

Marine Reptiles

Mariana M.P.B. Fuentes¹, Mark Hamann² and Vimoksalehi Lukoscsek³

¹ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, QLD 4811 Australia. mariana.fuentes@jcu.edu.au

²School of Earth and Environmental Sciences, James Cook University, QLD, Townsville, QLD 4811 Australia

³ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, QLD 4811 Australia

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What is happening

Local declines of sea snakes on coral reefs may be the result of changing environmental conditions. Warming beaches are changing long-term sea ratios of hatchling turtles.

What is expected

Some turtle nesting beaches will produce more females, but the long-term implications for turtle populations are unknown. Turtle nesting beaches will be lost due to sea-level rise and coastal development.

What we are doing about it

The Australian Government, together with the WA, NT and Qld Governments are currently supporting a project to monitor sand temperatures on key turtle nesting beaches. Monitoring programs focused on crocodiles and nesting turtles are ongoing.

Summary

Few additional observations have been made of impacts from changes in climatic variables on marine reptiles since the first report card in 2009. However, there are a growing number of studies that have started to explore potential impacts of climate change on marine reptiles. Still, most evidence for climate change impacts on sea turtles comes from studies on loggerhead and green turtles in eastern Queensland. There is still low knowledge about vulnerability of crocodiles to climate change. However, there is more confidence that warmer water temperatures will influence behavior and possibly the distribution of the estuarine crocodile. There still is very limited knowledge of how the effects of climate change will impact sea snakes and there are no studies directly investigating this issue. What is clear, however, is that sea snakes at Ashmore Reef have undergone unprecedented local extinctions over the past ten to fifteen years and dedicated research is urgently needed into the basic biology,

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ecology and physiology of sea snakes to understand the causes of these declines and the extent to which the effects of climate change are driving the disappearance of sea snakes on some coral reefs.

Introduction

Marine reptiles found in Australian waters fall into three major groups: sea turtles, crocodiles and sea snakes. Australia has ecologically, economically and culturally significant populations of six species of sea turtles (five Cheloniidae and one Dermochelidae) both nesting and residing within its jurisdiction (Environment Australia, 2003, Haman et al. 2007). Some of the nesting sea turtle populations in Australia are globally significant and among the largest in the world (Limpus et al. 2003). Two species of crocodile occur in Australia, the estuarine crocodile (*Crocodylus porosus*) and the freshwater crocodile (*Crocodylus johnstoni*), although only *C. porosus* is found in the marine environment. Thirty species of marine snakes from three Families (Elapidae, Hydrophiinae - 26 species; Acrochordidae – one species; Homalopsidae – three species) have breeding populations in Australian waters (Heatwole 1999, Heatwole and Lukoschek 2008). As such, Australia's sea snake species represent a significant and unique component of the world's sea snake biodiversity (which comprises ~80 species from four distinct lineages). Our knowledge about sea snakes lags far behind that of most other marine vertebrates. Indeed, a new species was recently described from the Weipa region of northern Australia (Ukuwela et al. 2012), highlighting the knowledge gaps in the taxonomy and distribution of species. This review builds from the 2009 report card and provides an update on how different climatic factors may affect each marine reptile group and discusses observed potential adaptation responses.

Multiple stressors

Marine reptiles have the potential to survive /adapt to climate change; marine turtles and crocodiles have been around for millions of years and during this time they have endured and survived dramatic changes in temperature and sea-level rise (Hamann et al. 2007). However, some populations of marine reptiles are now very depleted from past exploitation and/ or are being impacted by a range of anthropogenic activities. The cumulative impact of multiple stressors on marine reptiles is a major threat to their resilience and capacity to adapt to climate change (Fuentes et al. 2011a). Thus, concern exists on whether marine reptiles have the adaptive capacity to satisfactorily respond to present day climate changes, especially given the current rapid rates of warming, while being simultaneously impacted by a wide range of threatening anthropogenic activities (Poloczanska et al. 2009). Coastal development, in particular, is an issue since it hinders the natural evolution of beach systems and may reduce the availability of alternative nesting beaches for turtles and crocodiles to shift to as an adaptive strategy. For example, current distributions of marine reptiles include large areas of the relatively remote northern Australian coastline; however, increasing coastal development (both urban and industrial) is reducing habitat availability in this region. Moreover, the ability of all marine reptile species to undergo southward range-shifts will depend on the availability of suitable habitat (such as inter-tidal mangroves, coral reefs).

Observed impacts

Few additional observations have been made on impacts from changes in climatic variables on marine reptiles since the first report card. The Australian Government, together with the Western Australian, Northern Territory and Queensland Governments are currently supporting a project to monitor sand temperatures on key nesting beaches to examine changes in sand temperature exposure. Unprecedented weather conditions to Queensland in the summer of 2010-211 highlighted the magnitude and extent of impacts that can be expected from cyclonic activities and flooding on marine reptiles.

