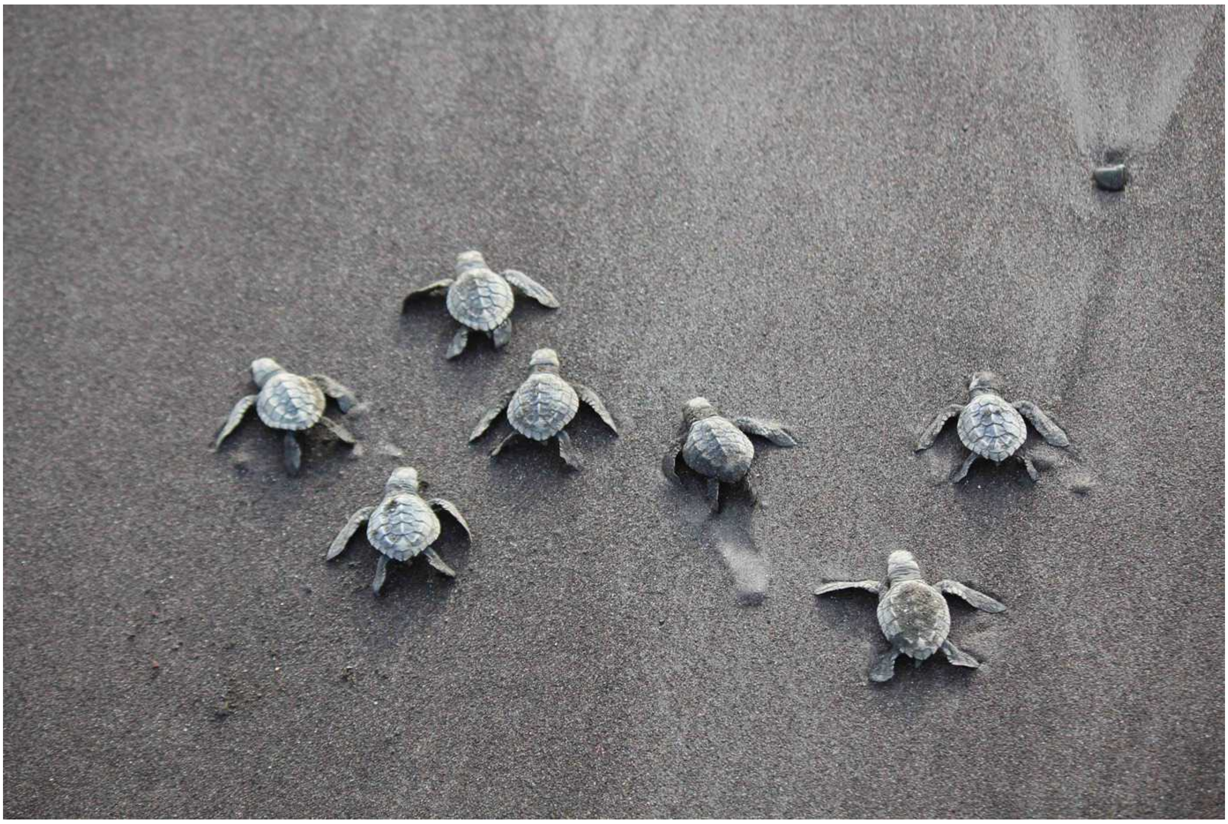
A study into arribadas at Playa del Ostional

A field investigation into the seasonal morphological and hydrodynamical differences of the nesting beach, the involved stakeholders and the key parameters influencing the occurrence of an arribada

Rosalie Mussert, Mathilde Claesen, Leon Ursem & Joost Kerkhof



Delft University of Technology

UNIDAD DE INGENIERÍA MARÍTIMA, DE RÍOS Y DE ESTUARIOS

UNIVERSIDAD DE COSTA RICA

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A field investigation into the seasonal morphological and hydrodynamical differences of the nesting beach, the involved stakeholders and the key parameters influencing the occurrence of an arribada

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in partial fulfilment of the requirements for the degree of

Master of Science

at the Delft University of Technology,

03-04-2023

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Place:	Universidad de Costa Rica, San José, Costa Rica
Project Duration:	February, 2023 - April, 2023

Abstract

Arribadas, a phenomenon of mass nesting behavior of sea turtles, attract millions of olive ridley turtles (Lepidochelys olivacea) to Playa del Ostional, a nesting beach in Costa Rica. The timing and size of these arribadas are influenced by various environmental factors, including temperature, tides, and moon phase [27]. The sea turtles are threatened by a variety of factors, like amongst others climate change. Rising temperatures and sea levels, changes in ocean currents, and more frequent and intense storms are all likely to have negative impacts on sea turtles [16]. Without intervention, climate change could lead to the disappearance or flooding of sea turtle nesting beaches, resulting in a loss of critical habitat for these creatures. To prevent such an outcome, it is imperative to gain a deeper understanding of the morphological and hydrodynamic characteristics of nesting beaches, as well as identify the factors that influence sea turtle nesting behavior.

This study aimed to identify and map the critical factors that must be considered to ensure persistence of the olive ridley sea turtle and arribadas at Playa del Ostional, Costa Rica. The objectives of this research were, therefore, (1) to map the seasonal morphological and hydrodynamical differences of the arribada nesting beach, (2) to identify the environmental parameters that have the greatest influence on the occurrence of an arribada, and (3) to map out the stakeholders involved. The study site is the beach that ranges from the northernmost part of Playa del Ostional down to the southernmost part of Playa Nosara, which is located on the northern peninsula at the west coast of Costa Rica. The part at Playa del Ostional where most turtles nest is called 'Main Nesting Beach' (MNB).

A field investigation was carried out to determine the seasonal morphological and hydrodynamical differences of the nesting beach. This field study comprised of two distinct components: (1) a characterization of the morpho- and hydrodynamics of Playa del Ostional in the dry season, and (2) a comparative analysis of these conditions during the wet and dry season. The morpho- and hydrodynamic beach characteristics consisted of the beach profile, sediment composition, hydrodynamic properties and other general environmental characteristics, such as vegetation and nearby rivers. The beach profile was measured by walking transects perpendicular to the shoreline using RTK-GPS equipment. Moreover, a drone was flown that made an orthophoto and collected 30 million data points. The difference in sediment composition was analyzed by obtaining sediment samples in the dry season, sieving these and comparing the obtained particle size distributions and D_{50} values of the dry and wet season. The hydrodynamical properties and the other general environmental characteristics are analyzed by means of literature review, observations and photography.

In order to identify the environmental parameters that have the greatest influence on the occurrence on an arribada, an autoregressive logistic regression model was used. The model that was made the previous research of 2022, was updated and automated. Also, design choices of the model were made and new data was added.

To map out the stakeholders, interviews have been conducted and a stakeholder map was created.

Through the use of GPS transects the beach profiles taken in dry season (February 2023) were compared to wet season (October 2022). To tackle normal spacial variance the comparison is done through the calculation of averages on three beach stretches with equal characteristics. Main findings were that beach width is equal in both seasons, slopes are more gradual in dry season, beach plateaus are on average 3.0m wider in wet season. Crossing rivers do not influence the beach profile below waterline in the dry season. For more river characteristic more offshore research is needed.

The sediment composition of the beach turned out to show significant differences between the dry and wet season. A significant difference is present in D50 values between the dry and wet season for almost all sediment samples. Moreover, during the wet season, the sediment tends to be coarser compared to the dry season. Additionally, during the dry season, coarser sediment tends to accumulate at the top of the slope, whereas during the wet season, coarser sediment accumulates near the waterline. These observations suggest that coarse sediment may move from areas close to the waterline to the submerged

part of the slope over time. This behavior implies that sediment transportation is affected by the seasonal fluctuations in wave energy. The findings altogether indicate that the sediment composition at Playa del Ostional, particularly at Main Nesting Beach, is notably affected by seasonal changes. The impact is more pronounced from the low tide waterline to the high waterline's end at the top of the slope, with a particular emphasis on the low tide waterline.

The wave climate surrounding Playa del Ostional is expected to be less turbulent, with lower wave energy during the dry season. However, the exact distinctions in both wave climate and tidal surroundings between the two seasons cannot be ascertained due to inadequate data availability.

The different stretches of Playa del Ostional demonstrate notable differences in environmental characteristics during the wet and dry seasons. The majority of rivers that flow out during the wet season are absent during the dry season. In addition, a beach scarp appeared during the dry season and not during the wet season, and an estuary that was observed in the dry season was not reported during the wet season research. On the other hand, the beach is mostly surrounded by vegetation in both seasons, with comparable grass and trees. Moreover, no significant difference in wildlife presence was observed between the dry and wet seasons at Playa del Ostional.

The autoregressive logistic regression model was trained on five year of arribada data and 116 individual environmental parameters. The weights of the parameters were plotted and analysed in multiple groups. This resulted in six parameters with the biggest influence: pdTIDE_P1, pdTIDE_mf, pdVELOCITY_IHC_rho, pdVELOCITY_IHC_rho, Mooncycle_third and Moon_v. The maximum probability of an arribada occurring during a certain day was 80%.

By conducting interviews and conducting a stakeholder analysis, the degree of awareness about climate change is assessed and mapped out, which appears to be quite high. The residents of Ostional are aware of the changes and willing to work in new projects. Moreover, the analysis showed that it is important to engage with two key stakeholders: the Refugio Nacional de Vida Silvestre Ostional and CITES.

Preface

This report is the final deliverable of the Master course CIE4061-09 'Multidisciplinary Project' at the Delft University of Technology. The project provides an opportunity for students to apply their engineering skills in a real-world context and to develop their ability to work in a team and communicate effectively with stakeholders from different disciplines and backgrounds. This report is made for educational purposes and made comprehensible for MSc students with an engineering background.

The duration of the project was seven weeks and it was carried out in San José and Ostional, which are located in Costa Rica. San José is the capital city of Costa Rica and home to the Universidad de Costa Rica. Ostional, situated on the West Coast of Costa Rica, is renowned for the mass-nesting events of the olive ridley sea turtles that occur there.

The primary objectives of this research project were to compare the characteristics of the sea turtle nesting beach, Playa del Ostional, during the dry and wet seasons of 2022 and 2023, to enhance the accuracy of predicting the timing of the arribadas, and to gain a deeper understanding of the stakeholders involved in these mass-nesting occurrences. During the project, two and a half weeks were dedicated to conducting fieldwork measurements in Ostional, while the remaining weeks were spent in San José, where the fieldwork was planned and all analyses were performed.

The multidisciplinarity of the project lied in the overlap between hydrodynamics, mathematics, biology and the sociological side to these.

We would like to thank Felipe Calleja Apestegui from the Universidad the Costa Rica (UCR) and iMARES for welcoming us at UCR with open arms and guiding and helping us throughout the project. We would like to thank to Ronald Víquez Acosta and Diego Cornejo Corrales from iMARES for helping us with all of the fieldwork in Ostional and practicing our Spanish skills. We would also like to thank Nelson Acuña, from LANAMME-UCR and Pedro Rojas from REFORESTA-UCR, for helping us with the analysis of the fieldwork samples.

We would like to thank our main supervisor José Antonio Álvarez Antolínez from the TU Delft, for guiding us and helping us throughout the project. Also from the TU Delft, we would like to thank Jakob Christiaanse and Camilo Jaramillo Cardona for their weekly contribution and feedback. Last but not least, we would like to thank Hayo and Nynke for their supervision on this project.

