Dissertation Report

MSc in Marine Biodiversity and Biotechnology

Academic Year: 2008/2009

Title: Nesting beach characteristics of endangered sea turtles in Las Perlas Archipelago, Panama

Author: Maria Rubio
Nesting beach characteristics of endangered sea turtles in Las Perlas Archipelago, Panama

Author: Maria Rubio

Submitted: September 2009

Submitted as part assessment for the degree of Master of Science in Marine Biodiversity and Biotechnology

Centre for Marine Biodiversity and Biotechnology
School of Life Sciences
Heriot-Watt University
Edinburgh
ACKNOWLEDGEMENTS

This project would not have been possible without the support from the Alumni funding from Heriot-Watt University, the Darwin Initiative Project, and the Smithsonian Tropical Research Institute in Panama, the grateful advices from Hamish Mair and Hector Guzman, and the gentle help provided by Fiona Monaghan, Hugh Barras, Sean McMenamy, Carlos Guevara, Catalina Gomez, Reyes, Angel, Eneida and Toribio.

Nomenclature

Las Perlas Archipelago (LPA), Particle size analysis (PSA), Smithsonian Tropical Research Institute (STRI), Heriot- Watt University (HWU), High Water Tide Level (HWL), Low Water Tide Level (LWL).
ABSTRACT

Las Perlas Archipelago in Panama has become a special area of conservation due to its ecological importance. Its nutrient-rich waters host an abundance of sea life such as whales, coral reef communities and sea turtles, creating a wonderful sanctuary of tropical biodiversity. Five out of the seven existing species of sea turtles worldwide select the beaches of LPA as potential areas for nesting, but little is known about these sites and the nest site selection process. This study has enumerated and developed findings on several environmental factors such as beach slope, sand temperature or sand particle size that are believed to affect the complex nest selection process in order to best understand and ideally protect sea turtles and their natural nesting habitats.
1. INTRODUCTION

GENERAL INTRODUCTION

Area

Las Perlas Archipelago (LPA) consists of a group of about 255 tropical islands and islets located in the Gulf of Panama, in the Pacific Ocean, about 70 km far away from Panama City (see Figure 1).

Figure 1. Special Management Zone of LPA

The area was designated a Special Management Zone in April 2007 including a total of 168,771 ha, being 33,153 ha of islands and islets, and 135,618 ha of surrounding
waters. The aim of the law is to protect the area’s natural resources and conserve the biodiversity of its ecosystems by promoting social and educational awareness and incorporating all the ecological, economical and cultural values (Panama's Gaceta Oficial, 2007).

This law was successfully pursued thanks to the Darwin Initiative funding, Heriot-Watt University and the Smithsonian Tropical Research Institute, whom developed a shared project with the aim of protecting and conserving Las Perlas Archipelago richness. This project has enabled STRI, Heriot-Watt University staff and several postgraduate students since 2003 to carry out different research studies within the area such as coral reef communities, benthic ecosystems or mangrove habitats.

Las Perlas Archipelago (LPA)

The Gulf of Panama forms part of the Tropical Eastern Pacific (TEP) biogeographic zone, which is characterized by having unique fauna and flora due to characteristic current systems and upwelling regimes which create a biological connectivity of about 5000 km and isolate the region (Allen and Robertson, 1994; Glynn and Ault, 2000). More specifically, the TEP is influenced by El Niño Southern Oscillation (ENSO), which brings wind-driven upwellings from cold, high-productive, deep waters during the dry season (from January to April) leading to a nutrient enrichment of its waters (Chavez et al. 1999). These waters attract several species such as humpback whales (*Megaptera novaeangliae*), five species of sea turtles and whale sharks, which migrate to the area for nursing and nourishment. LPA is also home for a rich diversity of fish, coral reefs, invertebrates and local populations of sea birds making LPA an important hotspot of tropical biodiversity. Moreover, LPA also hosts an important hydrological reserve composed of rich mangrove habitats in the biggest of the islands, Del Rey.
Island, which is also under protective legislation. However, the area’s natural resources have been exploited during many years by the local communities as the main source for their economic subsistence and more recently, tourism development have negatively influenced all these species and their natural habitats.

LPA has been witness of some dramatic ecological episodes which hard pressed establishing the current management and protection measures and have helped understanding that there are no unlimited resources. Two of the most important cases were the collapse of both the oyster and scallop populations.

Pearl oyster fishing takes us back to the Spanish colonists 16th century, when the region was discovered as a tropical paradise with plentiful of gigantic oysters (*Pinctada Mazatlantica*). The result was an almost extinction of the oyster’s population by the overfishing during hundreds of years. Nowadays pearl populations in LPA remain relatively scarce and the only purpose for its fishing is local meat consuming (Campbell, 2005).

![Figure 2](image.png)

**Figure 2.** Old painting of Vasco Nuñez De Balboa and his company of explorers (Panama Fishing and Catching, 2008)
The scallop *Argopecten ventricosus* became an important fishery for LPA during the 80’s but the massive exploitation during two decades and the lack of regulation led to a total collapse of the stock. Present studies have revealed that scallop populations have not been recovered yet since very low or zero densities of juveniles have been found within the different sites of the study. The reasons that do not allow scallop survival point towards the lack of suitable habitats, low food availability and predation. Proper corrective measures have been established, hopefully not too late (Medina, 2004).

**Figure 3.** *Argopecten ventricosus* fishery production statistics (1981-1991). (Dirección General de Recursos Marinos, 2004).

LPA it is known to be an important site for migrative sea turtles where they use the area as potential nesting sites. The problem is that all five species that go to LPA are currently in state of decline, it is hoped that with the current protective legislation, sea turtles would survive during years and years in LPA.
Sea Turtles of Las Perlas Archipelago

Five out of the seven existing species of sea turtles all over the world have been found to nest in LPA, specifically 37 nesting sites have been spotted in the area. That makes the area a very special site for conservation as all of them are threatened species. But very little is known about the nesting season and these nesting sites.

The main threats responsible for the decline of sea turtle populations worldwide are both intentional and incidental captures by fisheries, predation, direct egg poaching, pollution and tourism development (Koch et al., 2006; Lutz and Musick, 1997; Spotila, 2004).

According to the IUCN Red List of Threatened Species (IUCN, 2009), the current status of the five species of sea turtles nesting in LPA is summarized in Table 1:

<table>
<thead>
<tr>
<th>Turtle</th>
<th>Latin name</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green turtle</td>
<td><em>Chelonia mydas</em></td>
<td>Endangered&lt;br&gt;Population trend: decreasing</td>
</tr>
<tr>
<td>Loggerhead turtle</td>
<td><em>Caretta caretta</em></td>
<td>Endangered&lt;br&gt;(needs updating)</td>
</tr>
<tr>
<td>Olive ridley turtle</td>
<td><em>Lepidochelys olivacea</em></td>
<td>Vulnerable&lt;br&gt;Population trend: decreasing</td>
</tr>
<tr>
<td>Leatherback turtle</td>
<td><em>Dermochelys coriacea</em></td>
<td>Critically Endangered</td>
</tr>
<tr>
<td>Hawksbill turtle</td>
<td><em>Eretmochelys imbricata</em></td>
<td>Critically Endangered</td>
</tr>
</tbody>
</table>

**Table 1.** Current status and trends of the five threatened species of sea turtles nesting in LPA.
Green turtle *Chelonia mydas*

Loggerhead turtle *Caretta caretta*

Olive ridley turtle *Lepidochelys olivacea*

Leatherback turtle *Dermochelys coriacea*

Hawksbill turtle *Eretmochelys imbricata*

All images taken from NOAA fisheries, 2009.
Sea turtle taxonomy and general introduction

Class Reptilia

Order Testudines

Family Cheloniidae

Chelonia mydas  (green turtle)
Caretta caretta  (loggerhead turtle)
Lepidochelys olivacea  (olive ridley turtle)
Eretmochelys imbricata  (hawksbill turtle)

Family Dermochelyidae

Dermochelys coriacea  (leatherback turtle)

The two families of sea turtles diverged about 100 million years ago. As a consequence, leatherback turtles have exclusive morphological and physiological characteristics that differ from the other family species such as a bigger size (about 1000 kg), a leather-like flexible carapace composed of thousands of bones and a wider distribution worldwide, including colder and deeper waters due to its ability for controlling the blood flow (Reina et al., 2002).

Since sea turtles spend most of their time in water, their lungs are specialized to pelagic life with a greater area for gas exchange. In this way they do not need to go to breathe to the surface so often (Lutz and Musick, 1997).

