The sensitivity of sea turtles (*Cheloniidae*) regarding temperature-dependent sex determination in relation to global warming

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The sensitivity of sea turtles (*Cheloniidae*) regarding temperature-dependent sex determination in relation to global warming

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Preface

I, Sebastiaan Koelman, wrote this thesis about sea turtles. In my opinion it is important to preserve as many animal species as possible, even more so considered that we humans are the cause of the mass extinction event that is currently going on. Last year, whilst doing an internship in Australia I experienced first-hand how important and vital all animals are for the ecological balance on earth. During my internship, I worked with sea turtles and contributed to the conservation of those amazing animals. Climate change is a great threat to them and might even bring sea turtles to extinction on the short term. To further contribute to the conservation of sea turtles, I wrote this paper to determine the sensitivity of the sea turtles regarding TSD in relation to global warming.

For the support, I want to thank my teacher and coach, Roy Veldhuizen. For reviewing my paper to improve the quality, I want to thank my classmates and my second coach Martijn Hammers.

Enjoy reading!

Abstract

Climate change and global warming have a big impact on many animals that live on earth. Ice caps are melting, making polar habitats disappear, but the temperature rise has impact on other continents and oceans as well. Reptiles, which are ectothermic, are strongly affected by warmer environments since higher temperatures increase for example metabolic activity, leading to higher stress levels and mortality. In addition, many reptiles have temperature-dependent sex determination (TSD), which means that the sex of the offspring is determined by the surrounding temperature of the egg. Simply explained, there are two types, the first one being that at lower temperatures one sex develops and at higher temperatures the other sex develops. The other type gives rise to one sex when the temperatures are within certain temperature boundaries, and the other sex is developed when the temperature reaches out of those boundaries. Global warming will inevitably result in the development of one sex only for these reptiles. Sea turtles are a family within the reptile class that have TSD. Besides that, all seven sea turtle species are threatened under current circumstances, let alone in the future where the hotter climate has an increased impact on these species.

In this paper, a literature study is performed to determine how vulnerable the different sea turtle species are to global warming, regarding the TSD, which may inform conservation management for these species. By considering five factors the sensitivity of the different sea turtle species to global warming was determined. These five factors are: IUCN conservation status, population size, type of TSD, life expectancy and TSD width. These five factors contribute to the sensitivity of sea turtles to global warming differently and therefore, are considered with varying importance. The outcome of this research is that the hawksbill turtle (*Eretmochelys imbricata*) is most vulnerable to climate change and the rise in temperature that comes with it. Future research and information are needed to keep track with the latest developments and to get a better understanding in the factors influencing the sensitivity of the sea turtles.

Samenvatting

Klimaatverandering en het opwarmen van de aarde hebben grote gevolgen voor veel dieren op aarde. Door het smelten van de ijskappen verdwijnen poolgebieden, maar de gevolgen strekken zich ook uit tot het vaste land en de oceanen. Reptielen, een ectotherme groep dieren, worden getroffen door een warmer klimaat doordat bijvoorbeeld hun metabolismesnelheid stijgt. Hierdoor leven ze minder lang. Bij veel reptielen wordt hun geslacht bepaald aan de hand van de omgevingstemperatuur van het ei. Dit fenomeen heet 'temperatuurs-afhankelijke geslachtsbepaling' en heeft twee types. Type één houdt in dat er bij lagere temperaturen één geslacht wordt ontwikkeld terwijl bij hogere temperaturen juist het andere geslacht zich ontwikkelt. Bij type twee ontwikkelt het ene geslacht zich tussen bepaalde temperatuur waarden, terwijl het andere geslacht zich ontwikkelt als de temperatuur buiten die waarden valt. De opwarming van de aarde zal er voor deze reptielen onvermijdelijk voor zorgen dat één van de twee geslachten zich niet meer ontwikkelt. Zeeschildpadden zijn een familie in de klasse reptielen en hebben TSD. Daarnaast worden alle zeven soorten zeeschildpadden bedreigd onder de huidige omstandigheden. Dit zal alleen nog maar erger worden in een toekomst waarin het klimaat negatieve effecten heeft op deze soorten.

Deze literatuurstudie is uitgevoerd om te bepalen welke van de zeven zeeschildpadsoorten het kwetsbaarst is voor klimaatverandering en de opwarming van de aarde en welke om die reden het dringendst hulp nodig heeft. Om dit te bepalen zijn er vijf factoren onderzocht; de IUCN conservatie status, de populatiegrootte, het type TSD, de levensverwachting en de TSD wijdte. Deze vijf factoren dragen allemaal op een andere manier bij aan de gevoeligheid van de zeeschildpadden en worden daarom ook niet allemaal even belangrijk geacht. De conclusie van dit onderzoek is dat de karetschildpad (*Eretmochelys impricata*) het meest gevoelig is voor klimaatverandering en de temperatuurstijging. Vervolg onderzoek is nodig om op de hoogte te blijven van de laatste ontwikkelingen en om een beter inzicht te krijgen in de factoren die een rol spelen in de gevoeligheid van de zeeschildpadden.

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1. Introduction

Over the past two decades it has become clear that climate change has a great impact on the planet and on all life that resides here (van Dorland, 1999; Bradford, 2017). Since the early 1900's, the planet's average surface temperature has increased by 1 degree Celsius (°C). If this trend continues at the current rate, the planet's temperature will have risen with an additional 2.2°C by 2100. This is thus a difference of 3.2°C since the early 1900's (Christiansen, Bois von Kursk, & Haselip, 2018). Changes in climate and global temperature are no new phenomena on earth and have occurred multiple times in the past, but never before has any rise of temperature occurred at such a fast rate (Foster, Royer, & Lunt, 2017).

Global warming is induced by greenhouse gasses blocking the radiated solar heat from leaving the planet, making this heat unable to escape the atmosphere (van Dorland, 1999). One of these greenhouse gasses is carbon dioxide (CO_2), which is released during the combustion of fossil fuels. Due to the burning of these fossil fuels, the concentration of CO_2 will keep rising in the upcoming years. Because of this increase of CO_2, the temperature on earth will inevitably rise even faster (Foster *et al*., 2017).

Next to an increasing amount of CO_2, the melting of ice caps increases the rate of global warming as well. The bright colour of the ice caps reflects sunlight back into space. This mechanism cools down the planet. The melting of ice caps transforms the ice into water, water has a darker colour than ice and therefore absorbs more solar radiation. The result of this process is that the rate of global warming increases even further ("Climate and Ice | UCAR Center for Science Education", 2019). Besides the increase of CO_2 and the melting of ice caps, there are more components that contribute to climate change and global warming. Examples of these other factors are deforestation and pollution (Brown, Saunders, Possingham, & Richardson, 2014).

An example of an animal that is greatly affected by climate change is the polar bear. Its habitat vanishes because sea ice is melting due to global warming. Furthermore, seals, which also depend on sea ice for their survival, are decreasing in number. Since these seals are included in the diet of polar bears, climate change threatens polar bears in multiple ways (Wiig, Aars, & Born, 2008).

