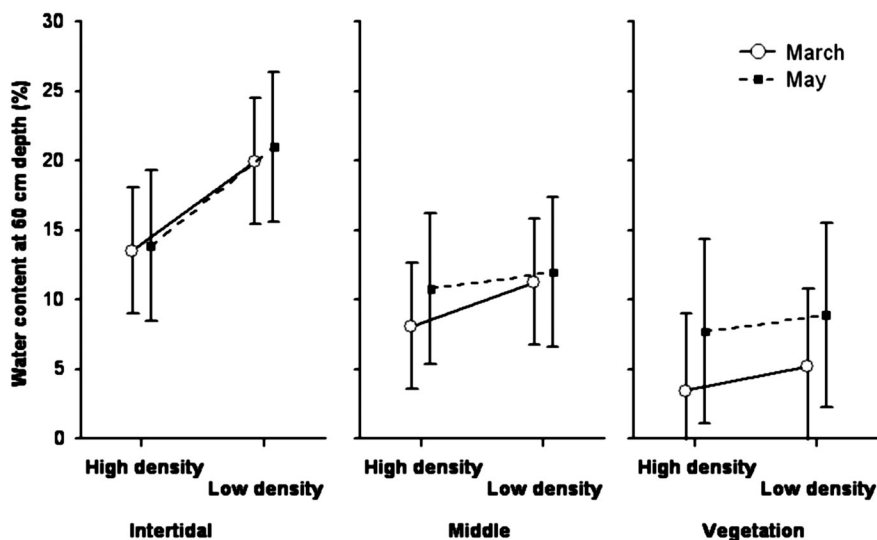


Fig. 3. Plots showing percent water content of incubation sand at 60 cm depth (mean and s.d.; indicated as hollow and filled circles and $\pm$ one standard deviation as vertical lines) of high and low density leatherback nesting beaches in the inter-tidal, beach and vegetated zones.

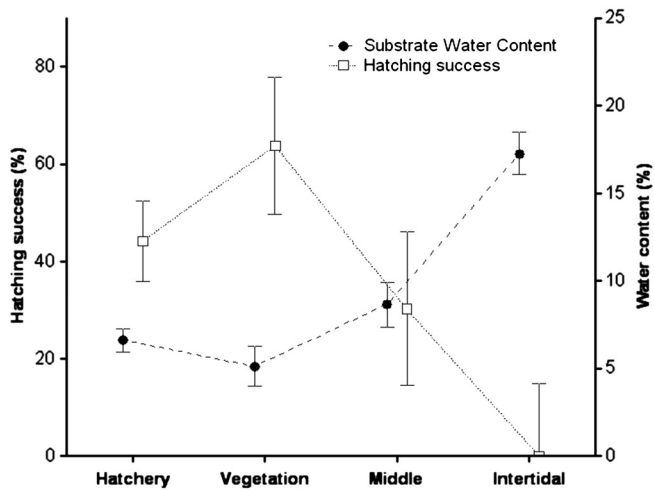


Fig. 4. Plot showing mean $\pm$ s.d. hatching success (hollow squares; primary y-axis) and percent water content of incubation sand (filled circles; secondary y-axis) of leatherback nests in-situ on the beach (in three zones) and in the hatchery.

Egg mass throughout incubation was affected by water content treatment (repeated measures ANCOVA: $F_{5,53} = 33.39$, $P < 0.001$; controlling for egg mass at oviposition as a covariate). It was possible to identify eggs throughout incubation as each of the 10 eggs was placed in marked locations in each container. Egg mass was also affected by embryonic development success (repeated measures ANCOVA: $F_{10,27} = 2.63$, $P < 0.01$; controlling for egg mass at oviposition). At the wettest treatment (12% water content) eggs took up water and thus gained on average 15% of their mass (Fig. 7). Conversely, at the driest treatment (1% water content) eggs lost water (and thus mass) throughout incubation, and eggs at the intermediate water content (6%) had a net water uptake. However, all live eggs lost water during the second half of development (Fig. 7).

