Figure 1.A female Leatherback venturing onto a beach to look for a suitable location to lay her eggs.

In many reptile species, including the Leatherback Sea Turtle*(Dermochelyscoriacea)*[Figure1],the sexual phenotype is partly determined by the temperatures in which the eggs are incubated. The process is known as temperature-dependant sex determination (TSD) as the sex of the young is influenced by external environmental factors rather than by the animals genes; this disregards genotypic sex determination which occurs in most mammals, for example[1]. It is during the middle one-third of the embryos development that this differentiation occurs, and this critical time is known as the thermosensitive period.

Two distinct outlines have been discovered within the process of this period, and are known to scientists as Pattern I, which is subdivided into IA and IB, and Pattern II. Pattern IA and IB have just one transition zone. The pivotal temperature describes the temperature which produces a male:female hatchling ratio of 1:1. During IA, eggs that are incubated below this pivotal temperature hatch as males and eggs that are incubated above it hatch as females. IB is the exact opposite, where male hatchlings were incubated above the pivotal temperature and females below it. Pattern II is different in that there are two transition zones, with males dominating the middle temperature range and females emerging at the two extremes[2].Leatherback sea turtles follow Pattern IA. For this species, the pivotal temperature is equal to 29.4 degrees Celsius (°C)[3]and incubation temperatures above this produce female hatchlings whilst cooler temperatures result in males.

Since the early 1800's, global warming has caused an increase of 1 °C in the global average temperature; during this time period, more than fifty percent of the increase has occurred after 1980. Since 1984, global temperatures reached the highest ever recorded, twice, in 1998 and 2010[figure 2]; between January and August in these two years, the global surface temperature of land and ocean combined reached 14.7 °C [4]. Data collected in 1984 was able to suggest that a 2°C increase in global temperature could potentially cause the vast majority of sea turtle hatchlings to be females. These early associations are described in a paper published by Mrosovsky et al. (1984)[5]and the results

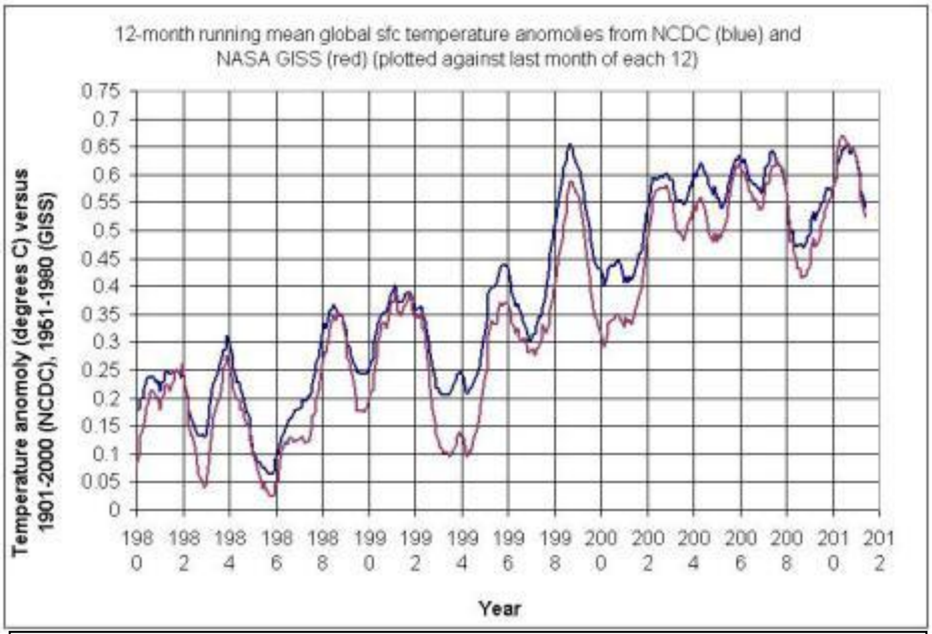

Figure 2.A graph to show the global surface temperatures from 1980-2012 with two peaks at 1988 and 2010.

of these predictions are worryingly accurate. With a decreasing number of male Leatherbacks, females are finding it progressively more difficult to find a mate and breed, and this is contributing to the rapid decline in the Leatherback population.