Contents

1 Introduction

1.1 Introduction to arribadas

In today's marine systems, sea turtles play a significant role as consumers, competitors, and prey. In addition, they act as hosts for parasites and pathogens, substrates for epibionts, transporters of nutrients, and modifiers of the landscape [11]. Sea turtles contribute to ocean ecosystems by supporting the growth of healthy seagrass beds and coral reefs, which are essential habitats for numerous marine species and help maintain the balance of marine food webs. Therefore, sea turtles are critical to the health and resilience of marine ecosystems, as they play various roles in maintaining the balance and productivity of food webs, nutrient cycling, and habitat structure [29].

One of the most abundant sea turtle species is the olive ridley (Lepidochelys olivacea). This species is characterized by its mass-nesting behavior, also known as arribada [27]. An arribada is the event of thousands to hundreds of thousands of sea turtles coming ashore to lay their eggs in a specific coastal areas. The turtles gather offshore before eventually laying their eggs on the beach simultaneously [2]. The combination of the unpredictable nature of mass-nesting events, their occurrence in specific locations, and the enormous size of the gatherings, all taking place at distinct times, makes this a special phenomenon. However, the olive ridley sea turtle, amongst many other sea turtle species, is listed by the International Union for Conservation of Nature as vulnerable [27].

The sea turtles are threatened by a variety of factors, including habitat degradation, poaching and illegal trade, accidental capture in fishing gear (bycatch), and climate change [1]. These threats have led to population declines and endangerment of all seven existent sea turtle species [29]. Rising temperatures and sea levels, changes in ocean currents, and more frequent and intense storms are all likely to have negative impacts on sea turtles [16].

Climate change and variability pose significant risks to sea turtle nesting sites as well, as they can alter the timing, location, and quality of nesting beaches, and affect the survival and development of eggs, hatchlings, and adults [17]. Sea level rise can reduce the availability of nesting beaches and disrupt the timing and success of nesting events, while also increasing the risk of flooding and erosion of nesting habitats [11].

The Intergovernmental Panel on Climate Change (IPCC) has projected that sea levels could increase by approximately 0.46 meters under the lowest Representative Concentration Pathway (RCP) 2.6 scenario, and up to 0.74 meters under the highest RCP 8.5 scenario by 2098 in Costa Rica [18]. Costa Rica provides home to more than 500,000 species, making it one of the 20 countries with the highest biodiversity in the world [19]. Within these species, four species of sea turtles live in Costa Rica: olive ridley, leatherback, green, and hawksbill sea turtles, of which the last three sea turtle species are endangered [13].

1.2 Relevance

Protecting sea turtles has multiple benefits, not only for their intrinsic value as living beings, but also for the ecological services they provide, such as enhancing biodiversity, supporting fisheries, and mitigating climate change [29]. Further research is needed to improve our understanding of the complex interactions between climate and sea turtle nesting, and to develop predictive models and monitoring systems that can help identify and mitigate climate-related risks to sea turtle populations [17]. Conservation and management strategies for sea turtles need to consider the potential effects of climate change and incorporate adaptive measures to enhance the resilience of nesting populations and habitats to changing conditions [17].

Without intervention, climate change could result in the disappearance or continuous flooding of sea turtle nesting beaches, resulting the loss of crucial habitat for these creatures. To prevent this outcome, it is essential to gain a better understanding of the morpho - and hydrodynamics of nesting beaches and identify the factors that influence sea turtle nesting behavior. By increasing knowledge and data on sea turtle nesting behavior, nature-based solutions can be developed to preserve these vital habitats against climate change.

1.3 Previous research

In September 2022, a valuable study into the morpho- and hydrodynamics of nesting beaches has been conducted by a TU Delft research group at Playa del Ostional, a nesting beach at the West Coast of Costa Rica. The study contributed to the future protection and preservation of the olive ridley sea turtles, by gaining a better understanding of their nesting area, its characteristics and their nesting behaviour.

Since Costa Rica experiences a tropical climate, it has two distinct seasons: a wet season and a dry season. These seasons are determined by the amount of rainfall the country receives throughout the year. The wet season in Costa Rica typically runs from May to November. During this time, the country experiences heavy rainfall. The humidity levels are high, and there can be frequent thunderstorms. The dry season in Costa Rica usually lasts from December to April. The temperatures are warm, but not as hot and humid as during the wet season. Playa del Ostional experiences arribadas throughout the whole year, but numbers show that there are far more arribadas in Ostional in the wet season, as well as more females laying their eggs per arribada [27].

The aim of the previous study was to map out the characteristics at Playa del Ostional based on three components: (1) the beach profile, (2) the sediment composition, and (3) other environmental characteristics. In addition, the study attempted to predict the timing of arribadas using an autoregressive logistic regression (ALR) model, which predicted a 60 percent chance of an arribada on a day an arribada occurred.

1.4 Problem statement

Although the research conducted in September 2022 identified some opportunities for further investigation, some potential areas were not covered within the previous research scope. This study has examined a range of possibilities for further research and identified the following actions as being best aligned with previous research and most likely to produce clear results

First of all, the importance to include data from both seasons. The beach profiles and sediment composition might have significant differences between the dry and wet season, but since there is only data collected data during the wet season in September, this is yet unknown. This means that important seasonal variations in environmental factors and sea turtle behavior may have been missed. To fully understand the factors that influence arribadas at Playa del Ostional, it is important to collect data during both the wet and dry seasons. This could help to improve predictions of arribada timing and inform conservation efforts.

Secondly, the ALR model impressively predicts an arribada with 60 percent chance on a day an arribada occurred, which gives the opportunity to further investigate the used environmental parameters. These parameters include the tidal constituents, ocean current velocities, moon cycle, Madden-Julian oscillation, El Niño Southern Oscillation and, sunspots. To conduct this investigation, the model needs to be modified to identify the parameters that have the greatest impact on causing an arribada to occur.

Thirdly, an opportunity is missed in not including the residents of Ostional, who have unique knowledge and experiences that can inform research and conservation strategies. Understanding the local community's awareness of climate change and its potential impacts on the beach and sea turtle populations is essential. Since climate change can affect sea turtle nesting habitat and alter environmental factors that influence sea turtle behavior, such as temperature, sea level rise, and storm patterns, it is important to talk with local residents to raise awareness about climate change and its potential impacts, and to identify ways to mitigate and adapt to these changes.

In order to use these opportunities, this study presents an analysis of the same study area collecting the same samples, but in the dry season in March 2023.

1.5 Research objectives

The goal of this research is to identify and map the critical factors that must be considered to ensure persistence of the olive ridley sea turtle and arribadas at Playa del Ostional, Costa Rica, despite the challenges posed by climate change and sea-level rise. To achieve this, the first research objective is to map the specific morpho- and hydrodynamic conditions of Playa del Ostional. To meet this research objective, the following research questions are formulated:

1. *How do the morpho- and hydrodynamics of Playa del Ostional vary between the wet and dry season?*

The second research objective of this research is to determine the environmental parameters that exert the greatest influence on the occurrence of an arribada at Playa del Ostional. To meet this research objective, the following research question is formulated:

2. *Which environmental parameters have the greatest influence on the occurrence of an arribada?*

The third research objective is to identify and map out the stakeholders who are involved in the occurrence of arribada at Playa del Ostional. Furthermore, to assess their understanding of climate change and potential alterations that may occur at the beach in the future. In order to achieve this research objective, the following research question has been formulated:

3. *How do the current stakeholders involved in the arribadas at Playa del Ostional envision the future of the site in the context of climate change, and what are their interests in this regard?*

1.6 Description of research site

The research area is limited to a part of 'Refugio Nacional de Vida Silvestre Ostional', located in the province of Guanacaste, Costa Rica. This refuge is located on the northern peninsula at the west coast of Costa Rica (latitude 9.993913 °N, longitude -85.700403 °W) and borders the Pacific Ocean, which is displayed in figure 1.1 [27]. Specifically, the research is focused on the part of the refuge where arribadas occur. The refuge consists mainly of Playa del Ostional, which is one of the largest known nesting sites for olive ridley sea turtles in Costa Rica [22]. The part of Playa del Ostional that is most popular for sea turtles to lay eggs, is called 'Main Nesting Beach' (MNB). During large arribada, however, the olive ridley sea turtles also occupy the beach sections of Playa Nosara next to Main Nesting Beach and Playa del Ostional to lay their eggs [27]. These different stretches are displayed in figure 1.2.

Figure 1.1: Topographic location of Playa del Ostional

Figure 1.2: Specific topographic locations within research site

Playa del Ostional has a length of approximately 4000 meters and an average beach width of approximately 50 to 70 meters. Adjacent to this beach lies the village of Ostional, which is home to roughly 700 inhabitants [15]. The beach stretch of Main Nesting beach reaches from the estuary at Playa del Ostional to the small river at the beginning of Playa Nosara (figure 1.2). It has a length of about 1000 meters and a beach width ranging between 40 and 60 meters.

To clarify, the research questions use the term 'Playa del Ostional' which encompasses the entire series of beaches stretching from the northernmost part of Playa del Ostional to the southernmost part of Playa Nosara.

1.7 Outline of report

The research consisted out conducting a comprehensive analysis of existing literature on arribada and the area of interest. After that, preparations were made for the fieldwork. Additionally, to prepare for the data analysis, the autoregressive logistic regression model was investigated and installed.

The fieldwork phase of the research was conducted during the dry season in February and March. This phase involved collecting data on the morpho- and hydrodynamic features of Playa del Ostional during the dry season and conducting interviews with local inhabitants and organizations of Ostional. The data analysis on the autoregressive logistic model also took place within this period but is, however, based on multi-year data.

The methodology employed for the fieldwork and the data analysis is described in chapter 2. The results of the obtained data out of the fieldwork and out of the data analysis are enlightened in chapter 3. A conclusion on these results can be found in chapter 4, followed by a discussion and recommendations for further research in chapter 5.

2 Methodology

In this section, the methodology used to address the research questions is outlined. To be able to answer the first research question a field investigation was carried out. The data obtained through the field investigation was compared to the data obtained by the research executed in October 2022. To be able to answer the second research question, a data analysis was executed, also a present autoregressive logistic model was used to find individual parameter dependence. To be able to answer the third research question, interviews were conducted and a stakeholder analysis was mapped. An elaboration on the fieldwork approach to obtain the required data to answer the first research question is discussed below first, followed by an explanation of the data analysis method employed on the autoregressive logistic model. Lastly, the approach for conducting interviews and mapping the stakeholders is discussed.

2.1 Fieldwork

The field study done during the dry season in March 2023 comprised of two distinct components: (1) a characterization of the morpho- and hydrodynamics of Playa del Ostional in the dry season, and (2) a comparative analysis of these conditions during the wet and dry season. The following sections describe these distinct components and the importance to consider each of them.

2.1.1 Morpho- and hydrodynamic beach characterization

The beach profile, sediment composition, hydrodynamic properties, as well as other general environmental characteristics, such as vegetation and nearby rivers, are included in the morpho- and hydrodynamic characterization of the beach. The entire length of the beach, spanning from Playa del Ostional to Playa Nosara, is once marked with numbered points at 50-meter intervals [2]. Playa del Ostional was designated marks 1-60, Main Nesting Beach had marks 61-79, and Playa Nosara was marked with numbers 80-140. These marks served as reference points for measurements on these beaches.