Only the females go to mainland in order to release their eggs, where they will be incubating for about 48-66 days, depending on factors such as temperature (Spotila, 2004). Their lifespan is thought to be up to 80 years and they present a very broad diet (depending on the species) such as grazing algae, sea grasses, crustaceans, jellyfishes or sponges. They are also thought to have an important role within the marine ecosystem by maintaining the vitality and stability of coral reefs (Chaloupka et al., 2008).
Sea turtle life cycle and ecology

There are many reviews about sea turtle biology but the best way to understand it is by summarizing a typical life cycle of a sea turtle:


According to Lutz and Musick, 1997, in general, sea turtles reach maturity after 20-30 years and migrate from foraging areas into mating areas for reproduction. After the copulation period, males return to foraging areas whereas females go to shallow water internesting habitats in order to release their eggs. And after this, females return to foraging areas in order to feed and accumulate energy for the next reproduction.
The number of clutches and the intervals between clutches depends on the species and area, but generally these intervals are thought to occur after 2-4 years (Miller et al., 2003) and the number of eggs per clutch is about 100. The process of releasing the eggs it is known as ovoposition (Lutz and Musick, 1997; Spotila, 2004).

It is well documented that female sea turtles return to the same area where they were born to release their eggs (philopatry) and that subsequent migrations between nesting and mating areas are performed very accurately (between 0-5 km). These are two different processes known as philopatry, which is the discrimination of a particular region, and the nesting site fidelity, which is the fine-scale homing to a particular beach (Lutz and Musick, 1997; Miller et al., 2003). These migrations can account for 2600 km. and sea turtles are thought to use the earth’s magnetic field to orientate and navigate themselves like happens in other migratory species (Lohmann, 1991). These facts lead to important conservation issues as these nesting sites where turtles migrate innately are crucial: if we don not protect these valuable nesting sites, sea turtles will irredeemable lose their natural habitat to lay their eggs.

Nesting seasons usually vary between species and zone, and not all the authors agree. In the eastern Pacific coast nesting periods for the five species of sea turtles nesting in the LPA islands are generally accepted to be (See Table 2):
<table>
<thead>
<tr>
<th>Sea turtle specie</th>
<th>Nesting season</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Chelonia mydas</em></td>
<td>October to January</td>
</tr>
<tr>
<td><em>Caretta caretta</em></td>
<td>May to August</td>
</tr>
<tr>
<td><em>Lepidochelys olivacea</em></td>
<td>July to December</td>
</tr>
<tr>
<td><em>Dermochelys coriacea</em></td>
<td>October to February</td>
</tr>
<tr>
<td><em>Eretmochelys imbricata</em></td>
<td>June to October</td>
</tr>
</tbody>
</table>

Table 2. Different nesting seasons for the sea turtles of the eastern pacific zone (Spotila, 2004)

The field work in this study was unfortunately out of the peak nesting period because of logistical reasons but some nests were found, as the study sites were based in previous nesting sites and the nesting season was just started for 2 of the species.
Factors affecting the selection of a potential nest site and its eco-biological consequences

The selection of a suitable nesting site is very important at many levels: not only for the female turtle but also for a proper embryo development, and the subsequent hatchling survival (Miller et al., 2003). Therefore, higher survival of the offspring represents a higher fitness for the parents (Wood and Bjorndal, 2000). The authors also suggested that nesting site selection is governed by a number of clues, depending on both internal physiological factors and external environmental factors.

First studies on sea turtle behaviour by Hendrickson, 1958; Carr and Ogren, 1960 and Carr et al., 1966; soon discovered that species from the Cheloniidae Family (loggerhead, green, hawksbill and olive ridley turtles), have an established practice just before the selection of a nesting site, which is to press their heads into the sand, probably to check suitable environmental characteristics of the area such as moisture, temperature or salinity.

According to Mortimer, 1990 and 1995, environmental factors of a suitable nesting beach must have: easy accessibility to the beach, nest placement at enough height for avoiding tidal inundations, sand properly cohesive for building a nest and ease gas diffusion, and specific temperatures for a proper maturation of the egg. Wood and Bjorndal (2000), also suggested that the nest placement must avoid being to far away from the sea (to avoid eggs dissecation, misorientation or hatchlings predation) or too close (to avoid inundation or erosion). Kamel and Mrosovsky (2004) suggested that sea turtle females may have developed the ability of placing their nests at intermediate distances from the high tide water line as a response to these opposing pressures.

Ackerman (1997) defined some environmental requirements for the embryo within the nest chamber such as small temperature variations (to provide isolation), high
humidity, low salinity and good ventilation to allow gas exchange between the embryo and the surrounding environment.

And finally, after the hatchling process, the suitable conditions for a new born must present low predation rates and meet the proper currents when first crawling into the sea to increase survival (Miller et al., 2003).

Although some factors may vary between species and area of the world, all the studies on the topic generally agree that a number of trends occur and nest site selection is not a random process. This can explain why some females abort some nesting attempts and leave a ‘false crawl’ without laying eggs (Lutz and Musick, 1997). In fact, it is logical to think about that a female is going to nest in the areas where the characteristics will favour an evolutionary success for the specie.

Therefore, these are the most important characteristics that may affect the placement of a sea turtle nest:

- Beach slope, width and length

Beach slope not only influences the female trying to ascend to the top of the beach but also the new hatchlings going all the way seawards. According to Wood and Bjorndal, 2000, slope is the most important factor influencing the nest site selection in loggerhead turtles, by the fact that is related with nest elevation, since a higher elevation of the nest may suppose a higher chance of nest survival (because it is more isolated and protected from tidal inundation). Another study enforces this hypothesis by describing a positive correlation between nest elevation and hatchling success in hawksbill turtles (Horrocks and Scott, 1991).

Other studies by López-Castro et al. (2004), defined that the characteristics of olive ridley nesting sites include smooth-sloped beaches. More gently slopes are generally
related with wider beaches. This has been explained as more smoothly slopes may favour the females approaching the nest site in a quicker and easier way (Garmestani et al., 1997). The same study defined loggerhead nesting beaches with significant preferences for the ones of > 8.5 m width.

Kikukawa et al. (1999), found that beach length has a negative correlation and beach height a positive correlation with nesting beach selection, therefore shorter and higher beaches are preferred by loggerhead turtles. Wood and Bjorndal (2000), found out that the average of beach length between a nest and the high water tide level for loggerhead turtles was about 23.5 m. Other studies with olive ridley turtle determined an average of length of 17.65 m (López-Castro et al., 2004).

- Nest elevation

As mentioned before, nest elevation is an important factor in order to isolate and protect the nest from tidal inundation, which is a common factor decreasing nest success. Hawksbill turtles tend to place their nests in elevations about 1.2 m and green turtles in elevations between 1-3 m (Horrocks and Scott, 1991; Johannes and Rimmer, 1984, respectively).

- Vegetation

Vegetation is a factor that may affect only certain species of sea turtles since it has been found that leatherback turtles prefer to place their nests in opened sand beaches while green turtles and loggerhead turtles prefer areas where supra-littoral vegetation occurs (Whitmore and Dutton, 1985; Hays and Speakman, 1993; Garmestani et al., 1997). However, nests placed too near the vegetation, may be disturbed by growing
roots that could destroy some of the eggs within the chamber or make difficult
digging the chamber (Wood and Bjorndal, 2000; Karavas et al., 2005).

According to Bilinski et al (2001) thick vegetation or refuse carried by tides
(generally logs or plastics) can obstruct the nesting areas and thus reduce the hatchling
success.

Studies with loggerhead turtles confirm that in areas where dried accumulations of the
seagrass *Posidonia oceanica* are found, nesting success decrease, as turtles may found
these dried accumulations as a barrier when trying to ascend the beach and start the
excavation (Margaritoulis, 2005).

- River or estuary presence

Nesting preferences of the olive ridley turtle include beaches where a river or an
estuary are present, generally areas where humidity levels are relatively high, as this
may help maintaining moisture levels within the nest chamber (Márquez, 1996).

- Timing

The moment of emergence of a female in search for a nest placement has been
correlated to the tide cycle, usually occurring at high tide. This fact may suppose an
evolutionary trend developed by sea turtles in order to reduce the distance of crawling
from the water line to the nesting site, which can be reduced from 100 m to 50 m thus
saving a lot of energy (Reina et al., 2002). In addition, short distances between the
nest and the high tide line can be understood as an advantage for the new hatchlings
by not getting misorientated when trying to crawl seawards and by decreasing the
time of exposure to predators (Kamel and Mrosovsky, 2004).
Sand temperature

Temperature is an important factor to take into account since sea turtles present temperature sex determination (TSD). In addition, embryo development and hatchlings emergence also depend on temperature (Ewert and Nelson, 1991; Janzen and Paukstis, 1991; Ackerman, 1997; Miller, 1997). These authors well documented the fact that at incubation temperatures higher than 30ºC, the likelihood of an embryo becoming a female extremely increases and the likelihood of becoming a male decreases. Another fact is that hatchlings do not start digging towards the surface until the temperature is not suitable for their emergence, so when they detect the low temperatures needed outside (during night time, extreme hot and predation rates are reduced) they can start excavating. However, when hatchlings find that the exterior temperature is higher than the one inside the chamber, emergence is cancelled (Lutz and Musick, 1997).