Adaptation to a changing environment is often a slow process that depends on the generation time of the species. With a long generation time, the number of offspring produced is small, resulting in slower adaptation to climate change. Because of this, it is highly unlikely that organisms like the polar bear, will be able to adapt to this rapid global warming in time. However, when species are under great (selective) pressure, this evolutionary process may differ and even increase in speed (Schildhuizen, 2018). Nevertheless, at the current rate of global warming many species will go extinct because the species are not able to adapt in time (Radchuk *et al*., 2019). For this particular reason, measures are needed to protect these organisms against changing climate and the rise of temperatures.

Animals that depend on temperature for their survival are especially vulnerable to temperature change. Reptiles (*Reptilia*), a class within the animal kingdom, have temperature-dependent cellular and physiological functions.

For example, in most reptiles, the sexual differentiation of gonads is determined by temperature, the so-called temperature-dependent sex determination (TSD). This means that the sex of the hatchling is determined by the temperature of the surroundings of the egg. There are two types of TSD, type *I* and type *II*. Type *I* is subdivided into type *Ia* and *Ib* (figure 1). Type *Ia* indicates the development of more females with high temperatures and more males with low temperatures. Type *Ib* indicates more females with low temperatures and more males with high temperatures. Type *II* indicates the development of females only below and above certain degrees Celsius (for example below 32°C and above 36°C), and only males if the temperature is between those two values. (Norris & Carr, 2013)

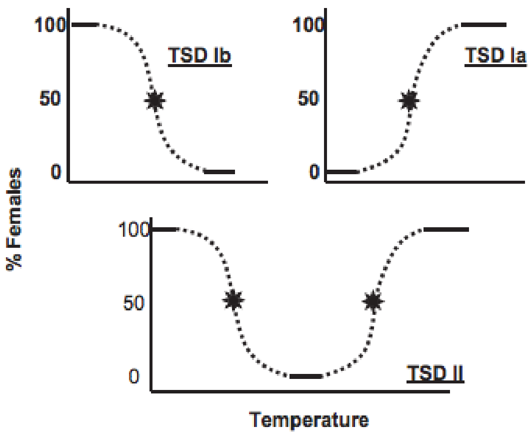


Figure 1; Temperature-dependent sex determination, type *Ia*, *Ib* and *II* (Valenzuela & Deeming, 2004)

Because the boundaries between males and females are so close to each other and the temperature on earth fluctuates between these boundaries, global warming will have a huge impact on these reptiles. Because the temperature will run away from one of the sexes, the few degrees the temperature will rise could, indirectly, be fatal for the reptile groups that use TSD for sex determination. The result is that one of the two sexes will no longer develop, which makes sexual reproduction impossible and will eventually result in the end of the species. (Norris & Carr, 2013)

Reptiles can grow very old, which could work in their advantage. For example, tuatara (*Sphenodon*) can live up to 200 years (Rout *et al*., 2013). This is helpful, because when one sex can no longer develop, these long-living animals are more likely to encounter multiple conditions favourable for the production of both sexes within their lifetime. Animals that live longer might also have more time to adapt to a new environment, by for example burying the eggs deeper into the sand, where the temperature is lower. Such a behavioural change might be more likely than a mutation that alters the genotype or phenotype of such long–lived species. Animals with a long lifespan usually have a long generation time, making changes caused by mutation less likely to occur and spread.

Rising temperatures accelerate the growth rate and causes thermal stress in reptiles. These two changes require high levels of metabolic activity, which can cause oxidative stress and eventually result in a faster ageing of individuals (Burraco, Orizaola, Monaghan, & Metcalfe, 2020). Due to this, the advantage of being able to grow old and using age as a buffer for changes, might lose functionality.

A possible positive effect of global warming for reptiles could be that they become more active. Since reptiles are ectothermic, their activity will increase with increasing temperatures. Possible benefits that come with this are that reptiles are more successful in finding food, finding a partner or in fight or flight mechanisms, simply due to the fact that they become more mobile.

Sea turtles (*Cheloniidae*) are a family within the class of reptiles, which includes seven species, the green sea turtle (*Chelonia mydas*), the hawksbill turtle (*Eretmochelys imbricata*), the flatback turtle (*Natator depressus*), the loggerhead turtle (*Caretta caretta*), the kemp's ridley turtle (*Lepidochelys kempii*), the olive ridley turtle (*Lepidochelys olivacea*) and the leatherback turtle (*Dermochelys coriacea*). All seven sea turtle species are marked as threatened or endangered species and for this reason, it is important to protect them against the impact of climate change. All seven sea turtle species have TSD and are therefore included in this paper (Hewavisenthi & Parmenter, 2002; Wibbels, Lutz, Musick, & Wyneken, 2003). The specification in different types of TSD between the seven species is described in chapter three (Results).

All sea turtle species share the same pattern regarding the reproductive cycle. Both males and females of the seven species migrate from the foraging areas to the mating areas, but migration distances differ between the species. Here, mating takes place, after which the males return to their feeding grounds. The females move on to lay the fertilized eggs in the nesting areas, after which they also return to the foraging areas. (Miller, Lutz, & Musick, 1997)

Due to climate change, powerful storms occur more often, destroying the habitat of the turtles. With rising sea levels, the beaches now used for egg laying may disappear, creating an obstacle for the sea turtle's reproduction. Furthermore, a rise in temperature changes the flow of the ocean, damaging the coral reefs some turtle species need to survive. ("Climate Change Puts Pressure on Sea Turtles", 2019)

Another negative impact of temperature rise is its effect on the TSD process of the sea turtles. When the temperature changes in such a way that only one sex will develop, the species as a whole could eventually go extinct. However, there is evidence that sea turtles can adapt to this form of climate change and so stall their demise, or even prevent extinction. Neeman, Robinson, Paladino, Spotila, & O'Connor (2015) showed in their research on leatherbacks that some individuals change the timing of nesting in response to changing temperature. This suggests that in the case of the leatherback, sea turtles are, up to a certain point, able to cope with the changing temperature. However, there is no doubt that a global temperature rise will be harmful for all sea turtle species (Fuentes *et al.*, 2009).

As indicated before, animals that rely on TSD for sex determination, such as sea turtles, will suffer from global warming and therefore need help, but it is not yet known whether it will affect the species differently. The aim of this paper is to determine which of the sea turtle species is most sensitive for temperature change, and why, and is therefore most in need of help. The research question is as follows: 'Why are some of the considered sea turtle species more sensitive to a rise in temperature than others, regarding the temperature-dependent sex determination and therefore, on the short term, require the most support for their survival?'

To determine which species are most in need of aid, the fitness of the sea turtles at high temperatures must be considered (regarding the TSD). However, the availability of this information is very limited (Peck *et al*., 2009). The following sub questions are drawn up to further investigate this topic and to be able to provide a well-funded answer to the research question.

