Rising Ocean Temperature and its Effect on the Loggerhead Sea Turtle Population

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Abstract:

Rising ocean temperatures are causing detrimental changes in loggerhead nesting sites, producing a gender bias among turtle offspring. Temperature change is discussed in relation to how it has altered gender development and why there is a female bias. The gender bias is a key factor affecting loggerhead survival, and understanding the causes is essential to the species longevity. Determining the effect that prey loss and decreased foraging grounds have will allow species management strategies to be created. Increased frequency of tropical storms is examined in relation to loggerhead population. The overall hypothesis of this paper is that loggerhead sea turtle populations, prey, and nesting grounds are critically sensitive to increasing sea surface temperature. Determining how temperature dependency affects the Loggerhead population, and what can be done to mitigate nest damage are critical to the survival of the species.

Introduction:

Loggerhead sea turtles are a species of turtle largely occupying the Atlantic and Pacific Oceans. They have extreme migratory ranges with some up to 8000 km (Whiteman, 2012). They are a species known to have temperature dependent sex determination, which means their embryos are influenced by the environment around them during the developmental stages (Patricio, 2017). They remain within an area close to breeding grounds up to two months before and after laying their eggs, meaning female loggerheads are sometimes away from foraging grounds for prolonged periods (Van Houtan and Halley, 2011). Turtle survival rate is already incredibly low with approximately 1 in 4000 turtle hatchlings reaching adulthood (Whiteman, 2012). Any added adversities could be detrimental to the loggerhead population and determining the effect rising ocean temperatures will have on the species is crucial to their survival.

The study of loggerhead turtle population decline is relatively new, with not much research dating before the 1980s. Although warming of the oceans is three times slower than warming of air temperature over land, marine species are shifting distributions and phenology at a greater rate than species in terrestrial systems (Patel et al. 2016). As noted by Van Houtan and Halley (2011), the long-term variability of marine turtle populations remains poorly understood, which is limiting the ability to do research and determine proper management for the species. One reason scientists are having difficulty linking specific events to population declines is the migratory nature of sea turtles, as they impact or are impacted by several ecosystems and migrate through a range of climate systems. They are particularly important in reef ecosystems, in which they eat sea grass and by doing so, allow reefs to thrive and maintain high levels of biodiversity (Patel et al. 2016). The absence of loggerheads in these densely populated reef ecosystems would influence economies that rely on ecotourism.

The future of the loggerhead population is currently uncertain. With many turtle populations below 10% of their pre-Columbian numbers it appears they are heading to extinction (Van Houtan and Bass, 2007). This paper aims to synthesize research regarding the effects that the steadily rising sea surface temperature (SST) has on loggerhead longevity. The main objectives are to investigate (1) how rising SST affects embryo development, (2) how rising SST

influences prey abundance and foraging grounds, and (3) what the effects of increasing tropical storm frequency are on loggerhead population. This subject has such limited research due to availability: there are far more opportunities to collect data on females, as males do not come ashore. The National Research Council (NRC) notes a lack of data on juveniles to be a significant scientific challenge as they are among the most numerous population segment; however, they are also the least accessible and understood (Van Houtan and Halley, 2011). This paper will start by discussing the effects rising SST has on embryo development.

Sea Surface Temperature Affecting Embryo Development

Loggerhead sea turtles occupy a substantial portion of the ocean, with the two main populations being the Atlantic and Pacific and smaller subpopulations ranging into the Mediterranean. Loggerhead turtles, like many turtles, lie in a grey area between being an ectotherm and endoderm. They are thermoregulating ectotherms, meaning they can moderate their own core body temperature to an extent (Patel et al. 2016). The embryos, however, do not have this ability and are thus susceptible to temperature changes meaning they have temperature dependent sex determination (Patel et al. 2016).