Leatherback Sea Turtles have roamed the oceans for longer than one hundred million years, but today the species is one of those that falls under the 'critically endangered'on the IUCN Red List of Threatened Species 2006. It is entirely the obligation of humans to reverse this, for more reasons than solely to save this giant and majestic creature. If the Leatherback Sea Turtles were to become extinct, the entire symbiotic relationship between the organisms of the ocean will be altered indefinitely. This is because the Leatherbacks, and many other turtle species, prey on jellyfish. They are able to consume up to their body weight of food every day, and for a Leatherback this is between can exceed 900 kilograms[6]. Without them, the jellyfish population would escalate so rapidly that their own pray of zooplankton, newly hatched fish and floating fish eggs would decline dramatically. This would further imbalance the ecosystem, as zooplankton, for example, are responsible for consuming millions of algae that would otherwise grow to out of control levels and again, this would continue to lead to progressively more complications.

Upon researching, it was challenging to find figures for the exact leatherback population and data varied dramatically. One document from Vancouver Aquarium stated that there are an estimated 30,000 leatherbacks (male and female) left in the world[7], whilst The WWF claims that there are just 2,300 adult females[8]. The IUCN red list also contained different information, stating that:

"the total global abundance across Leatherback subpopulations had declined from 90,599 nests yr^{-1} to 54,262 nests yr^{-1} over three generations until 2010. Using average conversion factors from different subpopulations to provide bracketed estimates of nesting female abundance (i.e. 5 and 7 clutches per female, three years for re-migration intervals, intermediate between subpopulation averages; TEWG 2007, Reina *et al*. 2002), these annual nesting abundance values correspond to approximately 12,943-18,120 nesting females yr^{-1} (or 38,828-54,359 adult females) three generations ago and 7,752-10,852 nesting females yr^{-1} (or 23,255-32,557 adult females) in 2010."

Figure 3.A quotation from the IUCN red list website for the Leatherback Sea Turtle.

Analysing these three figures showed ahigh degree of ambiguity. Firstly, the IUCN Red List gave a large range within their datafor the predicted number of adult females. The difference of around 15,500 shows a high level of uncertainty.Secondly, the estimations from Vancouver Aquarium state that the total population of the Leatherbacks, including both males and females, is 30,000. This is less than the IUCN red list's expected population of female Leatherbacks alone which is marginally more than 23,000. Lastly, the WWF's estimations are dramatically lower than the data from the other two sources. The WWF state that there are around 2,300 adult females, 20,955 fewer than the IUCN Red List's approximation, which claims there are at least 23,255.

With such varying information on the internet, it was difficult to understand exactly how the population of the Leatherbacks looks. I contacted Dr Larry McKenna, who has two PhD's, including one in Environmental Science and is the Founding Director of the S.O.L.O (Save Our Leatherbacks Operation) charity[9], to enquire as to why the estimations of the leatherback population were so varied and to ask him on his view. Dr McKenna informed me that:

"there are no estimates of the male (Leatherback) populations in the oceans. The males go to the sea (after hatching) and live there until death. The best estimations of the balance between the males and females is the nesting ratios of Non Nesting Events (NNE), when a female comes to shore and lays no eggs. A female can carry eggs for up to three years waiting for a sex encounter and the right biological conditions, (such as) a rich food supply. We have learned by doing (practical work), how to manipulate the sex before hatching. We have no intentions of playing God in this. Should natural conditions indicate more males are needed, we can advise or create the ratios desired. Couple that ability with our recent greatly improved hatch out percentages, and we are provided with the tools to change the landscape of hatchling populations. It is these dynamics which spur us to continue, as the 'book' has not been written on the Leatherback population. Attempts so far miss the mark."

Figure 4.A quotation from a personal interview with Dr Larry McKenna on the Leatherback population.

Using this information, it is considerably more clear as to why there is such uncertainty, and therefore variation, in data regarding the total number of Leatherback Turtles in the oceans today. What iscertain, however, is that biologists, conservationists and the public need to work towards saving the species from extinction.

