UNIVERSIDADE DA CORUÑA

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# Degree in biology

## Final Dissertation

### Literature review: Mechanisms of thermoregulation in sea turtles

### Revisión bibliográfica: Mecanismos de termorregulación en tortugas marinas

### Revisión bibliográfica: Mecanismos de termorregulación nas tartarugas marinas

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## SUMMARY

Some species of sea turtles have wide distribution ranges and therefore need mechanisms to cope with latitudinal changes in temperature that could negatively affect metabolism and molecular functions. The objective of this work is to collect the available scientific information on these mechanisms. After the review, four types of mechanisms have been found in the different species: behavioral, physiological, body mass and fat accumulation. The leatherback turtle, whose range of distribution is the largest of all, has the most specialized mechanisms, such as the accumulation of blubber and brown fat. We conclude that the mechanisms discovered until now seem to be enough to allow the adaptation of turtles to different temperatures, both higher and lower, but there is also a great lack of information in this regard.

## KEY WORDS

Fat accumulation, blubber, physiology, behavior

## RESUMEN

Algunas especies de tortugas marinas presentan amplios rangos de distribución y, por tanto, necesitan mecanismos para hacer frente a los cambios latitudinales de temperatura que podrían afectar negativamente a su metabolismo y funciones moleculares. El objetivo de este trabajo es recopilar la información científica disponible sobre estos mecanismos. Tras la revisión se han encontrado cuatro tipos de mecanismos en las diferentes especies: de comportamiento, fisiológicos, masa corporal y la acumulación de grasa. La tortuga laúd, cuyo rango de distribución es el mayor de todos, posee los mecanismos más especializados, como la acumulación de “grasa de ballena” y grasa parda. Concluimos que los mecanismos descubiertos hasta el momento parecen ser suficientes para permitir la adaptación de las tortugas a diferentes temperaturas, tanto más altas como bajas, pero también se evidenció una gran falta de información al respecto.

## PALABRAS CLAVE

Acumulación de grasa, grasa de ballena, fisiología, comportamiento

## RESUMO

Algunhas especies de tartarugas mariñas teñen amplos intervalos de distribución e, polo tanto, necesitan mecanismos para facer fronte aos cambios latitudinais na temperatura que poden afectar negativamente ao seu metabolismo e funcións moleculares. O obxectivo deste traballo é recoller a información científica dispoñible sobre estes mecanismos. Tras a revisión, atopáronse catro tipos de mecanismos nas distintas especies: de comportamento, fisiolóxicos, masa corporal e acumulación de graxa. A tartaruga laúd, cuxo rango de distribución é o maior de todos, posúe os mecanismos máis especializados, como a acumulación de "graxa de balea" e graxa marrón. Concluímos que os mecanismos descubertos ata agora parecen ser suficientes para permitir a adaptación das tartarugas ás diferentes temperaturas, tanto máis altas como baixas, pero tamén se evidenciou unha gran falta de información ao respecto.

## PALABRAS CLAVE

Acumulación de graxa, graxa de balea, fisioloxía, comportamento

# 1. INTRODUCTION

## 1.1 General characteristics and biological cycle of sea turtles

Sea turtles are reptiles belonging to the superfamily Chelonioidea that have adapted to live in the ocean. Unlike land turtles, they are not capable of retracting their limbs, head, or tail into their shell. In addition, their limbs have become strong fins, adapted to locomotion in the water, and allow them to reach high speeds and perform large migrations. One typical characteristic of sea turtles is their shell, which is formed by a bony dorsal part called carapace and a less bony ventral part called plastron, which offer protection and its shape improves the animal's hydrodynamics. In most species, both the carapace and the plastron are covered with keratinized shields called scutes (Witherington, 2006).

Although the fossil record shows that there were up to four families of sea turtles, currently there are only representatives of two of them, and all of the current species share the same ancestor that dates back to the Cretaceous (Figure 1). These two families are: *Dermochelyidae* and *Cheloniidae.* The *Dermochelyidae* family is characterized by the absence of scutes on the carapace and includes one currently living species, *Dermochelys coriacea (Vandelli, 17611)*. In the case of the Cheloniidae family, it is characterized by having scutes on the shell and includes six living species: *Lepidochelys kempii* (Garman 1880), *Lepidochelys olivacea* (Eschscholtz, 1829), *Chelonia mydas* (Linneo, 1758), *Eretmochelys imbricata* (Linneo, 1766), *Caretta caretta* (Linneo, 1758) and *Natator depressus* (Bocourt, 1868) (Witherington, 2006).

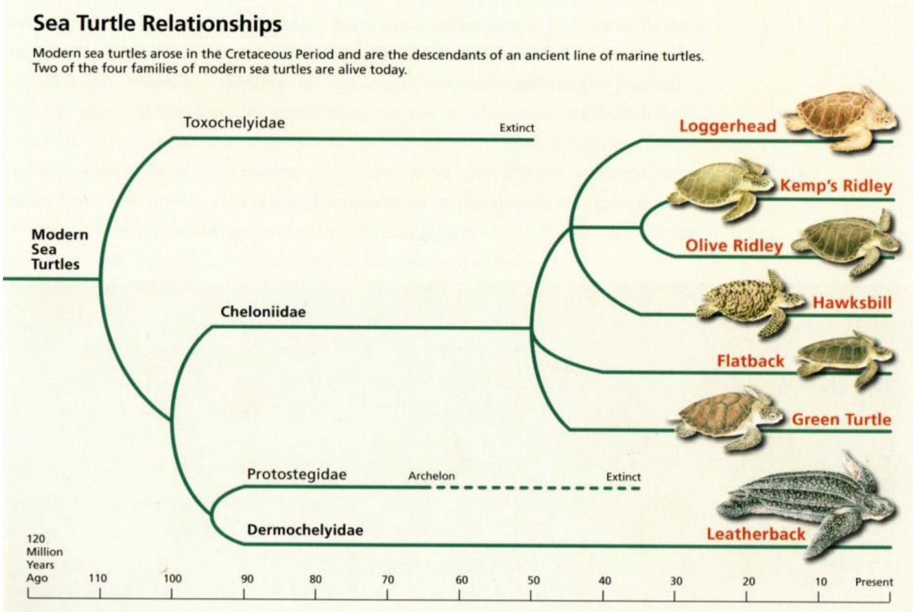


**Figure 1.** Sea turtles phylogenetic relationships (Spotila, 2004)

The life cycle of turtles is a complex and energetically expensive process. The adult turtles that reproduce migrate from the foraging area where they live, to the nesting beaches, which in most species, is the same beach where they were born. This journey can be thousands of kilometers and once there, they reproduce for several hours. Later, the males return to the foraging areas while the females keep the reproduction area and go out to the beaches to lay their eggs in nests that they dig themselves in the sand. In most species, the females carry out several spawnings spaced out over time, with the sperm they stored from the males. Once they have finished laying, they will leave the nesting beach and return to the foraging area. It should be noted that during the entire migration, reproduction and laying time, the females rarely feed, which implies an enormous energy effort in which they lose a large part of their body mass. This is the reason why most species need a few years to recover from the reproductive effort before reproducing again (Witherington, 2006).