Temperature

All marine reptiles have life history traits, behavior and physiology strongly influenced by temperature (Janzen 1994). They are all ectotherms, and thus are heavily tied to environmental temperatures for body functions such as digestion, reproduction and metabolism (Spotila and Standora 1985). The distribution of marine reptiles is believed to be linked with their thermal requirements and tolerances (Davenport 1997, Milton and Lutz, 2003, Hawkes et al., 2009, Witt et al. 2010). Distribution in the family Cheloniidae appears to be constrained by the 20°C sea surface isotherm (Davenport 1997), with sea surface temperatures below 15°C potentially impairing locomotion and altering foraging behavior (Read et al. 1996). Leatherback turtles (Dermochelidae) are often found in a wide range of sea surface temperatures (9-33°C), with its northerly distribution limit encapsulated by the position of the 15 °C sea surface isotherm (McMahonh and Hays 2006). Although there is a lack of data on the thermal range of crocodiles (Hamann et al. 2007), the importance of water temperature and basking behavior in crocodiles for the maintenance of physiological processes and behavior is becoming increasingly apparent (see Campbell et al. 2010a & b; Seebacher et al. 2005). Experimental studies show that the swimming ability of crocodiles is also influenced by temperature (Elsworth et al. 2003; Campbell et al. 2012).

Little is also known about the thermal requirements and tolerances of individual species of sea snakes. Much of the existing information is for *Pelamis platura*, (yellow-bellied sea snake) which is the most geographically widespread of all sea snake species. Its latitudinal distribution limits coincide with the 18°C surface isotherm (Heatwole, 1999). However, breeding populations of most sea snake species are not found outside the 20°C sea surface isotherm. The upper lethal thermal limits for four species that have been studied (*Astrotia stokesii*, *Hydrophis elegans*, *Hydrophis ornatus*, *Lapemis curtus*) range from 37.8 to 39.7°C (Heatwole et al. In Review). Upper lethal limits for *P. platura* ranged from 33.5°C to 36°C when snakes were placed directly into water at those temperatures from ambient sea water (26-27°C) (Dunson and Ehlert 1971; Graham et al. 1971). However, when *P. platura* were heated at a constant rate of 5°C/hr, snakes became hyperactive at 36°C and died at 39°C (Graham et al. 1971), suggesting some tolerance to temperatures around 36°C for short periods when heated slowly, as would happen in nature. Amphibious sea kraits (snakes) have thermal ranges within the boundaries of the five fully marine sea snake species studied (Heatwole et al. In Review), suggesting that the remaining sea snakes would have similar thermal tolerances.

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Warming temperatures will also influence reproduction. Timing of marine turtles' and crocodiles' reproduction is believed to be determined by a combination of photoperiod and temperature, since they have pineal glands that act via melatonin to interact with other endogenous cues to drive the appropriate time for breeding behaviour (Owens 1980, Hamann et al. 2002). Temperature is also a critical determinant for breeding of crocodiles (Webb 1989). In particular, high water levels and cool conditions late in the dry season are key stimuli for courtship and mating (Webb 1989, McClure and Mayer 2001, Fukuda et al. 2008). Sea snakes mate in winter and give birth to live young in summer four to six months later (Heatwole 1999). It is not known what triggers mating behaviour in winter but if it is related to cooler water temperatures, then mating behaviour may be disrupted by warming ocean waters.

Egg-laying marine reptiles (sea turtles and crocodiles) are strongly influenced by temperature during egg incubation (Spotila and Standora 1985). Successful egg incubation only occurs within a small thermal range; incubating temperatures above the upper thermal threshold (~34°C for sea turtles) will result in hatchlings with higher morphological abnormalities as well as lower hatching success (Miller 1985, Lang and Andrews 1994). In addition to this, sea turtles and crocodiles have temperature-dependent sex ratios, where sex ratio of hatchlings is determined by nest temperature during incubation (Spotila and Standora 1985, Lang and Andrews 1994). For sea turtles, warmer temperatures yield more females while temperatures below the pivotal temperature yield more males (Yntema and Mrosovsky 1980, Davenport 1997). The pivotal temperature differs slightly within and between sea turtle species and is generally around ~29°C. Crocodiles have a female/male/female pattern, where no males are produced below 29°C and above 34°C (Webb et al. 1987, Lang and Andrews 1994). Higher sand temperatures also decrease the incubation period of sea turtle eggs (Davenport 1997) thus decreasing hatchling body size (Booth and Astil 2001, Burgess et al. 2006). Hatchlings with smaller body size may reduce hatchling survival chances since smaller hatchlings have reduced swimming abilities and are more susceptible to predation as they cross the reef (Gyuris 1994, Booth and Evans 2011). Clearly, even small increases in temperature can have a profound impact on hatchling phenotype, performance and success (Mrosovsky 1980; Booth and Evans 2011). Indeed, the impacts of warmer temperatures are evident in Mon Repos, SE Qld, an important loggerhead turtle rookery, where sand temperatures at nest depth are regularly reaching as high as 36°C for weeks at a time during hatching season, causing increased debilitation and even death of eggs and hatchlings (Col Limpus pers comm.). Nevertheless, the 2010/2011 was one of the coolest years on record due to the above average rainfall that fell along the Bundaberg coastline throughout the summer (Col Limpus pers comm.).