3.4. Comparing natural, hatchery and experimental nests

Mean incubation temperatures in experimental nests were highly significantly correlated with control temperatures ($R = 0.86$, $p < 0.001$, Table 1).

Both mass and SCL of experimental hatchlings were similar to hatchlings from in-situ and hatchery nests (mass: $F_{3,88} = 1.33$, $P = 0.26$, SCL: $F_{3,91} = 0.46$, $P = 0.70$). Sand water content was negatively correlated with mean SCL of hatchlings ($r = -0.66$, $F_{1,11} = 8.57$, $P < 0.05$), as

hatchlings from eggs incubated in the driest sand (1%) were longer than those from the rest of the treatments. However, there was no correlation between hatchling mass ($r = 0.14$, $F_{1,11} = 0.23$, $P < 0.63$), SCW ($r = 0.24$, $F_{1,11} = 0.71$, $P < 0.41$) and run speed ($r = 0.25$, $F_{1,10} = 0.70$, $P < 0.42$) and sand water content. Hatchlings from eggs incubated in experimental containers were significantly faster than hatchlings from nests in-situ (ANOVA: $F_{3,62} = 4.06$, $P = 0.01$, post-hoc test—HSD $p < 0.05$). External malformations in hatchlings were very rare and their frequency was not related to sand water content levels.

4. Discussion

4.1. Knowledge gaps in research on marine turtles and climate change

Despite a rapidly growing interest in the effects of climate change to marine turtles (Fuentes et al., 2011; Hamann et al., 2007; Hawkes et al., 2010; Katselidis et al., 2012; Poloczanska et al., 2009), there are still significant gaps in our knowledge of both the direction and magnitude of responses by marine turtles to climatic factors, which preclude robust modelling of the future expected changes to marine turtle populations. The present study provides important information about the direction and magnitude of the effect of increased nest water content, which may result from increased sea level rise, as well as due to increase in frequency and severity of rainfall, storms and other weather events (Dickson et al., 2007; Goldenberg et al., 2001; Pike and Stiner, 2007a). Our study should be repeated elsewhere, as well as with different species of marine turtles, but suggests that increased water content in nests may have negative effects and could extend to significant nest mortality and thus reproductive loss for some populations.

4.2. Mechanisms behind reduced survival

In the present study it was clear that hatching success was reduced in sands with higher water content. The mechanism responsible for this has yet to be empirically described for marine turtles, but it is noteworthy that oxygen is approximately 200 times less soluble in water than in air (approximately 7.6 mg/L versus 1500 mg/L respectively at average nest temperatures for leatherback turtles in Colombia) (Patino-Martinez et al., 2012). In addition, oxygen becomes less soluble in water as temperature and salinity increase, which seem reasonably likely to happen based on future climate projections. Thus one might expect that increased sand water content around the nest may limit oxygen supply to developing embryos and thus may directly contribute to mortality. Wetter conditions in sea turtle nests has also been associated

