Saltwater crocodile (*Crocodylus porosus)* nest temperatures at Melacca Swamp, Northern Territory and the implications of climate change

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Introduction

Two species of the Order Crocodilia occur in Australia, the endemic freshwater crocodile, *Crocodylus johnstoni* and the estuarine or saltwater crocodile, *Crocodylus porosus* (Webb, 1991; Leach et al., 2009). Both are members of the Subfamily Crocodylinae or "true crocodiles" (Webb & Manolis, 1998). The present study concerns *C. porosus*, which is the largest living species of crocodilian in the world, and possibly the largest living reptile (Webb & Manolis, 1998).

Much of the crocodilian life cycle is influenced by climatic variables such as temperature and rainfall, including; nesting and incubation period (Webb et al., 1977), growth (Webb at al., 1978), feeding, movement, dispersal, regulation of body temperature (Johnson et al., 1976; Webb, 1991; Fukuda et al., 2007), and embryonic sex determination (Webb et al., 1987a; Webb & Cooper-Preston, 1989; Isberg et al., 2006). It is therefore predicted that changes in temperature and rainfall that may occur as a result of climate change, may have a profound effect on a number of aspects of crocodilian biology (Bickford et al., 2010). The current project examines how nest temperature varies with respect to external variables, including temperature and rainfall. Historic nest temperature data and weather station data are also analysed with the aim of determining whether there have been any measurable increases due to climate change.

Study Area

The Adelaide River and Melacca Swamp wetlands are located approximately 50 km north-east of Darwin (12º 20' 50.11" S 131º 14' 53.9" E) (Harvey & Hill, 2003) in the Northern Territory of Australia. Melacca Swamp is an elevated freshwater wetland adjacent to the Adelaide River and is permanently inundated by a spring fed creek (Figure 8) (Webb et al., 1983; Harvey & Hill, 2003). A population of approximately 440-530 saltwater crocodiles reside in Melacca Swamp year-round, with between 12 and 20 nests harvested annually (Webb & Manolis, 1993; Harvey & Hill, 2003; WMI, 2007).

Methods

Between January 2nd and February 9th 2013, temperature data loggers (TidbiT v2 Temp; part # UTBI-001) were placed in seven (N=7) saltwater crocodile (*C. porosus*) nests located in Melacca Swamp. Two data loggers with high visibility pink tape attached were placed in each nest to measure the temperature within the clutch of eggs (egg temperature), and the temperature within the nest, on the outside of the clutch of eggs (nest temperature). The two data loggers were placed approximately 10-15 cm apart. An additional data logger was attached to a tree near the nest (within 1.5m) at least 1m above the ground (close to meteorological height) and covered in shade cloth material to measure ambient air temperature (air temperature). Daily data for rainfall, maximum temperature (Tmax) and minimum temperature (Tmin) were downloaded from the Bureau of Meteorology website (http://www.bom.go v.au/climate/data-services/) for three sites (Darwin Airport, Middle Point AWS and Middle Point Rangers). Both of the Middle Point weather stations were located approximately 25 km from Melacca Swamp whereas Darwin Airport was located approximately 38 km away.

Results

Egg temperature tended to be coolest during the day (typically from 6-7 a.m. to 3-5 p.m.) and became warmer at night. This occurred despite much wider ambient air temperature fluctuation. Rainfall events caused substantial decreases in overall egg temperature (0.7-7.3°C) and temperatures took on average 3-5 days to recover. Egg temperatures also paralleled a seasonal decline in ambient air temperatures. Mean egg temperature appeared to increase approximately 1.5°C throughout the course of incubation. Several sources of variation (metabolic heat, rain events, time of year) made trends difficult to extract from the historical data and it was not possible to detect any changes in egg temperatures over time. Clear increases were found in maximum air temperatures, minimum air temperatures and rainfall, particularly in the last decade consistent with climate change predictions

Discussion

It has been suggested that cooler temperatures experienced in the egg chamber during the day are a result of evaporative cooling, whereby evaporation caused by heating of the nest has a cooling effect (Davenport, 1985; Heatwole & Taylor, 1987). Another factor contributing to this 24-hour temperature pattern is the “thermal inertia” (Nearing et al. 2012) of the nest mound due to the lag in time for the heat from solar radiation to reach the egg chamber. Egg temperatures were consistently warmer than both nest and ambient air temperatures for all nests (Table 4 and Table 5). Magnusson (1979) found that internal heat sources were capable of raising egg

cavity temperatures above that of ambient air temperatures in *C. porosus* nests, and the higher temperatures could be maintained because of the insulation created by the nest material.

Rainfall caused a considerable drop in egg temperatures. These results are consistent with those of Charruau (2012), who determined that normal rainfall caused a drop of between 1.3-3.4°C, whereas heavier rainfall associated with tropical storms caused a drop of between 1.5-7.7°C in the nests of American crocodiles (*Crocodylus acutus*). There was a significant difference of between 0.7-4.0°C (mean = 2.2°C) when comparing early and late stage mean egg temperatures (Table 9). These results are supported by Webb & Cooper-Preston (1989), who found that *C. porosus* nest temperatures increased by 1- 2°C with embryo age which reflected metabolic heating from within the clutch.

Conclusion

Using data taken from three weather stations, Darwin Airport, Middle Point Rangers and Middle Point AWS, it was possible to establish clear increases in maximum temperatures, minimum temperatures and rainfall, particularly in the last decade. An increase of 3°C in air temperature leads to an increase of 1°C in egg temperature. This suggests that some *C. porosus* nests may have the ability to buffer intermediate warming due to climate change. Higher rates of warming by 2070, however, may increase nest temperatures >33-34°C, leading to higher rates of temperature-induced embryo mortality, higher proportions of abnormal hatchlings, and the production of mostly female hatchlings. Increased rainfall has the potential to decrease mean egg temperatures to <26-29°C, which may also lead to higher proportions of female 81 hatchlings and higher mortality rates. *C. porosus* may have the ability to buffer these effects through behavioural means.

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