Conservationists have started researching into the effects of nest management methods on the sex ratio and hatching success of the leatherback species. Their aim: to determine whether different incubation strategies could create the pivotal temperatures needed during the thermo sensitive period, influence temperature-dependant sex determination and design an appropriate nest management scheme to enable a healthierbalance between themale: female hatchling ratio. At the very least, this should stabilise the Leatherback population and contribute to the prevention of the species endangerment.

Conservationist, Arturo Eduardo Herrera, carried out a study on Playa Gandoca, an 8.5 kilometer long beach on the southern Caribbean coastline of Costa Rica,and analysed three different Leatherback turtle nest management strategies. The first was a natural nest, whereby the original location chosen by the nesting female was left untouched and not moved. The second, was a hatchery nest, where chosen nests were relocated to a hatchery; this is a building or installation in which the hatching of turtle eggs is artificially

Figure 5.A photograph of the Habaraduwa Turtle Hatchery in Sri Lanka.

controlled[figure 5]. The final strategy studied by Herrera was known as a relocated nest and these nests were repositioned from their original site to a biologically and environmentally safer area of the same nesting beach[10]. A control was set at random nearby the experimental nests and used a temperature logger in order to record the sand temperature throughout the period of nesting and incubation.

In the investigation, Herrera studied hatching success and sex ratio. The hatching success was calculated using a simple formula:

$$hatching\ success\ (\%) = \frac{hatched}{total\ number\ of\ eggs} \times 100$$

Figure 6.

Sex determination is more complicated to determine, as the only precise method is to examine the gonads or genitalia of the young turtles under a microscope. This process is invasive and potentially life threatening and when taking into account their place on the IUCN Red List as critically endangered, the procedure could be more damaging than useful. Although it is always desirable to achieve the highest accuracy possible in the results of any experiment, it is also extremely important to take into consideration any risks and ethical matters. If any Leatherback hatchling were to die during the sex determination method of examination, it raises the impact that humans are having on the declining population. Any death of an animal on the IUCN critically endangered list is highly significant, and so in this case it was appropriate to find another method to try to determine the sex ratios. Therefore, Herrera used a less-invasive method: a formula[figure 7] using the mean temperature of each nest recorded by a Handheld Digital Thermometer three times per day during the middle one-third of incubation. The intricate formula gives an estimation of the sex ratio, however Herrera states that ‘since it is based on the best fit curve, the actual sex ratio will be slightly different than this estimated ratio’[11]. Although the results are less accurate than gonad or genitalia examination, it is undoubtedly appropriate for the formulation method to be used as an alternative.

$$sr(t) = \frac{1}{1 + e\left(\frac{1}{s}(P - t)\right)}$$

Figure 7.

In Herrera’s experiment data was collected from twelve nests that had been left naturally, twenty nests that were relocated and fifteen nests from the hatchery. The mean temperature recorded from the natural nests was 30.8 °C and is significantly higher than the pivotal temperature of 29.4 °C for the Leatherback Turtles. Herrera used the sex determination formula[figure 7] to estimate that the natural nests produced a ratio of 74.1% females to just 25.9% males[12]. This data provides important evidence into the importance of balancing the male: female ratio, especially as on average only one in one thousand Leatherbacks will survive into adulthood to be able to breed.

Data collected from the relocated nests showed that the mean temperature of these nests during the middle one-third of incubation was 30.4 °C. The 0.4 °C difference between the natural nests and the relocated nests is a noticeable success, however, the estimations for the relocated nests still showed a prominently imbalanced sex ratio with 30.4% of eggs hatching as males and approximately 69.6% females[13].