Beach profile

A beach profile consists of the beach length, width, elevation, plateau width and slope. To obtain a visual representation of the beach profile, numerous transect measurements have been conducted. To accurately capture the seasonal variability in the beach profile, transect measurements at approximately 100-meter intervals were taken during the field study. However, fewer transects were taken at Playa Nosara, since this beach was extremely homogeneous and it is considered less significant for sea turtle nesting, since fewer sea turtles nest at this stretch during arribadas. The transects measured are identical to the transects measured during the research of October 2022. The quantity of recorded coordinates and elevations differed across the various transects, ranging between 8 and 21, depending on the beach's width and slope at each transect. In order to obtain data identical to that of the wet season, measurements were carried out during the same tidal cycle as the previous measurements, which occurred during low tide. During this time, the beach is at its broadest, enabling a more extensive visualisation of the beach. An overview of the measured transects and points can be seen in figure 2.1. The coordinates of the points, as well as the elevation, measured along the transects were measured using RTK-GPS equipment (Real-Time Kinematic Global Positioning System).

Figure 2.1: Overview of the specific locations of the transects measured

RTK-GPS uses a combination of satellite signals and a ground-based reference station to determine the precise location of a GPS receiver. The reference station receives satellite signals and compares them to a known location on the ground, and then sends this correction data to the GPS receiver in real-time. This allows the GPS receiver to achieve a much higher level of accuracy than a standard GPS system, with positional accuracy of up to a few centimeters [9]. During the fieldwork, the reference station was installed at the beach on a tripod above a fixed location. The GPS rover receiver was carried along the beach to cover the different transects and to map the coordinates and elevations of the different locations. The maximum error of the rover receiver in relation to the base receiver is 5 cm, but due to the high number of satellites that can be accessed on the beach, the maximum measurement error is only 0.5 cm [9].

The RTK GPS measured the elevation (Z-coordinate) together with the longitude and latitude of the points measured along the transects. Once the coordinates of various points along the beach were obtained, the data was processed and analyzed using both Python and Excel. When looking at a standardized beach profile several characteristics are evaluated. The transects were evaluated according to the following parameters: maximum elevation, horizontal beach distance (from the waterline at Mean Sea Level (MSL) to the start of the vegetation line), slope width, slope elevation, slope angle and beach plateau width (figure 2.2).

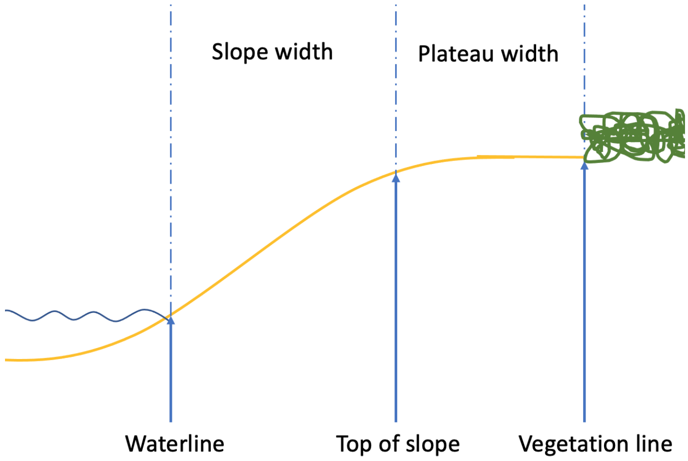


Figure 2.2: Schematic representation of the beach profile measurements

A beach is constantly subject to change by natural influences. Therefore the shape of a beach is impacted by geographic and environmental factors such as waves, tides, sediment availability, and geology. This results in spatial changes in the beach morphology [4]. Even a constant beach state will have spacial variability, so a small change will not directly mean the beach has taken on a different form. To counter this phenomenon of spacial variability samples were grouped and averages were taken. Subsequently, transects were grouped with other transects that were in the same homogeneous section of the beach. These grouped and averaged transects were compared to data of equal beach sections that has been collected during the research executed in October 2022.

Furthermore, an elevation map was created using all the GPS transect coordinates and elevations. Since there are limited data points, triangulation was used.

Sediment composition

The sediment distribution on beaches is strongly linked to the morphology of the beach, both spatially and temporally. Understanding the relationship between sediment grain size and beach profile is important for predicting how a beach will respond to natural and anthropogenic changes over time, such as a change in wave climate or sea level [14]. To analyze the sediment composition of the various sections of Playa del Ostional, sediment samples were collected and examined. Multiple sediment samples were taken at various transects to consider the spatial variability in both alongshore and cross-shore directions. The sediment sampling locations were identical to those of the research executed in October 2022. The samples were collected using the same approach as this research used as well. This approach included collecting four sediment samples per transect: (1) at the low tide waterline, (2) at 1/3 of the slope, (3) at 2/3 of the slope, and (4) near the vegetation line above the high tide waterline. In cases where sample 4 could not be taken because the high tide waterline met the vegetation line, three samples were collected. This situation occurred for all transects at Playa Nosara. Figure 2.3 shows the locations of the various sediment samples taken. In Appendix C the exact coordinates of the sediment samples are stated.

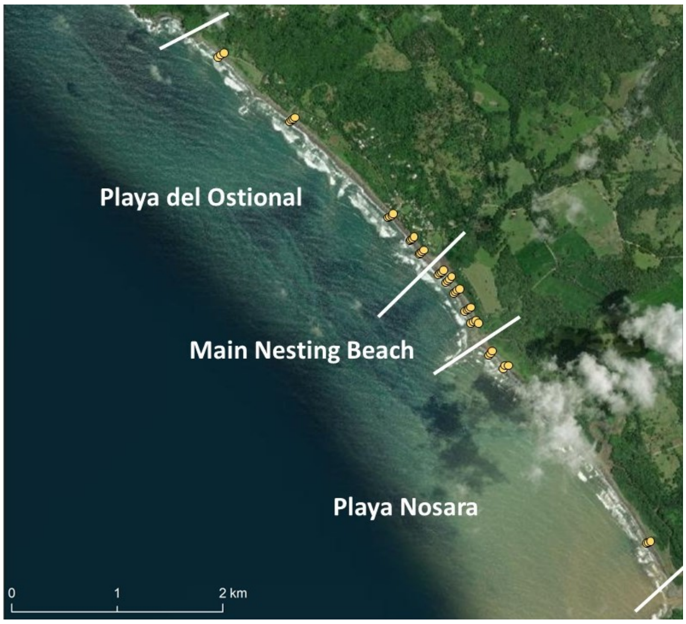


Figure 2.3: Overview of the specific locations of the sediment samples taken

In general, sediment samples of at least 500 grams are recommended for grain size analysis, and larger samples may be needed for greater accuracy and precision in the mapping [6]. Therefore, the sediment samples that were taken contained roughly 1000 grams of wet sediment which coincides with approximately 500-800 grams of dry sediment. In order to dry the sediment samples, the wet sediment samples were placed in an oven and dried at 105 °C for a minimum of 24 hours. To be able to evaluate the sediment composition of the samples, a sieve analysis was conducted afterwards. A sieve tower consisting of 10 sieves with varying diameters was used to conduct the sieving process, which was automated and shaken automatically. By dividing the weight of each sieve by the total weight, percentages were calculated. These percentages were then used to create a particle size distribution (PSD) of each sediment sample. Using the particle size distribution, the D_{50} of all sediment samples was calculated as well. The D_{50} (mm) is defined as either the median sediment grain size diameter of the PSD or the particle size at which 50 percent of the particles are larger and 50 percent of the particles are smaller [23].

An analysis of the difference in sediment composition between the dry and wet season at Playa del Ostional was conducted by comparing the D_{50} values and particle size distributions of the sediment samples collected during both seasons. The comparison of D_{50} values involved analyzing each D_{50} value of individual sediment samples collected during both the dry and wet seasons, as well as comparing the mean D_{50} values of sediment samples collected at a specific location along a transect for a particular stretch of the beach during both seasons. In order to determine the presence of a significant difference in D_{50} values, a statistical test was conducted: a t-test. A t-test is a parametric statistical test commonly used to test hypotheses about the difference in means between specific datasets [8]. The type of t-test used in this research is the one for two independent samples with unequal variances and for a two-tailed distribution. The significance level, also known as alpha (α), is the probability threshold used to determine whether the test result is statistically significant. In this research a significance level of 0.05 is used for this test. To compare the particle size distributions of sediment samples collected during both seasons, a two-sample Kolmogorov-Smirnov (K-S) test was conducted. A two-sample Kolmogorov-Smirnov (K-S) test is a non-parametric statistical test that is used to compare two probability distributions. The test compares the cumulative distributions of two samples to determine if they were drawn from the same population [26]. A significance level of 0.05 is used for this test as well.

Hydrodynamic properties
Determining the hydrodynamics at a beach is essential for understanding how coastal processes, such as waves, tides, and currents, affect the beach morphology, sediment transport, and ecosystem dynamics.

The hydrodynamics of a beach can be influenced by various factors, including wind, waves, tides, currents, and sea level rise, among others. By understanding the hydrodynamics at a beach, sediment transport rates can be quantified, area of erosion or accretion can be identified, and the impacts of human activities on the coastal environment can be evaluated. This information is crucial for coastal managers, engineers, and policymakers to develop sustainable coastal management strategies that ensure the preservation of the beach ecosystem and mitigate the risks of coastal hazards [12]. This notice is of great significance for both the olive ridley sea turtles and the residents of the neighboring villages regarding the future of the beach.

Hydrodynamical properties of a beach include among others the incoming wave characteristics, currents, tidal environment, and sediment transport characteristics [25]. These properties are determined through a combination of fieldwork measurements and analysis of literature, with the addition of data from the GOW-model developed by IHCantabria [28]. In addition, the current state of the beach is assessed and mapped through photography and the processing of literature information. The hydrodynamic properties and beach state during the dry season are then compared to those during the wet season.

General environmental characteristics
To provide a comprehensive characterization of the beach, other general environmental features such as vegetation, rivers, estuaries and present wildlife are also mapped out. To obtain these features, the entire length of the beach is walked, with photographs taken and notes made of noteworthy characteristics and their specific locations. To identify the location of the various observed elements, the existing transects markers were used. The assessment focused on the following features: (1) the boundary parameters of the beach including rivers and estuaries, (2) beach vegetation, and (3) present wildlife, particularly potential predators of sea turtle eggs and hatchlings, to determine the risk of predation. Subsequently, the features observed during the dry season were compared to those during the wet season.

2.2 Data analysis

To address research question 3, this section outlines the previous research conducted in the area, elaborates on the environmental parameters used, explains the autoregressive logistical regression model, and breaks down the analysis process.

2.2.1 Previous research

In research executed in October 2022 a first model is created. Exactly 114 environmental parameters were used as input data, thereafter a probability prediction of an arribada event could be made. The ALR model was run on the same computer as the rest of this study. The figure of the daily probability (3.36) is located in the results for comparison with the findings of this research. As stated before, the model yielded a prediction of 60 percent chance of an arribada on a day an arribada occurred. Also, a k-fold cross validation done, and the arribada data set was separated into four folds. This resulted in an average of 89 percent accuracy over all four folds.

2.2.2 Grouped environmental parameters

In this section, the environmental parameters utilized as input data for the autoregressive logistic regression model are described per group in detail. The parameters are grouped per category or source, which results in the following figure 2.4.

