# Climate change and the Hawksbill turtle

## Effects of climate change on its reproductive success, sex ratio and diet

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**Cover picture**: Kirby, s.d.

# Preface

Before you lays my bachelor thesis Climate change and the Hawksbill turtle, effects of climate change on its reproductive success, sex ratio and diet.

It has been written to fulfil the graduation requirements of the study of Applied Biology at Aeres University of Applied Science in Almere, Flevoland. I was engaged in writing this thesis from May 2022 to April 2023.

I have chosen this subject because I have been interested in the effects of climate change since the beginning of my study and the combination with one of my favourite animals seemed like a great subject.

I would like to thank my coach/mentor Bram Knegt for the support during this process. You have helped me with bringing this work to a higher standard and where my guide during this time.

I also want to thank all my friends for keeping me motivated and helping me work on this thesis.

I hope you enjoy reading.

Emmy Nijhuis

Almere, 09-06-2023

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# Summary

Climate change is a major threat for the Hawksbill turtle (*Eretmochelys imbricata*). A lot of research has been done on the possible effects, but a clear overview is still lacking. This literature review aims to provide an overview of the effects of climate change on the nesting success, sex ratio and diet of the Hawksbill turtle.

Results showed that Hawksbill turtles have individual preferences for the location of their nests, considering vegetation coverage. It also shows that the expected sea level rise can flood nests located to close to the sea. Sea level rise also threatens the surface area of possible nesting beaches around the world. Heavy rainfall and vegetation can influence the temperature within the nest, both having cooling effects. The temperature within the nest determines the sex ratio of the offspring. Warmer temperatures produce more females, while colder temperatures produce more males. The pivotal temperature is around 29 degrees Celsius. The expected increase in temperature will thus lead to a potential increase in female hawksbill turtles. These skewed sex ratios will not immediately lead to the same skewed ratios in adults, because males reproduce more compared to females. It is also possible that a point will be reached, where almost no males are produced. This could cause the population to collapse.

The diet of hawksbill turtles mostly consists of sponges, algae, and coral. Increasing temperature can potentially lead to mass sponge mortalities. As temperature influences the growth rate of algae, an increased temperature could also lead to a decrease in growth rate. Climate stressors can influence the herbivore-plant relationship between Hawksbill turtles and the algae. An increase in temperature will also cause more coral bleaching. A shift towards a sponge dominated reef is also possible. This could have positive effects on the species.

To conclude, climate change will thus lead to a change in nesting beaches and nesting places. Higher temperatures will lead to a higher production of female offspring, which does not immediately equal a skewed sex ratio in the adult populations. Changes in diet of foraging grounds can also be expected. Recommendations are to shade nests, relocate nests to close to the sea. Creation of marine protected areas is also recommended. Further research is necessary regarding the diet and possible effects of this on the Hawksbill turtle.

# Samenvatting

Klimaatverandering is een grote bedreiging voor de karetschildpad (*Eretmochelys imbricata*). Er is veel onderzoek gedaan naar de mogelijke effecten, maar een duidelijk overzicht ontbreekt nog. Deze literatuurstudie heeft tot doel een antwoord te vinden op de effecten van klimaatverandering op het nestsucces, de seksratio en het dieet van de karetschildpad, *Eretmochelys imbricata*.

Uit de resultaten blijkt dat karetschildpadden individuele voorkeuren hebben voor de locatie van hun nesten, rekening houdend met de vegetatiebedekking. Ook blijkt dat de verwachte zeespiegelstijging nesten die te dicht bij de zee liggen, kan doen overstromen. De stijging van de zeespiegel bedreigt ook de oppervlakte van mogelijke neststranden over de hele wereld. Zware regenval en vegetatie kunnen de temperatuur in het nest beïnvloeden; beide hebben een verkoelend effect. De temperatuur in het nest bepaalt de geslachtsverhouding van de jongen. Hogere temperaturen brengen meer vrouwtjes voort, terwijl lagere temperaturen meer mannetjes voortbrengen. De cruciale temperatuur ligt rond de 29 graden Celsius. De verwachte temperatuurstijging zal dus leiden tot een mogelijke toename van vrouwelijke karetschildpadden. Deze scheve seksratio's zullen niet onmiddellijk leiden tot dezelfde scheve ratio's bij volwassen dieren. Dit omdat mannetjes zich meer voortplanten dan vrouwtjes. Het is ook mogelijk dat een punt wordt bereikt, waar bijna geen mannetjes meer worden geproduceerd. Hierdoor zou de populatie kunnen instorten.

Het dieet van karetschildpadden bestaat voornamelijk uit sponzen, algen en koraal. Verhoging van de temperatuur kan mogelijk leiden tot massale sponssterfte. Aangezien de temperatuur de groeisnelheid van algen beïnvloedt, kan een hogere temperatuur ook leiden tot een afname van de groeisnelheid. Klimaatstressoren kunnen de herbivoor-plant relatie tussen karetschildpadden en de algen beïnvloeden. Een stijging van de temperatuur zal ook meer koraalverbleking veroorzaken. Een verschuiving naar een door sponzen gedomineerd rif is ook mogelijk. Dit zou positieve gevolgen kunnen hebben voor de soort.

Kortom, de klimaatverandering zal dus leiden tot een verandering van de broedstranden en broedplaatsen. Hogere temperaturen zullen leiden tot een hogere productie van vrouwelijke nakomelingen, wat niet meteen gelijkstaat met een scheve geslachtsverhouding in de volwassen populaties. Ook kunnen veranderingen in het dieet van foerageergebieden worden verwacht. Aanbevelingen zijn het aanbrengen van schaduw op de nesten en het verplaatsen van nesten naar de nabijheid van de zee. Ook de instelling van beschermde zeegebieden wordt aanbevolen. Verder onderzoek is nodig naar het dieet en de mogelijke effecten daarvan op de karetschildpad.

# Chapter 1 Introduction

*Figure 1* Photo of a Hawksbill turtle, *Eretmochelys imbricata*.

(Freund, 2010).

The hawksbill sea turtle (*Eretmochelys imbricata*) is found in tropical and subtropical oceans worldwide (Blanvillain et al., 2007). This sea turtle, also called the Hawksbill turtle (Figure 1) is a migratory species. Adult individuals travel hundreds to thousands of kilometres from foraging areas to nesting sites (Hesni, Tabib and Ramaki., 2016). The study of Meylan (1999) showed that adult hawksbill turtles in the Caribbean travelled distances of 110 to 1936 kilometres.
Although migration patterns differ between populations on different continents, individuals have been tagged on nesting beaches in Costa Rica and have occurred again on the coast of Nicaragua, Honduras and Panama.).

Its diet consists primarily of sponges and sometimes jellyfish (Blumenthal et al, 2009). The species has a critically endangered status according to the WWF (s.d.). In the last century, its numbers have declined by 80%. It is estimated that about 8000 females nest worldwide (Goodfellow., 2018). The species is most threatened by trade in turtles, but also developments and modifications to coastlines, fishing, overexploitation of females on nesting beaches, for trade in shells, food or egg collection. This causes many females to be taken away. Human encroachments that affect nesting habitats such as water pollution, oil spills, building hotels and or houses on nesting beaches, and climate change are also threats to the species (WWF, s.d.; El Kafrawy et al., 2020).

Climate change is a major threat to the hawksbill sea turtle. Much is known in the literature about the effects and possible consequences for this species, but a clear overview is lacking. Also, according to Richardson et al. (1999), more long-term, extensive research must be done on egg survival, immigration and emigration, and sex ratio. These factors are important for the survival of a hawksbill turtle population, apart from that these factors can also show how a population is doing in terms of survival. The sex ratio and egg survival have been the subject of much research in recent years, such as the study by Marcovaldi et al. (2014) and Hays, Schimada & Schofield (2022) on the sex ratio of the hawksbill turtle. Leighton, Horrocks & Kramer (2009) examined the survival of eggs under predation. They also studied how nest depth affects the process of predation. Immigration and emigration need further investigation. According to Hawkes et al. (2012) the migration of the hawksbill turtle is least described, compared to other turtle species. In this study the migration of female hawksbill turtles towards foraging areas was tracked, with the use of satellites.

As a lot of factors can have a positive or negative effect on the species, and it is particularly important to have a clear overview of their possible impacts, especially with major problems that can have a global impact. This is particularly relevant for government agencies that are drafting or enforcing laws regarding the conservation of the hawksbill turtle, and for wildlife organizations that want to protect the hawksbill turtle. Therefore, the purpose of this literature review is to provide an overview of the potential effects of climate change on the hawksbill sea turtle, and on its nesting sites, sex ratio and diet in particular. An overview as in this study could then provide a good handle on the effects of climate change on the species, based on which solutions can be devised to better protect the hawksbill turtle.

## Climate change in oceans

To understand how climate change may affect the hawksbill sea turtle, it is first important to understand how climate change may affect ocean environmental factors such as temperature, currents and sea level. In the paragraphs below, this influence will be briefly explained. Global ocean temperatures, like temperatures over land, increased, although less rapidly than air temperatures. The temperature rise is partly due to human-induced warming. The less rapid temperature rise is mainly due to the large thermal capacity of oceans (IPCC., 2007). The temperature of the surface water in the sea increased by an average of 0.88°C from 1850-1900 to 2011-2020 and 0.60°C from 1980 to 2020. Tropical oceans have been warming up much faster than other seas since 1950. The fastest warming is occurring in the tropical Indian Ocean and the western Pacific Ocean (Fox-kemper et al., 2021). In the future, the upper ocean layer is expected to rise first in temperature and then the deeper layers by the end of the twenty-first century (IPCC., 2007).

In addition to temperature, global sea levels have also risen in the 20th century faster than any previous century in the last three millennia. During the period 1901-2018, the sea level rose 0.20 m. Global sea -level rise has accelerated since the late 1960s. At an average rate of 2.3 mm per year during 1971-2018, increasing to 3.7 mm per year during 2006-2018. (Fox-kemper et al., 2021).

Marine heat waves have also become increasingly frequent during the 20th century. Since 1980, their frequency has roughly doubled, and they have become more intense and prolonged. This trend will continue on a global scale and will become four times more frequent in 2081-2100 compared to 1995-2014. The greatest changes will likely occur in the arctic and tropical oceans (Fox-kemper et al., 2021).