Bilinski et al. (2001) suggested that at higher temperatures, the length of incubation was reduced and the embryo mortality was enhanced. This fact influences negatively the hatchling success.

Wood and Bjorndal (2000), refused the hypothesis formulated by Stoneburner and Richardson, 1981 and strengthened the work by Camhi (1993); that a big shift in sand
temperature is used as a clue by sea turtles in order to start digging a nest. The authors did not find any significant differences amongst nesting site and non-nesting site temperatures.

According to Bustard, 1972; Caldwell, 1959; Ewert, 1979; Limpus et al., 1985; and Miller, 1985 and 1997; generally, incubation temperature for sea turtles ranges among 24ºC and 33ºC in nesting beaches. Out of this range, embryo survival does not generally occur. This range generally coincides with the female internal temperature and it is believed that this fact can avoid the embryo being exposed at big changes of temperature between the inside of the female and the nest chamber (Ackerman 1997).

As an example, studies with olive ridley turtle in Baja California determined that the mean temperature for ovoposition occurrence was at 32ºC, which is inside the previous interval (López-Castro et al., 2004).

- Sand moisture

According to Needham (1966), the majority of sea turtle eggs are noncleidoic, which means that need moisture for a proper embryo development. Posterior studies (Ackerman, 1977 and Mortimer, 1981) defined how hatchling success can be affected by an excess of moisture: this avoids the diffusion of gas within the nest chamber because the sand particles are obstructed with water. In addition to all this, the size of a hatchling may be also affected by moisture (Brooks et al., 1991).

It is also believed that moisture is necessary in the incubation process by regulating the transport of calcium to the embryo (Bilinski et al., 2001). Specifically, low rates in sand moisture and temperature accelerate the transport of calcium, thus increasing hatchling success.
In the study from Wood and Bjorndal (2000), moisture was reckoned not to be a reliable factor since it may easily vary due to changes in rainfall, although they described how a specific moisture level is necessary for keeping the nest chamber integrity and promote a proper embryo development in loggerhead turtles.

Studies with green turtles (Yalçın-Özdilek et. al, 2007) described how sand moisture and hatchling success are negatively correlated, with a very low hatchling or no hatchling occurrence when sand moisture was above 8%. Moreover, studies with olive ridley turtle (López-Castro et al., 2004) defined a relative humidity between 0,75 – 1,75 % for ovoposition occurrence, with higher rates of nesting success were taking place among this interval. However, the authors suggested that they found low values in nesting densities since the area had too low values of humidity making these beaches not suitable for nesting as the sand was too dry making difficult excavation.

On the contrary, experiments with loggerhead embryos incubated at different moisture percentages (0, 25, 50, 75 and 100) were designed with the aim of determining an optimal moisture level for egg incubation. The author found higher hatchling success when the moisture content was about 25%, and lower hatchling success when moisture rates were below or above 25% (McGehee, 1990).

- Sand compaction

Compaction of sand is related with gas diffusion within the nest chamber since the more compacted the sand is, the more gas diffusion is avoided. This can lead to dissecation, as drier sands may suppose more difficulties for nest excavation and for a proper embryo development, since it has been found that eggs mortality from green turtles increased in more dry sandy beaches (Mortimer, 1990). At similar conclusions arrived the study from Karavas et al. (2005) with loggerhead turtles, because it was suggested that a mixture in sand particles (poor-sorting) favoured the packing of sand,
since in these beaches nesting appeared to be deterred. The study found higher values of nest placements when there was a well sorting of the sand grains, which favoured nest chamber aeration and prevented collapse during the nest building.

- Sand particle size and mineral content

Although some studies did not find any significant correlation between sand preferences and nesting placements (Mortimer, 1990; Camhi, 1993; Johannes and Rimmer, 1984), there are many others describing the contrary for specific species. Johannes and Rimmer (1984), argued how nesting beach composition includes a broad variety of forms, from darker to lighter colours, from calcareous to igneous origin and from the finest particle sizes to coarse shells or coral pieces. Mortimer (1990), established that coarse-grained beaches presented a difficulty for green turtles for excavating the nest and how the nest placement attempts were consequently aborted. Margaritoulis (2005) added how the overall nesting success for loggerhead turtles is related to a combination of areas with low human disturbance and good sand conditions, since turtles tend to avoid nesting in areas with stones and pebbles that may make difficult the access to the beach and the excavation of a nest.

However, it was found that loggerhead turtles in Melbourne Beach, Florida (Wood and Bjorndal, 2000) tend to nest in areas with coarse-grained sand made of broken shells (calcium carbonate). In addition, studies with olive ridley turtle defined its nesting beaches in Baja California with coarse-medium particle sizes (López-Castro et al., 2004). On the contrary, nesting sand preferences for the leatherback turtle include beaches with fine grain sand (Kamel and Mrosovsky, 2004). Yalçın-Özdilek et al. (2007) found a mean particle size of 350 μm (fine-medium sand) at the nesting sites of green turtles and smaller sizes at non-nesting sizes. Other
studies with loggerhead turtles also found sand particle sizes ranging from fine to medium well-sorted grains in nesting beaches of Greece (Karavas et al., 2005). Garmestani et al. (1997) found a positive correlation between wider beaches and low calcium carbonate beaches (< 9%), being the ones where higher nesting values were found for loggerhead turtles. Shelliness (calcium carbonate content) was related with the biggest particle sizes (0.991mm, 1.397mm and 1.981mm). The authors explained this fact as more shelly beaches may be difficult the excavation of a nest. The same study did not find any significant correlation between nest placement and the amount of organic content, the proportion of water in the sand or the 5 smallest particle sizes. We can deduce there is a lot of divergence between the different species of sea turtles and it is difficult to consider sand particle size as a nesting factor affecting selection.

- Human disturbance

Human disturbance on nesting beaches is usually characterized by a non-controlled coastal plan of a tourism development that normally represents a reduction in the natural nesting habitat, artificial lightings, noise and people going to the beach at nights (time when the female tends to nest). In addition, building construction leads to an erosion of the beach and a reduction in the sand quality by removing the surrounding vegetation (Katselidis and Dimopoulos, 2000). Studies by Margaritoulis (2005) during 19 nesting seasons, found higher nesting densities of loggerhead turtles in beaches with lower tourism development whereas in areas with higher human presence, the nesting densities were dramatically decreased.
• Pollution (trace metals concentrations)

It is known that pollution in form of heavy metals, bacteria, parasites or biotoxins is enhancing sea turtle mortality by bioaccumulation within turtle tissues (muscles, kidney or liver). This may also suppose a hazard to local communities like toxic poisoning or even death since they directly consume sea turtle products (eggs or meat) (Gardner et al., 2006; Aguirre et al., 2004). The main heavy metals in marine ecosystems are found to be: iron (Fe), cadmium (Cd), zinc (Zn), nickel (Ni), manganese (Mn), lead (Pb), copper (Cu) and chromium (Cr) and concentrations on sea turtles vary depending on the specie, specifically their dietary habits, being carnivorous species the ones that present higher loads of metals (Storelli and Marcotrigiano, 2003).

• Natural processes

Natural hazards are environmental processes that reduce the hatchling success by enhancing the mortality of the eggs or hatchlings. Most common examples are hurricanes and tropical storms with strong winds and heavy rain that may destroy the nest chamber. Another fact is predators, which usually interfere by poaching the eggs or eating the new borns. Common predators in LPA are crabs, seabirds, snakes, and mammals such as raccoons, coyotes, pigs or dogs (STRI website, 2009). And other natural processes that reduce hatchling success are infections by fungi or bacteria which develop with high levels of moisture within the nest chamber (Packard and Packard 1994).
As some authors have already mentioned (Wood and Bjorndal, 2000), the selection of a nesting site is not only governed by a single factor, on the contrary, it is believed that a multiple interaction between the different factors described above take part in the process. The authors define a “sequential threshold hypothesis” where each factor is detected by the turtle at a certain threshold and as a clue for selecting a potential nesting site, being temperature the first factor that the turtle may find and subsequently detecting changes in the slope, moisture content or salinity, for finally start digging the nest and release its genes in form of eggs.
AIMS

This dissertation aims to evaluate the different beach characteristics influencing the sea turtles of LPA when selecting a particular site to lay their eggs. The aim of the two field trips was to get as much information as possible of the factors mentioned above from the identified nesting beaches of LPA and thus try to determine any patterns, since all the data collected is been subsequently analysed in the laboratory and presented in form of graphics and tables.