Loggerheads are currently listed on the US Endangered Species Act, partially due to ocean temperatures rising, but also to an unfortunate result of fishery bycatch, egg poaching, and beach erosion during storms (Van Houtan and Bass, 2007). Recently the loggerhead turtle subpopulation in the Mediterranean Sea was downgraded to Least Concern by the International Union for Conservation of Nature (IUCN). However, substantial declines in nest numbers have been reported at major nesting sites in the region (Patel et al. 2016).

Most turtles and other marine species function optimally within a few degrees due to their environments historically having limited fluctuation in temperature. A study done by Reneka and Kamel (2016) sought to better understand the degree to which mothers influence the sex ratios of their offspring. They analyzed 24 years of nesting data from loggerheads observed in North Carolina. They determined that maternal identity is the best predictor of nest sex ratio as they found significant variability among mothers, but a high degree of consistency within mothers, despite substantial spatial variations. This suggests that some individual mothers are more prone to producing clutches favoring female offspring, and others favor males. They determined that male offspring are produced within a tolerance range of 25-35 degrees C, but the optimal temperature producing a balanced ratio of 1:1 occurred near 29 degrees. However, ratios of female to males in recent years have been higher due to temperatures being over 29 degrees C producing a ratio of 3:1 in favor of females (McNeill et al. 2016). A study conducted by McNeil et al. (2016) observed nest gender production between 1998 and 2007, which showed minimal change to offspring ratios during that time. This study emphasizes the importance of longer studies to determine the long-term impacts of gender skew in offspring production as loggerheads are a long-lived species and slow to adaptations.

The dominant theory is that SST is the cause of the skew of the female dominated species, but whether that effect is increasing or has always been there and is just fluctuating over time is still under debate. Hays et al. (2014) used satellite tracking and the use of tags to track 23 male loggerheads to demonstrate that the skew was natural, as they had concluded that males mate more frequently than females. They did this by analyzing a historical model that was

supported by a bio-energetic life model, concluding that higher numbers of females promotes a more balanced operational sex ratio (Hays et al. 2014). A major problem with this theory involves the frequency with which males mate. If this is the case, inbreeding is bound to occur, which results in decreased genetic diversity making the population more susceptible to disease. This study was the only one of its kind that supported this hypothesis, and due to a small sample size and lack of replication, further research should be conducted to determine the legitimacy of these results.

Patel et al. (2016) studied a sub population of loggerheads combining historical data with their own on SST and air temperature using instruments which were calibrated to within 0.5 degrees to determine the changes affecting the loggerhead population nesting at Zakynthos, Greece. Over a 30-year period between 1982 and 2012 they confirmed nesting phenology was continually being impacted by the increasing breeding season temperature. It was also determined that the increasing temperature had no consistent relationship with the amount of offspring produced, and solely affected gender development. The conflicting studies undertaken by Patel et al. (2016), and Reneka and Kamel (2016) raise concerns as to the true effect rising SST has on the population. The study done by Patel et al. (2016) had a focus on documenting beach and air temperature of the three major nesting sites in the Mediterranean over a 30-year period, focusing less on the specifics of the gender ratios, whereas Reneka and Kamel (2016) looked at a single population over a similar duration. The differing results could be due to the different focus of the study or the location, as they are within different climate regions and would be affected differently. These conflicting results highlight the importance of further research and replication within the same regions to help determine conclusively how SST is affecting this species' development.

Long-Term Effects and Changes to Foraging Grounds

Sea turtles are what is known as a keystone species in several ecosystems, specifically in coral reef ecosystems. They are vital due to their consumption of sea grass and are crucial to maintaining high biodiversity levels in reef ecosystems. Loggerheads are also dependent upon reef ecosystems for food as females require specific amounts of food for vitellogenesis (formation of yolk in eggs) prior to migrating to the nesting beach (Patel et al. 2016). Loggerheads come into shallow waters just prior to breeding season to feed in preparation for the taxing process of reproduction (Patel et al. 2016). Loggerheads feed on slow-moving benthic organisms typically found within sea grass beds (Patel et al. 2016). Patel et al. (2016) highlighted the key role that water temperature plays in the physiology and overall survival of sea grasses and how rising temperatures will have a profound effect on their survival. Within the major turtle populations in the Mediterranean, 25% of all nesting activity occurs on just three beaches. Even if one region is affected by changing temperature in a way that is unrecoverable, it could be detrimental to the loggerhead population. Sea turtles spend a large amount of time before nesting away from foraging grounds, and the possible loss of the sea grass could result in delayed returns and less frequent nesting, causing further decline in population.