The eggs do not receive any kind of parental care and once the eggs hatch, the young will move toward the water. Once they reach the sea, the juveniles keep in the open ocean until reaching adulthood. This period is known as “the lost years” since the information on their biology from when they enter the sea until they become adults is very scarce. In most species, the probability of reaching adulthood is very low, only 1 in 1000 will do so. When adults, they move to the foraging areas where they live. Although adulthood is reached at 10 years, sea turtles begin to reproduce at around 20-50 years depending on the species. When the reproductive period arrives they migrate to the nesting beaches, starting the cycle again (Witherington, 2006).

## 1.2 Taxonomy of sea turtles

### 1.2.1 Family *Dermochelyidae*

#### 1.2.1.1 Leatherback turtle - *Dermochelys coriacea*

It is the largest species of sea turtle that exists today, being able to reach weights greater than 500 kg and lengths from 145 to 170 cm (Figure 2). Its shell is black with white dots and has no scutes on the head or shell. Its diet is based on jelly-like animals such as jellyfish (Witherington, 2006). It is currently in a vulnerable state of conservation. Its main threats are by catch, pollution, trade, tourism and recreational areas that mainly affect nesting beaches (IUCN, 2022)

**Figure 2.** Illustration of *Dermochelys coriacea* (Spotila, 2004)

## 1.2.2 Family *Cheloniidae*

### *1.2.2.1* Green Turtle - *Chelonia mydas*

It is one of the fastest species of turtles. It presents scutes on the carapace of brown color and patches of light or darker brown tones. They weigh between 80 and 220 kg and can measure from 80 to 120 cm in length (Figure 3). Its name does not come from the color of its shell but from the color of its fat, which is green due to its herbivorous feeding when it is an adult. It feeds mainly on algae and seagrass (Witherington, 2006). It is currently in an endangered state of conservation. Its main threats are tourism and recreational areas, as well as the by-catching of fishing (IUCN, 2022).

**Figure 3.** Illustration of *Chelonia mydas* (Spotila, 2004)

### *1.2.2.2* Loggerhead Sea Turtle - *Caretta caretta*

The shell of this turtle is dark-brown and is usually covered by different organisms such as macroalgae or barnacles. They weigh ranges between 70 to 170 kg and measure from 80 to 110 cm (Figure 4). They are omnivorous animals, although their basic diet varies depending on the area in which they feed for the first time, in the coastal zone or in the ocean (Witherington, 2006).

It is currently in an endangered state of conservation. Its main threats are by-catching in fishing, tourism and recreational areas, pollution, the maritime industry, the expansion of residential areas and diseases induced by viruses and viroids (IUCN, 2022).

**Figure 4.** Illustration of *Caretta caretta* (Spotila, 2004)

#### *1.2.2.3* Hawksbill Turtle - *Eretmochelys imbricata*

It is the species of turtle with the most striking coloration, it presents cream, amber, rusty reds, brown and black colorations, which together make unique patterns. They weigh between 40 and 80 kg and can measure from 75 to 80 cm (Figure 5). Their diet varies throughout their life cycle but in general they can be considered specialist sponge predators (Witherington, 2006). It is currently in a critically endangered state of conservation. Its main threats are by-catching in fishing, tourism and recreational areas, pollution, the maritime industry, the expansion of residential areas, climate change and the energy industry (mining and oil) (IUCN, 2022).

**Figure 5.** Illustration of *Eretmochelys imbricata* (Spotila, 2004)

#### *1.2.2.4* Olive Ridley - *Lepidochelys olivacea*

Is one of the smallest species of sea turtle, reaching a weight of 35 to 45 kg and measuring 60 to 75 cm (Figure 6). Its shell has a coloration from olive to gray and its shape is rounded. It also has more scutes than the rest of the species. Another characteristic fact is that it is one of the 2 species that carry out the “arribada”, which consists in the emergence to land of large groups of females for collaborative nesting during the night. The diet is mainly based on invertebrates, such as shrimp, sea urchins, molluscs or crabs (Witherington, 2006). It is currently in a vulnerable state of conservation. Its main threats are by-catching in fishing, aquaculture, tourism and recreational areas, pollution, the maritime industry, the expansion of residential areas and climate change (IUCN, 2022).

**Figure 6.** Illustration of *Lepidochelys olivacea* (Spotila, 2004)

#### *1.2.2.5* Kemp's Ridley - *Lepidochelys kempii*

It is another of the smallest species of sea turtles, weighing 35 to 45 kg and measuring 60 to 70 cm (Figure 7). It is very similar to Lepidochelys olivacea in its coloration and shell shape, but has fewer scutes. Like the olive ridley, it also performs “arribadas", but in this case during the day. Their diet is based on invertebrates, especially crabs, sea snails and sometimes jellyfish (Witherington, 2006). It is currently in a critically endangered state of conservation. Its main threats are by-catching in fishing and the energy industry (mining and oil) (IUCN, 2022).

**Figure 7.** Illustration of *Lepidochelys kempii* (Spotila, 2004)

#### *1.2.2.6* Flatback Turtle - *Natator depressus*

They receive this name due to the flat appearance of their shell, and their coloration is olive with cream tones. They are characterized by having the cleanest shell of all sea turtles, since they have an anti-fouling substance that prevents some organisms such as barnacles from adhering to it. They weigh from 70 to 80 kg and measure from 85 to 95 cm (Figure 8).

Their diet is based on small planktonic invertebrates and some jelly-like animals (Witherington, 2006). There is not enough data information to establish its conservation status (IUCN, 2022).

