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Effect of tidal overwash on the embryonic development of leatherback turtles in French Guiana

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ABSTRACT

In marine turtles, the physical conditions experienced by eggs during incubation affect embryonic development. In the leatherback, hatching success is known to be low in relation to other marine turtles as a result of high embryonic mortality. Moreover, the hatching success on Yalimapo in French Guiana, one major nesting beach for this species, is lower compared to other nesting sites. We assessed the rate of leatherback turtle embryonic mortality in order to investigate the tolerance of leatherback turtle clutches laid on Yalimapo beach to tidal overwash, and we highlight causes of poor hatching success. Of the 89 nests studied, 27 were overlapped by tide at least once during the incubation period (of which five nests were lost by erosion). The hatching success was on average significantly lower in overwashed nests than in non-overwashed, highlighting the existence of embryonic developmental arrest linked to tidal inundation. The stages of developmental arrest and their proportion are linked with time, frequency and level of overwash events. In the context of global warming and associated sea-level rise, understanding the detrimental effect of tidal inundation on the development of marine turtle nests is of interest in nesting sites where turtles are likely to be forced to nest closer to the tide line, thus exposing their nests to greater risk of nest overlap with sea and tidal inundation.

1. Introduction

For animals that lay their eggs in a nest, the selection of a nest site may strongly influence embryo development and offspring survival and may therefore have important consequences for the reproductive fitness of the adult. Indeed, for most oviparous species, the most vulnerable part of the life cycle is often the embryo stage, since eggs are typically left in fixed locations throughout their development without parental care (Wood and Bjorndal, 2000). Hatching success for organisms that lay eggs in a nest, such as sea turtles, is believed to be influenced by numerous biotic and abiotic factors such as predation, type of substrate, porosity, temperature, moisture content, salinity, slope of the beach, nest elevation, rainfall and tidal inundation (Mortimer, 1990; Horrocks and Scott, 1991; Ackerman, 1997; Wood and Bjorndal, 2000; Allen et al., 2001; Bilinski et al., 2001; Donlan et al., 2004; Foley et al., 2006). In many oviparous reptiles, however, environmental factors not only influence embryo survivorship (Horrocks and Scott, 1991; Resetarits, 1996), but also hatchling size (Packard and Packard, 1988), performance (Janzen, 1993), growth (Bobyn and Brooks, 1994), behaviour (Burger, 1991), and sex determination (Spotila et al., 1994). After the emergence of hatchling turtles, their survival may be strongly related to the distance at which the nest is laid from the sea and from supra-littoral vegetation behind the beach (Mrosovsky, 1983). Placement of nests close to the sea increases the likelihood of inundation and egg loss to erosion, whereas placement of nests farther inland increases the likelihood of desiccation, hatchling misorientation, and predation on nesting females, eggs, and hatchlings (Bustard and Greenham, 1968; Fowler, 1979; Whitmore and Dutton, 1985; Spencer, 2002).

Leatherback turtles (*Dermochelys coriacea*), classified as critically endangered by the Species Survival Commission (IUCN, 2006), often place their nests in the open sand near the water, but rarely in vegetation (Whitmore and Dutton, 1985; Kamel and Mrosovsky, 2004; Caut et al., 2006a). For this reason, researchers have investigated possible strategies and cues that might influence nest placement. Mrosovsky (1983), at the population level, and Eckert (1987), at the individual level, suggested that leatherbacks have developed a scatter nesting strategy whereby nests are randomly distributed along a beach to maximize clutch survival in an unpredictable nesting area. However, leatherback turtles often nest in places where their eggs are destroyed by high tides. Poor nest-site selection, where nests have been shown to completely fail, ranges from <2.5% in Malaysia to around 40% in the Guianas

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and appears to be related to beach topography (Mrosovsky, 1983). Leatherbacks generally have low hatching success (~50%) relative to other marine turtle species (~85% or more; see Bell et al., 2004). Predation could partly explain the low hatching rate, with the longer incubation period for leatherbacks increasing exposure to predators (Whitmore and Dutton, 1985). But this low hatching success of leatherbacks also seems to be mainly the result of nest-site selection and embryonic mortality (Whitmore and Dutton, 1985; Bell et al., 2004). Indeed, leatherbacks generally nest nearer to the sea than other marine turtles and nests are therefore subjected to erosion and inundation, sometimes leading to 50% nest loss on certain beaches in South America (Patino-Martinez et al., 2008). These overwashes of nests by sea water may lead to egg mortality from suffocation (lack of respiratory oxygen; Whitmore and Dutton, 1985) and/or disruption of metabolism as a result of exposure to higher salinities and therefore chloride toxicity (Bustard and Greenham, 1968) and/or critical cooling below minimum temperature for embryonic development (Hewavisenthi and Parmenter, 2002). Moreover, leatherback nests are deeper than those of others marine turtles, and water content and salinity are known to increase with depth, leading to a decrease in hatching success (Foley et al., 2006). The greater embryonic mortality in leatherback nests is therefore mainly due to the nest-site selection resulting in more nests being overwashed.