It is unclear if or how temperature affects the physiology of reproduction in live-bearing sea snakes.

Sea-level rise

Sea-level rise will cause erosion and increased inundation of coastal areas, beaches, mangrove forests and salt marshes, which will impact key sea turtle and crocodile habitats, nesting area stability and hatching success (Daniels et al. 1993, Fish et al.

2005, Baker et al. 2006, Fuentes et al. 2010a). The combined impact of erosion and flooding of the nesting habitat is expected to increase egg mortality and cause eventually loss of nesting beaches. Reduction of available nesting area may amplify density-dependent issues at sea turtle nesting grounds, potentially increasing the risk of disease in nests (Fish et al. 2008) and accidental destruction of nests by nesting females (Girondot et al. 2002). Currently, concern exists regarding the impacts of sea level rise to several sea turtle rookeries in Torres Strait (e.g. Bramble Cay), the far northern Great Barrier Reef (e.g. Raine Island) and the Capricorn Bunker group (e.g. Heron Island) based on anecdotal and empirical reports of long-term changes to beach shape and sand volume at these places (Fuentes et al. 2010a). Additionally, over the last ten years low hatching success has been observed at Raine Island, which is thought to be caused by rising groundwater and other geomorphic processes (e.g. movement of sand) (Limpus et al. 2003). However, mangroves, which are a critical habitat for crocodiles and some sea snake species, may increase in area in northern Australia as low-lying coastal areas are inundated (see Tidal Wetlands, this volume).

Extreme events (cyclones, storms and floods)

Tropical cyclones are amongst the world's most destructive natural hazards and can negatively affect sea turtles by disturbing their foraging and nesting habitats and increasing localized mortality of eggs (Pike and Stiner 2007, Fuentes and Abbs 2010). Further, associated heavy rainfall can potentially skew hatchling sex ratios towards females, due to a cooling effect (Fuentes et al. 2011b). Even though cyclones are short-term aperiodic drivers of change, repeated and/or regular exposure could influence the distribution of nesting sites (Fuentes et al. 2011b). Historically, Australian sea turtle populations nesting in Torres Strait, such as the hawksbill, and the Gulf of Carpentaria flatback turtle population have been the least exposed to cyclones while the Coral Sea green turtle population has been the most exposed to cyclonic activity (Fuentes et al. 2011b).

Changes to cyclone frequency, intensity and distribution will also impact crocodile populations by washing away nests or nest material, inundating eggs and disrupting normal nest attendance behaviour during flood events (Hamann et al. 2007). Similarly, changes in cyclones may also affect reef-associated sea snake species, such as *Aipysurus laevis* and *Emydocephalus annulatus*. These two species appear to have undergone recent local extinctions (at the level of individual reef) in the offshore Swain Reefs complex, southern Great Barrier Reef, where a trend for the absence or loss of snakes on outer exposed reefs was found (Lukoschek et al. 2007a). It is suggested that strong wave action associated with frequent storms may be affecting these species but the reasons for the localized population declines are unknown (Lukoschek et al. 2007a).

Apart from impacting nesting areas and the reproductive output of marine turtles and crocodiles, severe weather events can also be aperiodic drivers of change in coastal foraging habitats (Fuentes and Abbs 2010). Severe weather and associated heavy rainfall, coastal flooding, storm surge and increased wave action have each been implicated in the destruction of coastal intertidal and sub-tidal habitats such as seagrass. Repeated and/or more frequent extreme events, coupled with lowered habitat resilience due to water quality, turbidity and coastal use, have the potential to influence the ecosystem processes of the inter-tidal and sub-tidal habitats. Indeed, the

summer of 2010-11 brought above average rainfall and severe weather conditions to Queensland. 12 tropical cyclones were formed in Australia, and one, Cyclone Yasi, was one of the most powerful cyclones to have crossed the Great Barrier Reef (BOM-<http://www.bom.gov.au/>). Additionally, in central and southern Queensland rainfall was above average during the summer, up to 400 per cent higher than normal in some areas leading to large flood events. These extreme weather events damaged coral reefs and coastal seagrass beds, (GBRMPA 2012). A dramatic increase in the number of dead green turtles was reported from beaches in areas affected by extreme weather. Stranding reports for green turtles in Queensland were significantly higher than previous years. 1275 deaths of green turtles were reported up to November 2011 compared with 754 for the same period in the previous year (GBRMPA 2012). Many of the green turtles were malnourished at the time of stranding and it is likely that the destruction of coastal sea grass beds led to animals not being able to find enough food.