**Figure 8.** Illustration of *Natator depressus* (Spotila, 2004)

## 1.3 Distribution of the different species

The leatherback sea turtle (*Dermochelys coriacea*) is one of the sea turtle species with the widest distribution range. It can be found from tropical waters with a temperature greater than 30ºC to polar waters with temperatures close to 0ºC, and even so, it is able to maintain its body temperature in a constant range (Figure 9, A) (Bostrom et al., 2010). Green Turtle *(Chelonia mydas*) is found in tropical and temperate waters around the world, although nesting occurs mainly in the tropics, on lying beaches located at 20 degrees north and south latitude (Figure 9, B). Loggerhead sea turtle (*Caretta caretta*) can be found in the temperate and tropical waters of the Atlantic, Pacific and Indian oceans and in summer they extend their foraging area to the north of the United States (Figure 9, C). Hawksbill Turtle *(Eretmochelys imbricata)* is distributed throughout the tropical waters of the Atlantic, Pacific and Indian Oceans, while nesting occurs almost exclusively on tropical beaches like Mexico, the Seychelles, Indonesia or Australia (Figure 9, D). Olive Ridley (*Lepidochelys olivacea*) are distributed throughout the tropical waters of the Atlantic, Pacific and Indian Oceans, while nesting occurs mostly on tropical beaches (Figure 9, E). Kemp's Ridley (*Lepidochelys kempii*) is found mainly in the Gulf of Mexico and in temperate waters of the western North Atlantic, while their nesting areas are located almost exclusively on the beaches of Tamaulipas, in Mexico (Figure 9, F). Flatback Turtle (*Natator depressus)* is found exclusively in tropical marine waters between northern Australia and New Guinea. Nesting only takes place on beaches in Australia (Figure 9, G) (Witherington, 2006).

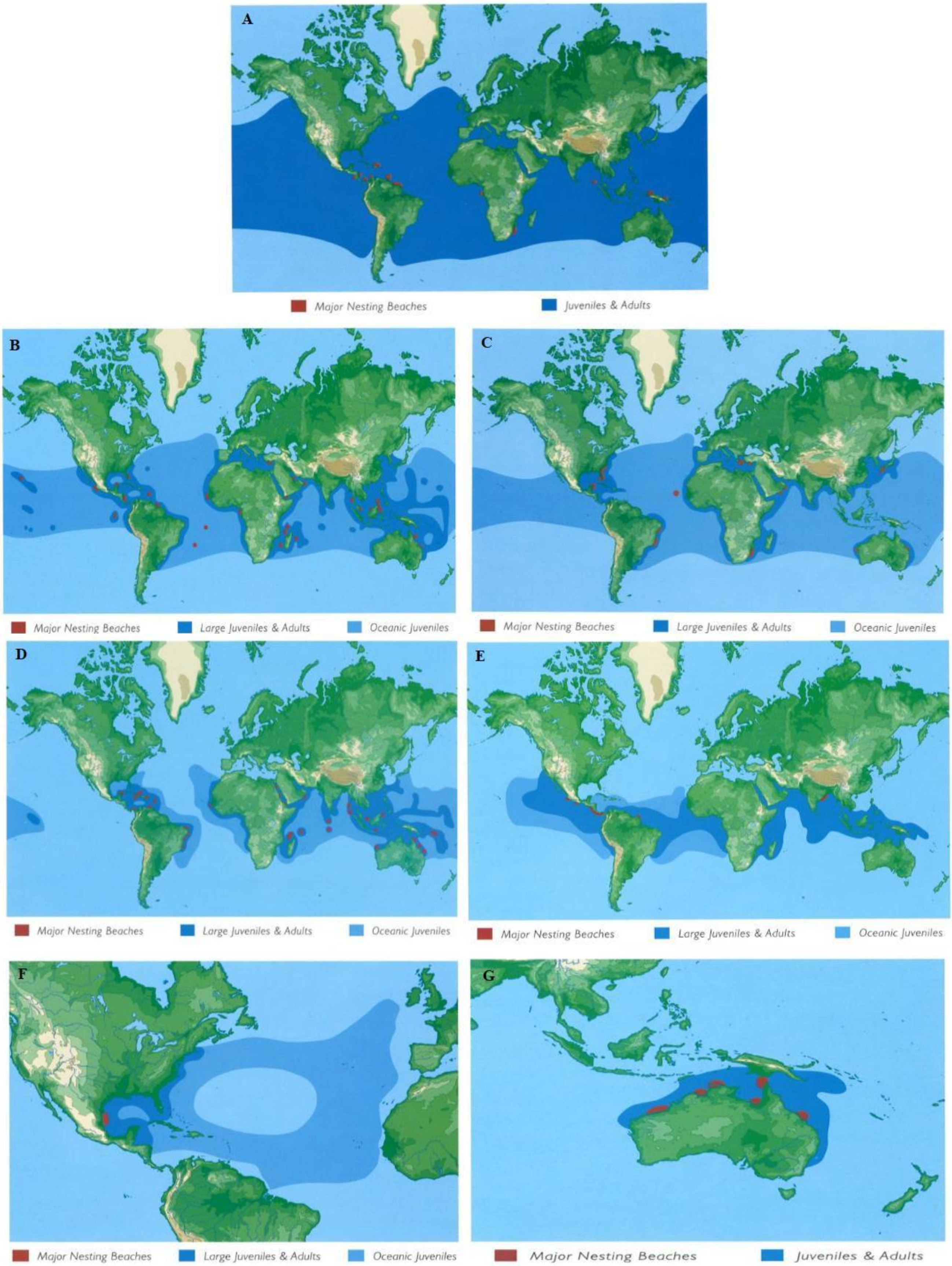


**Figure 9.** Distribution map and nesting beaches of different species. A) *Dermochelys coriacea* B) *Chelonia mydas* C) *Caretta caretta* D) *Eretmochelys imbricata* E) *Lepidochelys olivacea* F) *Lepidochelys kempii* G) *Natator depressus* (Witherington, 2006)

## 1.4 Thermoregulation

### 1.4.1 Ocean temperature and temperature gradient

The atoms and molecules that make up a substance are under constant random motion on an atomic and molecular scale. Therefore, temperature reflects the speed or intensity of those movements, while heat is a form of energy that comes from those random movements. Furthermore, an essential property of temperature is that it determines the direction of heat transfer, which can take place by thermal conduction, convection, evaporation or radiation (Levinton, 2014).

Ocean temperature is a very important factor because it affects other water-properties such as density, it is involved in the mixing of surface water with deep water, and therefore, in the amount of dissolved gasses, such as oxygen. It also determines the rate at which different chemical reactions or biological processes occur and determines the distribution of marine species (Waller et al., 1996).

The **surface temperature** of the ocean is influenced by the amount of solar radiation it receives, by superficial currents and upwelling processes. Therefore, since the amount of solar radiation it receives depends on the latitude and the period of the year, we can say that there is a latitudinal temperature gradient in the ocean, the higher the latitude, the lower the temperature and vice versa (Figure 10) (Waller et al., 1996).