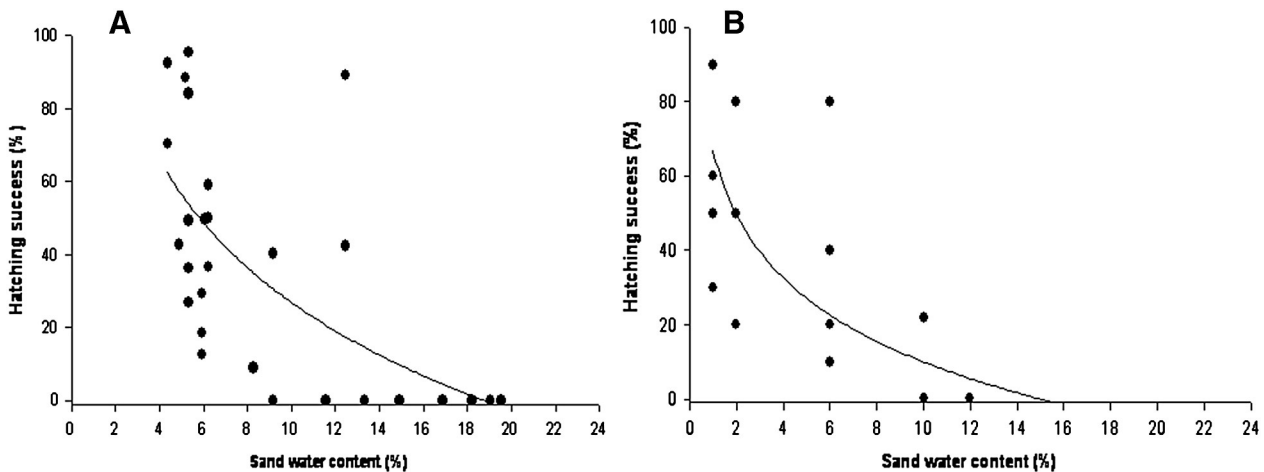


Fig. 5. Scatterplot showing the relationship between percent sand water content and hatching success (the proportion of eggs that produced live hatchlings that emerged from the nest at the sand surface) in leatherback turtle nests A) in-situ ($r = -0.73$, $F_{1,28} = 32.48$, $P < 0.0001$) and B) in experimental clutches in five different sand water content treatments ($r = -0.84$, $F_{1,19} = 45.59$, $P < 0.0001$). Black line shows linear fitted line.

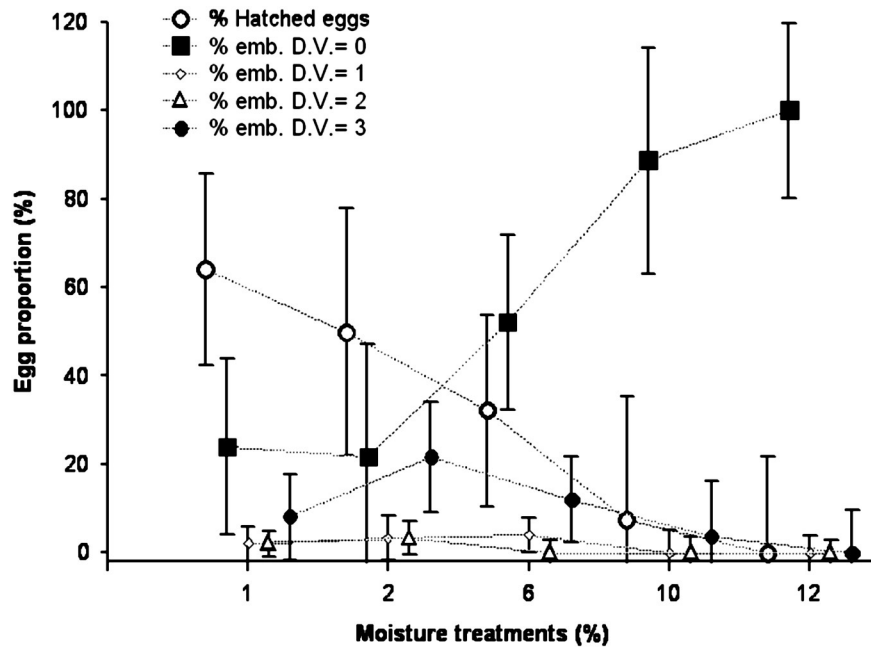


Fig. 6. Proportion of eggs that died at different developmental stages at different moisture treatments. D.V. = 0 = undeveloped, D.V. = 1 = early embryonic death, D.V. = 2 = middle embryonic death (20–40 mm in length), D.V. = 3 = late embryonic death (dead pigmented embryo > 40 mm).

with disease development by opportunistic microorganisms, and, a positive correlation between total number of isolated fungus and embryonic death has been demonstrated (Guclu et al., 2010). This area seems worthy of future laboratory investigation.