This dissertation also aims to encourage and develop a baseline for future research studies by characterizing the physico-chemical characteristics of the nesting beaches in LPA in order to best protect these valuable sites. The same methodology would ideally need to be repeated in future studies in order to obtain qualitative data for comparative purposes.
2. MATERIALS AND METHODS

In this section both field work and laboratory analyses are described. All the field work was based in LPA (Panama) and the laboratory work was carried out in both Panama and Heriot-Watt University facilities.

FIELD WORK

The field work was divided into two field trips: the first one designated to approach the northern islands of LPA and the second one the southern islands.

In order to choose the different beaches and set the transects, a previous aerial study by the Smithsonian Institute on nesting sites was taken into account. We located the different turtle tracks previously found in different maps and established a list of priority nesting beaches where to base the transects and proceed with the methodology.

Figure 6. Previous aerial study which located 37 nesting sites (red stars) in LPA (STRI website, 2009).
LPA islands were beach and transects were based for this study:

**Figure 7.** General overview of LPA islands from satellite view and priority nesting beaches located (Google Earth, 2009).

**Figure 8.** Northern islands of LPA with corresponding beaches studied (Saboga and Chapera) (Google Earth, 2009).
Figure 9. Midern islands of LPA with corresponding beaches studied (Bayoneta, Gibraleon, Viveros and Pedro González) (Google Earth, 2009).

Figure 10. Location of the different beaches studied in the southern island of Del Rey (Google Earth, 2009).
**First field trip** *(1st June- 11th June)*

The aim of the first field trip was to work in the northern islands of LPA, and the base for this study was in Contadora Island. A local fishermen (Toribio) with his own boat was contracted to help us access to the different beaches.

A total of 6 islands, 11 beaches and 39 transects were studied during this first trip.

<table>
<thead>
<tr>
<th>ISLAND</th>
<th>BEACH</th>
<th>TRANSECTS</th>
<th>COORDINATES</th>
</tr>
</thead>
<tbody>
<tr>
<td>SABOGA</td>
<td>01</td>
<td>A, B, C, D</td>
<td>N 08° 61’63”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>W 079° 06’60.2”</td>
</tr>
<tr>
<td></td>
<td>02</td>
<td>A, B</td>
<td>N 08° 37’57.4”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>W 079° 03’57.6”</td>
</tr>
<tr>
<td>CHAPERA</td>
<td>01</td>
<td>A, B, C, D</td>
<td>N 08° 35’16.6”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>W 079° 02’02.4”</td>
</tr>
<tr>
<td></td>
<td>02</td>
<td>A, B</td>
<td>N 08° 35’28.4”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>W 079° 02’07.1”</td>
</tr>
<tr>
<td></td>
<td>03</td>
<td>A, B</td>
<td>N 08° 35’04.1”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>W 079° 01’23.1”</td>
</tr>
<tr>
<td>BAYONETA</td>
<td>01</td>
<td>A, B, C, D</td>
<td>N 08° 29’29.9”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>W 079° 04’01.2”</td>
</tr>
<tr>
<td></td>
<td>02</td>
<td>A, B, C, D</td>
<td>N 08° 30’00.9”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>W 079° 03’47.2”</td>
</tr>
<tr>
<td>DEL REY</td>
<td>01</td>
<td>A, B, C, D</td>
<td>N 08° 16’03.3”</td>
</tr>
<tr>
<td>Grillo1</td>
<td></td>
<td></td>
<td>W 078° 55’56.3”</td>
</tr>
<tr>
<td>PEDRO GONZALEZ</td>
<td>01</td>
<td>A, B, C, D</td>
<td>N 08° 22’53.9”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>W 079° 05’42.6”</td>
</tr>
<tr>
<td></td>
<td>02</td>
<td>A, B, C, D</td>
<td>N 08° 24’03.4”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>W 079° 07’04.6”</td>
</tr>
<tr>
<td>GIBRALEON</td>
<td>01</td>
<td>A, B, C, D</td>
<td>N 08° 30’56.8”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>W 079° 02’51.2”</td>
</tr>
</tbody>
</table>

*Table 3. First field trip islands, beaches, transects and coordinates*
**Second field trip** (22nd June - 27th June)

The same methodology as the previous first trip was carried out for this second field trip. Our base was in a fishermen village called La Esmeralda, in Del Rey Island.

The aim for this second trip was the importance of this island, home for the greatest number of nesting sites spotted so far. The last day of this second trip was designated to perform beach profiles and sand collection in Viveros Island, which is being part of a big tourism plan development.

During the second field trip a total of 2 islands, 7 beaches and 30 transects were approached.

<table>
<thead>
<tr>
<th>ISLAND</th>
<th>BEACH</th>
<th>TRANSECTS</th>
<th>COORDENATES</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEL REY</td>
<td>02 Playa San Juan</td>
<td>A, B, C, D, F, G, H</td>
<td>N 08° 18′41.1” W 078° 51′10.8”</td>
</tr>
<tr>
<td></td>
<td>03 Playa Nispero</td>
<td>A, B, C</td>
<td>N 08° 14′12.3” W 078° 54′39.2”</td>
</tr>
<tr>
<td></td>
<td>(Tortuguera)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>04 Playa Azul</td>
<td>A, B, C</td>
<td>N 08°13′25.5” W 078°54′04.1”</td>
</tr>
<tr>
<td></td>
<td>05 Playa Grillo2</td>
<td>0, A, B, C, D, E, F</td>
<td>N 08° 16′44.6” W 078° 56′13.1”</td>
</tr>
<tr>
<td></td>
<td>06 Playa Ciénaga</td>
<td>A, B, C, D,</td>
<td>N 08° 18′05.0” W 078° 52′36.7”</td>
</tr>
<tr>
<td></td>
<td>07 Playa Mafafita</td>
<td>A, B, C</td>
<td>N 08° 17′10.5” W 078°55′08.5”</td>
</tr>
<tr>
<td>VIVEROS</td>
<td>01</td>
<td>A, B, C</td>
<td>N 08° 29′19.0” W 078° 58′38.0”</td>
</tr>
</tbody>
</table>

*Table 4.* Second field trip islands, beaches, transects and coordinates.
Beach profiles

The aim for studying a beach profile was to determine characteristics that may affect the nest selection process such as beach slope or length. The profile was measured from the vegetation line to the LWL line, taking into account the nesting site and the HWL in between. The material needed for the study of a beach profile was:

- Tripod with a level, in order to measure change of slope
- Pole
- Measuring tape for measuring beach length and nest depth
- Survey books for taking all the notes needed
- Water proof sheets and pencils
- Compass
- Cooler for samples storage
- Performance sheets to record other sort of information such as GPS datum

Figure 11. Some of the material used for a beach profile.
With all the information recorded in our survey books, we could proceed to plot the beach profile on a Microsoft Excel table.

The **Y axis** of the plot corresponds to the **Elevation** of the beach (m):

<table>
<thead>
<tr>
<th>Backsight</th>
<th>Inter</th>
<th>Foresight</th>
<th>Difference</th>
<th>Elevation from LW (m)</th>
<th>Elevation from chart datum</th>
<th>Distance from start point (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,063</td>
<td>0,85</td>
<td>0,686</td>
<td>0,787</td>
<td>4,048</td>
<td>7,248</td>
<td>0 (vegetation)</td>
</tr>
<tr>
<td>2,582</td>
<td>3,315</td>
<td>4,111</td>
<td>-0,164</td>
<td>3,261</td>
<td>6,461</td>
<td>4,6 (HW)</td>
</tr>
<tr>
<td>1,896</td>
<td>0,733</td>
<td>1,529</td>
<td>0,796</td>
<td>1,529</td>
<td>4,729</td>
<td>28</td>
</tr>
<tr>
<td>0,796</td>
<td>0,796</td>
<td>0,796</td>
<td>3,996</td>
<td>3,996</td>
<td>3,200</td>
<td>35</td>
</tr>
</tbody>
</table>

*Table 5. Elevation.*

In blue: information obtained from the readings of the pole with the level every time a change in slope was found, perpendicular to the vegetation line all the way seawards.
An important fact needed to take to account when calculating the Elevation was the chart datum, which differs through time and depends on tides, and that was added in the elevation column of the beach.