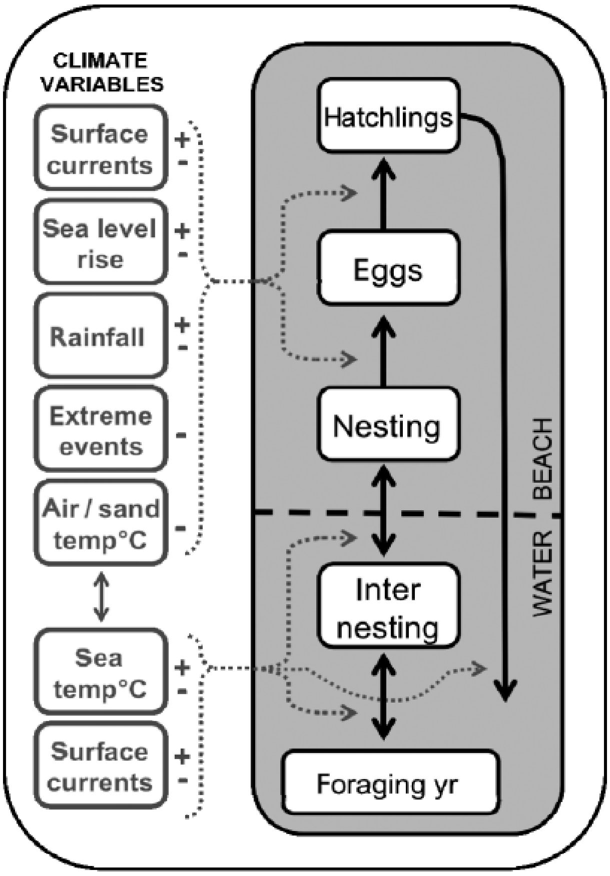
Next to changing temperatures and marine heatwaves, storms, cyclones and heavy rainfall are also expected to increase in the upcoming years. The storms, cyclones and heavy rainfall can differ a lot between individual ocean basins. (Fox-kemper et al., 2021). Tropical cyclones are typically classified in terms of their intensity, which is a measure of near surface wind speed. The strongest cyclones are also generally the rarest storms. (Seneviratne et al., 2012). The research of Thompson et al., 2021 studied a typical cyclone in the region La Réunion in the southwestern Indian Ocean. The results showed that on average, with a warming of 1.1℃ to 4.2 ℃, future cyclones will be 6.5% more intense. Future cyclones will also produce heavier rainfall, with an 33.8% average increase.

## Climate change on hawksbill turtle

The above factors of climate change have a lot of impact on the oceans. These factors could therefore affect the hawksbill turtle. The following paragraphs, therefore, provide a brief overview of how the effects of climate change could potentially affect the survival of the hawksbill sea turtle.

Sea level rise can have many effects on the habitats of endangered species including the hawksbill turtle (Fuentes et al., 2010). A rise in sea level can have major effects on the beaches where the species lays its eggs, and on the nests themselves. Excessive sea level rise could cause beaches and thus nesting sites to be flooded, preventing females from laying eggs, or the hatching of eggs. Storms, cyclones and heavy rainfall can have major effects on the nesting behaviour of females but will have the most impact on nests and eggs themselves, in that nest and eggs can be destroyed (Poloczanska et al., 2009). Figure 2 shows an overview of different climate factors and their potential effects on the hawksbill sea turtle.

*Figure 2  Effects of climate change on sea turtle.*




*Dotted arrows present potential climate variables and their indirect effects. + and - represent the probable direction of the effects. Copied from: Hawkes et al., (2009)*

In addition, a slight increase in temperature could already affect the sex ratio of nests. Whether hawksbill embryos develop into a male or a female depends on the temperature during the incubation of the eggs. It is likely that at higher temperatures more females will develop. Thus, a slight increase could already determine whether more females or males hatch. (Glen & Mrosovsky, 2004). This is important for population growth of the hawksbill turtle because females lay the eggs and thus determine how many offspring are produced. However, this can also have adverse effects in that fewer males develop which is detrimental to mating and fertilization. The slow maturation of sea turtles also makes it more difficult for the species to adapt to rapid climate changes (Glen & Mrosovsky, 2004).

Sea turtles mature on average after 20 to 35 years. As a result, they cannot have offspring until after 20 to 35 years. As it takes a long time to produce offspring, sea turtles adapt slowly to changes in the climate. (Hawksbill Turtle, 2020). This may then have negative consequences on the occurrence and survival of *E. imbricata*.

In addition, the hawksbill sea turtle has a narrow diet, consisting mainly of sponges, which renders it even more difficult for the species to adapt (Hawkes et al., 2009). Climate change may also indirectly affect food quantities It would be possible that with increases in temperature, sea level or other climate-related factors, fewer sponges will be available to eat from. Sponge populations are primarily affected by the warming and acidification of oceans. Also, the sea level may have effects on the survival of sponge populations. Between sponge species, there is much variability in responses to increases in temperature and sea level. Some species thrive at warmer temperatures and higher sea levels, while other species thrive at lower temperatures and lower sea levels. Nevertheless, thermal stress can limit the reproductive success of sponges. In addition, this stress could also affect sponge foraging behaviour by decreasing or increasing the filtration of water. (Carballo & Bell., 2017). This could cause sponge populations, on which the hawksbill turtle feeds, to decrease. It is necessary that more intensive research is done to give a clear view on the possible effects this may have on hawksbill turtle populations. As it is still not clear how sponges, of which the hawksbill turtle feeds, react to a changing climate, it is possible that this has no significant effect on the hawksbill turtle. According to Hawkes et al. (2009), the dietary breadth of this species is still understudied

In short, the hawksbill sea turtle is a critically endangered species that could potentially be further compromised by climate change (WWF, s.d.). Studies on how climate change may affect the survival of the hawksbill turtle are numerous, but an overview of them is lacking. Therefore, this literature review will seek to answer the following main question: What is the effect of climate change on the nesting success, sex ratio and diet of the hawksbill turtle, *Eretmochelys imbricata*?

Nesting success, sex ratio and diet are the focus of this study because it is expected that climate change has the greatest influence on them, and because these factors together and individually affect the survival and occurrence of the hawksbill turtle. To answer the main question, the following sub-questions have been formulated:

1. What is the effect of temperature and sea level rise on the nesting sites of the hawksbill sea turtle?
2. What is the effect of an increase in temperature on the sex ratio of the hawksbill turtle?
3. What is the effect of temperature and sea level rise on the diet of the hawksbill turtle?

Climate change is expected to affect sex ratio, nesting site habitat, and diet. Nesting site habitats will change due to increased storms and rainfall. Rising sea levels, for example, will cause beaches or parts of beaches to flood, making them unsuitable nesting sites. In addition, it is expected that due to rising temperatures, increased rainfall, biodiversity on beaches may also change so that they may no longer be suitable nesting sites, due to different vegetation or the complete disappearance of vegetation. Furthermore, temperature is expected to affect the sex ratio of nests, and more females are expected to hatch at warmer temperatures. (Glen & Mrosovsky., 2004). In addition, it is expected that the species will have to adjust its diet, and its food supply may decrease in response to rising temperatures and sea levels. It is possible that there will be fewer sponges to serve as food because an increase in temperature and sea level could cause a decline in sponge populations (Carballo & Bell., 2017).

## Reading Guide

The second chapter discusses how this thesis was conducted, the third chapter discusses the results found, divided into paragraphs by sub-question. In the fourth chapter the discussion can be found, in chapter five conclusions are made and in chapter six, recommendations for short- and long-term preservation are made.

# Chapter 2 Material & Method

## Type of research

This study is a qualitative literature review. A qualitative literature review, also known as a narrative review, describes a specific topic or theme from a theoretical point of view. A narrative review consists of a critical analysis of published literature in books and scholarly articles (Rother., 2007). Within this literature review, scientific articles address climate change in tropical and subtropical oceans and their potential effects on hawksbill turtles.

## Data collection

The data in this thesis paper will consist of literature: scientific published articles, books and information from relevant research and wildlife organizations such as the WWF. The data will be collected through the search engines: Google Scholar, Greeni, ScienceDirect, Springer, Wiley, and Wageningen University. Example keywords used in these search engines are listed in Table 1.The full list of keywords can be found in appendix 1.

**Tabel 1.**
keywords used in search engines

| **Kernwoorden** |
|---|
| Karetschildpad |
| Hawksbill turtle ecology |
| Hawksbill climate change |
| Hawksbill turtle diet |
| Eretmochelys imbricata voorkomen |
| Habitat Eretmochelys imbricata |
| Voorkomen karetschildpad Eretmochelys imbricata |
| Climate change in tropical seas |
| Climate change in tropical beaches |
| Climate change and marine turtles |
| Eretmochelys imbricata |
| Eretmochelys imbricata & climate change |
| Eretmochelys imbricata & conservation |
| Eretmochelys imbricata & climate change & conservation |
| Eretmochelys imbricata sex ratio |
| Eretmochelys imbricata sex ratio & climate change |
| Eretmochelys imbricata migration |
| Eretmochelys imbricata migration & climate change |
| Eretmochelys imbricata diet |
| Eretmochelys imbricata diet & climate change |
| Tropical storms |
| Tropical cyclones and climate change |
| Climate change and tropical cyclones on oceans |

Information is considered reliable if the assumptions being made can be substantiated by scientific sources, or if research has been conducted on it and it produced clear results. For scientific articles, the discussion can indicate how well the research was conducted, and why results may differ from other similar studies. Also, the publication dates of the articles will be considered, as outdated articles may be obsolete by now. For articles written before 2000, it will be examined whether other articles have shown that certain information is outdated or has been further substantiated. To determine whether an article is of value for this literature review, its relevance will first be assessed by reading the title and abstract. If subsequently the article is found to be of value, the results and discussion will be reviewed.

Searching will stop when the results lead to the same articles, and only refer to articles already reviewed.