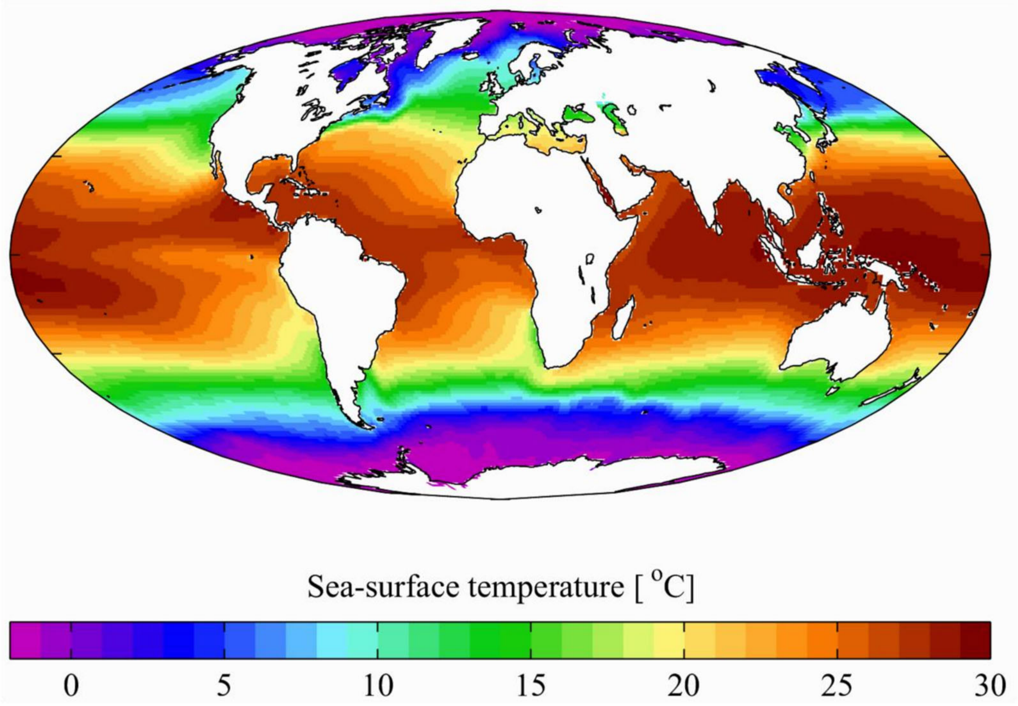


**Figure 10.** Sea surface temperature (Xiao et al., 2019).

These effects on temperature by solar radiation occur mainly at the surface, but water has the ability to store large amounts of heat without producing large temperature changes. This is a fundamental property for the life of many organisms, if the changes were higher, many could not resist them, since temperature fluctuations influences the rate of respiration, rate of growth, feeding and behavior (Waller et al., 1996).

Surface currents (Annex I) are produced by the interaction of the winds and the Earth's rotation. In the area of the equator the solar radiation is greater and therefore the air temperature as well. This warm air is displaced to higher latitudes, producing the wind that in turn produces the currents. But these air and currents are also affected by the Earth's rotation, which deflects them producing the Coriolis effect. In turn, winds and the Coriolis effect are responsible for coastal upwellings, which consists of the arrival of cold, nutrient-rich deep waters in coastal areas (Figure 11) (Levinton, 2014). Currently in more than 77% of the oceans, sea currents are faster and finer due to global warming. This has implications in the distribution of nutrients, in the cushioning effect of the ocean, and in addition, the acceleration of the turns or circles of currents decreases the speed of circulation of the lower waters, which is related to an increase in greenhouse gasses in the atmosphere. At the moment, no further implications or possible effects on marine species are known (Peng et al., 2022).

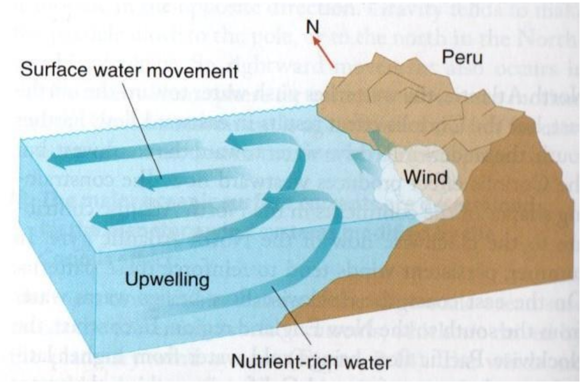


**Figure 11.** Upwelling in the coast of Peru (Levinton, 2014).

In addition, there is also a **vertical gradient,** as we descend in the water column, the temperature gradually drops to a depth of approximately 1000 m, after which it remains constant below 3ºC (Figure 12), mainly as the influence of solar radiation decreases (Waller et al., 1996).

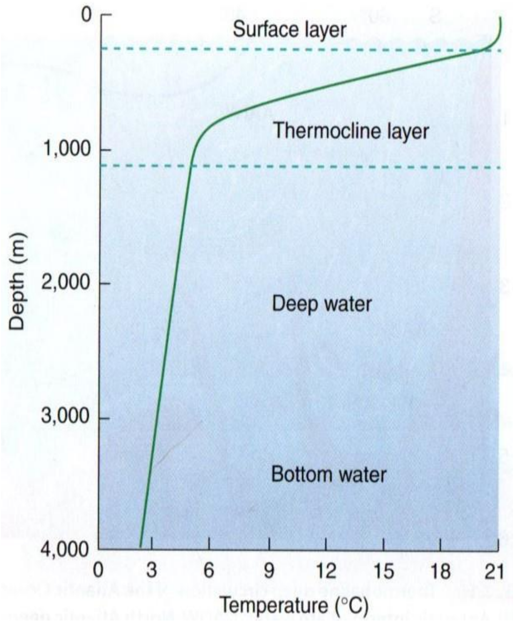


**Figure 12.** Vertical gradient of temperature in the ocean (Levinton, 2014).

### 1.4.2 Thermoregulation in reptiles

When we talk about the relationship between the internal temperature of the different organisms and the temperature of the environment, we can find different terms:

#### Poikilothermy and homeothermy

**Poikilothermy** simply refers to organisms in which body temperature varies with ambient temperature. This group includes almost all the animals except mammals and birds which are homeotherms, and a few reptiles, insects and fishes which can have different temperatures from the environment. **Homeothermy** refers to animals whose body temperature remains constant despite environmental fluctuations. They manage to keep their internal temperature constant mainly through behavioral mechanisms (Hill et al., 2006).

#### Endothermy and ectothermy

**Endothermic** organisms are those that keep their internal temperature constant or fluctuate very little in relation to the external temperature due to physiological mechanisms mainly. **Ectotherms** are organisms in which the main source of heat comes from the external environment and they lack physiological mechanisms to maintain their internal temperature constant, therefore, their temperature will vary with the temperature of the environment. The vast majority of reptiles are ectothermic (Seebacher & Franklin, 2005).