Tidal constituents
Astronomy has identified periodic motions between sun, moon and earth. The 37 most significant motions which affect water level are referred to as harmonic constituents. With these constituents you are able to reconstruct the tides at any given location on earth. Two methods can be used to obtain the tidal constituents: 1. Calculating the constituents from long term data or 2. Using a (global) ocean model. In this research the EOT20 model, developed by Hart-Davis et al. in 2021, is used. This EOT20 model's accuracy is confirmed by wave buoy and wave gauge data from around the world. To predict the tide at a specific location, the following formula (Parker, 2007) is used, which employs the amplitude, phase lag, and time at that location, along with the nodal factor and equilibrium argument obtained from the National Oceanic and Atmospheric Administration (NOAA). The nodal factor adjusts for variations in amplitude between consecutive years, while the equilibrium argument represents the theoretical phase of an equilibrium tide

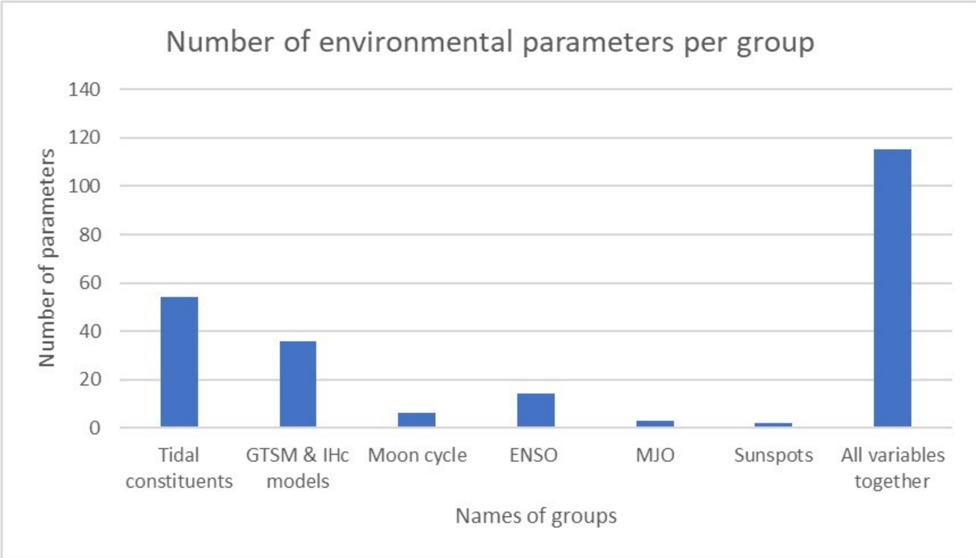


Figure 2.4: Number of environmental parameters per group

constituent.

$$h(t) = H_0 + \sum f_i * H_i * cos(a_i t + (V_0 + u)_{i,Greenwich} - k_i \quad (2.1)$$

Above formula is based on equilibrium theory. The variables obtained from the model are in Greenwich notation and therefore should be converted to the location of the study site using the following formulas.

$$V_0 + u = (v_0 + u)_{Greenwich} + aS/15 - \rho * L \quad (2.2)$$

$$k' = k + \rho L - aS/15 \quad (2.3)$$

Current directions and velocities
Ocean currents refer to streams of water circulating through oceans around the globe. These currents are caused by several factors including: tides, winds Coriolis force and land forms among others (NOAA Ocean Exploration, 2022). For Offshore Ostional the currents have been modelled. The magnitude and direction of these currents are used as input for the model. The Global Tide and Surge Model (GTSM) and IHCantabria Model (IHC) are both used as source of the current data (Deltares, 2022: IHCantabria, 2022).

Moon cycle
The moon reflects light from the sun, depending on the position of the moon relative to the earth and the sun, sunlight reflection on the moon is visible from earth. The moon has a circular pattern around the earth, and earth around the sun. Therefore, one period of the moon circling around the earth takes approximately 29,5 days. The reflecting surface of the moon that is visible from earth has been calculated with a sine function with a period of 29,53058796 days. The sine function is equal to 1 at full moon and equal to 0 at new moon.

Also Binary data is used in the prediction, this data is organized in 5 datasets. New-, first quarter-, Half-, Last quarter- and Full moon. On the day Full moon is reached the data is equal to 1 all other days the dataset is equal to 0. The other 4 datasets are built up equally sourced from (time and date AS, 2022).

$$visibility = cos((2 * \Pi * day - day_full moon)/Moonperiod) \quad (2.4)$$

Madden-Julian Oscillation (MJO)
The Madden-Julian Oscillation refers to a disturbance in cloud movement that travels in an eastward direction above the warm parts of the Indian and Pacific oceans. Typically this disturbance takes around 30-60 days to return to its original point. Anomalous rainfall is the most visible part of the overall circulation pattern (Gottschalck, 2014). The MJO is one of the biggest natural phenomena and several studies suggest that there is a relationship with the El Niño-Southern Oscillation [5].

El Niño-Southern Oscillation (ENSO)
El Niño is a climate variable triggered by oscillations of earth around its central vertical axis North-South. These oscillations lead to variations in surface temperatures of the ocean and therefore cause seasonal high and low pressure areas. The ENSO is characterized by two extreme states and several intermediate states. Two extreme states El Niño and la Niña. During EL Niño, warm water flows to the central and eastern part of the pacific causing big amounts of rainfall in these areas. During La Nina relatively cold water flows towards the Eastern Pacific resulting in a decrease in rainfall due to less evaporation (Lindsey, 2009). The ENSO Data is sourced from NOAA (NOAA,2022).

Sunspots
On the surface of the sun dark regions can appear, these are named sunspots. The dark spots are colder than their surroundings, therefore these areas are darker coloured. Strong magnetic fields within the sun are responsible for creating these sunspots (Dobreijevic, 2022). Data on sunspots in obtained from the World data center SILSO (WDC-SILSO) at the Royal Observatory of Belgium (2022).

2.2.3 Relevant terms
To fully understand the procedure of the model, it's necessary to first gain knowledge of several terms that are relevant to the model. These terms are listed below.

Arribada data
Individuals have been tracking the dates of arribada occurrences for several years, but this data is not publicly available. This data is processed to binary data (1 = arribada, 0 = no arribada), given every single day. However, with the help of Dr. Roldan Valverde, the data for the period of 2014 to 2021 has been collected, but it is confidential and not included in the document. This binary data is used to train the model for arribada prediction.

Logistic regression
Logistic regression is a statistical method used to analyze the relationship between a dependent variable and one or more independent variables. It is commonly used to predict a binary outcome, for this case the event of an arribada or not. The method involves fitting a logistic function to the data, which models the probability of the binary outcome as a function of the independent variables. In this model the sklearn formula [24] for logistic regression is used.

Covariates
Covariates are the predictor variables used to explain the variation in the outcome variable, while the parameters are values that specify the functional form of the model. The model includes the covariates as independent variables that influence the probability of the outcome variable

Constant term
In an ALR model the constant (or intercept) is an important parameter that affects the shape and position of the logistic regression curve. By including the constant term, the curve is shifted up or down along the y-axis, which can help to better match the observed data and improve the model's goodness-of-fit. It calls the direction and magnitude of the effect of the independent variables on the outcome variable.

Weights
The weights are numerical values that represent the strength and direction of the relationship between the predictor variables and the outcome variable. They indicate how much the probability of the outcome variable changes for every one unit increase in the predictor variable, while holding all other variables constant.

Normalisation of data
The covariate weights are affected by the varying minimum and maximum values present in the data sets that are loaded into the model. To ensure effective comparison of the weights, it is necessary to normalize the data. The method for normalisation choosen is Min-Max normalization: this method scales the data between a minimum and maximum value namely between 0 and 1. The formula for min-max normalization is:

$$x_{norm} = \frac{x - min(x)}{max(x) - min(x)} \tag{2.5}$$

where x_{new} is the normalized value, x is the original value, min(x) is the minimum value in the data set, and max(x) is the maximum value in the data set. Additionally, normalization prevents numerical instabilities and improves the calculation speed of the model.

Markov chain
A Markov chain is a mathematical model used to describe a system that changes over time in a probabilistic manner, where the future state of the system depends only on the current state and not on the history of the system. In this model a Markov chain is used to model the time-varying behavior of the binary arribada event outcome based on the previous state of the variable. The binary outcome variable is regressed on lagged versions of itself, whereas the order represents the number of days of lag.

Arribada classes
In the research of 2022 three arribada classes were used to predict the event of an arribada namely:

1. Real arribada data like presented in section 2.2.2
2. Only on the middle day of an arribada
3. Extra day before and after an arribada

Changing the arribada data has impact on the relative amount of arribada days over time. For example, when a adding an extra day before and after, a single day arribada creates a three day arribada and a three day arribada creates a five day arribada: that is a relative increase of 300% versus a rounded 67%. Therefore, the choice was made to only run the real arribada data set.

K-fold cross-validation
K-fold cross-validation will be used to evaluate the performance of the model, which is important because the model relies on time-series data and can be prone to overfitting. K-fold cross-validation helps to mitigate overfitting and provides a more accurate estimate of the model's ability to generalize to new data.

2.2.4 The autoregressive logistic regression model

The autoregressive logistic regression model is a statistical model that combines an autoregressive model with a logistic regression model to predict a binary response variable based on its past values and other the given variables which in this case is the event of an arribada. The following picture shows the input and output of the model 2.5.

Firstly, data is loaded into the model, which includes data from multiple years. The data is then fitted to the dates that are used, in this case 2014 till 2018. Then it is validated using the k-fold method. The accuracy of the model is then evaluated based on the performance of the validation sets. Normalization is then applied to the data to ensure that all variables are on the same scale. Next, the data is fitted to the model by checking might improve the model. When improving the model there is a chance this parameter has an influence in triggering an arribada. Therefore, the model uses specific weights and data as input parameters. Finally, simulations are carried out to predict a new year based on the historical data. This involves applying the model to the new data set and generating predictions based on the established relationships between the variables. The prediction is given for a single day.

2.2.5 Process of analysis

Historical data
To support the selection of data sets and understand how they may affect the triggering of nesting of sea turtles, compare the used data with historical arribada data. This data will also help visualize the seasonal variation of the frequency of arribadas and support fieldwork.

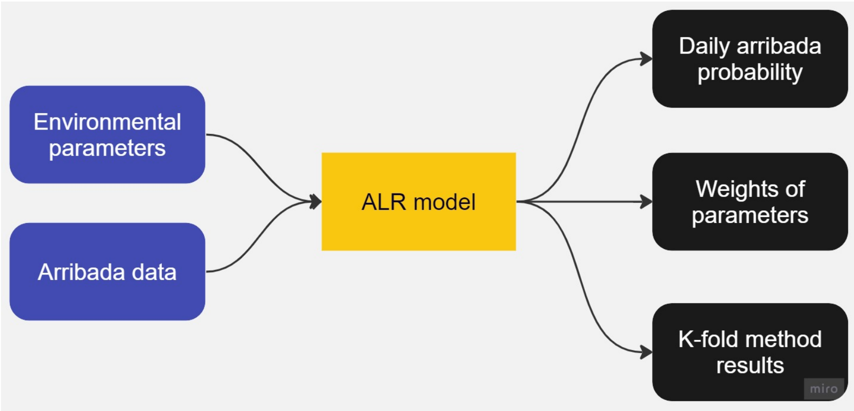


Figure 2.5: Input and output of the ALR model

Multiple regressions for identifying variable weights
In order to determine which factors have a significant impact on the onset of arribada events, it is necessary to follow a structured approach. The first step is to plot all covariate weights without deleting parameters during fitting (over-fitting) and with fitting. This process helps to reduce the scope, especially given the large number of parameters involved (120 in total). By examining the weights assigned to each variable, it becomes possible to identify those that have the greatest influence on arribada events.