However, the effect of tidal overwash on hatching success and embryonic development remains poorly understood and represents an important question for the future. Indeed, threats to coastal areas are increasing (Huang, 1997) with the projected rise in sea level resulting from anthropogenic global warming; the increase in the number and concentration of greenhouse gases in the atmosphere has the potential to cause an elevation in the global mean air temperature and mean sea level of 1–4.5 °C and 31–150 cm, respectively, by the year 2100 (IPCC, 2007). Therefore, many nesting beaches are particularly susceptible to coastal hazards such as storm surges and coastal erosion. However, although much effort has been expended over the last two decades to understand and mitigate the threats to marine turtles (Watson et al., 2005), the threat of climate change on this taxon has, until recently, been given little attention (for more information, see Hawkes et al., 2009). Studies of the effects of global warming on sea turtle populations have focused essentially on the loss of nesting beach habitat as a result of an increase in sea level and on the changes in sex ratio (Daniels et al., 1993; Davenport, 1997; Nicholls, 1998; Nicholls et al., 1999; Fish et al., 2005, 2008; Baker et al., 2006; Jones et al., 2007; Mazaris et al., 2009). Most of these studies examined the potential effect of sea-level rise on marine turtle nesting beaches with different models (e.g. elevation model, inundation flooding model), but they did not take into account how life history and ecological parameters that determine extinction risks will be affected by climate change (Isaac, 2009). The recent review on climate change and marine turtles (Hawkes et al., 2009) therefore indicated the importance for future research on climate change effects on key habitats upon which turtles depend and factors that influence nest-site selection and hatchling success. The effect of inundation and, indirectly, the sea-level rise on leatherback hatching success have been poorly studied (Whitmore and Dutton, 1985) to date, despite the tendency of this species to lay its clutches closer to the high-tide line than other sea turtle species. Results of studies concerning global warming have highlighted threats for coastal zones with accelerated beach erosion and greater frequency of flooding events (Kumar, 2006).

The beach of Yalimapo has one of the highest nesting densities of leatherback females, with about 30% of the world's population of nesting females and approximately 50% of all leatherbacks nesting in the region of French Guiana and Suriname (Girondot and Fretey, 1996), it should be noted that the exact proportion varies according to the year. However, hatching success on this beach is lower than at other leatherback nesting sites (Boulon et al., 1996). Depressed hatching success compounds the problem of population decline that results from adult mortality caused by incidental fisheries capture (Kaplan, 2005; Martinez et al., 2007), and understanding the causes of low hatching success would therefore be an important conservation step towards preventing extinction in a species (Ralph et al., 2005). In this study, we determined the level and frequency of tidal overwash and hatching success of leatherback nests in order to investigate the tolerance of nests to tidal inundation in the context of global warming and sea-level rise. We assessed the rate and stages of leatherback turtle embryonic mortality in order to investigate tolerance of leatherback turtle clutches laid on Yalimapo beach to tidal overwash and we highlight causes of poor hatching success.

2. Materials and methods

2.1. Study site and data collection

Research was carried out on the Awala Yalimapo beach in French Guiana (53°57′W–5°45′N). The beach is located within the Amana Nature Reserve, on the inshore plain of coastline between the Mana and Maroni Rivers. Guyana has a semi-diurnal tide (two daily high tides) with a period of approximately 12-and-a half hours. The beach is 4 km in length and the width varies from a few metres to 20 m, depending on the tide line. For this study, we chose a 300-m long section of beach with the same slope (approximately 10%), which was sufficiently frequented by turtles but also distant from sites frequented by tourists. The width of the sand beach depends on the strength of the tide (~5–30 m).

The nests analysed in the study were laid from 20 May to 4 June 2002. At the time of oviposition or later, during nest covering, we measured the minimum straight carapace length of the nesting female (SCLmin) (Bolten, 1999) and the female identity was recorded (Passive Integrated Transponder (PIT) tags). For each freshly laid nest encountered, we measured the minimum distance from the nest to the last high-tide line and to the vegetation line (sparse creeping vegetation (*Ipomoea pes-caprae*), sand still visible) with a plastic measuring tape. All nest locations were localized to within 1 m by triangulation using numbered stakes placed every 10 m along the vegetation of the beach. To locate specific nests after incubation, we placed a numbered ring of plastic-insulated copper in the sand above the clutch during the covering of the nest by the female. We used a metal detector that captured signals from probes in the copper at the end of incubation.

2.2. Embryonic development

Nest status was checked each day for signs of emergence, predation by dogs or erosion. We waited sufficient time for any live embryos to hatch and leave the nest before analysing the remaining embryos. All nests were excavated 48 h after the first signs of emergence; in the absence of evidence, we expected a period of 70 days of incubation, so no live embryos were excavated or sacrificed (authorization No. 1516 1D/1B/ENV of 27 August 2001, DIREN Guyane). We recorded the total number of yolked eggs (noted *YE*, including hatched and unhatched yolked eggs) and shelled albumin globs (noted 'yolkless' eggs). We dissected unhatched yolked eggs in situ and staged them in category using these criteria:

– *Category 1*: egg with no visible signs of development or dead embryo <10 mm in length.
– *Category 2*: egg with dead embryo ⩾10 mm and <30 mm in length.