## Delineation

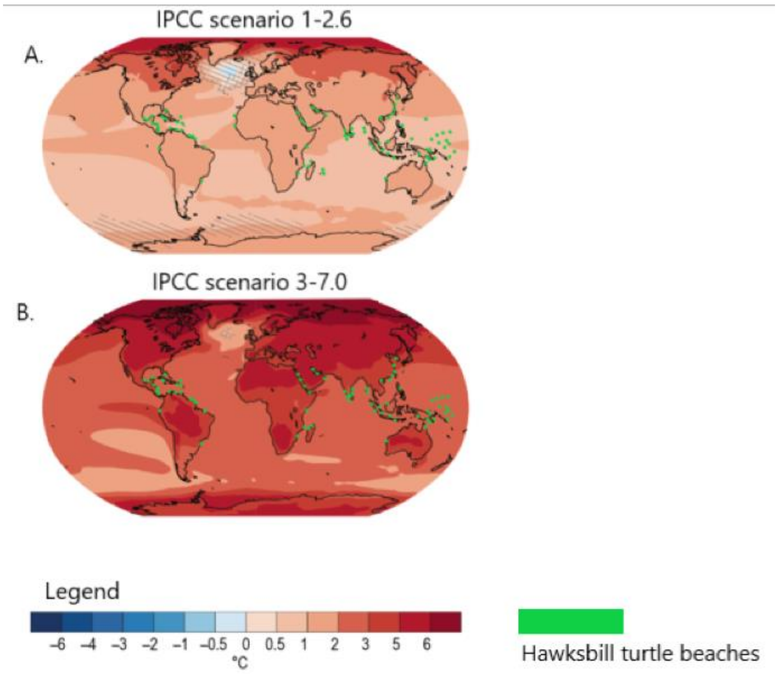
This study will only consider climate change in tropical and subtropical oceans and its effect, if any, on the reproductive success, sex ratio and diet of the hawksbill turtle, *Eretmochelys imbricata*. These factors will likely have the most impact on the occurrence and survival of the hawksbill turtle. Discussing the effects of these factors will provide a clear overview of the possible effects that climate change might have on this species. This thesis paper will not discuss the effects on juveniles because there is currently little information on the effects of climate change on juveniles, as this is very difficult to investigate.

# Chapter 3 Results

## 3.1 Nesting sites of the Hawksbill Turtle

In species where no "parental care" takes place, nest location is incredibly important. Where a female decides to lay her eggs affects her fitness, through the survival of her young (Kamel & Mrosovsky., 2005). Every 1 to 5 years, a hawksbill turtle female returns to the beach to nest. This occurs in the region where she hatched decades earlier. A hawksbill sea turtle lays three to five nests per season. Each of these nests averages 130 to 160 eggs. The nesting season generally occurs between April and November but varies by location. (NOAA fisheries, 2020). In figure 1 the nesting beaches of the Hawksbill turtle around the world are visible. Figure 3 also shows the changing temperature according to two scenarios of the IPCC. Scenario SSP1-2.6 is the next best scenario, in which global emissions are cut severely, with reaching net zero after 2050. In scenario 3-7.0 the emissions and temperature rise steadily. Emissions roughly double from current levels by 21000.

*Figure 3 Hawksbill turtle nesting beaches and rising mean annual temperature.*




*Based on Scenario's SSP 1-2.6 and SSP 3.7-0 according to the IPCC. Both maps show the increase in mean annual temperature for the year 2100. The green dots show the hawksbill turtle nesting beaches around the world.*
*Temperature information obtained from Figure 4.12 in IPCC, 2021.*
*Hawksbill turtle locations obtained from: (Network for Endangered Sea Turtles, 2016)*

Unlike other sea turtle species, hawksbill turtles select nest sites with specific vegetation characteristics (Kamel., 2013). It is also a widely accepted observation that vegetation is an important beach structure component that influences the nesting process of the hawksbill turtle (Hernández-cortes et al., 2018). The study by Kamel and Mrosovsky (2005) shows that hawksbill turtle nests are mainly laid in places on the beach with at least some vegetation, such as at a forest edge, in the forest or some low-lying vegetation. The average distance from the waterline (the boundary to where the water reaches the beach) was found to be 9.1 ± 4.5 meters. This study also showed that there are significant differences among turtles when it comes to their nest site choice. These individual differences are particularly evident in the distance from the forest edge, waterline and vegetation.

Horrocks and Scott (1991) examined the effects of nest location on nesting success of hawksbill turtles in Barbados. This study found that turtles nested more on the western coast than on the south and east coasts. This suggests, according to Horrocks and Scott, that hawksbill turtles prefer beaches with lower "wave energy" and "steeper beach slopes."

Considering the above, it appears that hawksbill turtle nesting and hatching sites are influenced by vegetation and personal preferences. But the success of a nesting site depends on the number of hatchlings that hatch, and how many of these survive the route from the nest to the water (Gravelle and Wyneken., 2021). This can be influenced by several factors, such as sea level rise, temperature and storms.

### 3.1.1 Effects of sea level rise on nesting sites

Hernándes-Cortes et al. (2018) expect that sea level rise in the coming decades, could have a strong impact on hawksbill turtle nesting and breeding sites. Fish et al. (2005) examined the nest site distribution on Bonaire, determining possible extent of beach habitat threatened by different sea level rise scenarios. Thirteen beaches were surveyed. Of these surveyed beaches, each is expected to be threatened by sea level rise. A rise of 0.5 meters could result in an average 38% decline of these beaches. The impacts per beach may vary depending on physical characteristics. However, it does appear that narrow beaches are more susceptible to sea level rise (Fish et al., 2005 & Hernándes-Cortes et al., 2018). The study by Fish et al. (2005) also shows that with a rise of 0.5 meters, 23% of current nesting sites are threatened by flooding, and a rise of 0.9 meters leads to 52% of current nesting sites being threatened by flooding. It is worth noting here that the physical characteristics of beaches, such as beach length, width, height, slope and vegetation, determine how severe the threat of sea level rise and thus flooding is. The most vulnerable beaches are beaches on which there are hotels. These are beaches that are often not preferred nesting sites for hawksbill turtles, as these beaches have been modified to attract tourism. Nevertheless, any loss of habitat has important consequences for turtle populations because it reduces the range of available nesting sites for females. (Fish et al., 2005).

Maneja et al. (2021) examined the coastlines of the Jana and Karan islands in the Arabian Gulf to assess long-term beach loss. This study showed that between 1965 and 2017, Jana Island lost 14,146 $m^2$ of beach and Karan Island lost 16,376 $m^2$ of beach. In 2017, Karan Island was 25,474$m^2$ or 2.6% smaller, compared to 1968. Declines in beach habitat for nesting sites are expected to occur on other islands and beaches as well. This may be exacerbated by rising sea levels.

Apart from the loss of nesting places for hawksbill turtles, high tides can also affect their breeding success. Nests can flood and eggs could potentially not hatch. The research by Kamel and Mrosovsky (2005) showed that of flooded nests, the average percentage of hatched eggs was 14.3% ± 12.3%. This compares with a hatching success of 84.6% ± 13.5% in nests that were not flooded.

### 3.1.2 Effects of temperature and storms on nesting sites

Glen and Mrosovsky (2004) examined the temperature of nests on Pasture Bay in Antiqua and compared these results with data from 1989. The results showed that sand temperatures at a depth of 60 centimetres were generally cooler than at a depth of 30 centimetres in 2003. In addition, it was found that at a depth of 30 cm, the temperature changed with the time of day, while at 60 cm the temperature remained nearly consistent over the course of the day. When compared to data from 1989 and 1990, it shows that in 2003 average sand temperatures were higher than 1989 and 1990. The temperatures of 1989 and 1990 was closer to the lowest temperatures found in 2003. The study by Mrosovsky et al. (1992) showed the results of the experiments done in 1989 and 1990. These results showed that the temperatures at 30cm depth and 60 cm depth are similar, although the temperature at 60 cm depth fluctuates less throughout the whole day. These studies show an increase in the temperature of sand, on the beaches where the hawksbill turtle nests.

It further shows that there is a relationship between nest temperature and vegetation around nests. Nests without vegetation are warmer than nests with partial or full vegetation. This is shown by Hernández-cortes et al. (2018). This study also shows that nests around creeping vegetation are warmer than nests around herbaceous and shrubby vegetation. In one population of hawksbill turtles on Trois Ilets beach in Guadeloupe, Kamel & Mrosovsky (2006) found a behavioural polymorphism for nest site selection related to microhabitat characteristics of the beach. Some females preferred coastal/shoreline forest, while some preferred more open, deforested areas. During this study, nest site selection was found to be consistent within and between breeding seasons, in two consecutive years. In addition, these preferences were consistent with changing environments. Differences in nest site preferences may cause different nest temperatures between different microhabitats. This suggests according to Kamel & Mrosovsky (2006), that maternal nest choice selection may determine the sex ratio of offspring. With the changing climate it would be possible that less vegetation is available on the beaches. This could potentially lead to more nests with little or without vegetation cover, which will then lead to higher temperatures within the nest, leading to sex-ratios skewed towards females. The females hatched from nests located under no or little vegetation could in the future also choose for a nest located in a similar location.

Heavy rainfall can also have a significant effect on nest temperature. The research by Staines et al. (2020) shows that heavy rainfall can lower nest temperatures. How this occurs is still unclear, but it is possible that this is due to evaporation. During the study, 125mm fell within two days, which was followed by more days of rainfall. During the period from Jan. 21 to Feb. 10, 199mm of rain finally fell. The results show that the average temperature for rainfall in nests without shade, was 31.3°C. The temperature in nests with shade was 30.4 °C. After the rainfall, temperatures were found to decrease by 4.1 °C and 3.4 °C, respectively. After this rainstorm, there was a period of 20 days where cool temperatures below 30 °C were observed. The average temperature of the nests was then 28.6 °C for nests without shade, and 27.9 °C for nests with shade. The occurrence of (heavy) rainfall can thus alter the temperature of a nesting site.

Fuentes, Bateman & Hamann (2011) conducted research on the distribution of existing sea turtle nesting sites and the historical patterns of tropical cyclones to investigate whether tropical flows affect the current distribution of nesting sites. This research found that all populations studied were disturbed by cyclone activity during the study period. The exposure frequency of tropical cyclones crossing each nest site varied greatly between and within sea turtle populations. This was mainly a result of spatial distribution of nest sites of each population. As a tropical cyclone brings changes in temperature, precipitation and wind (Peterson., 2021). This can disturb the ongoing incubation period, which could lead to different outcomes in the sex ratio.

## 3.2 Sex ratio of the Hawksbill Turtle

The sex of hawksbill turtle offspring is determined by environmental temperatures during the incubation period. The pivotal temperature, the temperature where 50% females and 50% males are born, is around 29 degrees Celsius (Ge et al., 2018). Above this pivotal temperature, mostly females are born, and below the pivotal temperature, mostly males are born. Thus, a small change such as 1°C or 2°C can make a significant difference in the sex ratio of a litter. (Ge et al., 2018). Sex is determined in the middle third of the embryo's incubation period. (Mrosovsky & Yntema., 1980). Primary sex ratios vary between beaches, within clutches and over the course of a breeding season (Hawks et al., 2013).