4.3. Water uptake by developing hatchlings

Sea turtle eggs contain a relatively high proportion of albumen compared with other (nonmarine) turtles and indeed other reptiles and non-avian reptiles (Hewavisenthi and Parmenter, 2002; Wallace et al.,

2006). In rigid shelled eggs, such as those laid by birds, much of the water uptake by the developing embryo comes from the albumen ('endohydric eggs') and water vapour conductance is thus low (Booth and Thompson, 1991). The results of the present study suggest that marine turtle eggs may have much of the water they require for successful development (including metabolism and growth), in that emergence success is optimal in drier incubation environments. Indeed lower values of humidity have been shown to facilitate calcium mobilization and embryo development in leatherback turtle embryos (Bilinski et al., 2001).

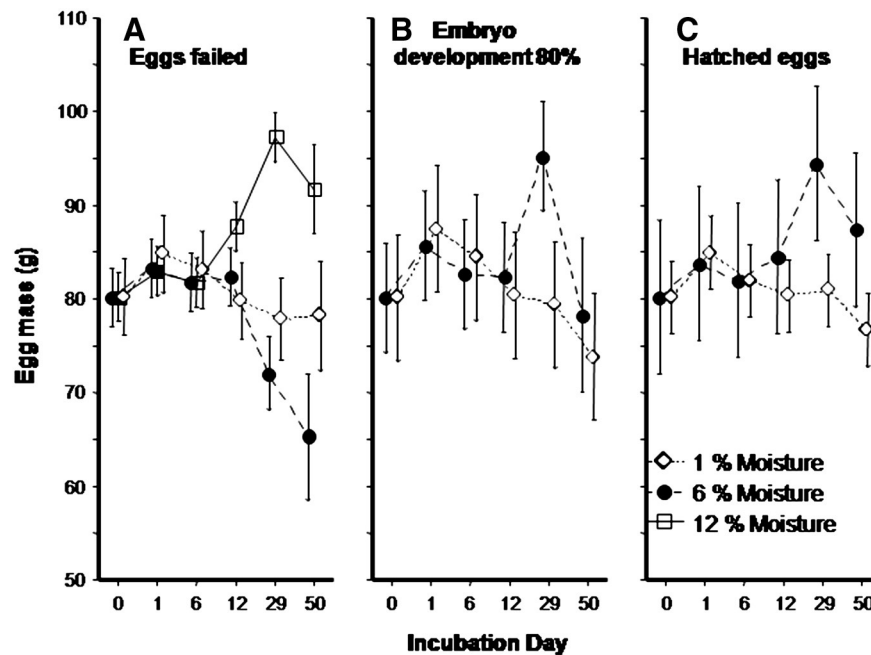


Fig. 7. Plots showing variation in egg mass during experimental incubation at three different moisture treatments (1%, 6% and 12%, shown as hollow diamonds, filled circles and filled grey squares respectively) for nests in which (A) eggs failed to develop; (B) the final degree of embryonic development was at least 80%; (C) hatched eggs.

Table 1

Mean temperature continuously recorded both in different incubation conditions and in the control sand without eggs.

Description	Successful natural nests	Doomed natural nests	Translocated nests	Experimental containers	Sand at 60 cm depth
Location	Beach	Beach	Hatchery	Hatchery	Beach
T° mean (°C)	30.58	29.54	31.27	30.02	30.15
Range (°C)	5.86	2.12	5.25	5.55	1.92
T° min (°C)	27.98	28.38	28.93	27.25	29.33
T° max (°C)	33.84	30.51	34.19	32.81	31.25
Daily fluctuation (°C)	0.35	0.17	0.43	0.69	0.34
N° dataloggers	3	6	6	2	2

4.4. Effects of future climate change on hatchling fitness

The results of the present study, although based on a limited sample size, suggest that the relationship between nest water content and hatchling survivorship may be complex. Earlier work has suggested that drier incubation environments may produce larger, more vigorous hatchlings that are perhaps better prepared for survival than smaller, weaker hatchlings (McGehee, 1990; Miller et al., 1987; Packard, 1999; Reece et al., 2002). Our study also showed that drier nests produced larger hatchlings, but we did not find any relationship with hatchling vigour.