**Table 6.** Chart datum (CD) values for our field trips in Panama, June 2009. (Free tide tables, 2009).
The X axis of the plot corresponds to the **Horizontal distance** of the beach (m):

![Diagram of a right triangle]

<table>
<thead>
<tr>
<th>Square horiz dist between each point</th>
<th>Horiz dist between each point</th>
<th>Horiz dist from LW</th>
<th>Distance from start point (m)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>20,541</td>
<td>4,532</td>
<td>44,759</td>
<td>0</td>
<td>vegetation</td>
</tr>
<tr>
<td>29,133</td>
<td>5,398</td>
<td>40,227</td>
<td>4,6</td>
<td>HW</td>
</tr>
<tr>
<td>320,405</td>
<td>17,900</td>
<td>34,830</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>48,463</td>
<td>6,962</td>
<td>16,930</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>99,366</td>
<td>9,968</td>
<td>9,968</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0,000</td>
<td>45</td>
<td>LW</td>
</tr>
</tbody>
</table>

*Table 7. Horizontal distance.*

In order to calculate the horizontal distance taking into account the slope of the beach, we need to imagine the profile of a beach as a right triangle, where we can apply the Pythagoras theorem. This formula was used in order to obtain the horizontal distance of the beach, from the low water tide level (LW) to the vegetation site:

![Diagram of a right triangle]

Taking into account that in a right triangle $c^2 = a^2 + b^2$, we can assume $c = $ height of the beach and $a = $ elevation of the beach. Therefore, we just need to figure out that $b^2 = c^2 - a^2$, being $b^2$ the horizontal distance.
Finally, by plotting the Elevation (y axis) and the Horizontal distance (x axis), a graphic for each transect measured was obtained:

![Profile Chart](image)

**Figure 12.** Example of a beach profile: Chapera Island, Beach number 2, transect A.

**Recording of information**

A performance sheet was developed for each transect in order to note and record all sort of information regarding beach characteristics that may influence nest site selection:

- General beach characteristics such as vegetation, river presence, boulders, rocky outcome, logs, human activity, temperature at nesting site and GPS coordinates. Temperature measures were taken with a digital thermometer, and measurements were around 60 cm deep (where the nest is usually dug), at 10 cm and 5 cm, where it is thought to be a change on temperature.

- Underwater (UW) measures: Extra GPS on depth measurements were taken offshore, at 2 random distances away from the shore following the transects. This was designated in order to have a more complete profile of the transect.

In addition, a number of pictures were taken with a digital camera in order to keep a visual proof of all the characteristics noted (see cd attached).
Table 8. Example of a performance sheet.
Sample collection

All the sand samples were collected and transferred into sealed plastic bags (in order to avoid moisture loss) with the corresponding labels and then kept in a cooler. A code system was developed in order to properly label all the samples and ease their storage. For example, the code BAY01B corresponded to:

Bayoneta Island, Beach number 1, transect B.

The transects followed the order A, B, C... where A was the first transect located as we looked at North point.

Samples collected at nesting site, were properly excavated with a spade at about 60 cm depth, where the nest chamber is thought to be dug by the female.

Figure 13. General Sketch representing the procedures carried out within the field trips on each nesting beach studied.
Labelling of sand samples for the subsequent analysis:

- **O+M** (Organic and Metal Analysis)

  These samples were taken at three different sites within each transect: top of the transect (nesting site), high water level (HWL) and at low water level (LWL).

  Minimum sample size required: 100g.

- **HC** (Hydrocarbons analysis)

  These samples were taken at the nesting site of the transect. Tinfoil was used in order not to contaminate the sample.

  Minimum sample size required: 250 g.

- **Minerals**

  These samples were taken at the nesting site of each transect and transferred into glass containers for a proper storage.

  Minimum sample size required: 100g

- **Sand compaction and moisture content**

  These samples were taken at the nesting site of each transect using a plastic core and carefully transferred into sealed plastic bags. Protocol:

  - Insert the core of known volume into the sand (height 19.3cm) and fill it up until we can not go further throughout the sand
  - Measure how much is left within the core (in cm)
  - Measure how much sample we have filled within the cylinder (volume of a cylinder formula)
LABORATORY

Moisture content, Sand compaction and Particle Size Analysis was carried out within the STRI laboratory facilities and was performed for the samples collected during the first field trip.

Moisture

Moisture content was calculated for all the top samples (at the nesting site) of all the transects, in total 39 samples.

Methodology followed:

- Transfer the sand sample from the plastic bag to a glass pot
- Weight wet samples (WS) in glass pots using the balance and taring the glass pot (about 201g)
- Dry all the samples overnight in the oven at about 45º C
- Weight the dried samples (DS)
- Difference WS-DS= moisture content (g)
- In order to plot the results, the amount of moisture in sand was obtained by dividing the moisture content (g) into the WS (g) and then multiplied by 100 in order to obtain percentages.

Note: Consider an error of +- 1 g due to balance mistakes.

Sand compaction

Sand compaction was calculated for all the top samples of all the transects, in total 39 samples, using the samples previously dried (for moisture content).

In order to obtain the volume of sand that was collected within the cylinder, I followed the next methodology:
As we know the volume of a cylinder’s formula: \( V = \pi r^2 h \), and the dimensions of our cylinder:

\[
\begin{align*}
\pi &= \text{number pi (3, 1415...)} \\
r^2 &= \text{squared radius} = 1,85^2 \\
h &= \text{height} (19,3 - x \text{ cm}) \text{ in this case we need to subtract the cm left within the cylinder (x), which will be different for each transect}
\end{align*}
\]

Then we could proceed to calculate the volume of sand collected:

\[
\begin{align*}
\pi &= \text{number pi (3, 1415...)} \\
r^2 &= \text{squared radius} = 1,85^2 \\
h &= \text{height} (19,3 - x \text{ cm}) \text{ in this case we need to subtract the cm left within the cylinder (x), which will be different for each transect}
\end{align*}
\]

Once I obtained the volume of sand collected \((V_i = \text{initial volume})\), then I had to measure the volume of air within this sand. Methodology followed:

- Add 100ml of water within a graduated tube
- Add the sand sample using a funnel
- Measure the difference between the 100 ml and the new measure, which gives us the displacement that the sand sample has done within the tube column after adding the water.

As the initial volume was obtained in cm\(^3\), which are equal to mL, I just needed to subtract the volume of sand displaced within the graduated tube from the initial volume, in order to obtain the volume of air within the sand sample \((V_i - V_{\text{displaced}} = V_{\text{air}})\). Finally, I calculated the percentage of air for each transect by dividing the volume of air into the initial sand volume calculated: \((V_{\text{air}} / V_i \times 100 = \% \text{ air})\).
Particle size analysis (sieving) (from O+M sampling)

Particle size analysis has been calculated for all the samples of all the transects (including top, HW and LW transects), in total 117 samples.

A sieving column has been used consisting of 6 different mesh sizes (2 mm, 1 mm, 500 µm, 250 µm, 125 µm and 63 µm).

According to the Udden-Wentworth grain-size classification scheme, the particle sizes of rocks can be classified in different classes:

According to the Udden-Wentworth grain-size classification scheme, the particle sizes of rocks can be classified in different classes:

<table>
<thead>
<tr>
<th>Millimeters (mm)</th>
<th>Micrometers (µm)</th>
<th>Phi (φ)</th>
<th>Wentworth size class</th>
<th>Rock type</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.006</td>
<td>-</td>
<td>-12.0</td>
<td>Boulder</td>
<td>Gravel</td>
</tr>
<tr>
<td>2.56</td>
<td>-</td>
<td>-9.0</td>
<td>Cobble</td>
<td>Conglomerate/Breccia</td>
</tr>
<tr>
<td>0.64</td>
<td>-</td>
<td>-7.0</td>
<td>Pebble</td>
<td></td>
</tr>
<tr>
<td>0.04</td>
<td>-</td>
<td>-6.0</td>
<td>Granule</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>-</td>
<td>-1.0</td>
<td>Very coarse sand</td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>-</td>
<td>0.0</td>
<td>Coarse sand</td>
<td></td>
</tr>
<tr>
<td>0.50</td>
<td>-</td>
<td>1.0</td>
<td>Medium sand</td>
<td>Sand</td>
</tr>
<tr>
<td>0.25</td>
<td>-</td>
<td>2.0</td>
<td>Fine sand</td>
<td></td>
</tr>
<tr>
<td>0.125</td>
<td>-</td>
<td>3.0</td>
<td>Very fine sand</td>
<td></td>
</tr>
<tr>
<td>0.0625</td>
<td>-</td>
<td>4.0</td>
<td>Coarse silt</td>
<td></td>
</tr>
<tr>
<td>0.031</td>
<td>-</td>
<td>5.0</td>
<td>Medium silt</td>
<td>Silt</td>
</tr>
<tr>
<td>0.0196</td>
<td>-</td>
<td>6.0</td>
<td>Fine silt</td>
<td></td>
</tr>
<tr>
<td>0.0078</td>
<td>-</td>
<td>7.0</td>
<td>Very fine silt</td>
<td></td>
</tr>
<tr>
<td>0.0039</td>
<td>-</td>
<td>8.0</td>
<td>Clay</td>
<td>Claystone</td>
</tr>
<tr>
<td>0.00060</td>
<td>-</td>
<td>14.0</td>
<td>Mud</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 14.** Udden-Wentworth grain-size classification scheme by Wentworth, 1922 (ODP-TAMU, 2009).