The molecular mechanisms determining sex are still difficult to understand. Epigenetic markers such as DNA methylation and histone modifications of known regulators of gonal differences, have been found to differ between temperatures in species with temperature-dependent sex determination (Ge et al., 2018). The sex of turtles is probably determined by several genetic and molecular processes linked to temperature. The molecular pathway for temperature dependent sex determination in hawksbill turtles is currently unknown, but there is a good possibility that sex is determined for this species in the same way as in the study by Ge et al., (2018) as Hawksbill turtles and the species researched in the study by Ge et al. (2018) belong to the Testudinata taxon

### 3.2.1 Effects of temperature on sex ratio

It turns out that warm temperatures have an effect on the sex ratio of hawksbill turtle nests. Warmer temperatures lead to more females and colder temperatures lead to more males. (Hawkes et al., 2009, Chatting et al., 2021, Macrovaldi et al., 2014). Climate change may therefore cause a change in the sex ratio of nests. The current trend of increasing temperatures has a great influence on this.

Chatting et al. (2021) projected hawksbill turtle incubation temperature in the Arabian/Persian Gulf from 1993 to 2100 using air temperature and statistical models. The results predicted that there were more female offspring throughout the study period. In addition, the data from this study forecasted a gradual increase in female offspring from 1993 to 2100. Poloczanska et al. (2009) indicated that rising temperatures may decrease, or eliminate, the occurrence of males.

Macrovaldi et al. (2014) projected the sex ratio of hawksbill turtles in Brazil. This study was conducted in northern Bahia (BA) and southern Rio Grande do Norte (RN). In this study, the sex ratio was determined by the relationship between incubation duration and sex ratio derived from laboratory experiments. This was used to convert the duration of incubation of a nest into the relationship between number of young and sex. In doing so, the researchers took into account an addition of 4 days to account for the interval between hatching, which occurs in naturally hatching sea turtle nests. The results of this study predicted that 96% of nests from BA consisted of females, and 89% in RN. In addition, it was observed that a higher percentage of males hatched at the end of the nesting season. Diez and van Dam (2003) found 2.4 tot 7.7 times more females than males in Caribbean hawksbill turtles, suggesting that 69% to 89% of the juvenile population sampled, was female.

### 3.2.2 Sex ratio of adult turtles and implications for reproduction

At population level, these skewed sex ratios can potentially lead to an Allee effect if too few reproductively active individuals are present (Allee., 1931). The Allee effect ensures that when small populations fall below a critical limit, they can only decline further until they become extinct. The reason for this is that the encounter rate between partners becomes so low that they can no longer find each other. It is also possible for the fitness of a population to decline due to inbreeding depression. Adverse recessive-homozygous traits then become more common within a population. (Van Straalen., 2020).

León and Diez (1999) found in Jaragua national park in the Dominican Republic, a foraging population of the hawksbill sea turtle. This population contained mostly juveniles and sub-adults. Within this population, the sex ratio was 2.71:1 for females. Thus, more females were present than males. Thus, it appears that a bias for females in the nest continues into the juvenile and sub-adult stages. Hays, Mazaris and Schofield (2014) examined the differences in reproductive periods between males and females. Results showed that 76% of males returned from their foraging grounds to their breeding bay within 1 year, compared to 0 females who returned within one year. In addition, the distance between breeding ground and foraging ground was found to be greater in individuals that did not return to breeding ground annually. This study shows that male hawksbill turtles breed more frequently than females. Which can translate into more balanced sex ratios between the adult turtles.

## 3.3 Diet of the Hawksbill turtle

The hawksbill turtle forages in several habitats with soft and hard bottoms in the tropics. (Brandis et al., 2014). The study by Brandis et al. (2014) shows the diet of the species in Seychelles. It shows that the hawksbill turtle mainly feeds on sponges, nettles, chordates and molluscs. The sponges belonged exclusively to the class of Demospongiae. Nettles were all of the class Anthozoa (flower animals) consisting of hard coral, soft coral, coranemones. Besides animal species, the hawksbill turtle also feeds on several plant species as this study also showed. For example, seaweeds and sea grasses were observed. However, the diet of *E. imbricata* consists 95% of sponges and other sessile invertebrates. Macroalgae occupy only a small portion of the diet.

Although the diet of hawksbill turtles is similar worldwide, it appears that there are differences between different populations. For example, Bell's (2012) study showed that turtles near the Howick Reef in Australia fed mainly on algae. Red algae, green algae and brown algae were 72.7% of the entire diet. The rest of the diet consisted of sponges (10.4%), soft corals and in vertebrates (12.6%)

and inorganic material (5.4%). A diet consisting mainly of algae is atypical for the species. But due to the global decline in quality in corals, seagrass habitats may become more important for the species (Bjorndal & Bolten., 2010). Bjorndal and Bolten concluded from examining the quality of seagrass meadows as habitat for the hawksbill turtle, that seagrass meadows can support healthy and productive hawksbill populations. But it is currently a small part of the diet of some populations.

Because the diet of the species varies widely among oceans, first the effects of temperature and sea level rise on the largest (shared) food source for the species, sponges, algae and coral, are examined. Subsequently, the possible consequences of these interactions on the diet of Hawksbill turtles are outlined.

### 3.3.1 Effects of climate change on food sources of the Hawksbill turtle

#### 3.3.1.1 Sponges

*Temperature*

Strano et al. (2022) experimentally exposed the species *Crella incrustans* to a marine heat wave with temperatures expected to occur over the next 40 years. This assessed changes in physiology, morphology and "recruitment" of the species. The results show that average temperatures predicted for the next 40 years do not directly affect the physiology of *C. incrustans*. Sponges exposed to + 2.5 °C above the current average temperature showed no changes in sponge respiration rate and morphology. But exposure to a simulated marine heat wave with temperatures of + 4 °C above the seasonal mean temperature increased respiratory frequency significantly. This indicates a stress response to temperature. In addition, signs of tissue necrosis were apparent at 22°C, and all individuals showed progressive tissue regression upon a sudden temperature increase.

According to Luter and Webster (2017) climate change can affect changes in the microbiome of sponges. This could lead to mass sponge mortalities, as have been seen during abnormally high sea water temperatures. The direct cause still needs further research, but Luter and Webster expect that an elevated seawater temperature has the largest impact on the health of sponges. Although there has been no research to date that linked the effects of climate change on sponges to the Hawksbill turtle, an effect seems likely when sponges die due to a higher disease incidence or rising temperatures.

#### 3.3.1.2 Algae

*Temperature*

The temperature-growth range of algae is important because it determines the range over which the algae are metabolically active and their distribution. Different algal species have different tolerances and physiological responses to temperature changes. (Teoh, Chu & Phang., 2010). According to the research of Li (1980), algae can survive extreme habitats with temperatures ranging from -2°C in the arctic, to 75°C in thermophilic hot springs. The response of algae to changes in temperature is quite different among species. In doing so, changes in temperature also determine the abundance and distribution of an algal species. The study by O'Connor (2009) showed that increasing temperature led to a 100% decrease in the average daily growth of algae, consumed by herbivores, at higher temperatures. Poore at al. (2012) stated that climate stressors can affect the strength of plant-herbivore interactions through changes in the sensitivity of plant tissues to herbivores. Indirect effects of increased temperature or $pCO_2$ on marine herbivores may occur if these stressors affect the composition of algal or seagrass tissues, and thus their quality as food.

#### 3.3.1.3 Coral reefs

Observations made in the study by Goatley, Hoey and Bellwood (2012) show that adult hawksbill turtles actively seek and eat leathery macroalgae when available on coral reefs. Bleached corals have reduced growth rates, reduced reproductive capacity, increased disease susceptibility and increased mortality rates. (The Nature Conservancy, s.d.).

*Temperature*

Increased water temperatures and strong sunlight cause thermal stress to corals. This can disrupt normal photosynthetic processes of small unicellular algal species (zooxanthellae) that live in symbiosis with corals. This disruption leads to coral bleaching. (The Nature Conservancy, s.d.)
Coral bleaching caused by thermal and environmental stress threatens coral reefs (McClanahan et al., 2007).
At temperatures above normal summer maximum, zooxanthellae can easily become overwhelmed by incident light. This leads to the production of reactive oxygen species, leading to oxidative stress in the coral's tissues. In response, the coral expels zooxanthellae to reduce or prevent further tissue damage. (The Nature Conservancy, s.d.)

*Sea level rise*

The definition of coral reef growth is the net accretion of reef structure, resulting from the growth of reef builders (corals, calcareous algae and crustaceans), over time and the accumulation and transport of loose sediments, balanced against erosion by physical and biological processes. Reef development is highly dependent on a balance between changes in sea level. (Camoin & Webster, 2015).
There are 3 possible reef growth models that represent the potential response to rising sea levels.

1. The keep-up model consists of reefs that grow as soon as the substrate is inundated. These develop simultaneously with a rise in sea level.
2. The 'catch-up' model is typical of reefs that showed a lag during development, and then caught up with sea level as sea level rise slowed.
3. The 'give- up' model consists of reefs that failed to catch up with sea level. These reefs drowned. (Neumann & Macintyre., 1985).

At slower rates of rise, reefs, if not constrained by other factors such as temperature or substrate, can recede. In this process, the reef re-establishes itself in a more inland location than the previous reef. The responses of coral reefs to sea-level rise vary widely within the same system. (Neumann & Macintyre., 1985). According to Montaggioni (2005) a complete reef system can be characterized as a reef that keeps up with or overtakes sea level rise.

### 3.3.2 Possible effects of climate change-induced alterations in food sources on Hawksbill turtle diet

According to Peck's (2005) research, organisms have a limited number of responses that enhance survival in changing environments. These are (1) coping with change using internal physiological flexibility, (2) evolving adaptations for the new conditions, or (3) migrating to areas where survival rates are higher. If organisms fail to adapt or migrate, the species will go extinct.

