Impacts of climate change on the largest green turtle population in the world: the nGBR green turtle population

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Sea turtles and climate change

Sea turtles are vulnerable to aspects of climate change because they have life history, physiological attributes and behaviour that make them extremely sensitive to environmental changes (Hamann *et al.*, 2007; Hawkes *et al.*, 2009; Poloczanska *et al.*, 2009). Arguably, the more detectable impacts of climate change to sea turtles will occur during their terrestrial reproductive phase (egg laying, egg incubation and hatchling success phase) since there are clear, and relatively straightforward, effects of increased temperature, sea level rise and cyclonic activity on sea turtle nesting sites and reproductive output (Hawkes *et al.*, 2009; Fuentes *et al.*, 2010a; Witt *et al.*, 2010).

Indeed, there has been a recent increase in research activity focusing on the potential impacts and implications of climate change to sea turtles' terrestrial reproductive phase (for reviews see Hamann *et al.*, 2007; Hawkes *et al.*, 2009; Poloczanska *et al.*, 2009; Witt *et al.*, 2010). While first identified as an issue in the mid 1980s recent studies have begun to investigate and predict how specific climatic processes will affect sea turtles' nesting habitats and reproductive output. However, most of the studies conducted to date are limited temporally, because (1) they predict how a single climatic process will affect sea turtles (e.g. Hays *et al.*, 1999, 2003; Glen & Mrosovsky, 2004; Fish *et al.*, 2005, 2008; Hawkes *et al.*, 2007; Fuentes *et al.*, 2009, 2010b, 2010c), yet processes are likely to occur simultaneously and cause cumulative effects (Fuentes *et al.*, 2010a), and (2) they typically focus only on one nesting ground used by a particular turtle population and this approach does not provide a full understanding of how a population (management unit) will be affected. Consequently, there is a need for a structured approach to investigate how multiple climatic processes may affect the full range of nesting grounds used by a turtle population (Fuentes *et al.*, 2010a).

Vulnerability assessment

A recent study by Fuentes *et al.* (2010a) addressed the issue of cumulative impact by using a systematic and comprehensive methodology to assess how multiple climatic processes will affect the northern Great Barrier Reef (nGBR) green turtle population under a conservative and an extreme scenario of climate change for both 2030 and 2070. The study used published literature to identify how key processes: (1) change in sediment traits (Fuentes *et al.*, 2010d), (2) increased temperature (Fuentes *et al.*, 2009, 2010c), (3) sea level rise (Fuentes *et al.*, 2010b), and (4) cyclonic activity (Fuentes & Abss, *in press*) will affect the nesting grounds (n= 7) that represent the nesting habitat for 99% of the nGBR green turtle population. After the information on how each process will potentially affect the selected nesting grounds was compiled, Fuentes *et al.* (2010a) used expert opinion to gather information on the relative impact of each process on sea turtle nesting grounds. This information was then incorporated into a climate change vulnerability assessment framework.

Fuentes *et al.* (2010d) found that the sediment from each of the studied nesting grounds is predominantly composed of well sorted, medium-grained to coarse-grained, sands and are dominated by Foraminifera, molluscs or both. Dissimilarities in the contemporary sedimentology between the nesting grounds suggest that each will respond differently to environmental impacts such as increased temperature, sea level rise and ocean acidification. The implications of changes to island sedimentology on sea turtle ecology include changes in nesting and hatchling emergence success, and reduced optimal nesting habitat. Both of these factors can influence sea turtles' annual reproductive output and thus have significant conservation ramifications (Fuentes *et al.*, 2010d).

The work on impacts from increased temperature (from Fuentes *et al.*, 2009, 2010c) on the nGBR green turtle population predicts a feminization of annual hatchling output into the nGBR green turtle population by 2030. Predictions are bleaker for 2070, when some of the nesting rounds (Bramble Cay and northern Dowar and Milman Island) used by this population are predicted to experience temperatures near or above the upper thermal incubating threshold (e.g. 33 ˚C) and likely cause a decrease of hatching success. Importantly, Fuentes *et al.* (2009, 2010c) identified that some nesting grounds (e.g. Raine Island, western Milman Island and Sandbank 7) will still produce male hatchlings, even under the most extreme scenario of climate change. This is crucial for future management as managers may choose to protect important male-producing regions to balance future population viability.

Further impacts to the nGBR green turtle population will potentially occur from sea level rise (SLR) (Fuentes *et al.*, 2010b). Using the predicted sea level rise values from the IPCC and CSIRO, Fuentes *et al.* (2010b) indicated that up to 34% of available nesting area across all the selected nesting grounds may be inundated as a result of predicted levels of SLR. The work suggests that low sandbanks will be the most vulnerable to SLR and nesting grounds that are morphologically more stable, such as Dowar and Raine Islands, will be less vulnerable.

More positively, the work by Fuentes & Abss (*in press*) indicates that as climate change progresses it is likely that impacts from cyclones to the nGBR green turtle population will be very low. The study used eleven of the latest regional climate models to investigate how cyclonic frequency will alter in a warming climate. Most models predicted a tendency for a reduction in cyclonic frequency in the future. Thus a reduction in the impacts that the nGBR green turtle population will experience from cyclones is likely.

After the predicted impacts from each climatic process was explored they were incorporated into a vulnerability assessment framework for climate change. The framework used by Fuentes *et al.* (2010a) is based on the IPCC framework for climate change and is described as a function of sensitivity, exposure and adaptive capacity. The framework allowed: (1) an assessment of how multiple climatic processes will affect the terrestrial reproductive phase of sea turtles; and (2) an investigation of how mitigating different climatic factors individually or simultaneously can influence the vulnerability of the nesting grounds. Thus, the work was able to provide informed suggestions of management options to mitigate the potential impacts of climate change to the nGBR green turtle population.

The vulnerability assessment by Fuentes *et al.* (2010a) indicated that in the short term (by 2030), sea level rise will cause the most impact on the nesting grounds used by the nGBR green turtle population. However, in the longer term, by 2070 sand temperatures will reach levels above the upper transient range and the upper thermal threshold and cause relatively more impact on the nGBR green turtle population. Thus, in the long term, a reduction of impacts from sea level rise may not be sufficient, as nesting grounds will start to experience high vulnerability values from increased temperature. Therefore, a stronger focus on mitigating the threats from increased temperature will be necessary for long term management of the nGBR population (Fuentes *et al.*, 2010a).

Management options

Some of the potential options to mitigate the impacts of increased temperature include changing the thermal gradient at beaches, nest relocation, and artificial incubation. The best management options will be site specific and dependent on a series of factors, including feasibility, risk (interaction and impact on other species and ecosystems), cost, constraints to implementation (both cultural and social), and probability of success in relation to selected sites. Thus, a "toolbox" with various strategies will be needed to address the impacts of increased temperature across the nesting sites used by the nGBR green turtle population (Fuentes *et al.*, 2010a).

The main strengths of the framework by Fuentes *et al.* (2010a) is that it can easily be adapted when information is obtained, and it can be transferable to different sea turtle populations and sea turtle life cycle phases provided the necessary data exist. The framework provides key information for managers to direct and focus management and conservation actions to protect turtle populations in the face of climate change. Thus, future work should use a similar approach and asses the impacts of multiple climatic processes on sea turtles to provide realistic information to managers.

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