Therefore our range of sizes is the next:

<table>
<thead>
<tr>
<th>Particle size</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 mm</td>
<td>Very coarse sand</td>
</tr>
<tr>
<td>1 mm</td>
<td>Coarse sand</td>
</tr>
<tr>
<td>500 µm</td>
<td>Medium sand</td>
</tr>
<tr>
<td>250 µm</td>
<td>Fine sand</td>
</tr>
<tr>
<td>125 µm</td>
<td>Very fine sand</td>
</tr>
<tr>
<td>63 µm</td>
<td>Coarse silt</td>
</tr>
</tbody>
</table>

**Table 9.** Grain size classification range for our study.
Methodology followed:

- Weight about 100g from each plastic bag and transfer it into a glass pot
- Dry all the samples overnight
- Weight again as it may lose some weight due to drying
- Add the sample into the sieving column and shake vigorously during some minutes
- Separate each sieve and weight each sub sample
- Calculate % for each grain size by dividing each sub sample into the initial sand weighted and multiplying by 100.

As a complement, we can establish the degree of sand sorting:

<table>
<thead>
<tr>
<th>Degree of Sorting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well sorted</td>
</tr>
<tr>
<td>Moderately sorted</td>
</tr>
<tr>
<td>Poorly sorted</td>
</tr>
<tr>
<td>mostly small</td>
</tr>
<tr>
<td>mostly large</td>
</tr>
<tr>
<td>small &amp; medium</td>
</tr>
<tr>
<td>large &amp; medium</td>
</tr>
<tr>
<td>mixture of large &amp; small</td>
</tr>
</tbody>
</table>

**Figure 15.** Degree of sand sorting (ISCS, 2009)

Metal analysis

The procedures for metal analysis were performed back at Heriot-Watt University laboratory. The methodology carried out for the analysis of the different metals has been done for all the B transects of each beach (B1- nesting site, B2- high tide level and B3- low tide level), in total 33 samples from the first field trip (from 6 different islands, 11 beaches). The reason for choosing only the B transects was that these transects were the ones in the middle of the beach, so we can obtain a more generalised results, not influenced by being at the edges of the beach.

Eight metals have been analyzed following the next protocol:
- Displace 5 g of the previously dried sand sample in a glass beaker (= dry weight extracted)

- Add 5 mL of nitric acid (HNO₃) which will dissolve the organic content of the sample

- Wait overnight for the acid to make its effect

- Add 45 mL of deionised water

- Transfer all the samples into a 65° C bath for 3 hours

- Filtering: pass the sample through a funnel with a glass-microfibre filter into a volumetric flask of 50 mL volume (= sample volume)

- Add the remaining up to 50 mL with deionised water

In order to quantify the concentration of the different metals within the sample, **Atomic Absorption Spectroscopy** (AAS) technique was used for each of the eight metals. The technique consists of aspiring some of the sample and exciting it by heat (a flame). The metal then will absorb ultra violet light into its characteristic wavelength and will produce a change in intensity that will be measured by converting this change from intensity into absorbance.

The machine picks up the corresponding lamp for a corresponding metal, switches on the flame and calibrates the standard solutions from the lowest to the highest concentration:

<table>
<thead>
<tr>
<th>Standard solution</th>
<th>ppm</th>
<th>ml of standard</th>
<th>ml of deionised water</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.312</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>0.625</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>1.25</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>2.5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
<td>0.1</td>
<td>9.9</td>
</tr>
</tbody>
</table>
In order to calibrate the different standard solutions, we started producing the highest 10ppm (0.1mL standard plus 9.90 mL deionised water) and respectively reduce concentration by diluting the solution.

The analysis starts by reading a blank (deionised water), the corresponding 6 standards in order to calibrate and finally the sample in mg/L range (ppm). The instrument measures 3 replicates for each sample and calculates the Mean, the Standard Deviation (SD), and the Relative Standard Deviation (RSD). With all this information we can therefore obtain the concentration curves.

A formula was used in order to obtain the results from the spectrometer in the required concentrations (mg/kg), taking into account the initial sample volume or any dilution made.

\[
\text{Concentration (ppm) x Dilution x Sample Volume (mL)} \div \text{Dry weight extracted (g)} = \text{mg/kg}
\]

In our case, we did not make any dilution, so concentration is the one given by the machine, the sample volume is 50 mL and the dry weigh extracted is 5 g.

**Mineral content**

The procedures took place back at Heriot- Watt laboratories and all the analysis was carried out using microscopic classification. The samples analysed were all at the middle transects from both first and second field trips (usually the B transects), a total of 18 samples.

This technique was aiming to find out what was the sample’s mineral composition and in which percentages the different minerals were present.
The methodology started firstly looking for biorefringence with the dissection microscope. Biorefringence is the production of a rainbow spectrum by a mineral using polar light, as the light cannot pass through the grain. Since metals do not give biorefringence, we can isolate the minerals presented in the sample. After this, we can observe the sample using the compound microscope which has a graticule quadrant of 10 x10 frames and we can count the number of grains for each mineral. Therefore we can establish percentages.

Our samples were mostly composed of calcium carbonate CaCO_{3} (which is what shells are made of) quartz and a little portions of accessory minerals such as garnet, emerald, amphibole or zircon.

We can relate type of minerals with particle size analysis, since certain sizes are related with certain minerals.

**Hydrocarbon analysis**

All the samples are kept frozen and stored within the STRI laboratories for future analysis.
3. RESULTS

- Profiles

A total of 3 nests were found during the field trips: BAY01B, DEL06A and DEL06D.

Bayoneta 01B

![Profile BAY01B (nest found)](image)

**Figure 16.** Profile were the first nest was found, in Bayoneta island 01, transect A.

The length of the beach is short and the slope is relatively smooth. The elevation of the nest is 1,13 m from the HWL.

![Excavation of the nest and type of vegetation surrounding](image)

**Figures 17 and 18.** Excavation of the nest and type of vegetation surrounding
The nest was superficially excavated and some measures were taken: 40 cm of depth and chamber temperature: 30, 3°C, at 10:00 am. The distance between HWL and nest was relatively short (10m). There were two temporary lagoons along the beach, and 2 lines of vegetation: a first line with brushes and a second line with different forest trees. GPS coordinates were N 08°29’29.9” and W 079°04’01.4” , and the beach presented human disturbance such as some rubbish accumulated at HW and local fishermen.

**Del Rey 06 A**

![Profile Del Rey 06A](image)

**Figure 19.** Second nest found in Del Rey island, number 6, transect A.

![Picture showing vegetation and HW](image)

**Figure 20.** Picture revealing change of slope in the second nest found.
The second nest found was emptied and there were no eggs left (probably poached by locals). In this case nest elevation was 0,89 m, and again, the distance between the HWL and nest is short (6m), there is also a lagoon next to the transect and two lines of vegetation (brushes and forest trees). The temperature within the chamber was 29, 9°C and time 10:00 am. GPS coordinates: N 08° 18'04.6'' and W 078° 52'40.8''.

**Del Rey 06 D**

![Profile of the third nest found in Del Rey island, 06 D.](image1)

**Figure 21.** Profile of the third nest found in Del Rey island, 06 D.

![Eggs hatched next to transect D of Del Rey Island, 06.](image2)

**Figure 22.** Eggs hatched next to transect D of Del Rey Island, 06.

In this third nest, elevation is 1,12 m, the distance between HWL and nest is 4m, temperature: 29, 9°C and time: 11:50 am. Lobster fishermen were around the beach, and the nest was near a lagoon. GPS coordinates N 08° 18'03.6" and W 078° 52'20.5".
**Moisture content**

The moisture content found on the first trip beaches ranged from 1.13 to 5.75%.

LOWEST VALUE = 1.13% (SAB01A)
HIGHEST VALUE = 5.75% (PED01C)

Mean values for moisture content (%):

**Northern beaches**
- Saboga 01 = 2.33
- Saboga 02 = 3.34
- Chapera 01 = 3.65
- Chapera 02 = 2.43
- Chapera 03 = 2.75
- Bayoneta 01 = **2.63** (NEST)
- Bayoneta 02 = 3.10
- Gibraleon 01 = 2.48

**Southern beaches**
- Del Rey 01 = 4.02
- Pedro González 01 = 4.18
- Pedro González 02 = 3.11
Figures 23, 24 and 25. Moisture content values for the first trip islands.