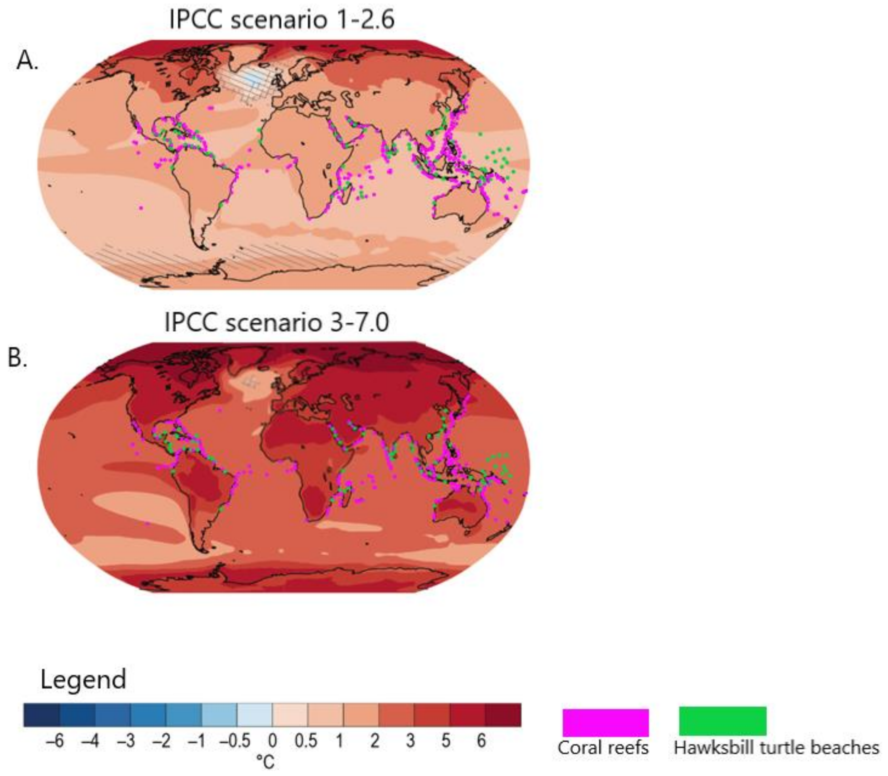
#### 3.3.2.1 Sponges

Studies on the effects of declining sea sponges on turtles have not yet been done. It can be expected that at a slight increase of + 2.5 °C, little change will occur. This is because no changes in morphology and respiration rates take place in sea sponge populations. Therefore, an increase in this temperature will have little to no effect on the survival of the turtle species. With an increase of +4°C, a stress response is observed in marine sponges, which can lead to tissue necrosis. This tissue necrosis could cause reduced reproduction (Strano et al., 2022). This reduced reproduction could lead to a decrease in numbers of sea sponges. A decrease in sea sponge populations could possibly result in insufficient food being available on foraging areas. This would force populations to migrate, or alternatively to change their diet. But these possible effects on Hawksbill turtle behaviour has not been researched yet.

### 3.3.2.2 Algae

As with marine sponges, the effects that will occur in the diet of algae depend on the species, and how much the temperature will rise. Thus, changes may occur in the distribution and numbers of the species the hawksbill turtle feeds on. This may cause fewer algae to occur, forcing the hawksbill turtle to adjust its diet or migrate to another foraging area where these algae are still present in large quantities. In addition, it is possible that the quality of food will be affected. As a result, individuals will have to feed more on the algae to get enough nutrients.

*Figure 4 Globally expected temperature increases combined with locations of Hawksbill nesting beaches and Coral reefs.*




*Hawksbill nesting beaches a represented as green dots and coral reefs are represented as purple dots.*
***Temperature information obtained from**: Figure 4.12 in IPCC, 2021.*
***Hawksbill turtle locations obtained from:** (Network for Endangered Sea Turtles, 2016)*
***Coral reef data obtained from:*** (National Oceanic and Atmospheric Administration, s.d.)

### 3.3.2.3 Corals

Coral bleaching causes a decrease in zooxanthellae on the coral (Saravanan, Lakshmanan, Jasmine and Joshi., 2017). This decrease may cause less coral to be available to the turtle as a food source. With the predictions for temperatures rising this could mean that in certain places, that the hawksbill turtle will no longer be able to feed from these zooxanthellae. A prediction of these locations could be made according to the suspected change in temperature. According to the IPPC scenario's SSP1-2.6 and SSP3-7.0.

According to scenario SSP3-7.0 highest change in annual mean temperature will happen around North Africa and Saudi Arabia. This higher annual mean temperature and high level of sunlight could lead to more thermal stress for the corals present. This thermal stress will disrupt the normal photosynthetic process of zooxanthellae in the coral. This disruption will then lead to coral bleaching. During high temperatures the zooxanthellae can also become overwhelmed. This led to the production of reactive oxygen species, which in turn leads to oxygen depletion and expulsion of zooxanthellae of the coral. (Reef resilience network s.d.)

This could force hawksbill turtle populations to change their diet or migrate to foraging grounds where these coral reefs are still available.

The effects of sea level rise and how a coral reef responds are difficult to determine. Any effects on the hawksbill turtle from this would need to be better studied. It is quite possible that some reefs could drown. This would result in the hawksbill turtle no longer being able to use these reefs. In addition, reefs may possibly expand. This will most likely have a positive effect on the foraging behaviour of the species.

Coral reefs can be found between the 30 degrees North latitude and 30 degrees South latitude on the world (National Oceanic and Atmospheric Administration, s.d). This can be seen in figure 4. Figure 4 also shows the occurrence of the Hawksbill turtle around the world. These images show that the areas where hawksbill turtles and coral reefs are presents are located between North and South America, Indonesia and Australia. When looking at this figure, it becomes clear that most Hawksbill turtles locations are close to coral reefs. It also becomes clear that both the turtles and reefs are present in regions where temperature is expected to rise the most.

# Chapter 4 Discussion

The results show that the survival of the Hawksbill turtle can be influenced by several different factors of climate change.

## 4.1 Nest sites

As stated in the results, hawksbill turtles select nest sites with specific vegetation. Most nests laid by this species are located on spots where there is at least some vegetation. But females that choose the nesting site have individual preferences in where they lay the nest. This could possibly determine the sex ratio of their offspring (Kamel & Mrsosvsky., 2006), because a female could choose to lay her eggs in a location with more vegetation cover. That would lead to a lower temperature in the nest, compared to nests that are placed at a location with less vegetation cover. The individual preferences for vegetation could have an evolutionary importance. It is an evolutionary advantage that more male offspring hatch. This will increase the genetic diversity within the population. This can change the individual preference for nesting places, in females, as more males hatch in nests with lower temperatures. Females with a preference to lay their eggs in places without shade or vegetation can potentially have an evolutionary disadvantage, causing this preference to eventually disappear.

The study of Staines et al. (2020) showed that rainfall can lower nest temperatures and thus alter the sex ratio of hawksbill turtle nests. This result is comparable to other research such as Wyneken and Lolavar (2015), which stated that the development of turtle embryos is correlated with environmental variables, such as rainfall and temperature. In this study Wyneken and Lolavar looked at the species *Caretta caretta* and found that more males were produced in years with more rainfall, even if the temperature was above the pivotal temperature. This shows that rainfall events have a positive effect on the production of males in different turtle species.

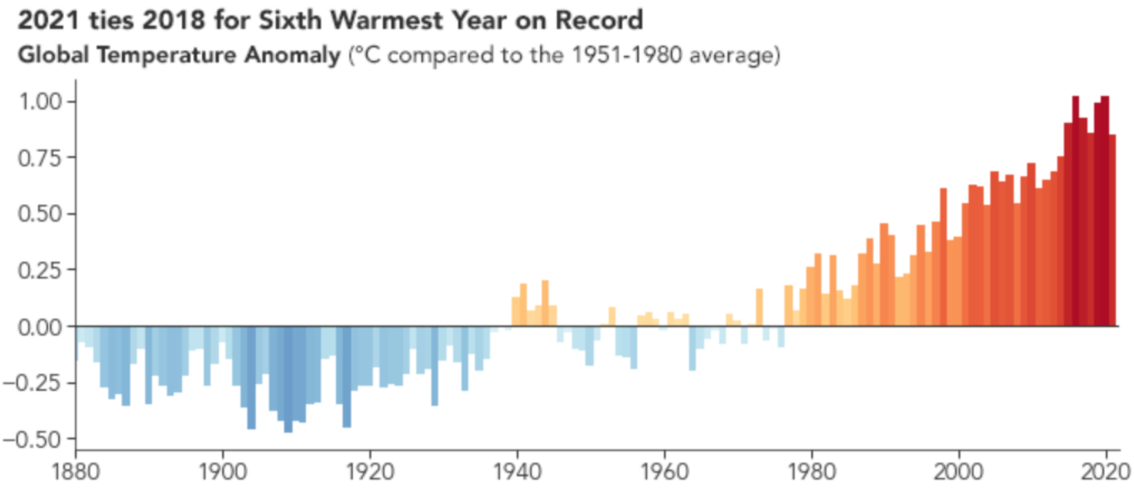
## 4.2 Sexratio

Many studies such as those by Hawkes et al. (2009), Chatting et al. (2021) and Poloczanska et al (2009) indicate that the increasing temperature expected in the coming years will cause more juvenile females than males. Nevertheless, sites are also found where equal sex ratios occur

Differences between the results of these studies may be due to different methods. The study by Diez & van Dam (2003) looked at testosterone levels and looked at the gonads in the abdomen. This differs from the method of the study by Chatting et al. (2021). During this study, nest incubation temperature was measured to give an indication of temperatures in the future, and in the past. The model of thermal reaction norm was then used, using maximum plausibility estimation based on collected incubation data.

The different methods of investigation may affect the results of the research done. In addition, it is quite possible that the different years in which the studies took place may also affect the results. The Diez & van Dam study was conducted from 1992-2000. In the study by Chatting et al. (2021), nest incubation temperature measurements were taken in 2016 and in 2017, which were then used to estimate the future and the past. Temperatures have increased since 1992. This can also be seen in Figure 5. This figure compares the temperatures per year with the average temperature from 1951 to 1980. In it, it can be seen that from about 1980 the temperature begins to increase. From about 2000 the temperature begins to rise more. This increase most likely influenced the differences in number of females : males in the studies of Diez and van Dam (2003) and Chatting et al. (2021).

*Figure 5. Rise in global temperature.*




*The average temperature per year compared to the average global temperature from the years 1951 to 1980. The years 1951-1980 do not necessarily appear warmer or colder than the other years because they were used as a standard against which the other years were compared. (NASA Earth Observatory, s.d.).*

The method used in many studies to determine the sex ratio of nests is by using temperature during incubation time and converting it to estimates. This is because physically examining for sex of juvenile hawksbill turtles results in death of individuals. Still, it is possible that there are errors in these estimates, and the sex ratios may be closer than thought, or the sex ratios may be even more skewed than thought. For correct numbers and ratios, it would be better to look at sex per juvenile, but this is difficult and harms the turtles.