- What are the current IUCN statuses of the selected sea turtle species?
- What is the current population size of each of the selected sea turtle species?
- Which type of TSD does each of the selected sea turtle species have?
- What is the life expectancy of each of the selected sea turtle species?
- What is the TSD width of each of the different members of the sea turtle (*Cheloniidae*) family?

It is expected that the rise in temperature is a great threat for all included species. Considering the fact that climate change will not be distributed equally over the planet, the hypothesis is that the species with the smallest habitat and thus the least possibilities to shift locations, will be affected the most by global warming (Eckstein, Künzel, Schäfer, & Winges, 2019). The two sea turtle species that have the smallest habitats are the kemp's ridley turtle and the flatback turtle and for that reason, it is expected that these two species will be most sensitive to a rise in temperature ("Sea Turtle | Species | WWF", n.d.).

The insights of this report may be used by organizations that aid sea turtles to improve their efforts by selecting the species that are most in need of protection. The IUCN already has a list on which the conservation status of animal species is shown, but since this paper takes both the IUCN status and the specific TSD processes into account (which the IUCN does not). It might be more valuable for the aid of sea turtles specifically because it gives additional insight into the threats the different sea turtles face.

In chapter two, the methods are discussed and choices that were made are explained. In chapter three, the results are presented. In the discussion and conclusion, chapter four and five, the results are discussed and the research questions are answered. There will also be some recommendations and suggestions for future research here. Finally, there will be a reference list (chapter six).

2. Method

In this chapter, the used methods are discussed and the reasons behind the choices that were made are elaborated on. Furthermore, it is explained how the results are acquired and what requirements the species must meet in order to be included into this paper.

2.1. Chosen species

As explained in the introduction, reptiles suffer from climate change. Temperature-dependent sex determination plays a big part in this threat. To prevent exclusion of species, the choice was made to include one whole family, the sea turtle family (*Cheloniidae*). All members of the sea turtle family have TSD, which makes them ideal for this research. Furthermore, all seven sea turtle species are either threatened or endangered, which makes the urge to aid them even more profound ("Sea Turtle | Species | WWF", n.d.). The outcome of this research, namely which of the seven sea turtle species is most in danger, can be used by organizations that are trying to protect sea turtles, for example by clarifying where the conservation money is best spent.

2.2. Literature

For the chapter introduction and method, scientific publishments that are peer reviewed could be used. The literature could not be older than 25 years and thus had to be published in 1996 or later. This decision was made to ensure information is still relevant. After 25 years the chance of information becoming outdated is substantial. The literature that was used for the results had to be published after 2009, meaning that publications before 2010 were not considered. Developments in this area of research on climate change and the interaction with species is changing rapidly and thus publications older than 10 years are considered less accurate. An exception was made for information acquired on TSD. The only way a species can change their TSD is through evolution and as mentioned in the introduction, these kinds of processes are in most cases very slow processes. For this reason, all literature used for determining the TSD of the seven species had to be from 1980 or later. The information determining the population sizes and life expectancy could also be as old as 1980, because these are also factors that do not change rapidly. When literature met the requirements set, it could be used for this paper.

Scientific books that are peer reviewed could be used too, as well as relevant websites. Relevant websites are web pages which are owned by professional companies regarding climate and animal welfare (WWF, Greenpeace, IUCN, etc.). A book or relevant website is met with the same restrictions, regarding the year of publication, as the scientific publishments described in the previous paragraph.

Both forward reference searching and backward reference searching (or chain searching) was used.

2.2.1. Keywords

Temperature-dependent sex determination, TSD, climate change, reptile species, population size, IUCN, red list, life expectancy, global warming, temperature rise, green sea turtle, hawksbill turtle, flatback turtle, loggerhead turtle, kemp's ridley turtle, olive ridley turtle, leatherback turtle and all possible combinations.

2.3. Calculations

To determine which of the species is the most vulnerable, a number of factors is considered. These five factors are listed below and are summarized in table 7. For each factor, a number ranging from 1 to 5 is given; the importance value. If this value is 1, then the species is not in danger regarding this factor, but if the value is 5, then the species is in great danger. This value was then multiplied by a multiply factor. The multiply factor indicates how much a factor weighs. The sum of all the factors times the multiply factor for one species was then calculated. The species with the highest final outcome needs the most protection.

There were five different multiply factors given to each of the five factors; IUCN red list, population size, life expectancy, TSD width and type of TSD. The given multiply factors were 1, 1,25, 1,5, 1,75 and 2, where 1 was given to the least important factor (IUCN), and 2 was given to the most important factor (TSD width). The distribution and the argumentation of the multiply factors is presented in table 1.

Table 1, the assigned multiply factors and argumentation

Factor	**Multiply factor**	**Argumentation**
IUCN red list	1	The IUCN red list factor is considered the least important, it is merely a description of the current situation and not a prediction of how the species will perform in the future.
Population size	1,25	Population size is considered to be more important than the IUCN red list factor. In this paper, the factor population size determines the size of the 'reserves' a species has before it is threatened with extinction, rather than it being just a present-day status, as is the case with the IUCN red list.
Type of TSD	1,5	The type of TSD is considered more important than the population size because the type of TSD gives a more in depth look on how a species will react to global warming, because it is ‘dependent on temperature’.
Life expectancy	1,75	Life expectancy is considered to be more important than the type of TSD, because life expectancy shows how much time a species has to change to a changing environment (meaning that life expectancy acts as buffer as explained in the introduction).
TSD width	2	TSD width is considered to be more important than life expectancy because this does not only act as a buffer but acts as a buffer specifically for rising temperatures (the wider the range, the more degrees the temperature can rise before the species enters the ‘danger zone’).

The choice to take multiply factors ranging from 1 to 2 was based on the fact that when multiply factors are close to each other, they contribute more equally to the final value then when they are not close to each other. When the multiply factors are ranging from for example 1 to 5, the factor with a multiply factor of 5 contributes the most to the final result and makes the factor with a multiply factor of 1 negligible.

In the conclusion, for each sub question the species with the worst score regarding that factor is addressed with a ‘’*’’. This gives insight into the distribution of sensitivity of the sea turtles among the different factors, which can be used by conservation organizations to best specify their efforts, as explained in the discussion.

2.3.1. IUCN red list

The first factor is the IUCN red list factor. IUCN gives a code to a species and tells whether this species is doing well. There are 8 codes, but for this paper, only 5 were used. DD, data deficiency, was not used, because this means that there is not enough known about the species to give any insight about it. EW, extinct in the wild, and EX, extinct, were not used either, because that means that the species does not live in the wild anymore and can therefore no longer be aided. The five categories that were used are LC, least concern, NT, near threatened, VU, vulnerable, EN, endangered, and CR, critically endangered ("The IUCN Red List of Threatened Species", n.d.). Respectively, the importance value 1-5 is linked to these 5 categories (table 2). The IUCN uses the following data to draw their conclusions; information about range, population size, habitat and ecology, usage and trade (by humans), threats and conservation (IUCN Red List Background & History, n.d.). The IUCN determines a status for species based on passed events, not on expected changes in the future. This means that temperature rise is not considered by the IUCN. The only factor that is used in both this paper and the IUCN status is 'population size' but as will be described in paragraph 2.3.2, as a separate factor, thus in contrast to how the IUCN uses it.

