Beach Shading: A tool to mitigate the effects of climate change on sea turtles

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Abstract

Climate change may greatly impact sea turtles as rising temperatures can have negative effects on their development and survival. Primary sex ratios may become female dominated, with no males being produced. Higher female sex rations are correlated to other factors of hatchling survival such as: succession, emergence, size, and locomotive abilities. There are lower rates of succession and emergence in hatchlings that developed in lower temperatures due to mutations and disorientation, resulting in death. Smaller and weaker hatchlings are being produced in high temperatures, resulting in turtles that are easy prey for predators. Increased temperatures also cause turtles to be slower crawlers and take longer to self-right themselves, further extending the time they are exposed to predators. Currently, shading is the most studied method to reverse the negative effects of increasing temperature on sea turtles. By balancing the sex ratio, increasing succession, emergence, size, and locomotive abilities there will an increase in the turtle population while maintaining an even sex ratio. This review synthesizes the effects of climate change on sea turtles and how to mitigate them with shading, to provide working tactics for future conservation.

1. Introduction

Climate change is predicted to increase Earth's temperature 2.6°C by 2050, having a large impact on terrestrial and marine environments (Wood et al., 2014). Rise in temperature and sea level are two predicted outcomes of climate change, which could have harmful effects on coastal marine animals. Therefore, as anthropogenic emissions of greenhouse gases are increasing, temperature sensitive animals such as sea turtles will have to learn to adapt to the changing environment (Hill et al., 2015). Sea turtles are an important marine species that require both land and sea to survive, putting them at a greater risk of being negatively affected by changes in their habitat. Patino-Martinez et al. (2014) state that rising sea level creates two harmful implications for the sea turtle populations. Firstly, rising waters may have harmful effects on turtles as an increase in moisture content of the nest may result in lower emergence and succession of turtle eggs. Succession is the percent of eggs that hatch within a clutch and emergence is the percentage of succession that makes it out of the nest. Secondly, the rising surface water is at a higher temperature due the transfer of solar energy. Sea turtles migrate to warmer waters to lay their eggs, and this journey is dependent on the temperature of their surroundings. Thus, changes in ocean temperature could result in an early or late start to migration, resulting in differing lengths of development for turtle eggs (Neeman et al., 2014).

An increase in temperature has negative influences as sea turtle embryos are extremely temperature sensitive during development (Tomillo et al., 2014). Having the temperature too hot or cold can cause mutations and even death to the developing embryos. Furthermore, developing turtles have temperature-dependent sex determination, which means different sexes (male vs. female) will develop at different temperatures. The thermosensitive period (TSP) is the period of time during which temperature determines the sex of the hatchlings. In order to have a ratio of 1:1 (50% males, 50% females) the temperature must be within the transitional range (TR), which is the range where both males and females will be produced within the clutch. A clutch is all of the eggs in one nest, from the same turtle (Davenport, 1997). Also, the TR has been noted to have an adverse effect on succession, emergence, locomotion, and size (Drake & Spotila, 2014). Death may even occur if the temperatures get too high, resulting in a loss of diversity in the ocean.

There are many reasons why humans should fight to keep the sea turtle populations thriving; they maintain biodiversity and generate a large income through the tourism industry. A leatherback turtle's diet consists mainly of jellyfish, a common annoyance to swimmers. Jellyfish consume phytoplankton, the energy produces of the ocean. If the turtles were to disappear, jellyfish may rise in abundance. A decline in turtles would also result in the loss of millions of dollars each year from the tourism industry, as live turtles and their nesting grounds could not be showcased. Therefore, by conserving the sea turtle populations, humans are protecting the biodiversity and productivity of the ocean ecosystem, keeping an aquatic pest at bay, and they are maintaining their yearly tourism profits.

There are very few conservation techniques researched in turtle conservation that are not time consuming and laborious in execution. This paper focuses on shading turtle nests, a technique that does not require much effort to be maintained (Wood et al., 2014). Thus, conservationists do not have to spend extra time and money to dig nests deeper in order to maintain a temperature suitable for optimal growth. Shading is done by creating a large tent-like structure to prevent the sun from heating the nest below. The effects of climate change on sea turtles are highly studied but there is a lack of evidence on efficient ways to mitigate the harmful effects of climate change (Hill et al., 2014). This paper synthesizes peer-reviewed articles on how climate change affects sea turtles and how to mitigate these effects with shading, providing a more effective way to conserve sea turtle populations, in the future.