Skewed sex ratios are (most likely) less present between adult individuals. This is partly because males reproduce twice as often as females. In addition, single males can fertilize many females and females can store the sperm of males and fertilize multiple clutches. One male can thus fertilize many eggs. (Hays, Mazaris & Scholfield., 2014). Thus, less males compared to females within a population will not cause immediate problems for the amount of nests that can be laid in one nesting season. And will thus not immediately lead to fewer offspring. The skewed ratios that occur when eggs hatch can thus be converted to a more balanced, operational ratio in sex (Hays, Mazaris & Scholfield., 2014). With the production of less males, a loss of genetic diversity is a high possibility. It also becomes possible that inbreeding within the species will increase. This inbreeding can eventually lead to a decrease in reproduction and survival and a decreased ability to adapt to climate- and environmental changes, which will increase the risk of extinction. (Ralls, Frankham & Ballou., 2014).

According to Hays et al. (2017), high temperatures may cause a point to be reached where almost no males are produced. In such a situation, allowing males to reproduce more frequently would have little impact on the population. Hays et al's. (2017) expectation, therefore, is that populations that now consist of 80% or more females have a real risk of extinction. Repeated exposure to conditions that promote highly skewed sex ratios may cause selection to restore the equilibrium sex ratio. In addition, this may also cause selection for other forms of sex determination or lead to population extinction. (Mitchell & Janzen., 2010). Population extinction could become a major problem for the species. The decreasing prevalence of the male sex may cause a loss in genetic diversity. In addition, there may be too few males to support the population. Populations that are already small may fall below the critical limit, and only further decline in numbers as a result. This will then most likely lead to the extinction of these small populations.

## 4.3 Diet

As outlined in the results, climate change has effects on coral reefs, and this can potentially affect the Hawksbill turtle. Although the consequences of coral bleaching for the Hawksbill turtle need further research, it is clear that the bleaching causes a decrease in zooxanthellae on the coral. Considering that on average 95% of the Hawksbill turtle's diet consists of sponges and invertebrates, coral bleaching need not have a big impact on the survival of the species. However, for local populations that depend more strongly on corals as a food source, bleaching may have a larger impact.

Another effect that a changing climate can have on coral reefs is a shift to a reef dominated by sponges (or algae). Bell et al., (2018) used models to assess the outcomes of reefs dominated by sponges. A shift towards a sponge dominated reef could occur if sponge abundance increases or if sponges exhibit high environmental resilience, which leads to a greater relative decline in coral abundance (Bell et al., 2018). A change in dominance can have many direct impacts on the ecosystem, such as a change in food availability for suspension feeding organisms.

A transition to a sponge dominance reef would cause the benthic community to shift from a dominance in phototrophic organisms towards a dominance in heterotrophic species. Next to that, a loss of biodiversity is also expected in sponge dominated reefs, due to a decline in habitats. In turn, this could reduce food availability to higher trophic levels (Bell et al., 2018). This could have an impact on the occurrence of the hawksbill turtle, as the food availability of zooxanthellae can change. Alternatively, an increase in the sponge community can also have positive effects for food availability. Nevertheless, the research of Bell et al. (2018) showed that the functional features of a sponge dominated reef are likely to vary between different geographical regions, and turtle populations do show differences in their diet (Bell, 2012). This could mean that some turtle populations have more disadvantages in food than other populations. For this, also more research is necessary.

Considering the research of Bell et al. (2018) which is based on a model, it is possible that the expectations may turn out differently than the model has calculated. This could be because the effects of climate change are hard to predict, due to the many factors being involved. Since no further research has been done on this, it is important that this be investigated further in the future.

It is also important to note that more research is necessary on the effects of climate change on sponges. Most of this research has been done in arctic regions. It is likely that sponges in tropic and subtropic waters have similar responses to longer periods of higher temperatures, but to accurately assess these impacts research needs to be executed.

Looking at all the research discussed in the results, it becomes clear that the literature that currently can be found has been assessed and used in this literary thesis, as during searches eventually no new literature could be found. It is clear that there are certain subjects where more research is necessary. This is the case for the possible effects of climate change on the diet of the Hawksbill turtle. Currently not much research has been done. This is definitely necessary for the effects of rising temperature on algae and coral reefs, and their indirect effects on the Hawksbill turtle.

# Chapter 5 Conclusion

In this thesis one main question with three sub questions where the centre of attention.

In this thesis the question: What is the effect of climate change on the nesting success, sex ratio and diet of the hawksbill turtle, *Eretmochelys imbricata*? was the centre of attention. To answer this question the three sub questions: what is the effect of temperature and sea level rise on the nesting of the hawksbill sea turtle?, What is the effect of an increase in temperature on the sex ratio of the hawksbill turtle? and What is the effect of temperature and sea level rise on the diet of the hawksbill turtle? will be answered in the following paragraphs.

**What is the effect of temperature and sea level rise on the nesting of the hawksbill sea turtle?**
Temperature and sea level rise affect the nesting sites of the hawksbill turtle. Although there are individual preferences among females for where to nest, it appears that they prefer sites that are (partially) shaded. This shade lowers the temperature within the nests, and thereby affects the sex ratio. A lower nest temperature could cause a higher production of males. This higher production of males could be important for the survival of the species. As a higher production of males will lower the loss of genetic diversity and the risk of extinction the species faces.
Rising sea levels mainly cause a decrease in beaches where hawksbill sea turtles can lay their eggs, but they also threaten the survival of nests, as rising sea levels can cause more nests to be flooded what influences the hatching success.

**What is the effect of an increase in temperature on the sex ratio of the hawksbill turtle?**
Warm temperatures influence the sex ratio of the Hawksbill turtle. Warmer temperatures lead to more females and colder temperatures lead to more males. With the projected increase in temperature, it becomes more likely that hawksbill turtle populations will nest more females than males. This is not an immediate problem as these skewed sexratios are less present between adults. Because males can fertilize multiple females, this need not lead to a decrease in offspring, but it will lead to a decrease in genetic diversity. It is also possible that a point will be reached, where the temperatures get so high that there is almost no production of males. When the point of no male production gets reached, the possibility of extinction increases drastically.

**What is the effect of temperature and sea level rise on the diet of the hawksbill turtle?**
The diet of hawksbill turtles exist mainly of sponges, algae and zooxanthellae in coral reefs. The predicted higher temperatures will become a problem for sponges when temperatures of +4 °C above the seasonal mean are reached. This will lead to stress responses, tissue necrosis and reduced reproduction. Abnormally high sea water temperatures can also cause changes in the microbiome of sponges which will then lead to mass sponge mortalities. A decrease in sponge populations could lead to insufficient food availability in foraging areas, forcing hawksbill populations to migrate or change their diet.
Response of algae species to changes in temperature is different between species. Too high temperatures can lead to a decrease in their growing rate. Climate stressors can affect plant-herbivore interactions and also the quality of algae as food. It can be expected that with the increasing temperatures, changes will occur in the distribution and numbers of algae species. This could cause a migration in the foraging places for hawksbill turtle populations. It is also likely that the quality of algae as a food source decreases, causing that individuals will have to eat more algae to get the nutrients they need.
Temperature and sea level rise both affect coral reefs and their zooxanthellae. Increased water temperatures and strong sunlight cause thermal stress, which disrupts the normal photosynthetic process. This led to coral bleaching. Zooxanthellae can easily be overwhelmed at temperatures above normal summer maximum, causing oxidative stress in the coral’s tissue which then leads to zooxanthellae expulsion. This could cause less zooxanthellae to be available as a food source. In the worst-case scenario, coral reefs will be lost forcing hawksbill turtle populations to migrate to different locations. Or to change their diet.

Thus, the answer to the main question; What is the effect of climate change on the nesting success, sex ratio and diet of the hawksbill turtle?
Climate change will lead to a change in nesting beaches and places. Warmer temperatures will lead to sex ratios skewed towards females. This need not necessarily form an immediate problem for the production of Hawksbill turtle offspring, but it could lead to a decrease in genetic diversity. The changes in climate will most likely also change the diet or foraging grounds of the Hawksbill turtle populations.

# Chapter 6 Recommendations

In this chapter recommendations for both the short term and long term, to protect the hawksbill turtle against climate change, will be discussed. Short term recommendations are quickly applicable protectants, this will also discuss where more research is necessary. Long term recommendations exist of protective measures that have long-term effects.

## 6.1 Recommendations for short term

Recommended is that when nests are located in places with little to no vegetation, these nests will be covered with artificially created shade. This can be done simply by covering the nest with a light-coloured cloth. The creation of shade will cause the temperature inside the nest to go down. When the temperature lowers there is a higher possibility for males to hatch from these nests. It is also possible to move the nest to another location on the beach, with more shade or vegetation cover. This will have the same effect, but more labour is necessary for this as all the eggs have to be dug out of the nest and a new nest will have to be created.

It is also recommended that nests found close to the shore are moved further away. The moving of the nest will make sure that the nest is not flooded in times of high water.

It is also important to conduct more research especially concerning the effects of rising temperatures on the diet of the Hawksbill turtle, and how this is linked to their survival. This research is also necessary for the effects of the rising sea level on the diet and thus survival of the species.

## 6.2 Recommendations for the long term

A recommendation for the long term is to create more marine protected areas around the world. These areas are geographically distinct zones for which protection objectives are set. In these areas impacts of humans and fisheries are not permitted (EEA - European Environment Agency, s.d.). Although there are multiple of these areas around the world, there are still little present in the locations where both Hawksbill turtles and coral reefs are present. Because Hawksbill turtles count on coral reefs as foraging places it is important that not only the species is protected but also their foraging grounds. The places where both occur should be considered for marine protected areas.