Table 2, IUCN red list categories and importance values

Category	**Definition**	**Importance value**
DD	Data Deficiency	
LC	Least Concern	1
NT	Near Threatened	2
VU	Vulnerable	3
EN	Endangered	4
CR	Critically Endangered	5
EW	Extinct in the Wild	
EX	Extinct	

2.3.2. Population size

It is important to consider the current population size of all species. It can be possible that a species is not threatened (IUCN), but if the population size is small, it can become extinct relatively quickly. This can be due to processes such as genetic bottleneck effects or genetic drift, where populations are exposed to chance events regarding the reproduction and survival of certain genotypes and phenotypes. Populations of species that have TSD, such as the sea turtles, can also be affected by temperature. If a species can only produce one sex, due to a change in temperature, species with a small population size have less flexibility than species with a large population. Five categories of population size were determined. The category with the largest population size, over 1.000.000 individuals left in the wild, gets an importance value of 1. Species with a population size between 500.000 and 1.000.000 get an importance value of 2. Between 250.000 and 500.000 gets a 3, between 100.000 and 250.000 gets a 4 and lastly, the species with the smallest population sizes, namely less than 100.000 individuals, gets an importance value of 5 (table 3).

Table 3, population size and importance values

Population size (individuals)	**Importance value**
> 1.000.000	1
500.000 – 1.000.000	2
250.000 – 500.000	3
100.000 – 250.000	4
< 100.000	5

The population size of a species is limited by the characteristics of the species, such as life expectancy. When a species can grow older than another one, it is more likely to have a large population size, because more individuals stay alive longer and these individuals can reproduce more often. For this research, the life expectancy is also taken into account and is considered more important than sheer population size. For this reason, it is not necessary to look at the characteristics that influence the (potential) population sizes of the seven sea turtles.

The current population sizes of all seven species are derived from Bandimere (2020) and Wallace *et al.* (2011), in which they display the most recent data available on sea turtle population sizes. In these sources, the minimum and maximum of population sizes were calculated. For this paper, the averages of those values are taken to ensure a safe range for this data.

2.3.3. Type of temperature-dependent sex determination

As explained in the introduction, there are two main types (three subtypes) of TSD, type *I* and type *II*. Type *I* (both *Ia* and *Ib*) is that lower temperatures give rise to one sex, while the higher temperatures give rise to the other sex. Type *II* indicates that at lower and higher temperatures, the developed sex will always be female, whilst if the temperature was in between these values, the offspring would be a male. For the determination of which species is most in need of aid, this factor was considered. If a species has TSD type *II* and the temperature rises, the females at the lower boundary are not produced anymore, but the females at the higher boundaries (and males at the intermediate temperatures) are. When the temperature rises, the TSD type *I* reptiles will lose the development of one of the sexes completely. This means that type *I* is more sensitive to temperature change than type *II* is. The importance value given for this factor is 2 for TSD type *II* and 4 for TSD type I (table 4).

Table 4, type of TSD and importance values

Type of TSD	**Importance value**
Type II	2
Type I	4

2.3.4. Life expectancy

The life expectancy of individuals of the species was considered as well. If the lifespan of an individual is short, the affected TSD will have more impact than that it would have on an individual with a longer life span. The benefits that come with having a long lifespan, as explained in the introduction, do obviously not apply on the species with a short lifespan. The importance values of the expected lifespan are as follows; if the life expectancy is between 0 and 25 years, the importance value is 5. If the life expectancy is 25 to 50 years, the importance value is 4. For an expected lifespan of 50 to 75 years, the importance value is 3 and for an expected lifespan of 75 to 100 years, the importance value is 2. For a species with an expected lifespan of over a 100 years, the importance value is 1 (table 5).

Table 5, life expectancy and importance values

Life expectancy	**Importance value**
> 100 years	1
75 – 100 years	2
50 – 75 years	3
25 – 50 years	4
0 – 25 years	5

2.3.5. Temperature-dependent sex determination width

Each of the chosen species has a different range for their TSD. When the temperature is shifting, the species with the widest range has the most chance to still be able to produce both sexes. For this reason, the width of the TSD is considered when determining which species is most in need of aid. The species with the smallest range of less than one-degree Celsius gets an importance value of 5, followed by an importance value of 4 for a width between 1 °C and 2 °C. 2 °C - 3 °C is assigned a 4, 3 °C – 4 °C will receive a 2 and a width of 4 °C or more gets an importance value of 1. (table 6).

Table 6, TSD width and importance values

TSD width	**Importance value**
≥ 4 °C	1
3 - 4 °C	2
2 - 3 °C	3
1 - 2 °C	4
≤ 1 °C	5

Because climate varies between regions on earth, temperatures between regions can also differ. Sea turtle populations may have adapted to these changes in temperature over the centuries resulting in a TSD width change between population but within the same species. This, however, does not mean two populations living in different regions are not comparable, but it might give a distorted outcome for the results of this report. For this reason, two studies regarding TSD width are considered in this study. The average of those findings is assumed to be a more precise TSD width of the particular species.

Table 7, the 5 factors and the corresponding importance values and multiply factors

Factor	**Importance values**	**Multiply factor**
IUCN red list factor	1 – 2 – 3 – 4 – 5	1
Population size	1 – 2 – 3 – 4 – 5	1,25
Type of TSD	2 – 4	1,5
Life expectancy	1 – 2 – 3 – 4 – 5	1,75
TSD width	1 – 2 – 3 – 4 – 5	2

3. Results

In this chapter, the information from the literature research will be presented. Each of the seven turtle species has a different paragraph in which the findings for that particular species are drafted.

3.1. Green sea turtle (*Chelonia mydas*)

The green sea turtle, or green turtle, is one of these seven sea turtle species (figure 2). Its conservation status according to the IUCN is endangered (EN), which gives this species an importance value of 4 regarding the IUCN red list (Seminoff, 2004). The current population size of the green sea turtle consists of 1.002.000 individuals (Bandimere, 2020; Wallace *et al.*, 2011). This number is higher than 1.000.000, which results in an importance value of 1.