Ocean currents, circulation and mixed layer depth

Marine turtle dispersal and distributions are linked to some degree by ocean and coastal current circulation, especially during hatchling dispersal from nesting beaches, the dispersal of post hatchlings and young juveniles through oceanic waters and the migration of adult turtles to and from breeding areas (Hecht et al. 1974, Putman et al. 2010, Hamann et al. 2011, Van Houtan and Halley 2011). A strong relationship is found between the locations of favorable nesting areas and proximity to ocean currents that can facilitate hatchling dispersal and shape future migrations and movements of individuals (Hamann et al. 2011). Further, oceanographic influences to juvenile recruitment are linked to breeding populations decades later (Van Houtan and Halley 2011). Estuarine crocodiles have also been shown to utilise tidal and oceanic currents to move large distances (Campbell et al. 2010c). It is unclear whether sea snakes are impacted by ocean currents, however the population genetic structure of those species that have been studied indicate limited dispersal for reef-associated species (Lukoschek et al. 2007b, 2008; Lukoschek and Shine 2012; Lukoschek unpublished data) but higher gene flow for inter-reefal species (Lukoschek unpublished data). Given that sea snakes give birth to live young that are able to swim and all but one species is closely associated with benthic habitats, it is unlikely that sea snakes will be significantly impacted by changes in ocean currents.



Figure 1. Seasnakes from Scott Reef. Courtesy: T. Skewes

Confidence Assessment: Observed Impacts

Amount of Evidence (theory, observations, models)

There is **HIGH** evidence that sea turtles and crocodiles have life history traits, behavior and physiology strongly influenced by temperature.

Sea turtles

There is **HIGH** evidence that breeding rates for green turtles from the two Great Barrier Reef (GBR) populations, and eastern Australian loggerheads are linked to climate processes. There is a **HIGH** level of agreement that climate processes drive reproductive events for green turtles in the Great Barrier Reef and loggerhead turtles from the eastern Australia.

Despite warmer sand temperatures being observed at some key Australian nesting rookeries, there remains **MEDIUM** evidence of a discernable population or species level impact of warming beaches on long-term sex ratios. In essence there are still insufficient baseline and/or long-term monitoring data to determine/detect specific trends or impacts from climate change on sea turtles distribution, nesting phenology and foraging ecology for most populations. There is **NO** evidence to indicate what degree of sex ratio is sustainable (i.e. 3F:1M 4F:1M...), nor is there evidence to demonstrate that sex ratios found on the beach continue through other life stages (Hamann et al. 2010, Fuentes et al. 2012).

There is **LIMITED** evidence that climate change is impacting turtle nesting beaches. Although there have been noticeable impacts to some Australian sea turtles nesting grounds (e.g. through erosion), there is no direct link or evidence that these result from climate change.

Crocodiles

There is **HIGH** evidence that increased air temperatures will affect crocodile behaviour. There is **LIMITED** evidence that reproductive capacity (i.e. nest success), sex ratios and the timing of breeding seasons will be affected by climate change such as changes to rainfall, flooding and temperature.

Sea snakes

Some sea snake species have undergone precipitous declines and/or local extinctions in Australian waters however we do not know the reasons for these declines. As such, there is **LOW** evidence that these declines have been the direct or indirect result of climate change.

Degree of Consensus (high level of statistical agreement, model confidence)

Sea turtles

There is **MEDIUM** consensus on the potential impacts of climate change on sea turtles. A study conducted by Fuentes and Cinner (2010), found that both managers and scientists perceived increased sand temperature to be the largest threat to the northern Great Barrier Reef green turtle population's reproductive output, followed by sea level rise and altered cyclonic activity. However, the relative impact from different climatic processes is perceived differently by managers and scientists

(Fuentes and Cinner 2010). There is HIGH consensus that climate change questions rank among the global priorities for research on marine turtles (Hamann et al. 2010).

There is LOW consensus between researchers as to whether sea turtles nesting grounds and/ or sea turtles are being impacted by climate change, as opposed to coastal development and/or other geomorphologic processes.

Crocodiles

There is HIGH consensus that increased air temperatures will affect crocodile behaviour (Campbell et al 2010). There is LOW consensus that reproductive capacity (i.e. nest success), sex ratios and the timing of breeding seasons will be affected by climate change such as changes to rainfall, flooding and temperature (Hamann et al. 2007).

Sea snakes

There has been little empirical or theoretical research conducted to evaluate the potential effects of climate change for any sea snake species and there is LOW consensus that the effects of climate change will impact sea snakes.

Confidence Level

Sea turtles

Most evidence for climate change impacts comes from studies on two species (loggerhead and green turtles) and these studies are essentially limited to eastern Queensland. There is very LIMITED information for other species or populations. Considering the limited scale (temporal and spatial) and scope of evidence and MEDIUM consensus on the observed impacts of climate change on sea turtles we have very LOW confidence that most Australian populations are currently being impacted by climatic change.

Crocodiles

Although there is MEDIUM evidence and HIGH consensus that increased temperature will impact behaviour, there is LIMITED evidence and LOW consensus about impacts to other life stages and or reproduction. Further, there are few datasets investigating climate change impacts to crocodiles, and limited monitoring to detect change. Overall we conclude that there is VERY LOW confidence that most Australian populations are currently being impacted by climatic change.