The most accepted classification nowadays is endothermy and ectothermy. While it is true that all poikilothermic animals are ectotherms, some ectotherms are capable of controlling their body temperatures within very tight limits, for example, snakes and lizards through behavioral changes. Therefore, using the term poikilothermia on many occasions is not accurate (Hill et al., 2006).

As already seen in section 1.3 of this work, turtles have a very wide distribution, there are species that only inhabit tropical areas, for example, the Flatback turtle. Others have higher distribution ranges, they live in tropical zones but also in temperate zones, like the Green turtle or Loggerhead turtle. One of the species can even reach polar areas, the Leatherback turtle. This wide range of distribution implies changes in the ambient temperature, due to the latitudinal gradient mentioned in section 1.4.1 of this work. In addition, in numerous studies it has been seen that sea turtles are capable of maintaining and even regulating body temperatures higher than the temperature of the environment. For example, Bostrom et al. (2010) show that in tropical waters, the Leatherback turtle has a temperature between 1.2 and 4.3ºC higher than that of water, but in polar regions, the thermal gradient between body and water temperature is greater, up to even 8.2ºC. In addition, in an experiment carried out with Leatherback turtles of different sizes, 16 and 37 kg, it has been verified that the thermal gradient increases as the temperature of the water decreases, and it is also greater in larger turtles (Bostrom et al., 2010). In other species such as the Loggerhead turtle, it has been seen that the difference between the temperature of the stomach and that of the water is only 1- 2ºC (Sato et al., 1995). Others, such as the Kemp's ridley and the Green turtle, cease to feed and become semi-dormant in waters with a temperature below 15ºC (Moon et al., 1997). Although in another study it was shown that Green turtles are capable of maintaining temperatures of up to 8ºC higher than that of the water for short periods of time, increasing their swimming activity (Standora et al., 1982).

All these experiments suggest that the turtles must have some mechanism that allows them to adapt to these changes in temperature when they move from one region to another. In fact, Standora et al. (1982) demonstrated the body regional endothermy of the Green turtle. Also Bostrom et al. (2010) demonstrate that leatherback sea turtles are endothermic when foraging in cool temperate waters, since they have mechanisms that allow them to control their body temperature. Some authors use the term gigantothermy instead of endothermic, which refers to ectothermic animals that, due to their large size, and therefore greater volume/surface ratio, are able to maintain their constant temperature, like tuna, manta rays or some sharks (Paladino et al., 1990).

## 2. OBJECTIVES

The aim of this work is to review the last scientific works on thermoregulation in sea turtles, in order to analyze the existence of interspecific differences in thermoregulatory mechanisms.

## 3. INFORMATION SEARCH

For the elaboration of this work, the Web of Science database was mainly used, as well as monographic on sea turtles and general physics textbooks to obtain basic information and clarify some concepts.

To search for the different articles several words related to the subject were used. In the first searches the words used were: sea turtle (and names of different species), thermoregulation, physiology, behavior. In the next search more specific terms were used: countercurrent system, blubber, fat and insulation. In addition, the bibliography of the different papers was also used to find more that could be of interest.

The first search was carried out on 15/02/2022 and the last one on 22/08/2022. Of a total of 48 papers selected for review in the various searches carried out in the mentioned period, 15 references have finally been included in the work, most of them being discarded because they contain obsolete information. The chosen papers were those that have been cited numerous times and preferably as recent as possible.

## 4. DEVELOPMENT

### 4.1 Mechanisms of thermoregulation observed in sea turtles

The ability of sea turtles to maintain constant body temperature regardless of water temperature depends on the rate of heat loss and gain, which in turn depends on different mechanisms or factors such as body mass, physiological and behavioral mechanisms, as well as other special adaptations, such as the accumulation of fat in the head and neck (Bostrom et al., 2010).

#### 4.1.1 Physiological mechanisms

In a study carried out with juvenile leatherback turtles, it has been observed that the surface area of the front and rear flippers combined represents 27% of the total surface area of each turtle but the total heat loss through them is only 6– 7% in cold waters and 30% in warm waters. The other heat loss takes place through the plastron and carapace. The physiological mechanisms proposed to explain this low heat loss through the flippers in cold waters are simply a reduction in blood flow to the flippers and the utilization of counter-current heat exchangers. Furthermore, these exchangers have only been found in the leatherback sea turtle and have not been found in the green turtle and the loggerhead turtle (Bostrom et al., 2010). In the case of the green turtle and the loggerhead turtle, a simpler mechanism is proposed, which consists of increasing the blood flow to the flippers in warmer waters, and when they enter colder waters, they reduce the blood flow to the flippers, maintaining the temperature inside the body (Hochscheid et al., 2002).

Later on, Davenport et al. (2015) demonstrated that leatherback turtles have arteriovenous plexuses in the roots of all four limbs. Moreover, the plexuses of the hindlimbs are situated wholly within the hip musculature, and that, at the distal ends of the plexuses, most blood vessels supply or drain the hip muscles, with little distal vascular supply to, or drainage from the limb blades (Figure 13.)

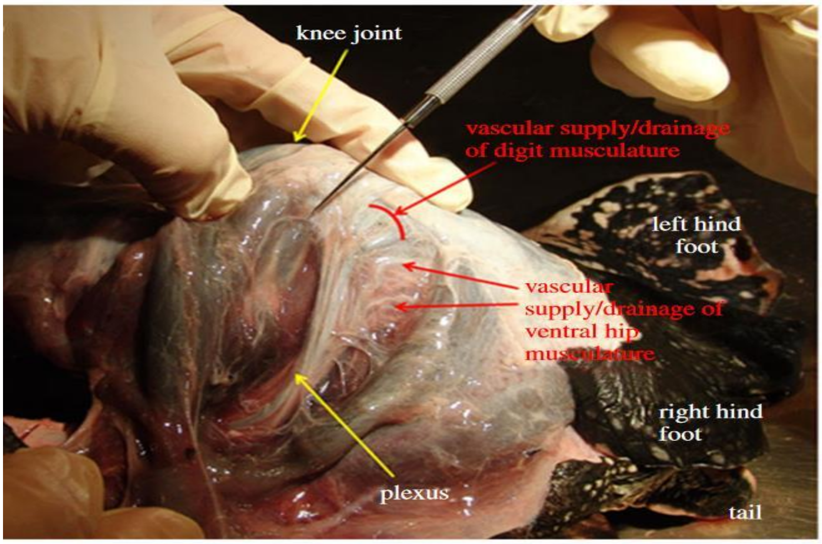


**Figure 13.** Laterodorsal view of hindquarter vascular plexus. Numerous vessels leaving/entering plexus that supply/drain flexor tibialis and ventral hip muscles, plus muscles of digits can be seen (Davenport et al., 2015)

Davenport et al. (2015) also showed that the counter-current heat exchangers on the limbs of leatherback turtles, did not work in the same way as in other groups such as mammals or birds. In the case of leatherback turtles, the exchangers function as retainers of the thermogenic heat produced by the motor muscles themselves (Figure 14).