Detailed analysis of grouped environmental variables
Once the influential variables have been identified, the next step is to validate the analysis and explain any correlations between variables. This can be achieved through several methods. Firstly, plotting the group covariate weights can help to clarify the impact that individual variables have on one another. By focusing on fewer variables, it becomes easier to understand their individual weights. Secondly, plotting the parameters alongside arribada data can provide a visual representation of the relationship between these variables. Finally, the Markov chain is kept in the analysis, as it has no real influence on the other weights but can provide better probability plots for the data.

2.3 Stakeholder analysis

To be able to answer research question 3, a literature study was carried out to identify and map the stakeholders involved. In addition, interviews with residents of Playa del Ostional and local organizations regarding the refuge and the arribadas were conducted. The objective of conducting interviews with the population of Ostional is to evaluate their level of awareness regarding climate change and its potential impact on the future occurrence of arribadas. This approach aims to provide valuable insight into how the community perceives and experiences this phenomenon. Engaging with stakeholders and identifying their interests can provide a more comprehensive understanding of the various perspectives and interests related to arribada research and management, leading to the development of more effective and sustainable solutions.

2.3.1 Stakeholder map

Conducting a stakeholder analysis is a beneficial approach to identify and comprehend the diverse parties involved in a specific situation or issue. Creating a stakeholder map is to visually represent the different stakeholders involved in a particular situation or issue, along with their level of interest and power. This allows for a better understanding of the relationships between stakeholders and how they might be impacted by potential decisions related to the issue at hand. Regarding the impacts of the arribadas and possible changes on the population of Ostional or other parties, the following stakeholders are considered:

- Local residents of Ostional: these individuals may be directly impacted by the occurrence of arribadas, as the influx of turtles and tourists could affect their daily lives and economic opportunities.
- Tourism sector: tourists may visit Ostional specifically to witness the arribadas and may have a great impact on the local economy and natural environment.

- Environmental organizations: these parties may be interested in the conservation of sea turtle populations and may have a stake in ensuring that the arribadas are managed in a sustainable way.
- Government officials: government officials may be responsible for regulating the arribadas and ensuring that they are managed in a way that is beneficial for all stakeholders involved and regarding the future.

By considering these various stakeholders and their interests, it may be possible to develop a more nuanced understanding of the effects of the arribadas on the population of Ostional, and to develop strategies for managing them in a way that is sustainable and beneficial for all involved. After identifying all of the stakeholders involved, the stakeholder analysis will be represented graphically using a matrix with two axes: power (low to high) and interest (low to high). The matrix divides stakeholders into four segments:

- High Power, High Interest: These stakeholders are the most important, as they have both high power and high interest in the research purposes. It is important to engage these stakeholders actively and involve them in decision-making processes.
- High Power, Low Interest: These stakeholders have high power but low interest in the research purposes. It is important to keep these stakeholders informed and engaged, but not to over-communicate with them or involve them unnecessarily.
- Low Power, High Interest: These stakeholders have low power but high interest in the research purposes. It is important to keep these stakeholders informed and engaged, and to address their concerns and needs where possible.
- Low Power, Low Interest: These stakeholders have low power and low interest in the research purposes. It is important to keep these stakeholders informed, but it may not be necessary to engage them actively in decision-making processes.

Overall, the stakeholder analysis helps to identify the key stakeholders, understand their needs and concerns, and develop strategies to manage their expectations and engage them effectively.

2.3.2 Interviews

In preparation for the stakeholder analysis, interview questions were developed to be conducted with local residents during the fieldwork visit to Ostional. The plan of approach is to speak with at least 6 people from different work fields, to get a clear overall image. The questions included in the interviews can be found in Appendix A.

Dr. eng. Felipe Calleja assisted in translating the questions into proper Spanish sentences and printing them out on separate sheets, which allowed the interviewees to write down their answers on the paper. This was done to facilitate the interview process and overcome any potential language barriers. During the process of conducting the interviews, language barriers and cultural differences that might arise were kept in mind. After conducting the interviews, the answers provided by the interviewees were analyzed and taken into consideration during the further progress of the research.

3
Results

This section provides the presentation of the entire research results. Firstly, the analysis of the data obtained from the field investigation in Ostional is presented, which includes a characterization of Playa del Ostional's morpho- and hydrodynamics during the dry season and a comparative analysis of these conditions during both the wet and dry seasons. Next, the section presents the outcomes of the data analysis executed, also individual environmental dependences are described using the autoregressive logistic regression model. The results of the stakeholder analysis and interviews are subsequently discussed and presented.

3.1 Morpho- and hydrodynamic conditions

3.1.1 Beach profile

Below the beach profiles and their variability in both October 2022 and March 2023 will be visualised and explained in figures. In these figures mean sea level is equal to elevation = 0. Next the parameters are tabulated and compared to the measurements done during the wet season in October 2022. The values for all three stretches are averaged to counter for small spacial variability. At transects where the beach profiles are effected by an estuary, this transect is left out of the stretch, and are therefore not included in the grouped averages. These transects are evaluated separately. All grouped transects for 2023 are visualised. The total beach of 7km (Playa del Ostional up to Playa Nosara) is divided into 3 homogeneous stretches as seen in figure 2.2, starting in the north at transect 1. Slope width and plateau width are measured as visualized in the schematic slope in figure 3.1. Width of the slope is measured form waterline to top of slope. Plateau width is measured from top of slope to the vegetation line (effective nesting space). Total beach witdh is measures from waterline to vegeation line.

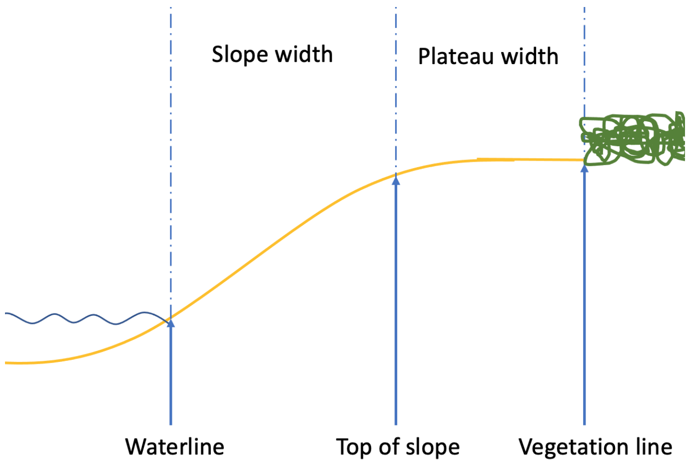


Figure 3.1: Schematic representation of the beach profile measurements

An overview of transects measured during the dry season in March 2023, is visible in the methodology section i figure 3.2.

Figure 3.2: Location of numbered transects

The morphology of Playa del Ostional is very homogeneous except for the part where a river estuary crosses the beach at transect 43 from the north as seen in 3.2. This transect is left out of the grouped average. In 3.3 all transects are plotted in one figure centered with waterline at coordinate (0,0) in the graph. Over the total stretch the morphology is very continuous.

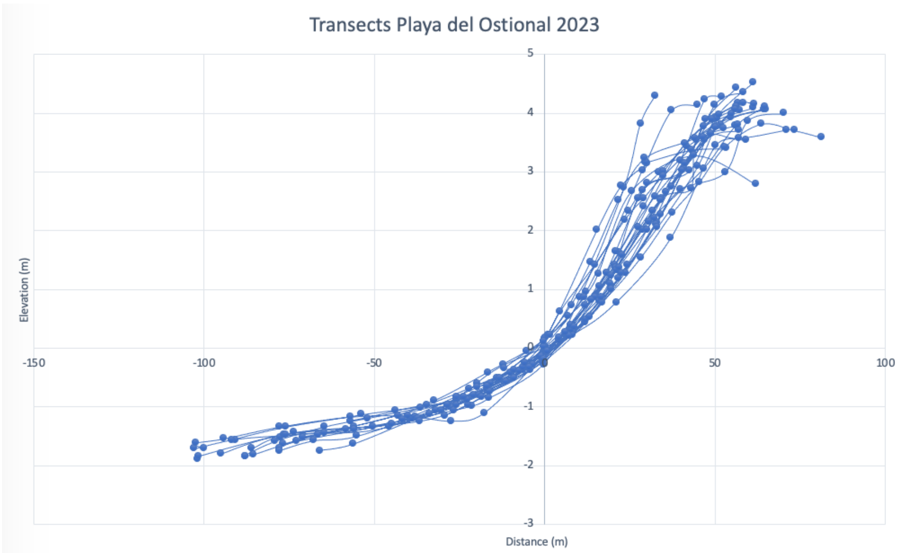


Figure 3.3: Transects in Playa del Ostional 2023, excluding transect 43

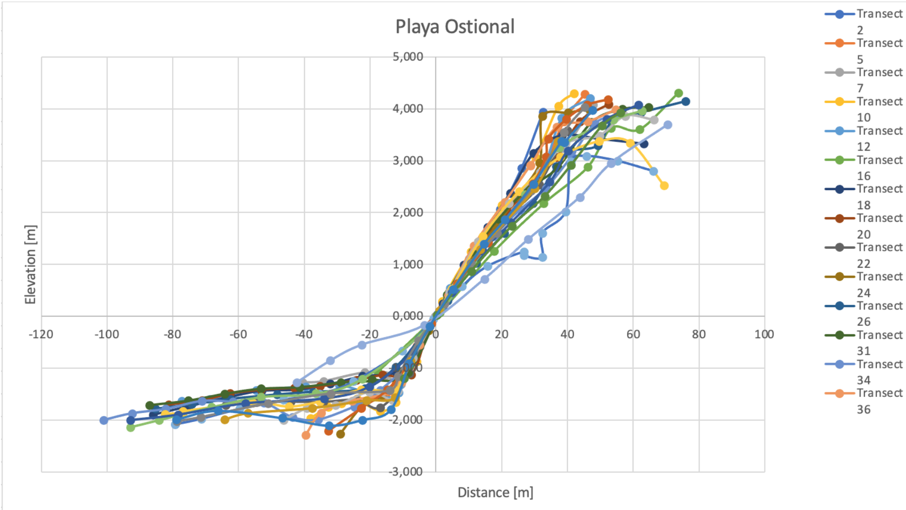


Figure 3.4: Transects in Playa del Ostional 2022

Table 3.1: Averaged values Playa del Ostional, excluding river transect 43

Parameter	Mar 2023	Okt 2022	Unit
Slope	8.5	8.0	degrees
Averaged Max. Elevation	4.0	3.9	meters
Width slope	48.6	42.2	meters
Width plateau	9.8	12.8	meters
Width beach	59.4	55.0	meters

In table 3.1 all avergaes are presented. From this table comparing dry and wet season, the max elevation is almost equal (4.0m in wet-, and 3.9m in dry season), during dry season the slope is more gradually increasing with the final part of the slope a bit steeper, the total slope angle average is higher in dry season at ostional. However the plateau is 30% wider in wet season (12.8m) resulting in 30% more preferred nesting space for nesting activities.

MNB which is located between two natural piers. It is also very homogeneous therefore this is assigned as the second stretch. One transect with a crossing river (transect 63 from the north 3.2) is left out and plotted later.