Sea snakes

There is LOW confidence that sea snakes are being impact by current climate change. In 2010 the first IUCN Red List Assessments of extinction risk for all sea snake were published (www.iucnredlist.org). Three Australian endemic species were listed as Critically Endangered or Endangered due to precipitous population declines over the past 10-15 years but the reasons for the declines are unknown. One third of the 70 sea snake species assessed were classified as Data Deficient, highlighting the knowledge gaps in the ecology, biology, and physiology of sea snakes (Elfes et al. in review). Most of the clearly defined effects of climate change to marine turtles relate to reproduction (egg-laying) but these are not relevant to any of the live-bearing sea snake species found in Australia (although they are relevant to the amphibious sea

kraits that occur in SE Asia). We do not know how the impacts of climate change affect any aspect of the sea snake life history. An assessment of the vulnerability of marine reptiles to the impacts of climate change on the Great Barrier Reef also concluded that there was insufficient information to assess the risks for sea snakes (Hamann et al. 2007).

Potential impacts by 2030 (and/or 2100)

Marine reptiles will be affected by changes to different, and multiple, climatic processes (e.g. increased air and sea temperature, sea level rise, precipitation and storm activity) at all life stages and at different temporal and geographical scales (Hawkes et al. 2009, Fuentes et al. 2011a). As change in climate will vary spatially and temporally, over the years, genetically distinct populations of marine reptiles will be impacted differently by the various processes. For example, Fuentes et al. 2011a used a vulnerability assessment framework and found that in the short-term (by 2030), sea level rise will cause the most impact on the nesting grounds used by the northern Great Barrier Reef (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. Whereas increase in temperature will likely cause the most impact on the nGBR green turtle population, other climatic processes may be more disturbing to other species of turtles. Sea level rise will likely be more of an issue for sea turtle populations that have key nesting grounds on low lying islands, where increase in temperature may not be an issue.

Temperature

Warming ocean temperatures are likely to extend the potential habitat of marine reptiles (McMahon and Hays 2006). It is likely that sea turtle distribution, both in terms of coastal and oceanic foraging areas and breeding regions will gradually expand southwards (polewards). At present, many sea turtle nesting beaches or coastal foraging grounds are on the sparsely-populated tropical coastline of Australia. Southwards shifts in sea turtle distributions will bring turtles into regions where there are site based management may be logistically difficult because of existing coastal development (Hamann et al. 2007, Hawkes et al. 2009). Southwards shifts in crocodile distribution are possible and these will increase human-crocodile interactions potentially leading to conflicts between conservation management and resident human populations (Hamann et al. 2007).

Most sea snake species have the potential to respond to increased sea surface temperatures (SSTs) by extending their distributions southward along Australia's east and west coasts. However, the ability for a species to undergo southerly range expansions will depend on corresponding range shifts in the preferred habitat types (coral reefs, mangroves, mudflats, estuaries) of each species. Given that coral reefs are unlikely to expand southwards and are considered extremely vulnerable to climate change, species restricted to coral reefs may be the most vulnerable to climate change. Habitat degradation from coral bleaching may cause loss or reduction of sea snakes from the genus *Aipysurus*, which occur predominantly in coral reef habitats and feed on small reef fish species. A subset of sea snake species occurs only in the Gulf of Carpentaria and/or Arafura Sea. It is not clear whether there are barriers to dispersal for these species to the east and west coasts, however, if such barriers exist, then

species restricted to the northern coastline are less likely to have the capacity to undergo southward range shifts in response to increased temperatures. Genetic and empirical mark-recapture evidence has documented extremely low dispersal for some reef-associated sea snake species over small geographic ranges (Lukoschek et al. 2007b, Lukoschek and Shine 2012), which raises concerns about the ability of reef-associated species to undergo range shifts.

Warming temperatures may lead to shifts in the reproductive phenology of both sea turtles and crocodiles. Sea turtles may nest earlier and change the duration of their nesting seasons as a result of warmer sea surface temperatures (Weishampel et al. 2004, 2010, Pike et al. 2006). Sympatric species of sea turtles may respond differently to warmer SST temperatures, with some species decreasing and other increasing the length of their nesting season (Weishampel et al. 2004, 2010, Pike et al. 2006). Implications to change in nesting periodicity and duration for sea turtle populations are still unknown. Increases in SST may positively affect sea turtle hatchling swimming ability, with hatchling turtles swimming in warm water having a faster stroke rate (Booth and Evans 2011). This may help avoid predation when crossing the reef (Booth and Evans 2011).