Populations of loggerhead sea turtles can be found in some part of nearly every ocean environment. When born, turtle hatchlings that make it to the water are easily eaten by predators, as they are unable to dive and only capable of swimming at about half a mile per hour (Whiteman, 2012). This causes them to have a very low success rate, which is why typical nest sizes are approximately 100 or more eggs (Van Houtan and Halley, 2011). Despite the

substantial number of eggs produced, with climbing ocean temperatures affecting the gender ratios of offspring, the future of the species is largely unknown. A study conducted by Van Houtan and Halley (2011) suggested that the Pacific population will be significantly reduced but the Atlantic population will increase substantially by the year 2040.They reached this prediction based on climate data and through the study of the El Niño Southern Oscillation index, and studies of the North Atlantic Oscillation, and the Pacific Decadal Oscillation. In a similar study that used climate models assessed by the Intergovernmental Panel on Climate Change (IPCC), Patel et al. (2016) projected that temperatures at key foraging grounds and breeding sites will rise by 3-5ºC by 2100. Studies predicting long-term population numbers of marine species such as loggerheads are critical for conservation efforts and future management solutions.

Nest Erosion in Relation to Natural Disaster Events and Sea Level Rise

Every species possesses some ability to adapt to changes in their surrounding environment. However, loggerheads are a long-lived species, and heritability of the sex ratio reaction is too slow for this trait to show a strong response to changes in climatic conditions (Reneka and Kamel, 2016). The rise in SST has been linked to the increased frequency of hurricanes and tropical storms, which causes major beach erosion, and can be shown to directly impact loggerhead turtle hatchling production as indicated in Figure 1 (Van Houtan and Bass, 2007). Van Houtan and Bass (2007) recorded hatching success in Dry Tortugas National Park Florida, from 1995 to 2004 between April and November. Volunteers conducted surveys marking recently dug nests and monitored them daily for 45 days after incubation. Nests were excavated after 70 days of inactivity. Figure 1A displays the decreasing rate of hatchling success of both loggerhead and green sea turtles over a 10-year period. Figure 1C indicates a drastically increasing trend of cyclone intensity, over the same time that hatchling success decreased. Finally, Figure 1D displays the direct correlation between increasing cyclone intensity and the increasing frequency of nests being flooded. Through recent historical models, there is a confirmation that warming ocean temperatures increase the frequency, duration and destructive power of tropical cyclones, particularly in the Atlantic Ocean (Van Houtan and Bass, 2007).