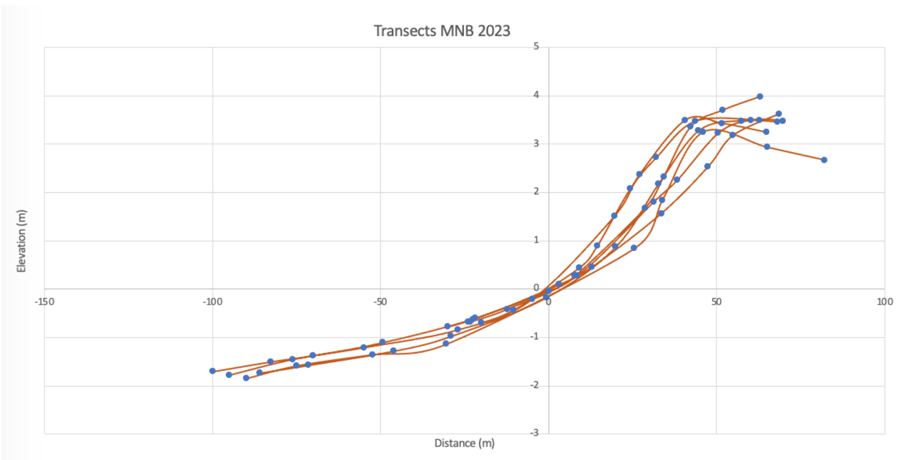


Figure 3.5: Transects at Main Nesting Beach 2023, excluding river transect at 63

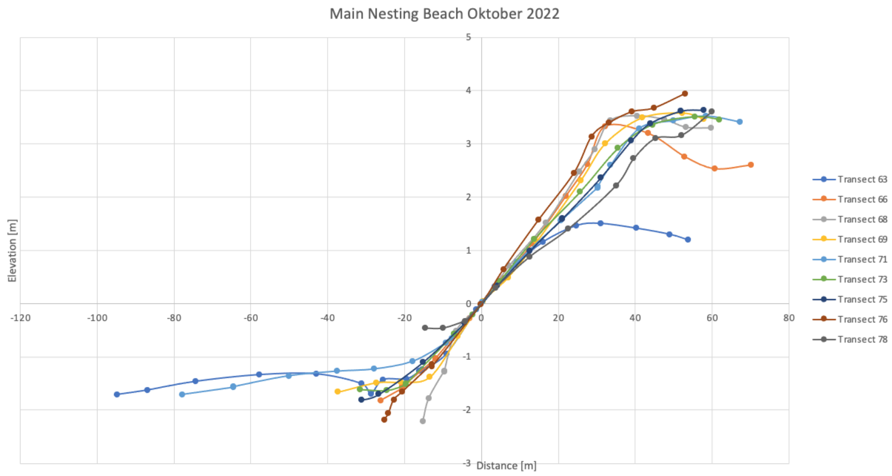


Figure 3.6: All transects at Main Nesting Beach 2022

Table 3.2: Averaged values Main Nesting Beach

Parameter	Mar 2023	Okt 2022	Unit
Slope	9.2	8.8	degrees
Averaged Max. Elevation	3.3	3.3	meters
Width slope	37.7	40.7	meters
Width plateau	14.6	15.0	meters
Width beach	52.3	55.7	meters

Main nesting beach is wider in rainy season, the plateau however is almost equal 14,6-15.0m, same for elevation. Again the slope is 0.5 degrees steeper in March 2023 compared to October 2022.

The wide bay of Nosara is the last homogeneous stretch. The five transects measured are grouped for the Nosara stretch. Due to the homogenity of this beach an representative average can be calculated.

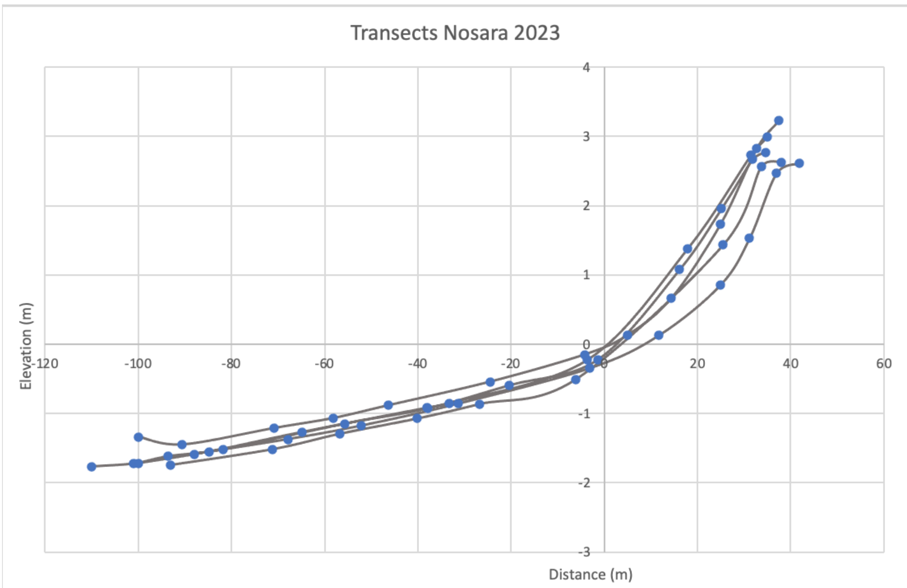


Figure 3.7: All transects at Playa Nosara 2023

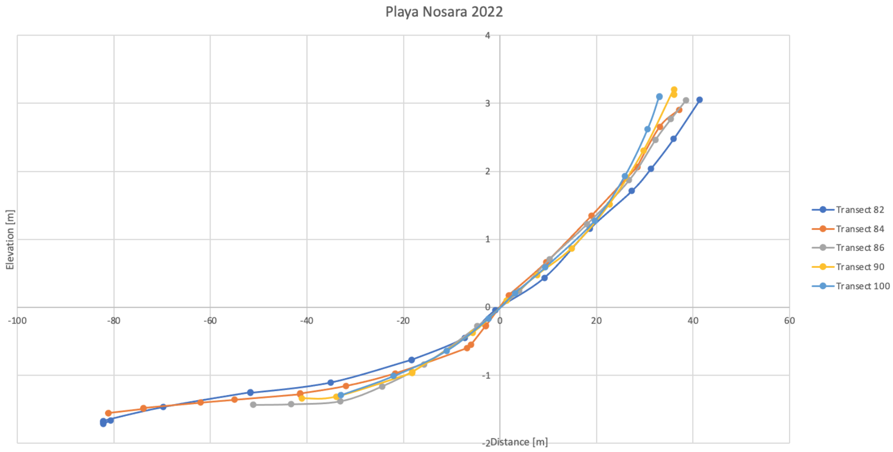


Figure 3.8: All transects at Playa Nosara 2022

Table 3.3: Averaged values Playa Nosara

Parameter	Value 2023	Value 2022	Unit
Slope	8.2	8.2	degrees
Averged. Max. Elevation	2.8	3.06	meters
Width slope	34.4	37.3	meters
Width plateau	3.0	0	meters
Width beach	37.5	37.3	meters

The main difference between playa Nosara in Oktober 2022 and March 2023 is the presence of a plateau. In 2022 no plateau was measured (0m). In the dry season (March 2023) a small plateau of 3.0m has been measured. Next to the plateau there are no clear differences in total beach width of slope angle. Transects 43 and 63 cross rivers making the beach morphology very different and incomparable to the rest of the stretch, therefore these two transects are plotted separately.

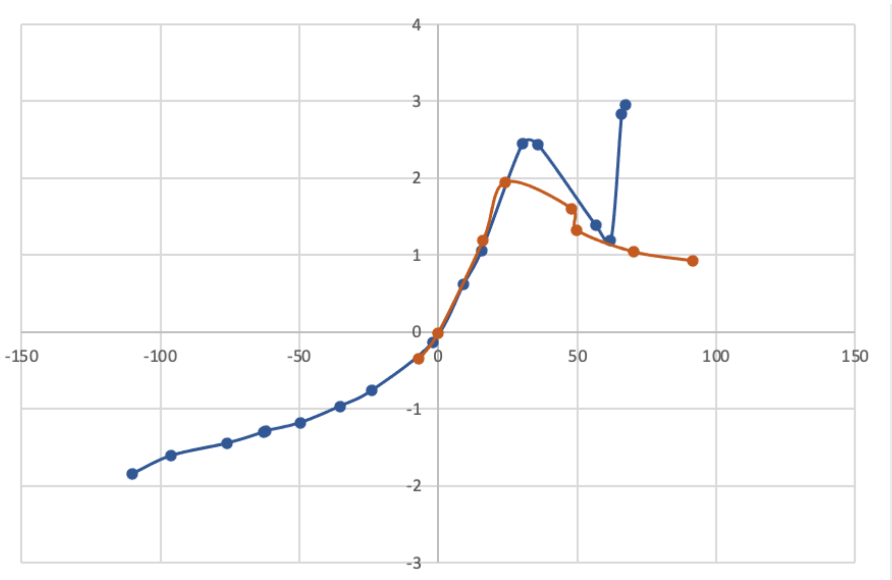


Figure 3.9: Two river transects 2023, Transect 43 blue and 63 orange

At transects where a river was present the bottom part of the slope is fairly equal to the bottom part of nearby transects without a present river crossing. Te main difference is visible in the top part of the slope, a plateau is missing since this previous existing plateau is eroded by the river.

All individual transects are available in Appendix G for possible future examination.

Elevation map
Besides the transect graphs extra visualisation was made of all the transect data points from Ostional up to Nosara. Even though this interpolated map is not visualized in the best possible way. It is possible to evaluated some differences between real situation and the triangulated model in the triangulation out of it. In this visualisation the estuary seems to be much bigger than it actually is, this is due to the fact that triangulation is used and one transect is taken in the estuary. The grid is very big due to the distance between transect of the transects measured due to the triangulation the estuary of less than 10 meter seems to look much wider. The grid of the transects is suitable for the total beach evaluation, however for evaluation of small derogation the measuring grid is too large.

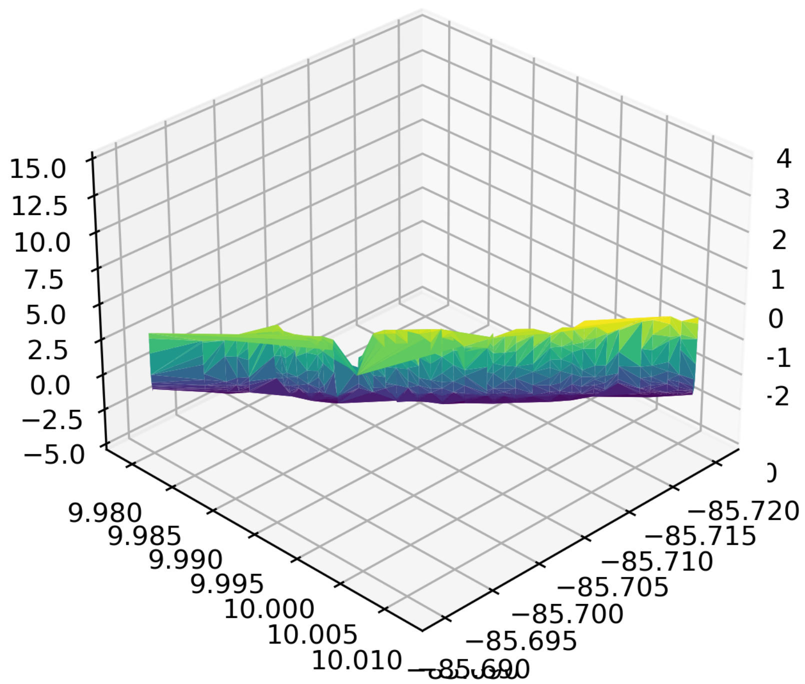


Figure 3.10: Elevation map using triangulation of all 3 stretches near Ostional

3.1.2 Sediment composition

The particle size distribution (PSD) for each of the 48 obtained sediment samples are displayed in Appendix B. Appendix C displays the calculated D_{50} of all sediment samples, of both the dry and wet season. Figure 3.11 and figure 3.12 provide an overview of the D_{50} values and the geographic distribution of the sediment samples in the dry and wet seasons, respectively. Additionally, a different representation of the D_{50} values for all sediment samples in both seasons is included in Appendix D, with the samples grouped based on their location along a transect.