### Sand compaction

**LOWEST VALUE** = 34,08 % (Saboga 01A)  
**HIGHEST VALUE** = 53,25 % (Del Rey 01B)

Mean values for sand compaction (%):

**Northern beaches**
- Saboga 01 = 40,84
- Saboga 02 = 45,93
- Chapera 01 = 44,28
- Chapera 02 = 46,18
- Chapera 03 = 48,07
- Bayoneta 01 = 47,22 (NEST)
- Bayoneta 02 = 48,08
- Gibraleon 01 = 47,63

**Southern beaches**
- Del Rey 01 = 50,09
- Pedro González 01 = 48,05
- Pedro González 02 = 48,34
Figures 26, 27 and 28. Sand compaction values for the first trip islands.
- Particle size analysis

- Nesting site sand

The most abundant particle size found at nesting site level is 250μm, which means that nesting sites are mainly composed of well-sorted fine sand. The exception was Bayoneta 01 where the first nest was found, as the sand was equally composed of medium and fine sand, so this nest was composed of moderately-sorted medium-fine sand.

Mean values for particle size majority class (%):

Northern beaches

Saboga 01 = 250μm (61,77%)
Saboga 02 = 250μm (75,99%)
Chapera 01 = 250μm (64,21%)
Chapera 02 = 250μm (61,78%)
Chapera 03 = 250μm (67,82%)
Bayoneta 01 = 500μm (47,20%) and 250μm (43,16%) (NEST)
Bayoneta 02 = 250μm (48,31%) and 125μm (40,82%)
Gibraleon 01 = 250μm (65,05%)

Southern beaches

Del Rey 01 = 250μm (56,59%) and 125μm (26,49%)
Pedro González 01 = 250μm (58,27%) and 500μm (22,93%)
Pedro González 02 = 250μm (51,55%) and 500μm (32,62%)
Figures 29, 30 and 31. Particle sizes at the Nesting site transects.
High Water Tide Level (HWL) sand

At HWL, the major particle size was found to be 250μm, similarly to the nesting site, and meaning that HWL sand is mostly composed of well-sorted fine sand.

Northern beaches

Saboga 01 = 250μm (70,58%)
Saboga 02 = 250μm (64,45%)
Chapera 01 = 250μm (58,68%) and 125μm (30,68%)
Chapera 02 = 250μm (72,23%)
Chapera 03 = 250μm (58,33%) and 125μm (32,95%)
Bayoneta 01 = 250μm (65,71%) (NEST)
Bayoneta 02 = 125μm (54,67%) and 250μm (42,55%)
Gibraleon 01 = 250μm (60,49%)

Southern beaches

Del Rey 01 = 250μm (50,86%) and 125μm (38,99%)
Pedro González 01 = 250μm (53,89%) and 500μm (25,29%)
Pedro González 02 = 250μm (65,21%)
Figures 32, 33 and 34. Particle sizes at High Water Tide Level (HWL) transects
• **Low Water Tide Level (LWL) sand**

At LWL, particle sizes ranged between 125 μm, 250μm and 500μm (very fine sand, fine sand and medium sand respectively), being the three classes differently abundant between the different beaches. We can define LWL sand as poorly-sorted with a mixture of different particle sizes. It was logical to find this at LWL, since wave erosion rates are higher in this area but can act differently among the different beaches, causing dissimilar breakage of sand into different sizes, depending on the degree of exposure.

**Northern beaches**

Saboga 01= 125μm (71,26%)

Saboga 02= 250μm (66,60%)

Chapera 01= 500μm (43,60%) and 250μm (40,19%)

Chapera 02= 500μm (40,50%)

Chapera 03= 500μm (46,66%) and 250μm (36,28%)

Bayoneta 01= 500μm (61,86%) (**NEST**)

Bayoneta 02= 125μm (37%) and 250μm (33,39%)

Gibraleon 01= 250μm (41,67%) and 500μm (36,40%)

**Southern beaches**

Del Rey 01= 125μm (45,45%) and 250μm (39,63%)

Pedro González 01= 250μm (48,34%)

Pedro González 02= 125μm (60,45%)
Figures 35, 36 and 37. Particle sizes at Low Water Level (LWL) transects.
- **Metal analysis**

All the values for heavy metal concentrations are considered to be ‘safe’ according to the Swedish Environmental Protection Agency health security standards (Sepa, 2007). Since LPA is not a high developed area with a harbour close in distance, we did not expect to find high values of metal contamination.

If we compare the values found with a previous study of heavy metal concentrations in LPA, the results are slightly different since the mean levels are a bit higher than ours (Greaney, 2005). Therefore we could argue that pollution levels in LPA have been reduced since 2005.

<table>
<thead>
<tr>
<th>METAL</th>
<th>CONCENTRATION 2009</th>
<th>CONCENTRATION 2005</th>
<th>CONCENTRATION ALLOWED BY SEPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>78.91 ppm</td>
<td>3864.50 ppm</td>
<td>no data available</td>
</tr>
<tr>
<td>Mn</td>
<td>39.18 ppm</td>
<td>72.09 ppm</td>
<td>no data available</td>
</tr>
<tr>
<td>Pb</td>
<td>31.64 ppm</td>
<td>120.74 ppm</td>
<td>110 ppm</td>
</tr>
<tr>
<td>Cr</td>
<td>19.80 ppm</td>
<td>20.28 ppm</td>
<td>70 ppm</td>
</tr>
<tr>
<td>Zn</td>
<td>13.01 ppm</td>
<td>38.30 ppm</td>
<td>360 ppm</td>
</tr>
<tr>
<td>Ni</td>
<td>7.78 ppm</td>
<td>15.63 ppm</td>
<td>100 ppm</td>
</tr>
<tr>
<td>Cu</td>
<td>1.98 ppm</td>
<td>15.87 ppm</td>
<td>80 ppm</td>
</tr>
<tr>
<td>Cd</td>
<td>0.49 ppm</td>
<td>3.41 ppm</td>
<td>3 ppm</td>
</tr>
</tbody>
</table>

**Table 10.** Mean values for the eight metals analysed in 2009, 2005 and the ones allowed by SEPA, 2007 (in mg/kg).

With our values, we can establish a progressive gradient in terms of concentration:

\[
\text{Fe} > \text{Mn} > \text{Pb} > \text{Cr} > \text{Zn} > \text{Ni} > \text{Cu} > \text{Cd}
\]

And compare it with the order established by Greaney, 2005:

\[
\text{Fe} > \text{Pb} > \text{Mn} > \text{Zn} > \text{Cr} > \text{Cu} > \text{Ni} > \text{Cd}
\]
1. CADMIUM (Cd)

![Cadmium Concentrations](image)

**Figure 38.** Cadmium concentrations of the first trip islands.

LOWEST VALUE = 0.13 (Saboga01)
HIGHEST VALUE = 0.71 (Saboga02)

| TOTAL MEAN | 0.4975 |

2. COPPER (Cu)

![Copper Concentrations](image)

**Figure 39.** Copper concentrations of the first trip islands.

LOWEST VALUE = 1.24 (Pedro González 01)
HIGHEST VALUE = 3.4 (Gibraleon 01)

| TOTAL MEAN | 1.9834375 |
3. IRON (Fe)

Iron results can not be taken into account since concentrations obtained were out of the AAS range, and after 2 dilutions, the concentrations were still too high to be analysed by the machine (concentrations were greater than 20 ppm). In any case, we obtained fairly high concentrations at LWL for many beaches, and this can be related to geological processes that may involve iron oxidation.

![Iron Concentrations of the First Trip Islands](image)

**Figure 40.** Iron concentrations of the first trip islands.

LOWEST VALUE = 12.4 (Saboga 02)
HIGHEST VALUE = 182.7 (Bayoneta 01)

| TOTAL MEAN | 78.9115625 |
4. ZINC (Zn)

Figure 41. Zinc concentrations of the first trip islands.

LOWEST VALUE = 6,73 (Gibraleon 01)
HIGHEST VALUE = 22,02 (Chapera 01)

TOTAL MEAN 13,01

5. LEAD (Pb)

Figure 42. Lead concentrations of the first trip islands.

LOWEST VALUE = 13,46 (Saboga 01)
HIGHEST VALUE = 45,06 (Chapera 01)

TOTAL MEAN 31,6475
6. CHROMIUM (Cr)

Figure 43. Chromium concentrations of the first trip islands.

LOWEST VALUE = 10.78 (Pedro González 01)
HIGHEST VALUE = 29.42 (Bayoneta 01)

TOTAL MEAN 19.800625

7. NICKEL (Ni)

Figure 44. Nickel concentrations of the first trip islands.