2. Sex Ratios

The largest physical change in sea turtles due to climate change, would be the shift in the embryo's sexual organs. With an increase in temperature Hill et al. (2015) predicts that there will be an increase in female-biased clutches, as well as female only clutches. Davenport (1997) suggests that even an increase of a few tenths of a degree Centigrade, in the nest could result in shifts towards female-biased clutches. A clutch will end up 100% male or 100% female if the temperature is below or above the TR respectively (Tomillo et al., 2014). Dudley and Porter (2014) show how sensitive the TR is in their review of turtle incubation. There was only a 1.1°C difference between the hottest all male clutch and the coldest all female clutch; this small difference implies that even minor changes in temperature could result in clutches developing mostly female. Tomillo et al. (2014) has observed the effects of higher temperatures, stating that current primary sex ratios are typically female-based. It is also not uncommon for clutches to be made up of 90% or more female hatchlings. There are multiple implications that extremely high female primary sex ratios would have on the future of the turtle populations. Most importantly, there could be a loss of future generations as there may not be enough males to sustain the population.

It has been known for a while that temperature has an effect on the sexual physiology of sea turtle hatchlings, with Davenport (1997) having done a review almost 30 years ago. However, Tomillo et al. (2014) used a field experiment to test the effects of temperature on the sex ratio of clutches. This type of experiment allows for direct measurement of both the temperature of the nest and the amount of males and females born from the clutch. However, it does not have a control group, so there is no way to know if there are any confounding variables in this study. While these studies support changes to the sexual organs of the turtles nesting temperatures will have further effects on the hatchling physiology.

3. Hatchling physiology

Wood et al. (2014) show that there is an inverse correlation between nest temperature and turtle size. Cooler nests produce larger turtles, both in mass and in the carapace (shell) size. Booth et al. (2004) states that this size difference may be due to turtles at lower temperatures consuming more yolk when in development. By consuming more nutrients, the turtles grow faster and become more developed than turtles at higher temperatures. Extra growth is advantageous to the turtles as it improves their locomotion performance when leaving the nest.

There are three main types of movement that hatchlings use to reach the ocean safely: crawling, swimming, and self-righting. Crawling and swimming speeds are similar to size in the sense that they have an inverse correlation with temperature, when tested for in the laboratory (Booth et al. 2004). By having larger muscles due to their increased development, hatchlings from lower temperature clutches can crawl and swim faster. Self-righting is the process of flipping onto their plastron (bottom) if they get turned upside down onto their carapace. This time is decreased in turtles from lower temperature clutches when compared to those of higher temperature (Wood et al. 2014).

Booth et al. (2004) used an laboratory experiment to determine their findings. By incubating new eggs in the laboratory the authors were able to precisely control the conditions the eggs were in. It may appear that this is beneficial to determine the effects temperature on locomotion, however, it limits the research in external validity, by decreasing its generalization to a real environmental example. On the other hand, Wood et al. (2014) used a field experiment which allowed him to take measurements of hatchlings in their natural environment, allowing for a greater generalization of how climate change will effect turtles in the wild. The increase in size due to climate change will also affect how many turtles survive and emerge from their nests.

4. Succession and emergence

Dudley and Porter (2014) state that as a result of their incubator models, higher temperatures will create a lower rate of hatchling succession and emergence. This is due to mutations during development that prevent the baby turtle from escaping the egg. Prolonged exposure (three days) to temperatures above 34°C in early development and 36°C in later development are fatal to turtle embryos (Wood et al., 2014). Drake and Spotila

(2001) suggested that multiple sea turtle species have a critical thermal maximum between 40-41°C. This means that if a hatchling was to reach this temperature locomotor abilities will shut down and the animal will die. Hatchlings should not emerge from their nest if temperatures are 36°C and above, as these temperatures can cause uncoordinated movement and death (Drake & Spotila, 2001). This is supported by Dudley and Porter (2014), as their models predicted that uncoordinated movements in leatherback hatchlings would occur when their internal body temperature rises above 33.6°C.

Dudley and Porter (2014) used empirical and mechanistic models, along with literature research to come up with their data. By using models, the authors are predicting an accurate result without harming the turtles. It was also stated that their models only used ellipsoidal shapes to represent turtle bodies. Turtles however, are not ellipsoid in shape and have flippers extending from their body. Due to the improper representation of the turtles' size the calculated temperature values may be slightly higher than real turtles. Thus, future models should be designed to incorporate the distinct shape of the turtle body in order to calculate more accurate thermal thresholds. However, Drake and Spotila (2001) did not run into the problem of body shape as they used live hatchlings as study subjects in their field experiment. The use of real turtles and environmental conditions allows the authors to generate more accurate data than a model, since it is based on direct measurements not calculated values. A field experiment was used by Wood et al. (2014) to emphasis the importance of shading as a tool for mitigating the harmful effects of rising temperatures due to climate change.

5. Shading: A mitigation tool

Due to the harmful effects that are caused by increased temperatures on turtle nests, scientists are looking to create environments that improve the survival rate of turtle populations. Wood et al. (2014) has shown that shading nesting sites can prove to be an effective way to combat increasing temperatures. Shading structures were constructed in a tent-like fashion with polls and a mesh fabric that partially blocked sunlight from reaching the beach and nests below. By blocking some sunlight there is a reduction in the amount of solar energy that reaches the beach. This prevented sand and nest temperatures from reaching critical levels that could result in death of developing turtles.