The reproductive output of both sea turtles and crocodiles will also be affected by increased temperatures, as global warming poses a threat of skewing sex ratios towards a predominantly female output and exposing their eggs to temperatures that exceed thermal mortality thresholds (Mrosovsky 1994, Hawkes et al. 2007, Fuentes et al. 2009, 2010b). Indeed, it is predicted that the nesting beaches used by the northern Great Barrier Reef green turtle population will produce a higher proportion of females by 2030 and will experience incubation temperature that constantly exceed the upper thermal incubating threshold by 2100; this will decrease hatching success unless the timing of nesting shifts (Fuentes et al. 2010b). Feminization of nesting beaches is also predicted for other regions and species of sea turtles (e.g. Patino- Martinez et al. 2012). However it is important to consider that sea turtle populations span several nesting grounds and although individual nesting beaches may be female-producing, other beaches within the region may produce the necessary males. The full impact of predicted feminization of turtle nesting grounds is not fully understood. Some nesting beaches have persisted with strong female biases over a few decades or even longer (Reed, 1980, Godfrey et al., 1996, Marcovaldi et al., 1997, Broderick et al., 2000, Hays et al., 2003). Further there is no evidence that a low production of male hatchlings has resulted in a low reproductive success within populations (e.g. Broderick et al. 2000, Glen and Mrosovsky, 2004), although it is possible that the long-term population declines due to exploitation and other factors may mask such effects (Poloczanska et al. 2009).

New evidence on sea turtle male mating patterns indicates that turtles may not be as vulnerable to warming temperatures and predicted feminization as first anticipated (see Hays et al. 2010, Wright et al. 2012). Wright et al. (2012) found that male reproductive intervals may be shorter than the 2-4- years typical for females, and that males move between aggregations of receptive females and may visit multiple nesting grounds. This will help to preserve genetic variation that may be critical if marine turtles are to adapt behaviorally or physiologically to a warming climate. Most likely

this has contributed to their persistence through historical climatic upheaval Wright et al. (2012).

Sea- level rise

Key habitat used by marine reptiles will be exposed to sea level rise (SLR) to varying degrees depending on their physical characteristics and location (Fuentes et al. 2010a). Sea turtle nesting beaches trapped in the 'coastal squeeze' between rising sea-level and coastal development may be particularly vulnerable (Fish et al. 2008). Small, tropical low-lying islands, such as coral atolls, especially those that are not vegetated or that lie on exposed reefs in areas of high tidal range are likely to be the most vulnerable to SLR (Woodroffe et al. 1999, Church and White 2006). Not surprisingly, Fuentes et al. (2010a) found that nesting grounds used by the northern Great Barrier Reef (GBR) green turtle population with lower elevation were found to be more susceptible to SLR as inundation was significantly and negatively correlated with maximum elevation under four different SLR scenarios. Under the most extreme SLR scenario proposed by the IPCC (2007) - a 0.59m rise the extent of inundation of individual nesting grounds ranges from 11% to 36%, with the beaches that support the highest levels of nesting being the least vulnerable to inundation (Fuentes et al. 2010a).

Low-lying rubble cays, mangroves and salt marshes used by crocodiles are also likely to be impacted by predicted SLR. It is also probable that sea level rise will influence the reach of the estuarine zone and expose current crocodile nesting sites in low lying areas of catchments. Sea level rise may also alter the distribution of key sea snake habitats resulting in a shift in distribution of sea snakes around northern Australia. In particular sea snakes in the Ashmore Reef complex (Timor Sea) may undergo local extinctions if reef growth does not keep up with the rate of sea level rise. The remote isolated reefs in the Timor Sea have the highest sea snake diversities in Australian waters and include the entire distributions of some Australian endemic reef-associated species. Local extinctions would, therefore, be conterminous with species extinctions.

The impacts of sea level rise will probably be more notable by 2100, however it is suggested that over the longer-term (more than 50 years) sea level rise may also help other coral cays to develop and/or stabilize and thus other areas may become available, or become better suited for marine reptiles.

Extreme events (cyclones, storms and floods)

Cyclonic intensity, frequency, distribution and seasonality are predicted to alter with climate change (Walsh & Ryan 2000, Webster et al. 2005, Abbs et al. 2007, Leslie et al. 2007, Kuleshov et al. 2008). Although predictions of cyclonic activity in a warming climate do vary, most studies predict an intensification of the strongest cyclones (Knutson et al. 1998, Walsh & Ryan 2000, Oouchi et al. 2006, Kuleshov et al. 2008) and a decrease in the global frequency of cyclones (Oouchi et al. 2006, Yoshimura et al. 2006, Bengtsson et al. 2007, Vecchi & Soden 2007). Projected intensification of storms will cause further destruction to key coastal habitats used by marine reptiles (Fuentes and Abbs 2010). There will also likely be an increase in the numbers of sea turtles and crocodile nests being flooded and thus decrease hatching success (Pike & Stiner 2007, Van Houtan and Bass 2007). In the other hand, changes in cyclonic distribution and frequency may be beneficial to marine reptile populations

that have historically been exposed to cyclonic activities. Indeed, Fuentes and Abbs (2010) used 11 regional climate model simulations for an A2 greenhouse gas emission scenario and found a tendency towards a reduction in cyclonic activity at sea turtle nesting grounds in eastern Queensland and, thus, a decrease in the effects on sea turtle nesting along the Queensland coast. A reduction in the frequency of cyclonic activity, as predicted in this study will reduce the frequency of nest disturbance and lengthen recovery times of nesting grounds after a cyclonic episode. Further, work is necessary to explore whether changes in cyclonic frequency will occur to other key nesting and foraging areas used by other populations of marine reptiles.