These generate enough heat to keep the limbs at a temperature higher than that of the core, a fundamental process to maintain the functionality of the limbs in cold waters, and they even produce enough heat to send some to the core through the exchangers (Davenport et al., 2015).

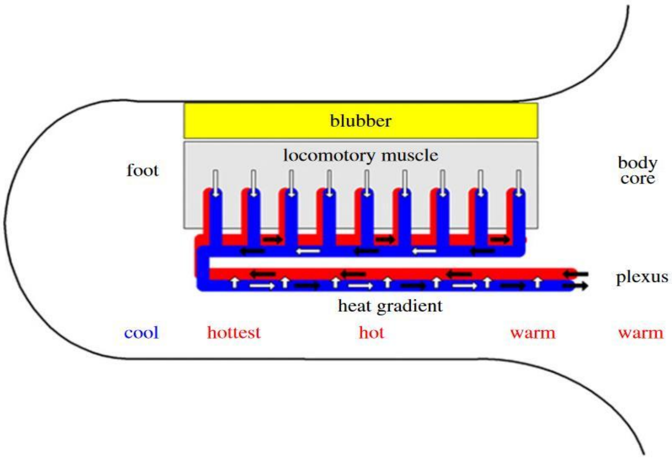
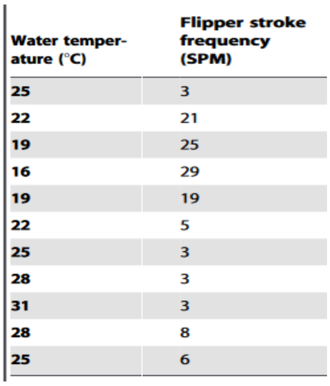


**Figure 14.** Schematic diagram of function of hindlimb vascular plexus in *Dermochelys coriacea*. Black arrows indicate blood flow, white arrows indicate heat flow. Red indicates arterial supply, blue indicates venous drainage (Davenport et al., 2015).

### 4.1.2 Behavioral mechanisms

It has been observed in juvenile leatherback turtles that at low temperatures of around 16ºC, swimming activity increases, that is, the number of strokes per minute increases markedly compared to higher temperatures. In temperatures from 16ºC to 22ºC, the frequency is on average around 23 strokes per minute, while in higher temperatures, from 22ºC to 31ºC, the frequency drops to an average of 4.5 strokes per minute (Figure 15). The function of this behavior would be to contribute to the production of internal heat to prevent the drop in body temperature (Bostrom et al., 2010).



| **Water temperature (°C)** | **Flipper stroke frequency (SPM)** |
|---|---|
| **25** | 3 |
| **22** | 21 |
| **19** | 25 |
| **16** | 29 |
| **19** | 19 |
| **22** | 5 |
| **25** | 3 |
| **28** | 3 |
| **31** | 3 |
| **28** | 8 |
| **25** | 6 |

**Figure 15.** Table that shows flipper stroke per minute (SPM) at different water temperatures (Bostrom et al., 2010).

In periods of high activity such as migrations made by turtles from foraging areas to nesting areas, one risk they face is overheating. One of the behaviors that has been observed in the leatherback sea turtle is to dive to great depths, to lower its body temperature. As they descend in latitude during the migration process, the frequency of dives and the depth of the dives increase, since the temperature is higher, and the risk of overheating increases (James et al., 2005). In other species such as the hawksbill turtle, migratory behavior has been seen in the populations of the Gulf during the summer months, since the surface waters reach very high temperatures, up to 37ºC, and are at risk of overheating, the turtles move to higher latitudes with lower temperatures to return to the Gulf once the summer is over (Pilcher et al., 2014).

### 4.1.3 Body mass

Resting metabolic rate increases with body mass, so animals with higher body mass are more efficient at maintaining a constant temperature and withstanding a larger thermal gradient. In the case of leatherback turtles, it has been observed that juveniles or smaller specimens were not able to regulate their temperature as effectively in cold waters. In fact, specimens with a length of less than 100 cm are not usually found in waters with temperatures below 26ºC. Nevertheless, this factor does not imply any risk of overheating, since they could increase blood flow to peripheral areas and cool down, especially when they are in tropical areas (Bostrom et al., 2010).

### 4.1.4 Fat accumulation

All species of sea turtles accumulate fat as a method of insulation but the leatherback turtle is the only one that has blubber (i.e. peripherally distributed fibro–adipose tissue). The blubber differs in fatty acid composition from seal/cetacean blubber and has a higher melting point. In total, adipose tissue represents 21% of the total volume of the head and neck but it is also present in other parts of the body as the limbs (Figure 16). This accumulation of fat serves as insulation as it prevents heat loss due to the difference in temperature between the interior of the body and the water and therefore, the cooling of the head due to the ingestion of cold food at high latitudes. This is essential since it is necessary to maintain the functionality of the brain, the eyes or the muscles of the jaw to be able to foraging at high latitudes (Davenport et al., 2009). As well, other structures of vital importance such as the lacrimal salt glands, since the main source of blubber are the jellyfishes which are rich in salt but poor in energy so have to be consumed in large amounts (Davenport, 2017).