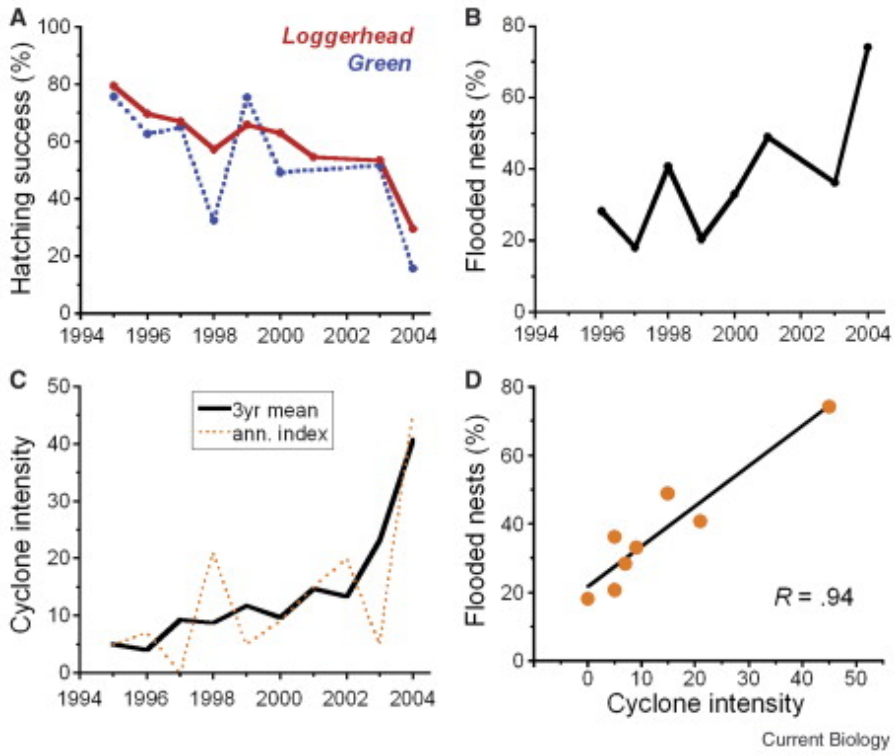

Figure 1. Tropical Cyclones increasingly reduce sea turtle hatching success (Van Houtan and Bass, 2007).

As sea level rises turtles must move farther up the beach to lay their eggs (an incredibly energy taxing procedure) or risk their nests being uncovered by simple tidal currents (Van Houtan and Bass, 2007). Through observational surveys there is a consistent record of weather systems along the western Atlantic creating enough wave energy to erode nesting beaches, even those nests above the high-water line (Van Houtan and Bass, 2007). The sea level rising has caused loggerheads to shift locations, in some cases settling for sub-optimal environmental conditions.

Loggerheads are adapting to the rising SST, but at a slower speed than is necessary to allow the species to retain its population. As a natural reaction to the increasing SST, loggerheads have begun shifting their nesting season earlier in the spring, to lay their eggs in the cooler beach temperatures (Patel et al. 2016). An experiment that included collaboration between the US Navy's Joint Typhoon Warning Center and the National Oceanographic and Atmospheric Administration's National Hurricane Center recorded positions and maximum sustained surface winds of tropical cyclones every six hours over the past 30 years. The study showed a direct correlation between increasing global mean temperature and hurricane intensity (Emmanuel, 2005). This could cause any potential benefits loggerhead turtles gain by shifting their nesting season to be negated. It could even cause the population to decrease further as hurricane season primarily takes place between June and November, often with the stronger storms occurring in mid to late summer, during the hatching period (Emmanuel, 2005). Patel el al. (2016) predicts that as SST increases, the nesting season will also shift earlier in the year by 50-74 days by the year 2100.

Conclusion:

Loggerhead turtles are a keystone species for coral reef ecosystems, and their population has been in decline for years. These turtles spend most of their time at sea, making data collection very difficult, and causing gaps in knowledge as to how the rising SST has affected the species, and what can be done to mitigate population decline.

Determining how SST affects embryo development, the abundance of food and foraging area, and the effects the increasing number of tropical storms have on the loggerhead population have been the focus of this paper. Based on these objectives, the following conclusions can be drawn: (1) The rise of ocean SST has caused a gender skew in this species that is producing an unsustainable ratio of females to males. (2) Current ocean temperature trends are indicating a slow but steady rise, which not only affects the loggerheads themselves but also their foraging grounds and a main source of food: sea grass. (3) Increasing frequency, duration, and strength of tropical storms and hurricanes are negatively affecting loggerhead nesting sites, and there is a strong correlation between cyclone intensity and nest erosion.

Future studies should focus on combining historical and current population levels of the species and gathering data from several nesting sites, noting the average numbers of males and female offspring produced and doing this with replication to produce conclusive results. Possible studies should test assorted designs for a possible solution to control nesting environments, protecting them from erosion by creating some form of barrier to absorb wave energy. However, this could cause issues of current flow and sediment deposition and could choke out living species between the coastline and this barrier.

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