Hatchery nests showed the most promising results: with a mean temperature of 29.5°C. The temperature varied slightly ranging from 28.6°C to 33.2°C, however, and this is perhaps the reason that the sex ratios were not closer to 1:1. The data was formulated, and nevertheless, the results were extremely pleasing with an estimate of 45.6% of the eggs from the hatchery nests produced female Leatherbacks while 54.4% resulted in males[14]. The results of the proportion of female hatchlings and the hatching success in each type of nest can be seen in Figure 8. Graph F shows that the proportion of females was far more evenly spread through the hatchery nests than the natural or relocated nests, which had a higher female density than males. The mean average is shown by the horizontal mark across each vertical line showing the range, and it is clear that the average for the hatchery nests was far nearer the 0.5 (50%) than the other two nest types. The hatching success rates indicated that 'the nests placed in the hatchery were more likely to have higher hatching success than natural relocated nest[15]' with these nests resulting in a 71.1% success compared to just 50.5% success for natural nests and 61.2% for relocated nests[16]. This can also be seen from Graph E from Figure 8, where the lowest success rate for the hatchery nests was around 40%, whereas the lowest rates for the natural nests was around 20% and 0% for relocated nests. This intruiging information shows how the use of hatcheries could be the cutting-edge for conservationists and biologists beginning to balance the sex ratios of the Leatherback Sea Turtles.

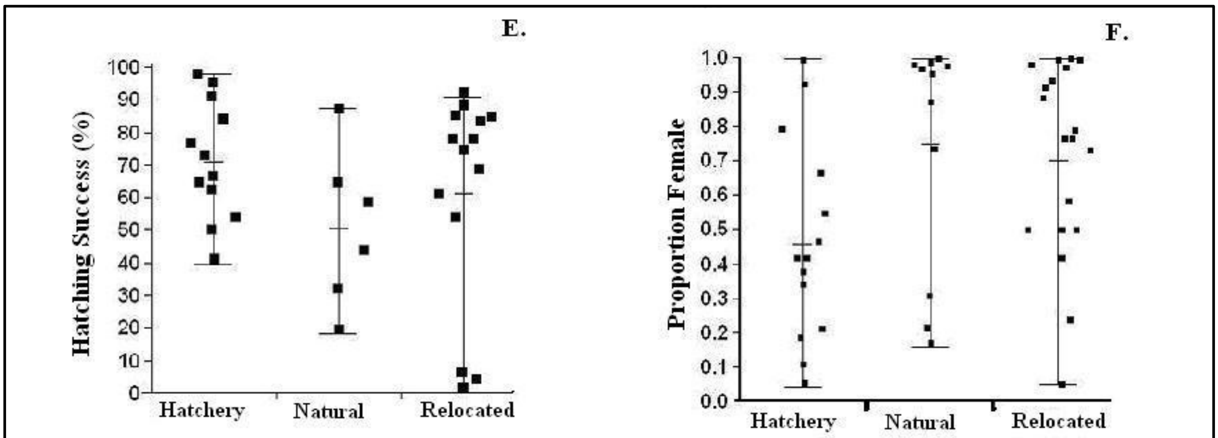

Figure 8.

During the course of the study carried out by Kerrera, nineteen nests were not included in the final results. Some nests were lost due to erosion, four had incomplete data and one nest was destroyed, potentially by poachers. The result that were collected from nests such as these were not sufficient as the nests had not completed the thermo sensitive period during the middle one-third of incubation when the sex determination is established[17]. In this experiment, one nest that was destroyed due to erosion and the only nest that was poached were both lost from relocated nests. This raises problems as it could be questioned as to whether the relocation of the eggs enhanced their chances of being destroyed. It is highly possible that the relocating process was overwatched by poachers, and so the exact location of the Leatherback eggs was known. Relocated nests were moved when there was a risk of tidal inundation, traffic, predation or erosion and these nests were theoretically moved to safer areas of the beach. It raises ethical questions as to whether the relocation of the nest lost to erosion was only destroyed due to the experiment: would the nest have survived had there been no human involvement? Although it can be argued that the relocation process was not a success in this case, it is also fair to say that Kererra took into account the fact that the original site of the nest must have had one or a combination of the previously stated factors that led the team into believing that the nest was in danger. Taking this into account, it can now be asked whether the nest had a chance to survive if it was left as a natural nest.

From the data provided by Herrera, it seems most appropriate to use the hatchery nest method. Results were extremely promising, and due to the fact these nests are carefully controlled in an installation, there is no chance that any nest will be poached or lost due to erosion. The temperature of the hatchery can be a controlled variable, whereas nests left on the beach cannot have their temperatures controlled. By being able to control the vital variable that determines the sex ratios, biologists and conservationists have a considerably higher chance of achieving progressive results.