Figure 2, green sea turtle, from https://www.cnet.com/news/drone-footage-captures-migration-of-64k-green-sea-turtles/

Stubbs & Mitchell (2018) showed that with higher temperatures, more females are born. This suits TSD type 1(a), giving the green sea turtle the corresponding importance value of 4. The estimated life expectancy for the green sea turtle is between 35 and 50 years (Godoy, 2016). Both of these values are within range of the importance value of 4 for life expectancy. The research of Stubbs & Mitchell (2018) shows that the offspring of the green sea turtle consisted of both males and females if the temperature was between 27,9 °C and 30,4 °C. This means that the TSD width is 30,4 °C – 27,9 °C = 2,5 °C. Another study show s that a mix of males and females is developed with temperatures ranging from 28,8 °C to 31 °C. This is a TSD width of 31 °C – 28,8 °C = 2,2 °C (King, Cheng, Tseng, Chen, & Cheng, 2013). The average of these two TSD widths is 2,35 °C and thus gets an importance value of 3.

All the values mentioned above are presented in table 8, along with the corresponding multiply factors and the total score of the green sea turtle.

Table 8, the determined importance values of the *Chelonia mydas* and the calculated scores

Factor	**Importance value**	**Multiply factor**		**Calculated score**
IUCN red list factor	4	1		4
Population size	1	1,25		1,25
Type of TSD	4	1,5		6
Life expectancy	4	1,75		7
TSD width	3	2		6
			Total Score	24,25

3.2. Hawksbill turtle (*Eretmochelys imbricata*)

Figure 3, hawksbill turtle, from https://www.earth.com/news/endangered-turtle-poached-jewelry/

The conservation status of the hawksbill turtle (figure 3) is critically endangered (CR), according to the IUCN red list (Mortimer & Donnelly, 2008). This status accounts for an importance value of 5. The hawksbill turtle nowadays has a population size of 57.000, giving it an importance value of 5 (Bandimere, 2020; Wallace *et al.*, 2011).

Research shows that the hawksbill turtle produces fewer male offspring with lower temperatures. This corresponds to type I(a) of TSD), with an importance value of 4 (Flores-Aguirre, Díaz-Hernández, Salgado Ugarte, Sosa Caballero, & Méndez de la Cruz, 2020). According to Mayne, Tucker, Berry, & Jarman (2020), the estimated lifespan of the hawksbill turtle is 53,2 years. This puts the species in the 50 – 75 years range (table 3), resulting in an importance value of 3. Flores-Aguirre *et al.* (2020) also shows that between 28,5 °C and 30,2 °C the offspring consisted of both males and females. This indicates a TSD width of 30,2 °C – 28,5 °C = 1,7 °C. Another study shows that a mix of males and females are born with temperatures varying between 26,7 °C and 29.8 °C (Esteban, Laloë, Mortimer, Guzman, & Hays, 2016). This is a width of 29,8 – 26,7 = 3,1 °C. The average of these two outcomes is 2,4 °C, resulting in an importance value of 3.

All the values mentioned above are presented in table 9, along with the corresponding multiply factors and the total score of the species hawksbill turtle.

Table 9, the determined importance values of the *Eretmochelys imbricate* and the calculated scores

Factor	**Importance value**	**Multiply factor**		**Calculated score**
IUCN red list factor	5	1		5
Population size	5	1,25		6,25
Type of TSD	4	1,5		6
Life expectancy	3	1,75		5,25
TSD width	3	2		6
			Total Score	28,5

3.3. Flatback turtle (*Natator depressus*)

Figure 4, flatback turtle, from http://www.turtle-live.net/flatback-turtle/

The flatback turtle (figure 4) does not have an IUCN conservation status, due to a data deficiency (DD) (Red List Standards & Petitions Subcommittee, 1996). To still give this species a conservation status, the website of the Australian government was consulted. The flatback turtle lives in Australian waters and the government keeps track of the status of this animal. Around Australia, the conservation status of this animal is vulnerable for all three Australian regions where the flatback turtle lives (Australian Government, 2008). This status corresponds with one of the IUCN conservation options, vulnerable (VU), thus giving the species an importance value of 3. The current population size of this animal is 23.000, resulting in an importance value of 5 for the flatback turtle (Bandimere, 2020; Wallace *et al.*, 2011).

The offspring of the flatback turtle consists of more females at higher temperatures, and thus more males at lower temperatures, corresponding with a TSD type *I(a)* (Bentley, Stubbs, Whiting, & Mitchell, 2020; Stubbs, Kearney, Whiting, & Mitchell, 2014). The matching importance value is 4. The life expectancy of the flatback turtle is 50,4 years (Mayne *et al.*, 2020). This corresponds with an importance value of 3, because 50,3 falls within the coverage of 50-75. According to Bentley *et al.* (2020), the TSD width is 1,5 °C; between 29,6 °C and 31,1 °C, both males and females are developed in the eggs. Another study showed the development of both males and females between temperatures of 27.7°C and 31.1°C, resulting in a TSD width of 3,4°C (Stubbs *et al.*, 2014). The average of those two TSD width values is 2,45 °C, giving the flatback turtle an importance value of 3 regarding the TSD width.

All the values mentioned above are presented in table 10, along with the corresponding multiply factors and the total score of the species flatback turtle.

Table 10, the determined importance values of the *Natator depressus* and the calculated scores

Factor	**Importance value**	**Multiply factor**		**Calculated score**
IUCN red list factor	3	1		3
Population size	5	1,25		6,25
Type of TSD	4	1,5		6
Life expectancy	3	1,75		5,25
TSD width	3	2		6
			Total Score	26,5

3.4. Loggerhead turtle (*Caretta caretta*)

Figure 5, loggerhead turtle, from https://www.worldwildlife.org/species/loggerhead-turtle

The IUCN red list conservation status of the loggerhead turtle (figure 5) is vulnerable (VU) (Casale & Tucker, 2017). The corresponding importance value for this status is 3. The current population size of the species consists of 314,000 individuals (Bandimere, 2020; Wallace *et al.*, 2011). Thus, the species gets an importance value of 3.

Studies show that the loggerhead turtle has type *I(a)* TSD, resulting in more males with lower temperatures and more females with higher temperatures (Tuttle & Rostal, 2010; Carreras *et al.*, 2018). The loggerhead turtle gets the according importance factor of 4 regarding the type of TSD. The estimated life expectancy of this species is 62,8 years (Mayne *et al.*, 2020). Because this is within the range 50-75 years, the loggerhead turtle gets an importance value of 3. The offspring of the loggerhead turtle consists of both males and females when the incubation temperature varies between 28,6 °C and 30 °C (Tuttle & Rostal, 2010). This implies a TSD width of 1,4 °C. Another study shows that the TSD width is 3 degrees Celsius; below 28 °C only males are developed, and above 31 °C only females are developed (Carreras *et al.*, 2018). The average of those two findings is a TSD width of 2,2 °C, resulting in an importance value of 3.

All the values mentioned above are presented in table 11, along with the corresponding multiply factors and the total score of the species loggerhead turtle.