The shading structure used by Wood et al. (2014) is very different then ones used by Hill et al. (2015). Wood et al. (2014) used a single large shading structure to cover a greater amount of nests compared to Hill et al. (2015), who used much smaller structures but more of them. Wood et al. (2014) allowed for a boarder coverage of turtle nests, thus increasing the sample size and accuracy of their results. Table 1 is made from data collected by Wood et al. (2014) and shows how shading can have a positive effect on physiology, performance, and survival. They compared nests that received different amounts of sunlight based on their position under the shading structure. For the purpose of this paper, only data from the most shaded part is used as it showed the most significant results.

Table 1: Comparison of Shaded and Unshaded Sea Turtle Nests on Factors Affecting Sea Turtle Survival, [from Wood et al. 2014]

Affected Factors	No Shade	Most Shade
Mean sand temperature (°C)	30.2 ± 0.1	28.4 ± 0.1
Mean nest temperature (°C)	31.7 ± 0.1	29.8 ± 0.1
Estimated females (%)	95.0 ± 1.8	54.6 ± 4.4
Hatchling success (%)	83.1 ± 7.1	83.7 ± 1.3
Emergence success (%)	74.6 ± 3.5	81.5 ± 3.2
Hatchling mass (g)	19.5 ± 0.7	20.9 ± 0.5
Carapace area (mm^2)	1484.4 ± 3.9	1596.5 ± 3.9
Crawling speed (cm/s)	3.87 ± 0.07	5.68 ± 0.09
Self-righting time (s)	2.93 ± 0.40	2.51 ± 0.16

There was a significant drop of 2.4°C in mean nest temperatures during the sex determination period, between nests that received no shading to the most shaded. This drop resulted in a 40% decreases in the female biased clutches, making the primary sex ratio almost 1:1. Wood et al. (2014) found no significant rise in hatchling success as they remained around 83% but did find a significant increase of 6.9% in emergence success. An increase in emergence success is attributed to two factors: the decline in surface sand temperatures and an increase in turtle size. Due to the shading there was a 1.8°C drop in surface sand temperatures which allows for turtles to crawl out of the nest, without damage to their internal navigation system. Turtles were stronger climbers as they had larger muscle development. There was an increase of 1.4 g in mass and 112.1 mm^2 in carapace area. The larger turtles had improved locomotion performance as well. Crawling speed was improved by an average of 1.81 cm/s and self-righting time was reduced by an average of 0.42 s. Enhanced locomotion allows turtles to spend less time on the beach where they are easily preyed upon. Also, larger hatchlings are less likely to be prey as they are hard for animals to transport (Wood et al., 2014).

Currently shading is the leading method to combat the negative effects of climate change however there are still some minor flaws that need to be considered (Wood et al., 2014). The flaws are that shade structures are not practical for use over large areas and can be considered unappealing to the eye of the public. One benefit of the shading structure is that there will not be any pollution emitted by this structure. Also it will not physically harm the turtles by being located so close to their nests, as is it easy for the turtles to crawl around the legs of the structure.

6. Conclusions

As shown through this review, an increase in temperature due to climate change could have significant negative effects on turtle populations. Firstly, the sex ratios of clutches are becoming female dominated, resulting in a lack of males for future reproductions. Secondly, turtles at higher temperature do not develop as large as their lower temperature counterparts. Furthermore, do to their smaller sizes they maintain poor locomotive skills during crawling, swimming, and self-righting. Thirdly, the hatchlings are less likely to hatch or make it out of their nest because of the higher temperatures. Shading is the most supported method of reversing the negative effect of increased temperature on sea turtles. By establishing shading structures humans can artificially lower the temperatures of the turtle nests and the surrounding sand. Therefore, this technique can help balance sex ratio, increases succession, emergence, size, and locomotive abilities. All of these changes can lead to an increased and balanced sea turtle population for future generations. It is important for us to maintain these populations to ensure that our oceans remain divers and rich with life. These animals are a multimillion dollar industry to humans that provides us with food and entertainment.

For future studies Wood et al. (2014) has suggested the use of organic shading, where trees are used instead of creating artificial shade. Trees can be planted along the entire beach, with their main advantages being that they are cheaper and easier to maintain than built structures. The main downside to this however is that it may take some time for the trees to grow and cover all nests. However, there should be future studies that compare each type of shading to investigate if one could produce stronger shading effects. By using a procedure similar to Wood et al. (2014) for each type of shading, one could determine if a certain type of shading is better than the other at lowering environmental temperature. Future efforts for conservation of sea turtles should take into account all that is mentioned and decide the proper strategy for the specific species and nesting environment. In order to keep these animals on our planet, lots of effort will need to be put forth to stop climate change and maintain their nesting temperatures.

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