Ecology and conservation of leatherback sea turtles in Brazil

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Introduction

Leatherback turtle ecology

The leatherback turtle (*Dermochelys coriacea*) is the largest existing chelonian (turtle) and individuals are known to cross ocean basins, generally nesting on tropical beaches but also found foraging in temperate waters (Hays *et al.* 2006; Fossette *et al.* 2014). Those nesting and foraging areas can be thousands of kilometres distant from each other, and leatherback turtles perform great migrations, possibly using navigational cues such as geomagnetic fields and currents (Shillinger & Bailey 2015) to find their way to natal nesting beaches (Dutton *et al.* 1999) and specific foraging grounds (James *et al.* 2005).

Leatherbacks in the Atlantic Ocean

In the south-western Atlantic Ocean, leatherback turtles nest primarily only in the state of Espírito Santo state, eastern Brazil (Thomé *et al.* 2007), with very occasional nests found elsewhere along the Brazilian coast (Barata & Fabiano 2002; Loebmann *et al.* 2008). This rookery is genetically distinct from others in the Atlantic (Dutton *et al.* 2013) and it is considered to have a high genetic diversity (Vargas *et al.* 2019). The small population size and restricted geographic distribution contributes to this population being regionally classified as Critically Endangered by the International Union for Conservation of Nature (IUCN; Wallace *et al.* 2013).

Marine turtles in the area

The beaches on the northern coast of Espírito Santo state started to be monitored by Projeto TAMAR (the Brazilian Sea Turtle Conservation Programme) in 1982 (Fig. 1). Monitoring currently covers 160km of nesting beaches in the region, which are important nesting grounds not only to leatherback turtles, but also to loggerhead turtles (*Caretta caretta*) and a small number of nests of olive ridley (*Lepidochelys olivacea*) and hawksbill turtles (*Eretmochelys imbricata*) (Marcovaldi & Marcovaldi 1999).

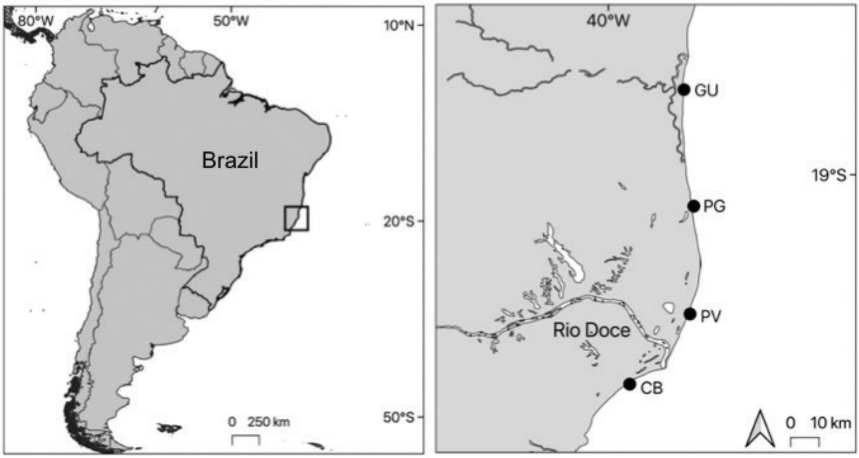

Fig. 1. (Left) Map of Brazil: the study area is depicted by the black frame. (Right) Map of Espírito Santo state, Brazil. Black circles represent the TAMAR stations where the data were collected. From south to north: CB = Comboios, PV = Povoação, PG = Pontal do Ipiranga, GU = Guriri. Rio Doce = Doce River. Figure from Colman (2018).

Fig. 2. The region near the Rio Doce's mouth is home to a globally important leatherback turtle population. This is an aerial photograph showing the impact of a tailing dam failure. Photo by Centro Tamar-ICMBio.