Table 11, the determined importance values of the *Caretta caretta* and the calculated scores

Factor	**Importance value**	**Multiply factor**		**Calculated score**
IUCN red list factor	3	1		3
Population size	3	1,25		3,75
Type of TSD	4	1,5		6
Life expectancy	3	1,75		5,25
TSD width	3	2		6
			Total Score	24

3.5. Kemp's ridley turtle (*Lepidochelys kempii*)

Figure 6, kemp's ridley turtle, from https://www.nestonline.org/kemps-ridley-lepidochelys-kempii/

The kemp's ridley turtle (figure 6) is marked as critically endangered (CR) on the IUCN red list (Wibbels & Bevan, 2019). This gives this species an importance value of 5. For the factor 'population size', the kemp's ridley turtle also gets an importance value of 5. This is because there are 21.000 individuals of this species, which is less than 100.000 (Bandimere, 2020; Wallace *et al.*, 2011).

LeBlanc, Wibbels, Shaver, & Walker (2012) showed in their research that the kemp's ridley turtle develops more males with lower temperatures. This indicates a TSD type *I(a)*, giving this species the corresponding importance value of 4. The life expectancy of the kemp's ridley turtle is not that well known, but it is estimated at 30-50 years (Klug, 2006). For this paper, the difference between 30 and 50 years is negligible, because both values are within the 25 – 50 range, meaning that this species gets the corresponding importance value of 4. Below 28,3 °C only males are developed, whilst with temperatures above 32,5, °C only females are being developed (LeBlanc *et al.*, 2012). This gives the kemp's ridley turtle a TSD width of 32,5 °C – 28,3 °C = 4,2 °C. The kemp's ridley turtle gets an importance value of 1.

All the values mentioned above are presented in table 12, along with the corresponding multiply factors and the total score of the species kemp's ridley turtle.

Table 12, the determined importance values of the *Lepidochelys kempii* and the calculated scores

Factor	**Importance value**	**Multiply factor**		**Calculated score**
IUCN red list factor	5	1		5
Population size	5	1,25		6,25
Type of TSD	4	1,5		6
Life expectancy	4	1,75		7
TSD width	1	2		2
			Total Score	26,25

3.6. Olive ridley turtle (*Lepidochelys olivacea*)

Figure 7, olive ridley turtle, from https://www.worldwildlife.org/species/olive-ridley-turtle

The conservation status of the olive ridley turtle (figure 7) is marked as vulnerable (VU) on the IUCN red list (Abreu-Grobois & Plotkin, 2008). This gives the olive ridley turtle an importance value of 3. Its current population size is the biggest of all seven sea turtle species: 6.618.000 (Bandimere, 2020; Wallace *et al.*, 2011). The importance value associated with this number is 1.

Various research shows that in the eggs of the olive ridley turtle, more males develop at lower temperatures, and females at higher temperatures (Vinicius, Renan, Dos Santos, & Jaqueline, 2018; Sandoval, Gómez-Muñoz, & Porta-Gándara, 2017). This data indicates a type *I(a)* TSD, corresponding with an importance factor of 4. According to Mayne *et al.* (2020), the olive ridley turtle can live up to 54,3 years. This gives the species an importance factor of 3 regarding life expectancy. The study of Vinicius *et al.* (2018) showed that between temperatures of 28,8 °C and 32,3 °C, both males and females are developed. This is a TSD width of 32,2 °C – 28,8 °C = 3,4 °C. A different population of this species showed to develop both sexes when the temperature varied within the range of 27,4 °C and 32,7 °C, a TSD width of 32,7 °C – 27,4 °C = 5,3 °C (Sandoval, Gómez-Muñoz, & Porta-Gándara, 2017). The average TSD width for the olive ridley turtle is 4,35 °C, giving it an importance value of 1.

All the values mentioned above are presented in table 13, along with the corresponding multiply factors and the total score of the species olive ridley turtle.

Table 13, the determined importance values of the *Lepidochelys olivacea* and the calculated scores

Factor	**Importance value**	**Multiply factor**		**Calculated score**
IUCN red list factor	3	1		3
Population size	1	1,25		1,25
Type of TSD	4	1,5		6
Life expectancy	3	1,75		5,25
TSD width	1	2		2
			Total Score	17,5

3.7. Leatherback turtle (*Dermochelys coriacea*)

Figure 8, leatherback turtle, from https://spirit-of-diving.com/the-worlds-largest-sea-turtle-the-leatherback-could-come-off-endangered-list

The final sea turtle addressed in this paper is the leatherback turtle (figure 8). Its IUCN red list conservation status is vulnerable (VU) (Wallace, Tiwari, & Girondot, 2013). This status gets the species an importance value of 3. The population size of the leatherback turtle consists of 426.000 individuals (Bandimere, 2020; Wallace *et al.*, 2011) . 426.000 is within the range of 250.000 – 500.000 and is thus assigned an importance value of 3.

Binckley & Spotila (2015) show in their research that more females are being developed at high temperatures. This means that the leatherback turtle has a TSD type *I(a)*, and therefore gets an importance value of 4. The leatherback turtle lives the longest of all the sea turtles; 90,4 years (Mayne *et al.*, 2020). This matches with an importance value of 2, because the life expectancy value is located within the 75 – 100 years range. The study of Binckley & Spotila (2015) also showed that both sexes are developed when the temperature varies between 28,8 °C and 30,5 °C. This gets the leatherback turtle a TSD width of 30,5 °C – 28,8 °C = 1,7 °C. Another study shows a different result. The eggs of leatherbacks in Costa Rica develop only males below 28,9 °C and only females above 30 °C (Tomillo *et al.*, 2014). This shows a TSD width of 30 °C – 28,9 °C = 1,1 °C. The leatherback turtle shows an average TSD width of 1,4 °C and is therefore given an importance value of 4.

All the values mentioned above are presented in table 14, along with the corresponding multiply factors and the total score of the species leatherback turtle.

Table 14, the determined importance values of the *Dermochelys coriacea* and the calculated scores

Factor	**Importance value**	**Multiply factor**		**Calculated score**
IUCN red list factor	3	1		3
Population size	3	1,25		3,75
Type of TSD	4	1,5		6
Life expectancy	2	1,75		3,5
TSD width	4	2		8
			Total Score	24,25

4. Discussion

The aim of this paper is to determine the sensitivity of the sea turtles regarding TSD in relation to global warming. With that knowledge, conservationists can better determine which species need support, and thus prioritize their efforts. However, it is important to realize that all seven sea turtle species are already in danger. This paper only concludes which of the species is most vulnerable under the current circumstances and which species will be most threatened in the future due to global warming. However, the results should be discussed before conclusions can be made.

The first result being adaptations; it is possible that, in time, the sea turtles might change their behaviour as an adaptation to the rising temperatures. When the sea turtles, for example, lay their eggs earlier in the season or burry their eggs deeper into the sand, the temperature is lower and both sexes will still develop. Other possibilities for sea turtles to survive or at least to prolong their survival, are the occurrence of a 'cold year' and relocating their nesting sites. When, due to a 'cold year', the temperature is lower than usual, both sexes might develop, resetting the countdown (lifespan of the male turtles). By relocating the nesting sites to colder areas, the sea turtles might prevent 'one sex development'. Future research is needed to find out what behavioural changes might contribute to the survival of the sea turtles in the face of climate change.