Figure 3.11: D_{50} of samples in dry season, with a focus on Main Nesting Beach

Figure 3.12: D_{50} of samples in wet season, with a focus on Main Nesting Beach

By examining the data presented in figure 3.11 and figure 3.12, a significant contrast in the D_{50} values between the dry and wet seasons can be observed across almost all samples. The figures clearly indicate that the sediment on the beach is generally coarser during the wet season than during the dry season. Moreover, figure 3.11 indicates that in nearly all transects, the sediment samples at the crest of the slope are of a larger grain size compared to those at the waterline. Conversely, in figure 3.12, the opposite trend can be observed: the sediment samples at the waterline are coarser compared to those taken at the crest of the slope. These findings suggest that coarse sediment may move from locations around the waterline during the wet season to the submergent part of the slope over time, resulting in the observed difference in grain size between the two seasons. This indicates that the sediment transport process is likely influenced by the incoming wave energy, which is associated with seasonal changes. Generally, in the wet season, high wave energy moves larger sand grains further down the beach, while finer sand grains remain behind. Conversely, in the dry season, lower wave energy moves finer sand grains back up the beach, leaving larger grains behind [30]. This phenomenon can be recognized when looking at both figure 3.11 and 3.12.

Upon observing the distinct stretches of Playa del Ostional, Main Nesting Beach and Playa Nosara, several remarkable features were identified as well. Comparing the visualized data of the figures in Appendix D reveals a substantial difference in the D_{50} between the dry season and wet season of almost all samples situated at the waterline, which is in line with the figures 3.11 and 3.12. The sediment samples at the waterline from the transects of Main Nesting Beach (transect 64 to 76) exhibit the greatest difference in D_{50} between the dry and wet season. Additionally, this comparison reveals that nearly all sediment samples positioned at the waterline display a substantially greater D_{50} during the wet season in comparison to the dry season, with the exception of those at Playa Nosara (transect 82 to 128) and at transect 59, which is situated at Playa del Ostional. In addition, upon examining figures D.3 to D.6, which compare the D_{50} values of sediment samples from the middle and high sections of the slope during the wet and dry seasons, it is evident that transects 82 and 86 exhibit a considerably higher D_{50} in the dry season as compared to the wet season. On the other hand, comparing figure D.7 to figure D.8 reveals that there is little difference in the D_{50} values of sediment samples at the top the slope between the dry season and the wet season.

Main Nesting Beach

The box plots presented in figures 3.13 to 3.16 are consistent with the significant difference in D_{50} observed between the dry and wet seasons of samples on Main Nesting Beach. Figure 3.13 and figure 3.14 particularly highlight this difference, with the mean D_{50} of sediment samples collected during the wet season being considerably higher than that of samples collected during the dry season. Furthermore, figure 3.16 confirms that there is little variation in D_{50} values between the dry and wet seasons of sediment samples collected from the top of the slope.

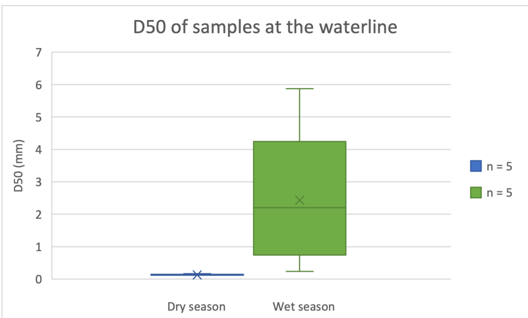


Figure 3.13: D_{50} of samples situated at the high part of the slope in dry season

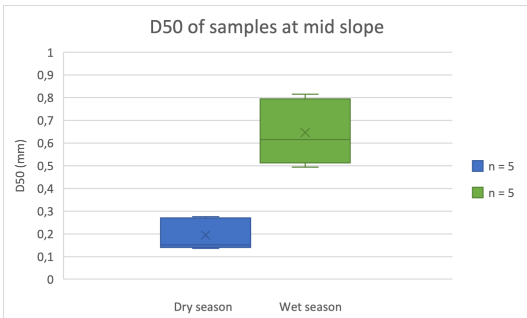


Figure 3.14: D_{50} of samples situated at the high part of the slope in wet season

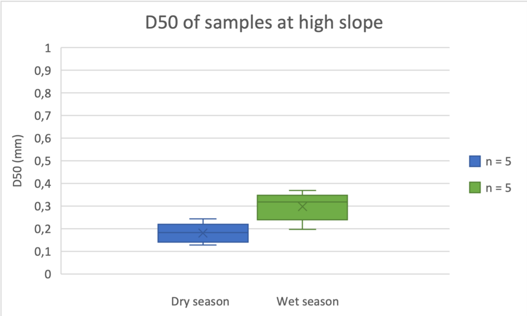


Figure 3.15: D_{50} of samples situated at the top of the slope in dry season

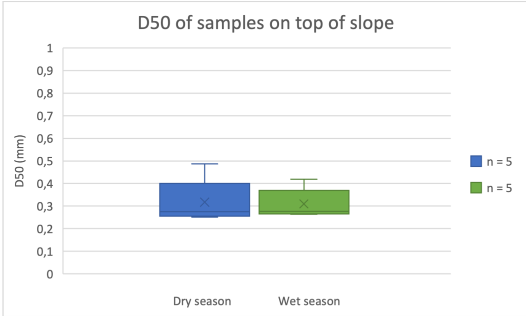


Figure 3.16: D_{50} of samples situated at the top of the slope in wet season

Additionally, the results of the performed statistical t-tests support this significant difference in D_{50} values between the dry and wet seasons of sediment samples located at Main Nesting Beach. Table 3.4 displays the results of these performed statistical t-tests. Although the t-test does not show a significant difference between the mean D_{50} of sediment samples at the waterline of Main Nesting Beach, it is very close to the significance level of 0.05. This suggests that the test still supports a substantial difference in mean D_{50} between the dry and wet seasons of sediment samples situated at the waterline of Main Nesting Beach.

Table 3.4: Results of the t-tests performed on average D_{50} of sediment samples at MNB

Location on transect	p-value t-test	Significant difference
At the waterline	0.07312	no
At the middle of the slope	0.00084	yes
At the high part of the slope	0.01203	yes
On top of the slope	0.88231	no

The results of the two-sample K-S tests, conducted on the particle size distributions of sediment samples from Main Nesting Beach during both seasons, indicate a significant difference between the two seasons for sediment samples located at the waterline, but not for those at other locations. Table 3.5 displays the results of these statistical tests. Both the K-S test statistics and the p-values of the distributions of the sediment samples located at the waterline indicate a significant difference between the two seasons. The differences in particle size distributions between the dry and wet seasons are also visualized and depicted in the histograms in Appendix E. The observed differences in particle size distributions between the two seasons may be attributed to the highly dynamic wave environment that exists at the waterline during the wet season, in contrast to the milder wave climate during the dry season.

Table 3.5: Results of the two-sample K-S tests performed on the PSD's of the sediment samples at MNB

Sediment sample ID	Location on transect	K-S test statistic	p-value	p-value < 0.05?
21	At the waterline	0.7	0.012	yes
22	1/3rd of the slope	0.4	0.418	no
23	2/3rd of the slope	0.2	0.994	no
24	Above the waterline	0.2	0.994	no
25	At the waterline	0.8	0.002	yes
26	1/3rd of the slope	0.3	0.787	no
27	2/3rd of the slope	0.3	0.787	no
28	Above the waterline	0.2	0.994	no
29	At the waterline	0.8	0.002	yes
30	1/3rd of the slope	0.6	0.052	no
31	2/3rd of the slope	0.2	0.994	no
32	Above the waterline	0.2	0.994	no
33	At the waterline	0.8	0.002	yes
34	1/3rd of the slope	0.5	0.168	no
35	2/3rd of the slope	0.5	0.168	no
36	Above the waterline	0.1	1.000	no
37	At the waterline	0.8	0.002	yes
38	1/3rd of the slope	0.4	0.418	no
39	2/3rd of the slope	0.3	0.787	no
40	Above the waterline	0.1	1.000	no

Playa del Ostional
The statistical t-tests conducted on the sediment samples from Playa del Ostional reveal no significant difference in the mean D_{50} between the dry and wet seasons, as documented in Appendix F.0.1. However, the two-sample K-S test, also depicted in Appendix F.0.1, demonstrates a significant disparity in particle size distributions between the sediment samples located at the waterline during the dry and wet seasons at Playa del Ostional. Specifically, three out of the five PSDs of sediment samples at the waterline show significant differences in the dry season compared to the wet season. Conversely, sediment samples at other locations on the transect at Playa del Ostional exhibit no significant differences between the dry and wet seasons.

Playa Nosara
The statistical t-tests carried out on the sediment samples collected from Playa Nosara, as presented in Appendix F.0.2, show a significant difference in the mean D_{50} between the dry and wet seasons of sediment samples located at the waterline. Furthermore, the two-sample K-S test confirms that there is a significant disparity in particle size distribution between the dry and wet seasons of the sediment samples situated at the waterline at Playa Nosara. The results of these tests are included in Appendix F.0.2.

3.1.3 Hydrodynamical properties
The research executed in October 2022 established that the coast of Playa del Ostional, including Main Nesting Beach and Playa Nosara, can be classified as a leading-edge coast due to its proximity to convergent tectonic plates. A leading edge coast is recognized for its usually cliffed coastline, tectonic activity, and narrow continental shelf. The west coast of Costa Rica is characterized by a complex seafloor topography, which includes several submarine canyons that run perpendicular to the coast. These canyons have been formed through tectonic processes, sedimentary processes, and the erosion caused by ocean currents and waves [21]. It is likely that the coast of Playa del Ostional has relatively less sediment in its coastal zone year round, as is typical for leading-edge coasts characterized by submarine canyons, despite the potential for large quantities of sediments to be transported to the coast by the present rivers.

During the dry season in Playa del Ostional, the rivers and estuaries that normally flow into the sea during the wet season do not do so because their water levels are too low 3.1.4. This is because the reduced rainfall during the dry season leads to less water flowing downstream, causing the water levels in the rivers and estuaries to drop. As a result, the water level is not high enough to overcome the elevation of the upper shoreface of the beach, so the water does not flow into the sea. As a result, the coastal zone has a reduced amount of sediment during this time of year.