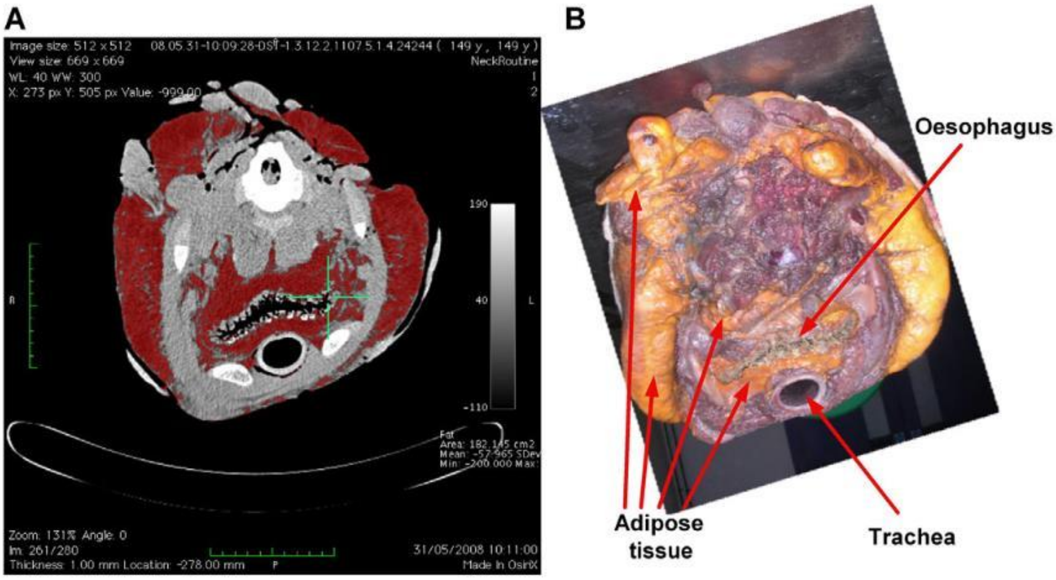


**Figure 16.** Transversal cut of the neck. A) Tomography that shows adipose tissue in dark red B) Photograph of cut surface of neck where the adipose tissue can be seen (Davenport et al., 2009).

The leatherback sea turtle also has layers of fat in the carapace and plastron area. This adipose tissue has two layers; a more superficial layer, whitish, with a solid consistency and connective tissue made up of short fibers, which suggests a structural and heat-insulating function (Figure 17). On the other hand, the deepest layer has a brown color, lobular appearance, total absence of connective tissue elements and great vascularization, which suggests a function of heat generation (Goff & Stenson, 1988).

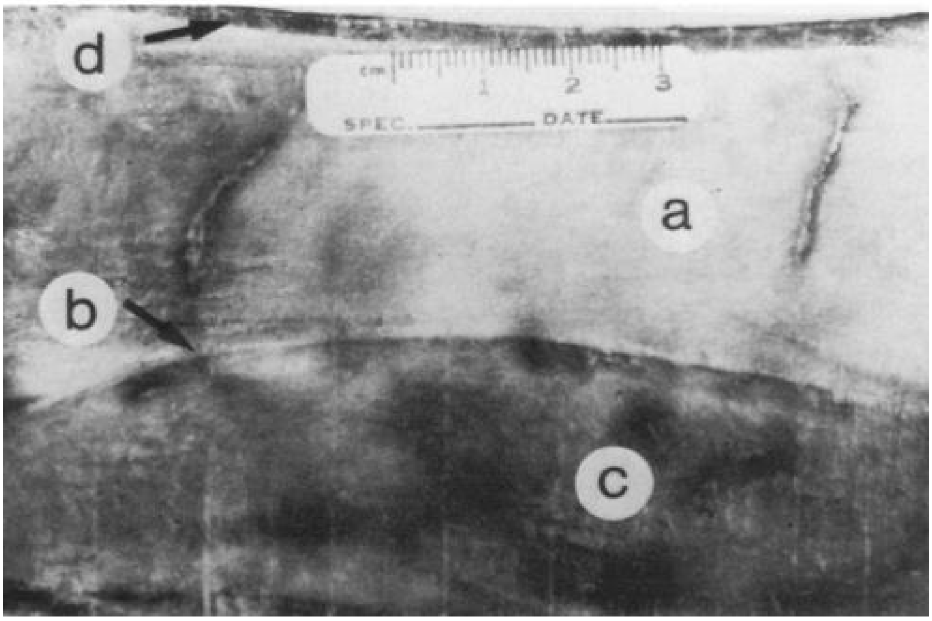


**Figure 17.** Adipose tissue of Leatherback Turtle a) White layer. b) Crisscrossing connective tissue fibers adipose layers. c) Brown layer. d) Carapace epidermis (Goff & Stenson, 1988).

## 5. CONCLUSIONS

Sea turtles have different mechanisms to modify or maintain their body temperature within certain limits regardless of variations in the environment. But after the literature review carried out, we can reach a series of conclusions:

The first of these is the clear lack of information related to the thermoregulation of sea turtles, as evidenced by the scarce and not very recent bibliography provided after the review. This problem is greater in some species such as the olive ridley sea turtle, the Kemp's ridley sea turtle and the right sea turtle. This could be due to their limited distribution area, since they are species that are only distributed in tropical areas, and therefore thermoregulation mechanisms do not seem to be too necessary.

The second conclusion we can reach with the actual information is that there are differences between the thermoregulatory mechanisms among the different species, especially between the Dermochelyidae and the Cheloniidae families. In the case of the leatherback sea turtle, the only representative of the Dermochelyidae family, we find a greater number of mechanisms. Behavioral and physiological mechanisms such as countercurrent exchangers, accumulation of blubber on the head and fins, as well as the presence of brown fat. In the case of the species belonging to the Family Cheloniidae, specifically the species for which information was found (the Green turtle, Loggerhead turtle and Hawksbill turtle) seem to present simpler and less specialized mechanisms than the leatherback turtle, such as reducing the flow of blood to the fins in colder latitudes in the case of the Green turtle and Loggerhead turtle or behavioral mechanisms such as seasonal migration in the summer months of the Hawksbill turtle. But it is difficult to know if all the species of this family present the same mechanisms or not, or if they present some to majors because there is a lack of information in this regard.

As final conclusion, in order to compare and better understand the mechanisms of thermoregulation of sea turtles, it would be necessary to carry out studies on the 7 existing species, in search of the mechanisms already known in some species and other possible ones that we still do not know about.

## CONCLUSIONES

Las tortugas marinas tienen diferentes mecanismos para modificar o mantener su temperatura corporal dentro de ciertos límites independientemente de las variaciones en el medio ambiente. Pero tras la revisión bibliográfica realizada, podemos llegar a una serie de conclusiones:

La primera de ellas es la clara falta de información relacionada con la termorregulación de las tortugas marinas, tal y como evidencia la escasa y poco reciente bibliografía aportada tras la revisión. Este problema es mayor en algunas especies como la tortuga olivácea, la tortuga lora y la tortuga franca. Esto podría deberse a su limitada área de distribución, ya que son especies que solo se distribuyen en zonas tropicales, y por tanto, los mecanismos de termorregulación no parecen ser demasiado necesarios.