Study area

Leatherback turtle nesting is concentrated in the southern part of the study area, near the mouth of the Doce river, between the beaches of Comboios and Povoação (Fig. 1). A portion of the nesting site (15km) is within a protected Biological Reserve (Reserva Biológica de Comboios) and the section south of this area (an additional 22km) falls within indigenous land where access is restricted under federal law. No federally protected areas exist to the north of the Doce river; however, local and state legislations provide some coastal zone protection in the region (Thomé *et al.* 2007). This area was impacted by a large-scale mining disaster caused by the collapse of a tailing dam in an iron ore mine in the state of Minas Gerais, Brazil, in November 2015. The dam's collapse released tens of millions m^3 of mining waste into the Doce river (Marta-Almeida *et al.* 2016), which reached the Atlantic Ocean in Espírito Santo, in the middle of the primary stretch of nesting beach for leatherback turtles (Fig. 2).

Study aims

Marine turtles are long-lived and late maturing migratory animals and for such species, effective conservation strategies should consider multiple approaches to understand ecology and threats (Seminoff *et al.* 2012; Fossette *et al.* 2014). Knowledge of important ecological parameters such as distribution, population size and trends, movements and habitat use are essential to understand population dynamics, as well as to drive informed conservation efforts and to identify and mitigate threats. We conducted a four-year PhD research project at the University of Exeter, UK, in partnership with Fundação Pró-TAMAR and Centro TAMAR-ICMBio in Brazil and with the support of a Science Without Borders scholarship from the National Council for Scientific and Technological Development (CNPq) in Brazil. Additional funding was provided by the British Chelonia Group and Rufford Foundation. We used a combination of techniques to generate a better understanding of this important leatherback turtle population. While many of the techniques are regularly individually applied during turtle studies, it is highly unusual to see such a multi-disciplinary approach at the same time and place. Here we present what we expect of our research strategy and what we expect to learn from each of these techniques, including the reproductive biology, nesting environment, population trends, marine habitat use, threats and conservation of this globally important leatherback turtle population in Brazil.

Fig. 3. Nesting female being measured (left) and tagged (right) in Espírito Santo, Brazil. Photo by L.P. Colman.

Methods

During the nesting seasons (September to March) between 2015-2017, we conducted daily morning patrols along the entire study area (160km), to quantify nesting activity from the preceding night. Additionally, we conducted night patrols using quad bikes over 30km along the southern part of the study area. Whenever nesting females were seen, we would tag them on both hind flippers with inconel tags (National Band and Tag Co., USA) and measure their curved carapace length (CCL) with a flexible tape (Fig. 3; Thomé *et al.* 2007).

We marked the nests with a wooden stake, monitoring them during the entire incubation period and excavated them when the majority of hatchlings had emerged. To monitor nest temperatures and analyse seasonal sand temperatures and the change of temperature associated with the metabolic heating of eggs during incubation, we deployed 29 data loggers (Tinytag-TGP-4017 from Gemini Data Loggers) within nest chambers, during oviposition. They remained there during the entire incubation period and were retrieved upon post-hatch excavation. Additionally, we deployed six control data loggers at nest depth in the sand. To study leatherback movements, we attached Platform Terminal Transmitters (PTTs) to four adult female leatherback turtles at Comboios beach in Espírito Santo, during the nesting season in 2017-2018. Turtles deemed suitable (in good physical condition, with no obvious injuries or abnormal nesting behaviour) had SPLASH10-295C PTTs (Wildlife Computers, USA) directly attached to their carapace during oviposition (Fig. 4; Witt *et al.* 2011). The direct attachment procedure was also used by Fossette *et al.* (2008) and Witt *et al.* (2011). It was chosen because it is believed to potentially cause less impact on turtles than the harnesses that were previously used in tracking studies with this species (Fossette *et al.* 2008). We also collected skin samples from nesting females and their offspring (hatchlings) and egg yolk from eggs to study their habitat use through analysis of stable isotope ratios of carbon and nitrogen.

Fig. 4. Researchers deploy a satellite tag (PTT) on a nesting female leatherback turtle in Espírito Santo, Brazil. Photo by H.L. Souza.