Ocean currents, circulation and mixed layer depth

Changes to ocean currents can potentially influence (positive or negatively) the ecology of post hatchling and juvenile sea turtles and, decades later, nesting numbers and patterns. The positive/negative aspects are still difficult to predict at present. However, a recent study by Van Houtan and Halley (2011) and Hamann et al. (2011) suggests that oceanographic influences to juvenile recruitment are a major factor affecting breeding populations decades later. Van Houtan and Halley (2011) used basin-scale climate indices and regional surface temperatures and suggest that the Pacific population of loggerheads will be significantly reduced by 2040, but indicate the Atlantic population of loggerheads may increase substantially. No basin scale study has been conducted for populations of sea turtles in Australia. It is unclear how ocean currents and circulation will affect sea snakes however, all but one sea snake species is benthic and, as far as we know, juveniles do not undergo long distance dispersal so it seems unlikely that changing ocean currents will have a major impact on sea snakes.

Confidence Assessment: Projected Impacts

Amount of Evidence (theory, observations, models)

Sea turtles

There is MEDIUM evidence that turtles will be affected this century by climate change. There is a growing body of theoretical research that predicts how sea turtles will be affected by climate change based on what is currently known about sea turtle species. Most theoretical studies have focused on the impacts of increasing temperatures to the reproductive output and distribution of sea turtles and/or the impacts of sea level rise to nesting habitats. Few studies have investigated how other climate changes (e.g. in ocean currents) may affect sea turtles and/or how their foraging ecologies may be impacted. There are few baseline data for most northern and western Australian populations to underpin statistical models so evidence is LOW for these.

Crocodiles

There is LIMITED evidence that crocodiles will be impacted this century by climate change. There are several knowledge gaps and research priorities related to understanding and addressing the impacts of climate change on crocodiles.

Sea snakes

There is LIMITED evidence that sea snakes will be impacted this century by climate change. There are many knowledge gaps and research priorities related to understanding and addressing the impacts of climate change on sea snakes. Key knowledge gaps relate to sea snake thermal tolerances, reproductive physiology, and the biology and ecology of juveniles.

Degree of Consensus (high level of statistical agreement, model confidence)

Sea turtles

Although there is a HIGH degree of consensus that sea turtles will be broadly impacted by climate change, there is a LOW level of consensus on how individual species and populations in Australia will be impacted, therefore, overall the consensus level is MEDIUM.

Crocodiles

There is LOW consensus that crocodiles will be impacted this century by climate change. There are several knowledge gaps and research priorities related to understanding and addressing the impacts of climate change on crocodiles.

Sea snakes

There is LOW consensus that sea snakes will be impacted this century by climate change. There are many knowledge gaps and research priorities related to understanding and addressing the impacts of climate change on sea snakes.

Confidence Level

Sea turtles

Even though there is a MEDIUM degree of evidence and consensus that sea turtles will be impacted by climate change there is LOW confidence on the magnitude and extent of impact. This is reflected by the lack of knowledge on the adaptive capacity of marine turtles. In order to properly understand the impacts of climate change on sea turtles knowledge of how they might adapt is trivial. Predicted impacts of climate change may alter if sea turtles adapt or respond to climatic changes. For example, as highlighted by Fuentes and Abbs (2010), the predicted impacts of cyclones on sea turtle nesting grounds will also be affected by any change in their behaviors as an adaptation strategy. If turtles nesting on the eastern Queensland coast start to nest earlier as a result of warmer SST, a behavior which has been observed for loggerhead turtles in Florida (Weishampel et al. 2004, Pike et al. 2006), the level of disturbance that they may experience as result of cyclones may change. Similarly, if sea turtles shift their nesting sites to a more southerly beach to adapt to a rise in sea level or warmer sand temperatures (as suggested by Hays et al. 2001), cyclonic disturbance in their new nesting grounds may be different, as sea turtle populations with more southerly nesting grounds have historically had and are predicted to have a higher frequency of cyclone hits in a year (Fuentes and Abbs 2010).

Crocodiles

There is VERY LOW confidence that crocodiles will be impacted this century by climate change. There are several knowledge gaps and research priorities related to understanding and addressing the impacts of climate change on crocodiles.

Sea snakes

There is VERY LOW confidence that sea snakes will be impacted this century by climate change. There are many knowledge gaps and research priorities related to understanding and addressing the impacts of climate change on sea snakes.