4.5. Novel experimental field technique

The present study also demonstrates the use of a novel and extremely cheap method for study of humidity effects on incubating eggs that lack parental care. This methodology is of particular utility in the design of field experiments where resources such as electricity or incubators may be limited. Eggs isolated in plastic containers can be incubated with natural sand, without affecting natural thermal conditions, providing emergence successes similar to those found in natural nests and without altering physical conditions of the hatchlings. Caveats associated with this technique include the use of low egg density to prevent over-heating during late embryonic stages and the need to fully bury experimental containers as appropriate at natural incubation depths to avoid sun exposure and nocturnal cooling.

4.6. Adaptation to future climate change

If future sea level rise occurs as predicted, and does reduce hatchling survival and hatching and/or emergence success, it seems sensible to explore how sea turtle populations might adapt. For example, turtles could adapt egg shell permeability, they could adapt nest depth, they could alter spatial nesting variation (nesting elsewhere), alter temporal nesting variation (nesting during drier seasons) or, they could do nothing. First, alterations to eggshell structure and permeability, or even maternally derived components such as salt and water content of the yolk and albumen, could limit water uptake (Warner et al., 2011). This seems extremely unlikely though, given that such changes would need to occur within one generation of turtles and age to maturity is thought to be on the order of several decades (Avens and Snover, 2013).

Second, the ability to alter nest depth in response to microhabitat conditions has not been demonstrated in marine turtles, although it is common for females to cease nest excavation when they encounter the water table (Patino-Martinez, 2010). There is no evidence that turtles can distinguish between high and low humidity sand while digging, rather turtles appear to restrict their nesting only to areas where they are able to successfully excavate a nest chamber.

Third, spatial variation in nest placement is known for sea turtles. For example, in French Guiana many leatherback nesting beaches are highly dynamic and can be completely eroded and accreted between nesting seasons yet nesting persists between these and more stable beaches elsewhere (Kelle et al., 2007), presumably because some individuals have low site fidelity and thus nest in widely dispersed locations

(Katselidis et al., 2014; Pike, 2008; Tucker, 2010). In the context of the present study, nests are spread across different zones of the beach and the location of one nest is independent of (or very weakly correlated with) the previous nest of the same female (Mrosovsky, 2006). This possibly represents an adaptive balance between the cost of nesting in upper areas of the beach (time, energy and female or hatchling predation risks) and the benefit of higher emergence success. Thus, reduced site fidelity should increase the chances of turtles laying nests on beaches with a variety of sand water contents.

Fourth, changes in nesting phenology have been well documented in marine turtles (Hawkes et al., 2007; Weishampel et al., 2004). These adaptations are limited by a complex network of factors, such as food availability (Broderick et al., 2001; Pike and Stiner, 2007b), marine water and air temperature (Weishampel et al., 2004) and the cues that initiate mating and migratory behaviours, among others.

Finally, a “do nothing” strategy for marine turtles may in itself afford ‘adaptive capacity’ (Dawson et al., 2011), as variation in nest placement may maintain the chance of nests being laid in suitably dry sites. Although nest site fidelity has been observed for leatherback turtles (Nordmoe et al., 2004) there is no apparent selection of nest sites with regard to beach zone (inter-tidal, mid zone, vegetated zone).

5. Conclusions

We show, through field and experimental studies, a strong negative correlation between sand water content and leatherback turtle emergence success, such that successful development and hatching is severely impacted at sand water contents higher than 10%. Hatchlings from dry sand were bigger (SCL) but their vigour was not affected by the sand water content. Projected climate change and sea level rise may thus negatively affect leatherback turtle nesting success, although there are several avenues for adaptation to such future change. We recommend further examination of our findings in other populations of leatherback turtles and in other species of marine turtles.

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