Nesting ecology and population trends

Long-term datasets are key to understanding demographic parameters, assessing the status of populations and evaluating the effectiveness of conservation strategies (Brook *et al.* 2000; Groom *et al.* 2017). Through nest counts and mark-and-recapture of nesting females we can study the nesting ecology, population trends and conservation status of this leatherback turtle colony. A previous study conducted by Thomé *et al.* (2007) using data from 1988-2003 observed an increasing trend for this population. We aimed to investigate if this population trend has been maintained, updating the monitoring results with additional 14 years of data. We found that this population exhibits an increasing, although variable, nesting trend (Colman *et al.* 2019), with a high fluctuation in the annual number of nests (Fig. 5). The mean annual number of nests increased from 25.6 nests in the first five years of the study (1988-

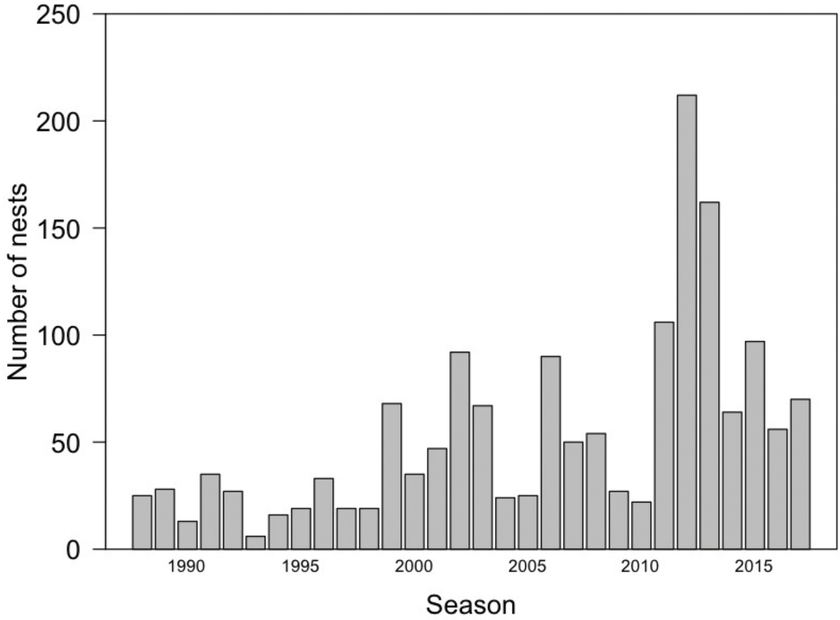

Fig. 5. Number of leatherback nests per year in Espírito Santo, Brazil, 1988-2017. Data from Colman *et al*. (2019).

1992) to 89.8 nests during the last five years of the study period (2003-2017; Colman *et al.* 2019). The mean size of nesting females, which was 166.3cm CCL in the first five years of the study period and 149.9cm during the last five years of the study period, decreased throughout time, which is suggestive of recruitment of young and new females to the population (Colman *et al.* 2019). We aimed to address a number of priority research questions identified by Rees *et al.* (2016), including: population trends, analysis of reproductive parameters and an evaluation of the conservation situation of leatherback turtles nesting in Espírito Santo. We suggest that conservation efforts in the area possibly contributed to the gentle recovery of this population. However, the results should be interpreted with caution, since the persistence of several threats, combined with the small population size and restricted geographic distribution, still make their extinction risk high.

Stable isotopes and tracking

Marine megafauna species such as marine turtles are inaccessible during most parts of their life cycles, and satellite telemetry can provide valuable insights into animal movements, including their seasonal migrations, connectivity between foraging and reproductive grounds and habitat use (Shillinger *et al.* 2008; Fossette *et al.* 2014; Jeffers & Godley 2016). However, tracking is expensive and consequently sample sizes are generally small (Godley *et al.* 2008). In recent years, stable isotope analysis (SIA) has become a powerful tool in ecological studies, providing information on trophic levels, food sources and migratory behaviour in species which are difficult to observe in their natural habitat (Haywood *et al.* 2019). The presence and abundance of certain stable isotopes within chemical elements in nature allows us to understand the energy flow through the food web and thus infer the dietary ecology and habitat use. The skin (epidermis) collected from the females (n = 44) and from their offspring (hatchlings, n = 16, and egg yolk from eggs, n = 16) will be used to identify the isotopic signatures of this population. Specifically, we are using forensic techniques (SIA) to study their foraging strategies. We will combine the results obtained from SIA of a larger number of turtles with the ones from the satellite tracking of a few individuals, extrapolating the results to the wider breeding population. We will also analyse the stable isotope composition from offspring (egg yolk and hatchlings) from assigned females to determine whether these offspring tissues can be used as a proxy for inferring the female isotope signatures. Our results will provide key insights into habitat use and can inform conservation strategies, such as the design and establishment of marine protected areas based on distribution, movements and foraging strategies of this species in the South Atlantic Ocean. Preliminary analyses have yielded promising results.