Current and planned research effort

Turtles

Fuentes et al. is conducting a comprehensive survey with the Marine Turtle Specialist Group to elicit expert opinion on the relative influence/ importance of various variables to the resilience of sea turtle regional management unit to climate change. This will provide a broader understanding of sea turtles' ability to cope and to persist (resilience) to climate change. The work is expected to be finished by 2013. For further information contact Mariana Fuentes.

There are several ongoing projects at a variety of local and regional scales to investigate climate change impacts. These include, but may not be limited to, understanding broader scale variation in exposure to air and sea temperatures for marine turtle populations (Hamann and Fuentes), understanding sand temperature variation across index sites for nesting turtles in Australia (Col Limpus QDERM and other state coordinators).

Crocodiles

At present there is no research dedicated to investigating the impacts of climate change on crocodiles

Sea snakes

At present there is no research dedicated to investigating the impacts of climate change on sea snakes.

Observation Programs

Turtles

Monitoring programs operate on turtle nesting beaches around Australia. The longest program is that at Mon Repos, SE Qld, which supports the largest concentration of nesting turtles on mainland Australia. The majority of nesting turtles at Mon Repos are the loggerhead turtles, though green and flatback turtles also nest there. The Queensland Turtle Research Program began in December 1968 at Mon Repos and was expanded in 1974 to include the Heron Island rookery. Recently, satellite tagging of adult turtles is providing information on their movements among habitats. Since 2005, Indigenous people from Torres Strait and the Land and Sea Unit of the Torres

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Strait Regional Authority have conducted projects to improve the understanding of how climate change will impact turtle populations in Torres Strait. One of the ways in which some communities are tackling the issue is by starting to collect baseline information on the current situation, so they will be better placed to predict impacts.

Through a north Australian wide project coordinated by the North Australian Indigenous Land and Sea Management Alliance, Indigenous Australians across north Australia are working together to address the many threats to sea turtles – including climate change. Traditional Owners working with their Sea Ranger programs are engaged in a range of turtle management activities including mapping and monitoring populations and habitats, cleaning beaches of marine debris, rescuing turtles from ghost nets, controlling feral animal predation on turtle nests, managing tourism and other human impacts as well as community education and awareness raising.

The Western Australian Department of Environment and Conservation (DEC) is involved in marine turtle conservation and the Western Australian Marine Turtle Program has been operational since 1985. DEC works in partnership with Pilbara Iron, Woodside Energy, Chevron Australia, Apache Energy, The University of Western Australia and Mundabullangana Station to address many of the impacts faced by sea turtles.

The Australian Government, together with the Western Australian, Northern Territory and Queensland Governments are currently supporting a project to monitor sand temperatures on key nesting beaches.

Crocodiles

Although not directly climate change related, crocodile monitoring, including habitat use, distribution and abundance are currently being carried out by several organizations such as The University of Queensland, QDERM and the NT Government.

Sea snakes

At present there are no systematic monitoring programs of sea snake populations being conducted anywhere in Australia. Some adhoc surveys have been conducted at Ashmore Reef and neighbouring Timor Sea Reefs over the past ten years by researchers from several institutions, primarily James Cook University, Charles Darwin University and SEWPaC. The most recent surveys for sea snakes at Ashmore Reef found only one species, the olive sea snake *Aipysurus laevis*, in a very restricted area of the large Ashmore Reef complex, which confirmed that the five other sea snake species previously recorded in high numbers from Ashmore Reef have become locally extinct in the past 10-15 years, but there are no clear indications as to the reasons for these population declines. Ongoing dedicated sea snake surveys are needed at Ashmore Reef and other Timor Sea reefs.

Since 2003 CSIRO and the Northern Prawn Fishing Industry have been collaborating on a bycatch monitoring program for the Northern Prawn Fishery. All catches and/or interactions with sea snakes in the tiger and banana fisheries are recorded by crew-member observers (CMOs), as part of a larger program monitoring interactions with all threatened, endangered and protected (TEP) species in trawls. Data collected for

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sea snakes, which include photos for ID purposes, are used to estimate Catch Per Unit Effort (CPUE). Every three years CSIRO runs a sustainability assessment on the data and the next assessment report is currently being produced. Fisheries Queensland also have an observer program with several dedicated observers undertaking trips with commercial fishers throughout the year. In addition, there is an ongoing species of conservation interest (SOCI) logbook database to record fisher interactions with protected species. Although not directly related to climate change, these long-term data may prove useful for analysis of climate-change impacts.

Further information

Sea turtles

Dr. Mariana Fuentes-

<http://eprints.jcu.edu.au/view/jcu/ED315081385B6FA83C6E3450173910E2.html>

Dr. Mark Hamann -

<http://eprints.jcu.edu.au/view/jcu/7867BC880C57F396C4387452AC73CB26.html>

Marine Turtle Research Group - <http://www.seaturtle.org/mtrg/pubs/>

Crocodiles

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Sea snakes

Dr. Vimoksalehi Lukoschek-

<http://eprints.jcu.edu.au/view/jcu/23D164BD470C5C4E172D26BC2347C44B.html>

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