In sea turtle eggs, only females will develop when the temperatures rise. This means that the male-female ratio will shift, resulting into more females than males. This does, on the short term, not need to be a problem, considering the fact that one male can fertilize different females (Schofield, Katselidis, Lilley, Reina, & Hays, 2017). However, in the long term it can certainly become a problem, when there are just too few males to fertilize a fit population (Laloë, Cozens, Renom, Taxonera, & Hays, 2014). To clarify this subject, future research is needed on the impact of shifting male-female ratios in sea turtles.

As explained in the previous paragraph, when the temperature rises, only one sex will develop in sea turtle eggs. However, even though this is true, it suggests that the temperature can keep rising and that one sex will still develop. A study performed by Fisher, Godfrey, & Owens (2014) showed otherwise. They showed that the loggerhead turtle (*Caretta caretta*), produced no offspring at all when the temperature was above 32 °C. Another study showed that with increasing temperatures, less females would develop in the leatherback turtle, even though this species has type *I(a)* TSD (Tomillo *et al.*, 2014). Tomillo *et al.* (2014) also showed that no females at all were developed by temperatures above 34 °C. This information suggests that (extreme) temperature rise has even more impact than previously was expected on sea turtles. To be able to draw better conclusions on this topic, future research is needed, for example the impact of global warming on the development of sea turtle offspring.

Secondly, the multiply factors that were used in this paper are non-fixed values. When the priority of the factors changes, or the outcome of future research differs, the multiply factor values should be redefined. This will then probably lead to a different outcome of this research. Furthermore, it is not necessary to take the type of TSD into account in future research. Since they all have type *I(a)* TSD, there is no difference.

For the determination of the TSD width of the kemp's ridley turtle, only one source was used. This study is titled; 'Temperature-dependent sex determination in kemp's Ridley sea turtle: effects of incubation temperatures on sex ratios'. This was because many of the other studies on the kemp's ridley turtle used this same study as the bottom line and therefore, it was considered to be true. Another reason to only use one study is the lack of studies on this particular species.

Furthermore, due to a lack of data, the IUCN red list has no conservation status available for the flatback turtle. For this information, the website of the Australian government was consulted. Because it is likely that the IUCN and the Australian government use other statistics, data and priorities, the used conservation status may differ from the conservation status of the IUCN on the flatback turtle, would they have had one.

Other information that is missing is a study on the population stability index (PSI) of all seven sea turtle species. The outcome of that research may give more insight on how the populations of sea turtles perform and contribute to the chances of survival of the sea turtles. Furthermore, it is also important to take a more in depth look into the local differences of climate change. Global warming results in mean temperatures getting higher, but there will still be fluctuations around this mean. These fluctuations may cause local differences and might cause the TSD width to be less relevant, because the temperature in a particular area does not rise as quickly as in another location.

This paper has looked at five factors regarding the sensitivity for climate change and global warming, but there are more factors that affect this sensitivity, for example the change in activity in ectothermic animals. Another example is the spread of diseases. When the temperature increases, diseases might spread more easily, which in turn may increase the risk of illness for the sea turtles (Khasnis & Nettleman, 2005). Future research on these other factors may provide more knowledge on the impact of global warming on the sea turtle species.

Besides global warming, there are other causes for the decline in number and the decrease in fitness in the populations of the sea turtles. Two examples of these causes are fisheries and habitat destruction by storms. Further research may find a correlation between the impact of global warming and the effect of these other distortions.

It is explained that the species with the highest total score needs the most help globally, but this urge may differ locally. When a species performs well in one region, but performs worse in another region, the global score might be bad. If conservationists want to aid a species, there may be a subpopulation of a species locally that is more in need of protection than the species that is globally the most sensitive. It is up to them to consider the local differences for their geographical location.

Besides considering the local circumstances, it is also important to keep track of the latest developments in the two relevant fields of research, sea turtles and climate change. This is because in time, the results of this paper might become outdated. Next to that, it is important to monitor the developments of the sea turtles, both globally and locally. This can be done in future studies and would be beneficial for aiding the sea turtles, because it could result in a shift of conservation priority.

5. Conclusion

In this chapter, the sub questions will be answered first. After that, a conclusion will be drawn regarding the research question. Lastly, some recommendations will be made as a guideline for future research and organisations for sea turtle conservation.

5.1. Sub questions

The sub questions will be addressed in the same order as in the introduction. Per sub question there will be addressed which species, according to that particular factor, is most in need of protection. This is shown with ''*''.

- <u>What are the current IUCN statuses of the selected sea turtle species?</u>

Four out of the seven species are marked as vulnerable (VU), this accounts for the flatback turtle, the loggerhead turtle, the olive ridley turtle and the leatherback turtle. The green sea turtle has the conservation status of endangered (EN). The remaining two species, the hawksbill turtle and the kemp's ridley turtle are both classified as critically endangered (CR) (table 15). Assuming this factor only, the hawksbill turtle and the kemp's ridley turtle are most in need of aid.

Table 15, conservation status of each of the seven sea turtle species

Species	**Conservation Status**	**Abbreviation**
Green sea turtle	Endangered	EN
*Hawksbill turtle **	Critically endangered	CR
Flatback turtle	Vulnerable	VU
Loggerhead turtle	Vulnerable	VU
*Kemp's ridley turtle **	Critically endangered	CR
Olive ridley turtle	Vulnerable	VU
Leatherback turtle	Vulnerable	VU

- <u>What is the current population size of each of the selected sea turtle species?</u>

Only the green sea turtle and the olive ridley turtle have a population of more than 1.000.000 individuals. The global population of the green sea turtle consists of 1.002.000 individuals and that of the olive ridley turtle consists of 6.618.000 individuals. The loggerhead turtle and the leatherback turtle are the only species of the remaining 5 species that have a population size in the 100.000's. The loggerhead has a population size of 314.000 individuals and the leatherback has a population size of 426.000 individuals. The remaining species, whom all have less than 100.000 individuals, are the hawksbill turtle (57.000), the flatback turtle (23.000) and the kemp's ridley turtle (21.000) (table 16). According to population sizes, the kemp's ridley turtle is most in need of aid, closely followed by the flatback turtle.

Table 16, population sizes of each of the seven sea turtle species

Species	**Current Population Size**
Green sea turtle	1.002.000
Hawksbill turtle	57.000
Flatback turtle (*)	23.000
Loggerhead turtle	314.000
*Kemp's ridley turtle **	21.000
Olive ridley turtle	6.618.000
Leatherback turtle	426.000

- <u>Which type of TSD does each of the selected sea turtle species have?</u>

All seven sea turtle species have the same (sub)type of TSD. For this factor there is thus no difference, which would result in the conclusion that all species are equally in need of help regarding this factor.