La segunda conclusión a la que podemos llegar con la información actual es que existen diferencias entre los mecanismos termorreguladores entre las distintas especies, especialmente entre las familias Dermochelyidae y Cheloniidae. En el caso de la tortuga laúd, única representante de la familia Dermochelyidae, encontramos un mayor número de mecanismos. Mecanismos conductuales y fisiológicos como intercambiadores de contracorriente, acumulación de grasa en la cabeza y aletas, así como la presencia de grasa parda. En el caso de las especies pertenecientes a la Familia Cheloniidae, específicamente las especies para las cuales se encontró información (la tortuga verde, la tortuga boba y la tortuga carey) parecen presentar mecanismos más simples y menos especializados que la tortuga laúd, como reducir el flujo de sangre a las aletas en latitudes más frías en el caso de la tortuga verde y la tortuga boba o mecanismos de comportamiento como la migración estacional en los meses de verano de la tortuga carey. Pero es difícil saber si todas las especies de esta familia presentan los mismos mecanismos o no, o si presentan algunos a mayores porque falta información al respecto.

Como conclusión final, para poder comparar y comprender mejor los mecanismos de termorregulación de las tortugas marinas, sería necesario realizar estudios sobre las siete especies existentes, en busca de los mecanismos que ya conocemos en algunas especies y otros posibles que aún desconocemos.

## CONCLUSIÓNS

As tartarugas mariñas teñen diferentes mecanismos para modificar ou manter a súa temperatura corporal dentro de certos límites independentemente das variacións do medio. Pero tra la revisión bibliográfica realizada, podemos chegar a unha serie de conclusións:

A primeira delas é a clara falta de información relacionada coa termorregulación das tartarugas mariñas, tal e como evidencia a escasa e pouco recente bibliografía aportada tras a revisión. Este problema é maior nalgunhas especies como a tartaruga mariña olivácea, a tartaruga lora e a tartaruga franca. Isto podería deberse á súa escasa área de distribución, xa que son especies que só se distribúen en zonas tropicais, polo que os mecanismos de termorregulación non parecen ser necesarios.

A segunda conclusión á que podemos chegar coa información actual é que existen diferenzas entre os mecanismos termorreguladores entre as distintas especies, especialmente entre as familias Dermochelyidae e Cheloniidae. No caso da tartaruga mariña de coiro, única representante da familia Dermochelyidae, atopamos un maior número de mecanismos. Mecanismos de comportamento e fisiolóxicos como intercambiadores a contracorrente, acumulación de graxa na cabeza e nas aletas, así como a presenza de graxa marrón. No caso das especies pertencentes á Familia Cheloniidae, concretamente as especies para as que se atopou información (a tartaruga verde, a tartaruga boba e a tartaruga carey) parecen presentar mecanismos máis sinxelos e menos especializados que a tartaruga de coiro, como reducir o fluxo sanguíneo ás aletas en latitudes máis frías no caso da tartaruga verde e da tartaruga boba ou mecanismos de comportamento como a migración estacional nos meses de verán da tartaruga carey. Pero é difícil saber se todas as especies desta familia presentan ou non os mesmos mecanismos, ou se presentan outros porque falta información ao respecto.

Como conclusión final, para comparar e comprender mellor os mecanismos termorreguladores das tartarugas mariñas, sería necesario realizar estudos sobre as 7 especies existentes, na procura dos mecanismos xa coñecidos nalgunhas especies e doutros novos que aínda non coñecemos.

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## ANNEX I

Below is a simplified map of ocean currents around the planet (Figure 1A). The typical gyres are represented in the areas that are found between the continents.

In this link, https://youtu.be/CCmTY0PKGDs, a more detailed view of the currents movement is shown.

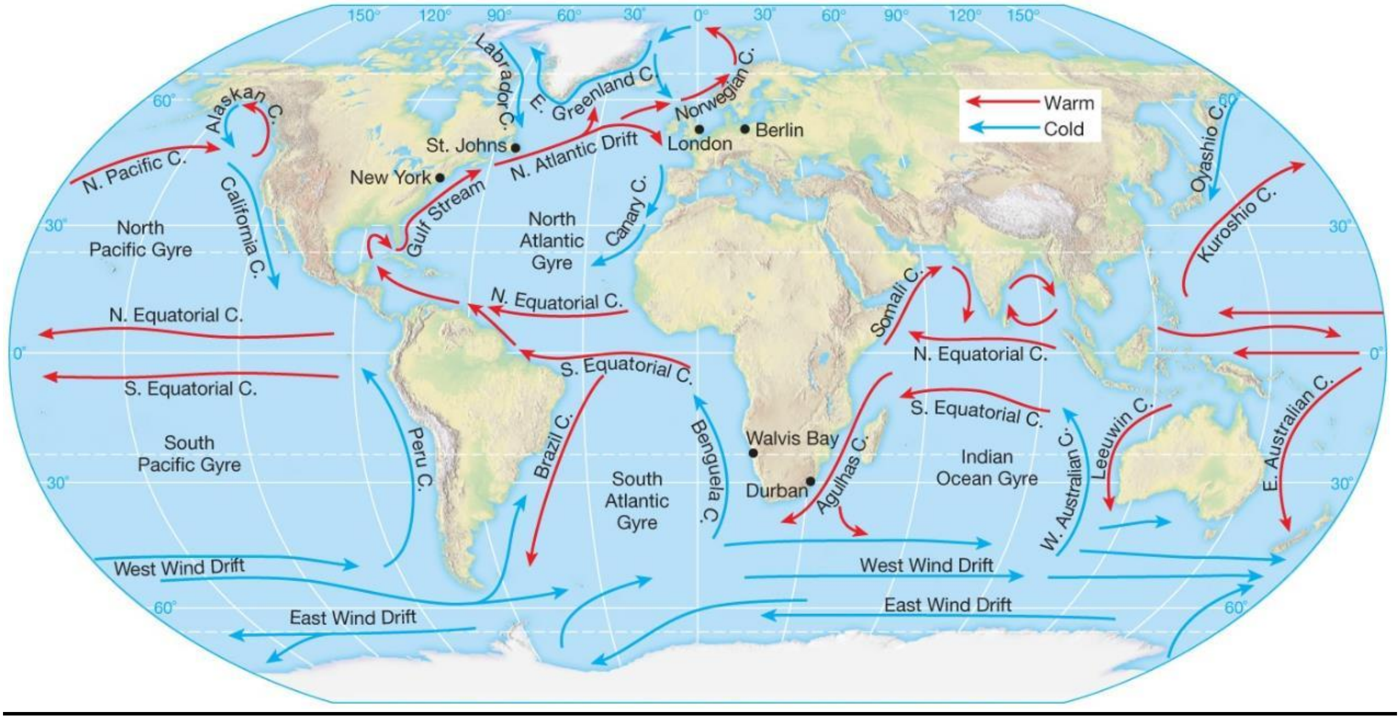

**Figure 1A.** Surface marine currents (Leviton, 2014).