Temperature

As in many reptiles such as alligators, most turtles and some lizards, marine turtles exhibit temperature-dependent sex determination (TSD), where offspring sex is determined by the incubation temperature during the thermosensitive period (TSP) and the development of gonads (Bull 1983). Because the primary sex ratio is determined by the incubation temperature, this parameter is key in marine turtle population dynamics (Hays *et al.* 1999). Extreme temperatures could result in the production of hatchlings of a single sex, thus making marine turtles particularly vulnerable to the impacts of climate change (Fuentes *et al.* 2011; Santidrián Tomillo *et al.* 2012; Patrício *et al.* 2017). Knowledge on sex ratios of species with temperature dependent sex determination (TSD) is key to provide baseline information which can be used in management strategies and predictions of how climate change can affect populations. Using reproductive parameters such as incubation duration and the temperature data collected by the data loggers, we aim to conduct a long-term analysis (30 years) on incubation durations of leatherback turtles in Brazil and estimate hatchling sex ratios from that nesting ground. Our results will present baseline data on nest temperatures and estimated sex ratios for the region. Those are key to guide future management strategies for the south-western Atlantic Ocean leatherback turtle population.

Fig. 6. Loggerhead turtle (*Caretta caretta*) nesting at Comboios beach, in Espírito Santo, Brazil. The photograph shows the artificial light from the village of Regência in the back. Photo by Leonardo Merçon.

Artificial light pollution

Light pollution can impact species and ecosystems. These impacts can include changes in orientation systems, ultimately causing consequences for foraging, reproduction, migration and communication (Longcore & Rich 2004). Coastal areas provide critical nesting habitat for marine turtles (Fig. 6) and understanding how artificial light might impact particular populations is key to guide conservation strategies (Kamrowksi *et al.* 2012; Mazor *et al.* 2013; Weishampel *et al.* 2016).

Remote sensing can be used to measure artificial night-time light and worldwide measurements of artificial light have been collected by the US Air Force Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) since 1992 (Elvidge *et al.* 2007). We use these yearly satellite images to investigate the extent to which nesting populations of four marine turtle species – leatherback, olive ridley, hawksbill and two subpopulations of loggerhead turtles – are potentially exposed to light pollution across 604km of the Brazilian coast. We aim to determine the proportion of nesting areas experiencing detectable levels of artificial light and how this has changed over time. Based on nest densities we can also identify reproductive hotspots and assess whether they are located in areas potentially exposed to light pollution and/or experiencing increasing light levels. We also investigate the relationship between light levels and nest densities for the different species and contextualise results considering the improved conservation status of all species/subpopulations across the study period. We use the findings to (1) investigate whether nest site selection would be influenced by the presence/absence of light and (2) reflect on conservation strategies in Brazil and whether they have been successful in contributing to reducing impacts on nesting beaches. We highlight that light possibly impacts hatchlings not only on the beach, but also in coastal waters, and any impact on population recruitment may take long periods to fully manifest in nesting numbers.

With one chapter completed and published (Colman *et al.* 2019) and three more currently in final preparation, we have taken great steps forward in generating a better understanding on the status of this unique population. The south-western Atlantic leatherback population show signs of population recovery, most likely influenced by the conservation efforts started in the 1980s with the protection of females and eggs on nesting beaches. However, the persistence of several threats, such as fisheries bycatch, coastal development, climate change and pollution, means this population still remains a subject of conservation concern. Additional seasons of work are expected to build on this knowledge and to answer key ecological questions, such as a better understanding of population size and habitat use, specifically regarding the area used during the internesting period (time interval between clutches in a same nesting season; Eckert *et al.* 2012).

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