## Literature list


1. Allee, W. C., (1931). *Co-Operation among animals.* American Journal of Sociology, 37(3), 386–398. http://www.jstor.org/stable/2766608
2. Bjorndal, K. A., & Bolten, A. B. (2010). *Hawksbill sea turtles in seagrass pastures: Success in a peripheral habitat.* Marine Biology, 157(1), 135–145. https://doi.org/10.1007/s00227-009-1304-0
3. Camoin, G. F., & Webster, J. M. (2015). *Coral reef response to quaternary sea-level and environmental changes: State of the science.* Sedimentology, 62(2), 401–428. https://doi.org/10.1111/sed.12184
4. Chatting M., Hamza S., Al-Khayat J., Smyth D., Husrevoglu S., & Marshall CD (2021) *Feminization of hawksbill turtle hatchlings in the twenty-first century at an important regional nesting aggregation*. Endang Species Res 44:149-158. https://doi.org/10.3354/esr01104
5. EEA - European Environment Agency. (s.d). *Marine protected areas - European Environment Agency (EEA)*. Accessed on 3rd April 2023, obtained from: https://www.eea.europa.eu/themes/water/europes-seas-and-coasts/assessments/marine-protected-areas
6. El Kafrawy, S. B., Said, R. E., Saber, S. A., Soliman, M. A., & Al Attar, N. M. (2020). *Using remote sensing and geographic Information system to assess the status of the nesting habitat of hawksbill turtles (Eretmochelys imbricata): At Big Giftun Island, Red Sea, Egypt*. The Egyptian Journal of Remote Sensing and Space Science, 23(1), 77-87. https://doi.org/10.1016/j.ejrs.2018.07.005
7. *: Figure 4.12 in IPCC, 2021: Chapter 4. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Lee, J.-Y., J. Marotzke, G. Bala, L. Cao, S. Corti, J.P. Dunne, F. Engelbrecht, E. Fischer, J.C. Fyfe, C. Jones, A. Maycock, J. Mutemi, O. Ndiaye, S. Panickal, and T. Zhou, 2021: Future Global Climate: Scenario-Based Projections and Near-Term Information. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 553–672, doi: 10.1017/9781009157896.006 .]*
8. FISH, M. R., CÔTÉ, I. M., GILL, J. A., JONES, A. P., RENSHOFF, S., & WATKINSON, A. R. (2005). *Predicting the Impact of Sea-Level Rise on Caribbean Sea Turtle Nesting Habitat.* Conservation Biology, 19(2), 482-491. https://doi.org/10.1111/j.1523-1739.2005.00146.x
9. Fox-Kemper, B., H.T. Hewitt, C. Xiao, G. Aðalgeirsdóttir, S.S. Drijfhout, T.L. Edwards, N.R. Golledge, M. Hemer, R.E. Kopp, G. Krinner, A. Mix, D. Notz, S. Nowicki, I.S. Nurhati, L. Ruiz, J.-B. Sallée, A.B.A. Slangen, and Y. Yu, 2021: Ocean, Cryosphere and Sea Level Change. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1211–1362, doi: 10.1017/9781009157896.011.
10. Fuentes, M. M. P. B., Bateman, B. L., & Hamann, M. T. (2011). *Relationship between tropical cyclones and the distribution of sea turtle nesting grounds.* Journal of Biogeography, 38(10), 1886–1896. https://doi.org/10.1111/j.1365-2699.2011.02541.x
11. Ge, C., Ye, J., Weber, C., Sun, W., Zhang, H., Zhou, Y., Cai, C., Qian, G., & Capel, B. (2018). *The histone demethylase KDM6B regulates temperature-dependent sex determination in a turtle species*. Science, 360(6389), 645 648. https://doi.org/10.1126/science.aap8328

12. Glen, F., & Mrosovsky, N. (2004). *Antigua revisited: The impact of climate change on sand and nest temperatures at a hawksbill turtle (Eretmochelys imbricata) nesting beach.* Global Change Biology, 10(12), 2036-2045. **https://doi.org/10.1111/j.1529-8817.2003.00865.x**
13. Goatley CHR, Hoey AS, Bellwood DR (2012) *The role of turtles as coral reef macroherbivores.* Plos one 7(6): e39979. https://doi:10.1371/journal.pone.0039979
14. Goodfellow, J. (2018, 14, November). *Why are Hawksbill turtles critically endangered?* Olive ridley project. https://oliveridleyproject.org/sea-turtles/why-are-hawksbills-critically-endangered#:~:text=Laamu%20Atoll%2C%20Maldives-,Hawksbill%20turtles%20are%20currently%20classified%20as%20Critically%20Endangered%20by%20the,8%2C000%20nesting%20females%20left%20globally.
15. Hawkes, L., Broderick, A., Godfrey, M., & Godley, B. (2009). *Climate change and marine turtles.* Endangered Species Research, 7, 137–154. https://doi.org/10.3354/esr00198
16. Gravelle, J., & Wyneken, J. (2022). *Resilient Eggs: Highly Successful Loggerhead Sea Turtle Nesting Sites Vary in Their Characteristics.* Frontiers in Ecology and Evolution, 10. https://doi.org/10.3389/fevo.2022.853835
17. Hesni, M.A., Tabib, M., & Ramaki, A.H. (2016). *Nesting ecology and reproductive biology of the Hawksbill turtle, Eretmochely imbricata, at Kish island, Persian gulf.* Journal of the Marine biological association of the United Kingdom, 96(7), 1373-1378. doi:10.1017/S0025315415001125
18. Hawkes, L., McGowan, A., Godley, B., Gore, S., Lange, A., Tyler, C., Wheatley, D., White, J., Witt, M., & Broderick, A. (2013). *Estimating sex ratios in Caribbean hawksbill turtles*: *testosterone levels and climate effects*. Aquatic Biology, 18(1), 9–19. https://doi.org/10.3354/ab00475
19. Hays, G. C., Mazaris, A. D., & Schofield, G. (2014). *Different male vs. female breeding periodicity helps mitigate offspring sex ratio skews in sea turtles*. Frontiers in Marine Science, 1. https://doi.org/10.3389/fmars.2014.00043
20. Hays, G.C.,Mazaris, A. D., Schofield,G and Laloë, J.O (2017) Population viability at extreme sex-ratio skews produced by temperature-dependent sex determination. *Proceedings of the Royal Society B: Biological Sciences*, *284*(1848), 20162576. http://doi.org/10.1098/rspb.2016.2576
21. Hernández-Cortés, J. A., Núñez-Lara, E., Cuevas, E., & Guzmán-Hernández, V. (2018). *Natural beach vegetation coverage and type influence the nesting habitat of hawksbill turtles (Eretmochelys imbricata) in Campeche, Mexico*. Chelonian Conservation and Biology, 17(1), 94-103. https://doi.org/10.2744/CCB-1280.1
22. Horrocks, J. A., & Scott, N. McA. (1991). *Nest site location and nest success in the hawksbill turtle Eretmochelys imbricata in Barbados, West Indies*. Marine Ecology Progress Series, 69(1/2), 1–8. http://www.jstor.org/stable/44634759
23. IPCC, 2007: *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp.
24. Kamel, S. J., & Mrosovsky, N. (2005). *Repeatability of nesting preferences in the hawksbill sea turtle, Eretmochelys imbricata, and their fitness consequences*. Animal Behaviour, 70(4), 819-828. https://doi.org/10.1016/j.anbehav.2005.01.006
25. Kamel, S. J., & Mrosovsky, N. (2006). *Inter-seasonal maintenance of individual nest site preferences in Hawksbill sea turtles.* Ecology, 87(11), 2947-2952. https://doi.org/10.1890/0012-9658(2006)87[2947:IMOINS]2.0.CO;2
26. Kamel, S.J. (2013). *Vegetation cover predicts temperature in nests of the hawksbill sea turtle: Implications for beach management and offspring sex ratios.* Endang Species Res 20:41-48. https://doi.org/10.3354/esr00489
27. León, Y. M., & Diez, C. E. (1999). *Population structure of hawksbill turtles on a foraging ground in the Dominican Republic.* Chelonian Conservation and Biology, 3(2), 230-236.

28. Li, W.K.W. (1980). *Temperature Adaptation in Phytoplankton: Cellular and Photosynthetic Characteristics*. In: Falkowski, P.G. (eds) Primary Productivity in the Sea. Environmental Science Research, vol 19. Springer, Boston, MA. https://doi.org/10.1007/978-1-4684-3890-1_15]
29. Luter, H.M., Webster, N.S. (2017). *Sponge disease and climate change*. In: Carballo, J., Bell, J. (eds) *Climate Change, Ocean Acidification and Sponges*. Springer, Cham. https://doi.org/10.1007/978-3-319-59008-0_9
30. Maneja, R. H., Miller, J. D., Li, W., Thomas, R., El-Askary, H., Perera, S., Flandez, A. V. B., Basali, A. U., Alcaria, J. F. A., Gopalan, J., Tiwari, S., Al-Jedani, M., Prihartato, P. K., Loughland, R. A., Qasem, A., Qurban, M. A., Falath, W., & Struppa, D. (2021). *Multidecadal analysis of beach loss at the major offshore sea turtle nesting islands in the northern Arabian Gulf*. Ecological Indicators, 121. https://doi.org/10.1016/j.ecolind.2020.107146'
31. Montaggioni, L. F. (2005). *History of Indo-Pacific coral reef systems since the last glaciation: Development patterns and controlling factors*. Earth-Science Reviews, 71(1-2), 1-75. https://doi.org/10.1016/j.earscirev.2005.01.002
32. Mrosovsky, N., & Yntema, C. (1980). *Temperature dependence of sexual differentiation in sea turtles: Implications for conservation practices.* Biological Conservation, 18(4), 271–280. https://doi.org/10.1016/00063207(80)90003-8
33. NASA Earth Observatory. (s.d.). *World of Change: Global Temperatures*. Accessed on 29th August 2022. Obtained from: https://earthobservatory.nasa.gov/world-of-change/global-temperatures
34. National Oceanic and Atmospheric Administration. (s.d.). *In what types of water do corals live?* National Ocean service. Accessed on 29 May 2023, from https://oceanservice.noaa.gov/facts/coralwaters.html
35. Neumann, A. C. (1985). *Reef response to sea-level rise: Keep-up, catch-up, or give-up.* In Proceedings of the fifth international coral reef congress Tahiti, 27 May-1 June 1985 volume 3: Symposia and seminars (A) (pp. 105-110). Antenne Museum-EPHE.
36. Network for Endangered Sea Turtles. (2016, 16 oktober). *Hawksbill (Eretmochelys imbricata) - Network for Endangered Sea Turtles*. https://www.nestonline.org/hawksbill-eretmochelys-imbricata/
37. O'Connor, M.I., (2009). *Warming strengthens an herbivore–plant interaction*. Ecology, 90(2), 388-398. https://doi.org/10.1890/08-0034.1
38. Peck, L. S., Clark, M. S., Clarke, A., Cockell, C. S., Convey, P., Detrich, H. W., Fraser, K. P. P., Johnston, I. A., Methe, B. A., Murray, A. E., Römisch, K., & Rogers, A. D. (2004). *Genomics: applications to Antarctic ecosystems. Polar Biology, 28(5), 351–365*. https://doi.org/10.1007/s00300-004-0671-8
39. Peterson, A. (2021). *Effects of Tropical Cyclones on Incubation and Hatch Frequency of Marine Turtles in Broward County, FL: An Exploratory Look for Potential Cues of Environmentally Cued Hatching (ECH).* Master's thesis. Nova Southeastern University. Retrieved from NSUWorks,. (45) https://nsuworks.nova.edu/hcas_etd_all/45.
40. Poore, A. G. B., Campbell, A. H., Coleman, R. A., Edgar, G. J., Jormalainen, V., Reynolds, P. L., Sotka, E. E., Stachowicz, J. J., Taylor, R. J. K., Vanderklift, M. A., & Duffy, J. E. (2012e). *Global patterns in the impact of marine herbivores on benthic primary producers.* Ecology Letters, 15(8), 912–922. https://doi.org/10.1111/j.14610248.2012.01804.x
41. Ralls, K., Frankham, R., & Ballou, J. (2014). *Inbreeding and Outbreeding*. Reference Module in Life Sciences. https://doi.org/10.1016/B978-0-12-809633-8.02152-X
42. Staines, M.N., Booth, D.T., Madden Hof, C.A. *et al*. Impact of heavy rainfall events and shading on the temperature of sea turtle nests. Marine Biology 167, 190 (2020). https://doi.org/10.1007/s00227-020-03800-z
43. Saravanan, Raju & Lakshmanan, Ranjith & Jasmine, Suryavamsi & Joshi, K K. (2017). *Coral bleaching: Causes, consequences and mitigation.* Marine Fisheries Information Service. Accessed on 29-05-2023, from:

https://www.researchgate.net/publication/320058030_Coral_bleaching_causes_consequences_and_mitigation