- <u>What is the life expectancy of each of the selected sea turtle species?</u>

Table 17, life expectancy of each of the seven sea turtle species

Species	**Life Expectancy**
*Green sea turtle **	35 – 50 years
Hawksbill turtle	53,2 years
Flatback turtle	50,4 years
Loggerhead turtle	62,8 years
*Kemp's ridley turtle **	30 – 50 years
Olive ridley turtle	54,3 years
Leatherback turtle	90,4 years

The sea turtle species that can grow oldest is the leatherback turtle, 90,4 years, followed by the loggerhead turtle with 62,8 years. Three of the seven species have a life expectancy somewhere between 50 and 60 years: the hawksbill turtle (53,2 years), the flatback turtle (50,4 years) and the olive ridley turtle (54,3 years). The green sea turtle and the kemp's ridley turtle both have a range expectation. For the green sea turtle, this is 35 – 50 years, for the kemp's ridley turtle, this is 30 – 50 years (table 17). Assuming this data, the green sea turtle and the kemp's ridley turtle are most in danger.

- <u>What is the TSD width of each of the different members of the sea turtle (*Cheloniidae*) family?</u>

Regarding this factor, the kemp's ridley turtle (a width of 4,2) and the olive ridley turtle (a width of 4,35) score best. Four out of the remaining five species are within the range of 2 – 3. These four species are the green sea turtle (2,35), the hawksbill turtle (2,4), the flatback turtle (2,45) and the loggerhead turtle (2,2). Only the leatherback turtle has a TSD width of less than 2, namely 1,4 (table 18). It can be said that regarding the TSD width, the leatherback turtle is most in need of aid.

Table 18, TSD width of each of the seven sea turtle species

Species	**TSD Width**
Green sea turtle	2,35
Hawksbill turtle	2,4
Flatback turtle	2,45
Loggerhead turtle	2,2
Kemp's ridley turtle	4,2
Olive ridley turtle	4,35
*Leatherback turtle **	1,4

5.2. Research question

Now, the research question will be answered; ‘Why are some of the considered sea turtle species more sensitive to a rise in temperature than others, regarding the temperature-dependent sex determination and therefore, on the short term, require the most support for their survival?’

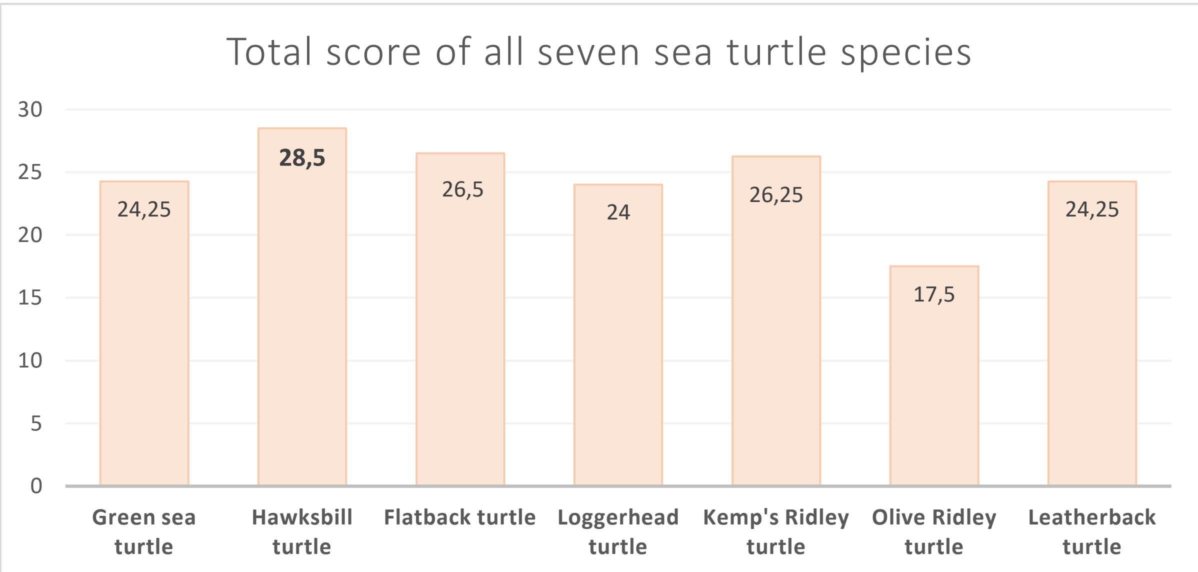
There are different factors that contribute to the sensitivity for global warming. The most prominent one is the gradient of temperature-dependent sex determination. As explained in the method, this can be divided into two elements: the type of TSD and the TSD width. Other factors that contribute to the sensitivity are population size and life expectancy. Furthermore, the current conservation status is important too, because this gives an insight in how well a species performed in the past. These five factors together determine the sensitivity of a species. Each species scores differently for each of these factors, meaning that all sea turtle species have another level of sensitivity to climate change. In table 19, the scores of all seven species are shown. These scores are visualised in graph 1. The species with the highest score, the hawksbill turtle, is most sensitive to a rise in temperature and is therefore most in need of aid.

Table 19, total scores of each of the seven sea turtle species

Species	**Total Score**
Green sea turtle	24,25
Hawksbill turtle	**28,5**
Flatback turtle	26,5
Loggerhead turtle	24
Kemp’s ridley turtle	26,25
Olive ridley turtle	17,5
Leatherback turtle	24,25

The hypothesis was that the kemp’s ridley turtle and the flatback turtle were the species to be most affected by global warming, because they have the smallest habitat. However, the results of this study suggest that the hawksbill turtle may be most vulnerable to increases in temperature and therefore, the hypothesis is rejected.

Graph 1, total scores of each of the seven sea turtle species



5.3. Recommendations

For organisations involved in sea turtle conservation, the following recommendation is made. Before putting effort in aiding a species, take an in depth look into the habitat and local performance of the local sea turtles, and base your research on that consideration. As explained in the discussion, the urge of help may differ locally.

There are some possible future research possibilities. These are explained in the discussion, but are listed here as well, because they are recommendations for the future. Future research is needed on the following topics:

- Behavioural changes in sea turtles as a response to climate change.
- The effect of the male-female ratio shift in sea turtles.
- The development of offspring with (extremely) high temperatures (mean of >32 °C).
- Population stability index (PSI) of all sea turtle species.
- Factors influencing the sensitivity of sea turtles regarding global warming that are not considered in this paper, for example metabolic activity in ectothermic animals and the spread of diseases.
- Causes other than global warming that disrupt the life of the sea turtles and their correlation with global warming, such as fisheries and habitat destruction.
- Local differences in temperature rise in the future.
- The latest developments on the two relevant fields of research; sea turtles and climate change.
- The performance of sea turtles globally and locally by monitoring them.

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