LOWEST VALUE = 4.91 (Pedro González 01)
HIGHEST VALUE = 10.56 (Chapera 01)

TOTAL MEAN 7.78125
8. MANGANESE (Mn)

![Manganese Concentration Chart]

**Figure 45.** Manganese concentrations of the first trip islands.

LOWEST VALUE = 12.57 (Saboga 02)
HIGHEST VALUE = 94.52 (Del Rey 01)

**TOTAL MEAN**  **39.181875**
- **Mineral content**

**First field trip**

The trend amongst the majority of the northern islands is quite similar: These sand samples are mostly composed of calcium carbonate CaCo₃ (which is what shells are made of), quartz and little portions of accessory minerals such as garnet, emerald, amphibole or zircon. The only exception is Saboga 02 which presented quartz as its major component. Therefore we could say northern islands from LPA are very organic islands, as the main component is shell.
Figures 46 to 56. Mineral composition for the first field trip islands.
Second field trip

There is a repeating pattern in Del Rey island since the sand collected in the different beaches is mainly composed of CaCO$_3$ (shell), and, differing from the northern islands, no quartz was found, only little portions of accessory minerals, such as zircon or amphibole. We can include Pedro González 01 and 02, and Del Rey 01 from the first field trip as southern islands following similar patterns, with no presence of quartz.

The most significant fact was to find out that Viveros beach, which is currently being part of a big tourism development, is only composed of quartz. That could mean that this sand is not natural and could have been imported from some place outside the Archipelago.
Figures 57 to 63. Mineral composition for the second field trip islands.

Figure 64. Beach in Viveros island, where sand is only composed of quartz.
Temperature values within the nest chamber (at about 60 cm depth) ranged from 27.9 °C to 30.6 °C for 61 out of the 67 transects studied. This range is inside the suitable temperature levels for a proper embryo development and survival established by different studies previously mentioned. This range is also maintained within a short interval with very little variation, which can suggest that turtle species in LPA restrict their development within a particular range of temperature of only ± 2.7 °C of variation.

**Figure 65.** Mean temperature values for both first and second field trip beaches at about 60 cm depth. Note: For Saboga 01 and 02, temperature values were taken at 10 cm so I can not include them in the study.
- **Human activity**

The types of human disturbance found in the islands studied were basically rubbish carried by tides that normally accumulated at HWL, and local fishermen along the coast, principally snorkelling for lobsters. Rubbish is probably coming from the surrounding islands, for example Contadora Island and Saboga island are the most developed islands. Unfortunately people inhabiting LPA do not seem to be aware about the problematic of wastage contamination. For example, in Del Rey Island, our base for a week, even not being a very developed island, we could presence how local people tend to get rid of their wastage by throwing it into the sea. This fact is totally negative for turtle nesting sites as rubbish tend to accumulate within HWL posing a barrier for females when try to ascend the beach and start digging the nest.

**Figure 66.** Rubbish and logs accumulated at HW in Chapera 01 C

**Figure 67.** Local fishermen in Bayoneta 02 D
4. DISCUSSION

This dissertation is the first attempt to describe sea turtle nesting beach characteristics in LPA as no previous studies in the area have been done so far. Being aware that the study is more theoretical than practical, as we based our transects in “theoretical” nesting sites, rather than “real” nests, the discussion is particularly taking into account the 3 nests found during the field trips as a priority. In any case, I have found a number of trends occurring within the 3 nests found that can be correlated with the hypotheses discussed within the review section:

- The 3 nests found were located near a lagoon, and this can be related to maintain moisture levels constant within the nest chamber in order to avoid eggs dissecation and promote a proper embryo development.

- Moisture levels were low, ranging from 1.13 to 5.75 %. As previous studies have mentioned, low moisture values are related with a faster mobilization of calcium to the embryo enhancing its biological success. Other studies have mentioned that low moisture levels also avoid fungi and bacteria development within the nest chamber that may result in infections.

- Compaction levels revealed that sand in LPA is not highly compacted (values between 34 -53%), therefore gas diffusion is favoured, providing a good interaction between the environment and the nest chamber.

- There was a line or two of vegetation behind the nest (at about 2 m inland). Since previous studies revealed a lot of dissimilarities between species and area, we can establish that nesting beaches in LPA are typically composed of supra-littoral vegetation such as palm trees, brushes and other tropical forest trees.
- The distance between the HWL and the nest was usually short (ranging from 4 to 10 m), which can be related to the benefits that a reduction of the crawling distance made by the turtle both inland and seawards helps on saving energy and reducing the time of exposure to predators.

- The elevation of the nest ranged from 0,89 m to 1,12 m, which supports the fact of placing the nest high enough in order to reduce the risk of inundation.

- There was a lot of similarity between all the nest chamber temperatures at about 60 cm depth, ranging between 27,9ºC - 30,6ºC. These values are inside the suitable range for embryo success and do not present a high variation. We could therefore define that chamber temperatures at the nesting sites in LPA are naturally maintained inside a small interval of ± 2,7ºC variation, that ensures little disturbance within the nest chamber while the embryo is developing.

- Particle sizes within the nest chamber were mostly about 250 μm, which is attributed to the fine sand class. Fine sand is generally related to smooth slopes where wave exposure is usually in low intensities. All these characteristics also account for LPA nesting beaches studied.

- Minerals present in sand within the 3 nests presented high abundances of calcium carbonate (ranging from 85% to 100%), therefore turtle species nesting in LPA select very organic beaches.

- Pollution levels for the 8 metals analysed were low, as was expected to be since lower that values found in a previous study 4 years ago, therefore pollution values in LPA seem to be reduced since then.
Generally speaking, the characteristics from the 3 nests found do not differ too much from the rest of the transects analysed. In this way, nesting beaches from LPA follow a number of trends which could be summarize as: short length beaches, smooth in slope, with low moisture levels, fine sand particle sizes, organic sand with high abundances of calcium carbonate, low levels of pollution, mean temperature of the nest chamber around 29ºC, lagoon or river generally present and vegetation composed of different species such as palm trees or brushes.

These nest site characteristics coincide with some of the previous studies but as mentioned in the review section, it seems that there are a number of dissimilarities depending on the area and/or species studied. To support this fact, LPA is a particular ecosystem within the Tropical Eastern Pacific biogeographic zone so we could expect specific or individual preferences by the turtles nesting there and then it would be difficult to apply these preferences to other nesting areas of the world for the same species. Nevertheless, the importance of all this is to properly identify the nesting beach characteristics and the nests distribution within LPA in order to best protect sea turtles and their valuable nesting sites.

I would suggest future research within LPA would need to incorporate detailed studies between the nesting beaches and the non-nesting beaches in order to make proper comparisons and define patterns amongst both habitats. Only then we will be able to understand why some beaches are rejected by sea turtles or why some nest excavations are aborted.

Molecular studies of DNA would be also necessary in order to establish if there are or not specific preferences for each species of turtle nesting in LPA, and ideally map their distribution for conservation and management purposes.
Since little is known from these nesting sites, a better understanding of their characteristics will provide worthwhile information which will need to be incorporated into the current protective legislation in order to fully protect these valuable areas. In-situ protection measures like the patrolling of beaches are a common resource carried out by many conservation programmes with the similar problem of protecting endangered species. This not only would protect nesting beaches but also would help in maintaining natural sex ratios of sea turtle species and would enhance survival rates. Moreover, these measures would also involve local communities by providing environmental education and awareness, and would also ideally create local job positions at the same time that nesting beaches are protected.

I have been witness how LPA is currently being under pressure in different ways (tourism development, overfishing, eggs poaching...), so research studies need to carry on and then we will hopefully still be on time for stopping or at least reducing the threats that are nowadays harassing sea turtle populations and their valuable nesting sites. I wanted to finish my dissertation with a green message since I feel so lucky to have visited this pearl of biodiversity, that I fully reckon us, people whom caused sea turtle decline are responsible for their recovery, and only then Las Perlas Archipelago will coexist in balance with Mother Nature again.
REFERENCES


Downloaded 31st August 2009.


Downloaded 31st August 2009.


Downloaded 31st August 2009.


**Lohmann Lab.** (2009) Sea turtle navigation. The, University of North Carolina


**Miller, J.D., Limpus, C.J. and Godfrey, M.H.** (2003) Nest site selection, oviposition, eggs, development, hatchling and emergence of loggerhead turtles. In


Downloaded 31st August 2009.


Downloaded 31st August 2009.


Downloaded 31st August 2009.


Downloaded 31st August 2009.


Downloaded 31st August 2009.


APPENDICES

Since a lot of space would be required for this section, please see attached dvd to this dissertation, which includes all the excel tables, graphics and calculations made for all the first and second field trip transects regarding information about:

- Performance sheets
- Pictures
- Beach profiles
- Moisture analysis
- Sand compaction analysis
- Particle size analysis
- Metals analysis
- Mineral analysis
- Temperature analysis