44. Strano, F., Micaroni, V., Davy, S. K., Woods, L., & Bell, J. J. (2022). *Near-future extreme temperatures affect physiology, morphology and recruitment of the temperate sponge Crella incrustans.* Science of The Total Environment, 823, 153466. https://doi.org/10.1016/j.scitotenv.2022.153466
45. Teoh, M. L., Chu, W. L., & Phang, S. M. (2010). *Effect of temperature change on physiology and biochemistry of algae: A review.* Malaysian Journal of Science, 29(2), 82-97.
46. Reef Resilience Network (s.d.). *Bleken van effecten* | *Reef veerkracht*. Accessed on 25th August 2022, obtained from:https://reefresilience.org/nl/stressors/bleaching/bleaching-impacts/
47. Van Straalen, N. M. (2020, 3 mei). *Allee-effect*. Ensie. Accessed on 3rd September 2022, obtained from: https://www.ensie.nl/nico-van-straalen/allee-effect
48. Von Brandis, R. G., Mortimer, J. A., Reilly, B. K., Van Soest, R., & Branch, G. M. (2014*). Taxonomic Composition of the Diet of Hawksbill Turtles (Eretmochelys imbricata) in the Republic of Seychelles.* Western Indian Ocean journal of marine science, 13(1), 81 91. https://www.ajol.info/index.php/wiojms/article/download/66534/110347
49. WWF. (z.d.). *Hawksbill Turtle | Sea Turtles | Species | WWF*. World Wildlife Fund. Accessed on 29-05-2023, from: https://www.worldwildlife.org/species/hawksbill-turtle
50. Wyneken J., & Lolavar,A. (2015) *Loggerhead sea turtle environmental sex determination: implications of moisture and temperature for climate change based predictions for species survival*. J Exp Zool B Mol Dev Evol 324(3):295–314. https://doi.org/10.1002/jez.b.22620
51. Yntema, C. L., & Mrosovsky, N. (1982). *Critical periods and pivotal temperatures for sexual differentiation in loggerhead sea turtles.* Canadian Journal of Zoology, 60(5), 1012–1016. https://doi.org/10.1139/z82-141

# Appendix I Search words

| search words | Search engine |
|---|---|
| **Nesting behaviour hawsbill turtle** | Google scholar |
| **Nesting behaviour hawsbill turtle** | Google |
| **Hawksbill turtle nesting** | Green i |
| **Nesting hawsbill turtle and sea level rise** | Google scholar |
| **Hawksbill turtle nesting and temperature** | Google scholar |
| **Tidal changes on nesting hawksbill turtle** | Google scholar |
| **Sea sponges and climate change** | Google scholar |
| **Sea sponges and sea level rise** | Google scholar |
| **Migratory behaviour hawksbill turtle during climate change** | Google scholar |
| **High temperature on nesting places hawksbill turtle** | Google scholar |
| **Changing currents on nesting hawksbill turtle** | Google scholar |
| **temperature changes on nesting hawksbill turtle** | Google scholar |
| **Sex ratio hawksbill turtle** | Google scholar |
| **Seksratio karetschildpad** | Google |
| **Sexratio eretmochelys imbricata** | Google scholar |
| **Sexratio turtles** | Google scholar |
| **Hoe werkt seksratio bij schildpadden** | Google |
| **Sexratio eretmochelys imbricata** | Green i |
| **Sexratio on reproduction hawksbill turtle** | Google scholar |
| **Sexratio hawksbill turtle on adults** | Google scholar |
| **Sexratio hawksbill turtle adults** | Green i |
| **Karetschildpad** | Google |
| **Hawksbill turtle ecology** | Green i, WUR |
| **Hawksbill turtle climate change** | Science direct, Google scholar |
| **Hawksbill turtle diet** | Science direct, Google scholar |
| **Eretmochelys imbricata voorkomen** | Google, Google scholar |
| **Habitat eretmochelys imbricata** | Science direct, Green i, Wiley |
| **Voorkomen karetschildpad** | Google |
| **Voorkomen karetschildpad eretmochelys imbricata** | Google, Google scholar |
| **Climate change in tropical seas** | Google scholar, Green i, Wiley, Science direct |
| **Climate change in tropical beaches** | Google scholar, Green i, Wiley, Science direct |
| **Diet hawksbill turtle** | Google scholar |
| **Foraging Hawksbill turtle** | Google scholar |
| **Diet of adult Hawksbill turtle** | Google scholar |
| **Sea sponges** | Google |
| **Effects of temperature on sea sponges** | Google scholar, Science direct |
| **Effects of temperature on sea sponges in tropical seas** | Google scholar, Science direct, Wiley |
| **Rising temperature on sea sponges** | Green i, Wiley, Google scholar |
| **Rising temperature on ocean algae** | Green i, Wiley, Google scholar |
| **Rising temperature on the abundance of ocean algae** | Google scholar |
| **Rising temperature on nesting places hawksbill turtle** | Wiley + Google scholar |
| **Rising temperature effects on coral** | Google scholar |

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|---|---|
| **koraalverbleking** | Google |
| **Rising sea level on coral reefs** | Google scholar |
| **Coral bleaching** | Google |
| **Long term protection hawksbill turtles** | Google |
| **Long term protection measures for hawksbill turtles** | Google |
| **Hawksbill turtle nesting beaches map** | Google Images |
| **Why return male hawksbill turtles to their breeding grounds** | Google |
| **What sponges do hawksbill turtles eat** | Google |
| **Breeding locations hawksbill turtles** | Google |
| **waar paren hawksbill turtles** | Google |
| **Nesting places hawksbill turtles** | Google |
| **Nesting beaches hawksbill turtle preferences** | Google scholar |
| **Hawksbill turtle nesting beaches** | Google |
| **Hawksbill turtle nesting beaches preferences** | Google scholar |
| **Temperature changes on marine sponges** | Google |
| **2.5 change in temperature on sea sponges** | Google scholar |
| **Coral reef sponges list of species** | Google+ Google scholar |
| **Encrusting sponges** | Google |
| **Vase sponges** | Google |
| **Coral reef sponges species** | Google |
| **sea sponges necrosis and temperature changes** | Google scholar |
| **Coral** | Wiley |
| **Protection measures coral reefs** | Google |
| **sea level rise on coral reefs** | Google scholar |
| **Catch up model for coral reefs** | Google+ Google scholar |
| **How does a lag in coral development happen** | Google scholar |
| **Lag in coral development why** | Google scholar |
| **Lag in coral development** | Google scholar |
| **sea level rise on coral reefs** | Google scholar + Wiley |
| **Map of coral reefs in the world 2020** | Google |
| **Map of coral reefs in the world** | Google |
| **Map of coral reefs in the world 2023** | Google |
| **Coral reef sponges list of species** | Google |
| **Climate change on algae** | Google scholar |
| **Sea temperature changes around the world** | Google |
| **Temperature around the world in 2050** | Google |
| **IPCC rapport** | Google |
| **Prediction sea temperature rise around the world** | Google + Google scholar |
| **Karetschildpad en koraal kaart** | Google |
| **Karetschildpad en koraal** | Google |
| **Voorkomen koraaletende karetschildpad** | Google |
| **Sexratio's on sperm competition hawksbill turtle** | Google scholar |
| **Impacts of skewed sex ratios on sperm fertility hawksbill turtle** | Google scholar |
| **Sea surface temperature** | Google |
| **World sea surface temperature predictions** | Google |

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|---|---|
| **Sea temperature rise around the world** | Google |
| **Temperature rise around the world** | Google |
| **Highest temperature rise for the future map** | Google |
| **Highest temperature rise map** | Google |
| **Temperature on marine sponges** | Google+ Google scholar |
| **Temperature on sponge morphology** | Google scholar |
| **Sea level on hawksbill turtle** | Google |
| **Rising sea level on nesting hawksbill turtle** | WUR |
| **Maturation time hawksbill turtle** | Google |
| **Hawksbill turtle in cold climate** | Google |
| **Aantallen hawksbill turtle** | Google |
| **WWF hawksbill turtle** | Google |
| **Hawksbill turtle voortbestaand** | Google |
| **How do sponge dominated reefs function** | Wiley |
| **Climate change and marine turtles** | Google+ Google scholar |
| **Eretmochelys imbricata & climate change** | Green i, Wiley, Google scholar |
| **Eretmochelys & conservation** | Google scholar |
| **Eretmochelys imbricata & climate change & conservation** | Green i, Wiley, Google scholar |
| **Eretmochelys imbricata sex ratio** | Green i, Wiley, Google scholar |
| **Eretmochelys imbricata sex ratio & climate change** | Wiley, Google scholar |
| **Eretmochelys imbricata migration** | Wiley |
| **Eretmochelys imbricata migration and climate change** | Green i, Wiley, Google scholar |
| **Eretmochelys imbricata diet** | Google scholar, Green i |
| **Eretmochelys imbricata diet & climate change** | Google scholar, Green i |
| **Tropical storms** | Google+ Google scholar |
| **Tropical cyclones and climate change** | Google scholar |
| **Climate change and tropical cyclones on oceans** | Google+ Google scholar |
| **How does a cyclone disturb a turtle nest** | Google |
| **Betekenis cyclone disturbance** | Google |
| **IPCC tropical cyclones** | Google |
| **Marine protected areas** | Google |
| **Ecology Hawksbill turtles** | Google scholar+ Wiley |
| **Manipuleren nest temperatuur hawksbill turtle** | Google scholar+ Wiley+ Google |