For hatchlings in the wild, the short course from the nesting site to the water is one of the most dangerous journeys they will take in their life. There are countless risks and preditors waiting to catch these vulnerable creatures in their first moments above the safety of their nest. This accounts for the species having such an incredibly low survival rate with only around 1 in 1,000 Leatherback turtles surviving to adulthood. Mother Leatherbacks do not stay with their nest and leave as soon as they have laid their eggs; this leaves the hatchlings completely alone during this hazardous time. As seen in Herrera's study, nests are prone to the coastal processes of erosion and the egg clutch will be washed away.Inside the nest, insects sometimes chose to lay their eggs in the turtle clutch, allowing their larvae to hatch and feed on the turtle foetus [18]. If the turtles survive long enough to be able to hatch, hatchlings face more dangers as soon as they leave their nest, such aspredatory animals including birds, racoons and wild dogs[19]. Although unfortunate, these natural processes are crucial for enabling the species as a whole to survive as only the strongest, most well adapted turtles stay alive. This is known as natural selection and was a theory proposed by Charles Darwin in 1859[20] the basic principle is that each individual will have a different set of unique genes, which show as a wide range of phenotypes. Individuals with characteristics that are most suited to the environment are the most likely to survive and reproduce. This allows only the strongest genotypes to be passed on to the offspring of the next generation and the weakest genotypes will be lost. Due to this, the species as a whole should theoretically get stronger with every generation.[21]

The process of natural selection has occurred from the origins of life, and it is highly likely, if not certain, that organisms today are characterised as we see them due to the survival of the fittest. With this in mind, it is clear to understand that the natural risks to the Leatherback species, which have been explained above,are not causing their decline. The Leatherbacks are the only remaining species of a family of turtles that can be traced back more than 100 million years to around the Cretaceous or even Jurassic Period[22] [figure 9] and it is only in recent years that their population has declined so significantly. This leads us to believe that it is therefore the actions of humans which has caused the Leatherback population to plummet to near extinction.

Aside from global warming and temperature change, humans are causing great harm to the Leatherbacks. Poachers often steal eggs for meat and in some countries they are seen as a delicacy. Certain cultures around the world believe that sea turtle eggs are aphrodisiacs and also have the ability to enable humans to live a longer life. Although these claims have no scientific proof, traditions among groups of people mean that poaching of turtle eggs, although an illegal trade, leads to a continuous source of income[22]. Also, young hatchlings are known to suffer from what is known as disorientation. New hatchlings emerge from their nests a few days after breaking free from their egg; they climb upwards and remain just below the sand. The temperature of the sand is important again, as they wait here until the surface above them is cool. This indicated that it is the night, and therefore any predators will find it more difficult to see and catch them. However, this also causes problems due to human light pollution. This is because hatchlings are prone to disorientation. Disorientation occurs because the young turtles use the natural light horizon lying over the ocean as well as the white crests from waves breaking ashore to determine where the sea is. Light sources from buildings and infrastructure sometimes lead the hatchlings into believing this is the light horizon and they travel in the wrong direction [23]. The young Leatherheads are often run over by oncoming cars as well as spotted by predators as they venture further from the safer waters and nearer to traffic and light.

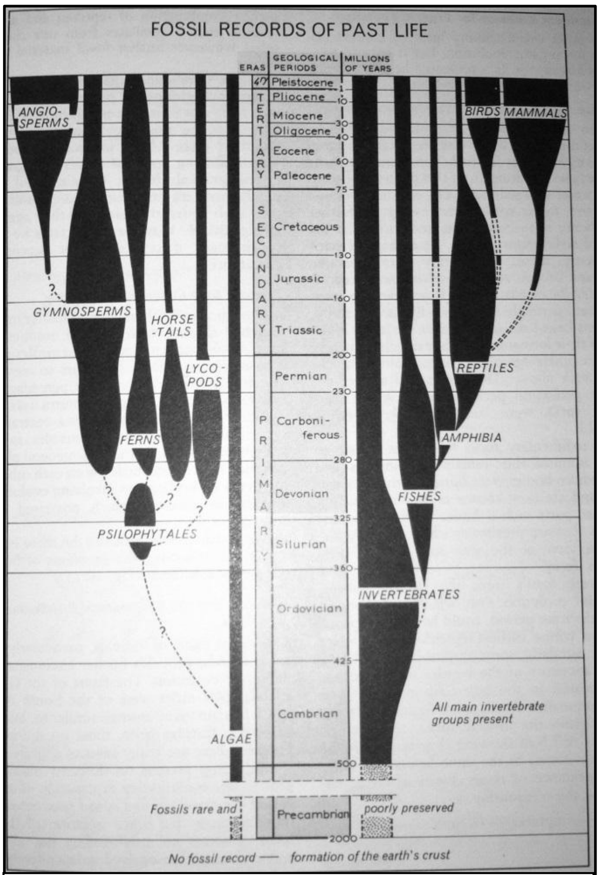

Figure 9.a diagram to show the fossil records of past life. The thickness of the branches indicates the abundance of the group.

Using this information, it can be concluded that from the three management strategies in Herrera's study, hatcheries are most definitely the primary scheme in order to prevent the Leatherback species from extinction. Under close supervision away from the temperature effects of global warming, predators, erosion, poaching and disorientation, young hatchlings have the best chance of survival. The only main risk here is that we prohibit natural selection of the hatchlings as they venture to the oceans, however when studying the positive results of Herrera's study and looking at the endangerment level of the species, this compromise looks suitable and beneficial.

Sources

During my research, I came across a video clip[24] promoting the conservation of leatherbacks and explaining the human threats. The commercial was presented by Dr Larry McKenna. Upon further investigation into Dr McKenna's work, I found a charity which was founded in 2005 known as Save Our Leatherbacks Operation (S.O.L.O) in which McKenna is the founding director. The charity describes McKenna as a 'filmmaker, photographer,author, and adventurer; beneath the ocean and on top of mountains'[25].

I chose to contact Dr McKenna for my research due to my confidence in the reliablility of his knowledge and information, primarily because McKenna has two PhD's in Environmental Science and Business Administration. He is an author of a published book called 'Almost Gone' and when I enquired as to purchasing a copy for my research, it was unfortunate because every copy had sold out (enquired 02-02-14). The fact McKenna had written a non-fictional account of the Leatherbacks in the Pacific Ocean led me to believe that his knowledge and research was valid. This belief was reinforced due to the fact Vivid-Pix, a provider of revolutionary underwater photography, began working in partnership with S.O.L.O in November 2013[26]. Lastly, Dr McKenna provided me with confidence in the reliability of his work due to his dedication. The charity claims that his long time plans include: 'reversing the extinction spiral of the Pacific Leatherback sea turtles over the next 3 years'. It also states that the 'foundation is composed of all volunteers in (the) USA who are not paid wages or benefits' [27]. The fact that McKenna and the team at S.O.L.O are working so greatly on saving the Leatherbacks without any drive from employment or income leads me to understand how the charity are working purely due to their devotion to the species. When talking to Dr McKenna during a personal interview, he came across as extremely knowledgeable and informative. Together, these indications lead me to completely trust the information I have included in my report.

A second source used for my report is a biological study by Arturo Eduardo Herrera. The report is extremely in depth, and all experiments and data were carried out and collected by the author. Herrera was studying at the Conservation Biology Centre for Ecology and Conservation University of Exeter in Cornwall, United Kingdom, at the time the paper was published. The study has a disclaimer written by Herrera claiming that 'all original research was carried out by the author and agree with the contents of the manuscript and its submission to the journal[28].' The claim shows that Herrera's results and documents are written first hand and this leads to the possibility of a biased result. For example, it must be taken into consideration that Herrera may have relocated nests to a different site in order to acquire a certain result. I do, however, trust Herrera's study as it is so highly detailed and documented. Also, many errors, such as the nests that were poached and eroded, were accounted for but they were not included in the final results. Taking out anomalies makes the study more reliable.