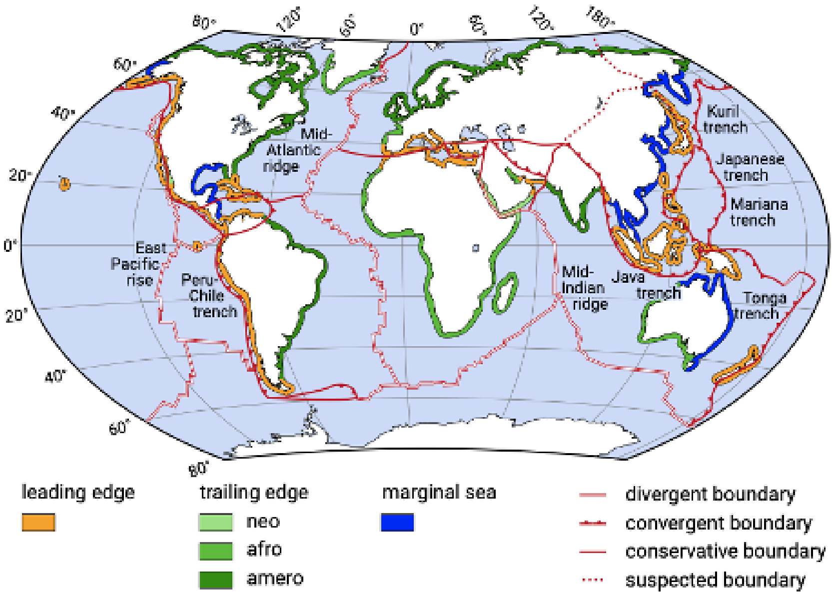


Figure 3.17: Tectonic-based classification of coasts [3]

Ocean currents have a significant influence on the hydrodynamics at a beach. The movement of water due to currents affects the distribution of sediment along the shoreline and can impact the wave characteristics, which in turn affects the sediment transport and the beach morphology [3]. Around Playa del Ostional, currents flowing off the Guanacaste coast move towards the northwest due to the equatorial counter-current separating from the coast of Central America, creating northerly currents off Costa Rica and southerly currents off Panama. The inshore currents are complex and influenced by tides, local winds, and eddies within coastal embayments. However, a consistent feature of the coastal circulation is the northwesterly current that runs along Punta Guiones and Cabo Velas. This current diverges from the indented shoreline and creates a large clockwise eddy in the Gulf of Papagayo [20]. Figure 3.18 displays the year-round current velocities and directions of currents closer to the shore. These directions and velocities were obtained from the WaveWatch III model.

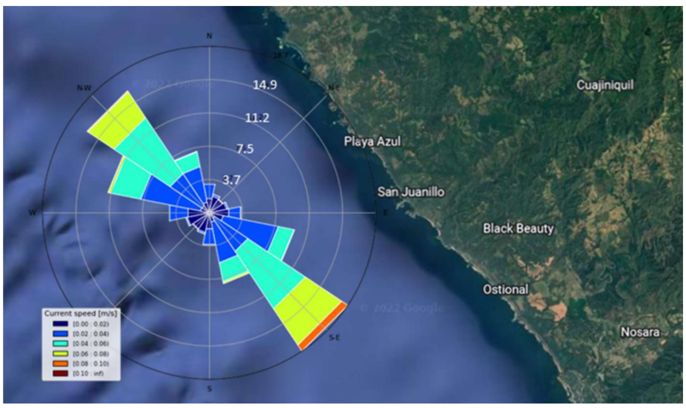


Figure 3.18: Current velocities and direction close to research site

The wave climate near Playa del Ostional, according to the research executed in October 2022, is identified as a west coast swell wave climate. The research found that the majority of waves in the area are long waves with periods exceeding 10 seconds, and their height is generally moderate, ranging between 1 to 2 meters. However, the area of Playa del Ostional is characterized by a dry and wet season. Generally, the wave climate during the wet season is characterized by high wave energy, while lower wave energy prevails during the dry season, leading to a relatively calm wave climate [30]. The presence of stronger and more intense winds during the wet season, which have the ability to generate larger and more powerful waves, is the cause for the higher wave energy during the wet season.

Over the timescale of wave events, the upper shoreface profile and plan form of a coast may exhibit highly dynamic variations. These so-called morphodynamic regimes, also known as beach states, are categorized in scientific literature based on their overall appearance, which if often linked to previous weather conditions and wave climate spanning daily to monthly timescales. Wright and Short (1984) divided beaches into six different categories, with the highest being the dissipative state and the lowest being the reflective state. They also identified four in-between states [3]. According to this characterization of beaches, Playa del Ostional during the dry season falls more towards the reflective end or is considered intermediate. This is because of the presence of rip currents, channels, and plunging waves, which are common features of this type of beach state, and which are observed during the beach observations of the field investigation.

3.1.4 General environmental characteristics

The general environmental characteristics of the beach are classified into three groups: (1) boundary parameters such as rivers and estuaries, (2) beach vegetation, and (3) wildlife, including potential predators of sea turtle eggs and hatchlings. When comparing the data collected from Playa del Ostional during the research in the dry season in March 2023 with that of the research in the wet season in October 2022, several significant differences as well as similarities were identified. The shoreline exhibited considerable variation in environmental characteristics between the wet and dry season. Figure 3.19 provides an overview of the general environmental characteristics of the beach found during the dry season.

Figure 3.19: General environmental characteristics seen in March 2022 at Playa del Ostional

Boundary parameters

Along the coastline different boundary parameters were observed, such as built structures, vegetation, rivers and estuaries. The biggest boundary parameter at Playa del Ostional is vegetation ranging from transect 1 to 47, where similar grass and trees are found in both the wet and dry seasons (figure 3.20 and 3.21). The amount of grass at Playa del Ostional in the dry season is a bit less compared to the wet season, and due to the dry season its color is more yellow. At the height of the Ostional village, houses and buildings mark the boundary of the beach.

Figure 3.20: The vegetation line in the wet season at transect 1-47

Figure 3.21: The vegetation line in the dry season at transect 1-47

At the beginning of Playa del Ostional, a rocky coastline was identified together with an estuary that was not reported in the research executed in October 2022 at transect 1 (t1). Additionally, a large beach scarp was identified at t44 that was not reported in the research of October 2022 (figure 3.22). Furthermore, an estuary was observed at transect 77 at Main Nesting Beach that was not reported in the research of October 2022 (figure 3.23).

Figure 3.22: Beach scarp at transect 44

Figure 3.23: An estuary seen at transect 77

Between transects 60 and 63, another estuary marks the border of Main Nesting Beach in both seasons (figure 3.25 and 3.24). In the wet season, a river was observed at t60; however, it was not directly identified during the dry season. Upon closer examination of the sand, it became evident that the water was still flowing towards the sea during low tide as the stream was visible at the waterline.

Figure 3.24: The estuary at transect 60-63 in the wet season

Figure 3.25: The estuary at transect 60-63 in the dry season

Quite a few small rivers observed in the wet season during the research of October 2022 at transects 8, 18, 29 and 41 are not observed during the dry season. Figure shows the remains of the river at transect 8 in the dry season. Moreover, the large river Rio de Mantaña at t140 that was discovered during the wet season, was not discovered in the dry season as possibly the water in the river had evaporated too much.

Figure 3.26: Remains of the dried up river at transect 8

Beach vegetation

Different types of grasses, plants, cacti, and trees were observed along the entire coastline, both in the wet and dry season. A difference between Playa del Ostional, MNB and Playa Nosara in terms of vegetation, however, was noticeable. In the wet season as well as in the dry season, cactus bushes (Bromelia pinguin) form the border of the beach at Playa del Ostional from transect 1-47 seen in figures 3.27 and 3.28.

Figure 3.27: The Bromelia pinguin cacti in wet season

Figure 3.28: The Bromelia pinguin cacti in dry season

An remarkable observation were the piles of small stacked stones at Playa Nosara that were not reported in the research executed in October 2022 (figure 3.29). Furthermore, a great number of wooden logs was found along the shore of Playa Nosara next to the vegetation line, in both seasons (figure 3.30).

Figure 3.29: Piles of small stones at Playa Nosara

Figure 3.30: Wooden logs along the shore of Playa Nosara

Present wildlife

Throughout both the wet and dry seasons, an abundance of crabs have been observed along the entire expanse of the shoreline from Playa del Ostional to Playa Nosara, distinguished by their burrows and tracks (figure 3.32). Furthermore, the presence of black vultures in great amounts was noted at Playa del Ostional and Main Nesting Beach (figure 3.33), where these birds frequently picked turtle nests for eggs. This behavior was especially seen on Main Nesting Beach, where the largest number of turtle nests and eggs were found (figure 3.34). In addition, quite a few stray dogs were spotted at Playa del Ostional and Main Nesting Beach in the dry season, as was the case in the wet season (figure 3.31). Notably, there were no significant differences between the dry and wet season in the amount of present wildlife observed at Playa del Ostional.

Figure 3.31: A dog at Playa del Ostional

Figure 3.32: Signs of crabs at Playa del Ostional

Figure 3.33: Black vultures at MNB

Figure 3.34: Black vultures preying upon a sea turtle nest

3.2 Data analysis

3.2.1 Model improvements

Each time the program was run on the same computer (Zbook G7), this due to the fact that a different computers generated different results in probability and relative weights. When run on the same computer, the model generates the same covariates and relative weights during the fitting process, although the daily probabilities of an arribada event differ every simulation.

The changes in the model (compared to the 2022 research) led to significant improvements in the analysis of arribada event triggers. Firstly, updating the second and third order of the Markov Chain has resulted in a faster model with more accurate results. Secondly, the use of normalization has enabled faster model analysis and allowed more comprehensive weight analysis of the covariates. Additionally, the incorporation of new data as covariates resulted in more accurate results in the daily probability simulation. Altogether, these improvements resulted in a significant decrease in the time taken to run the model, with the average time decreasing from an average of 10 minutes to under 5 minutes. Furthermore, the probability results increased from 60% to nearly 80% on a given day (see figure 3.35), compared to the research executed in September 2022 (see figure 3.36).

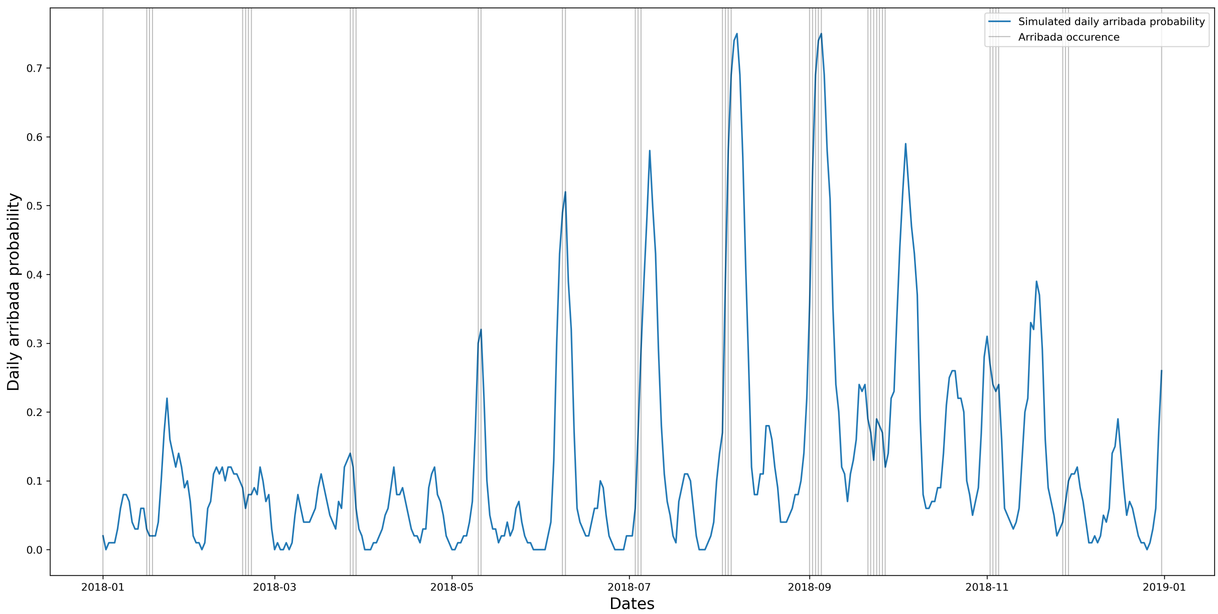


Figure 3.35: Probability using all covariates

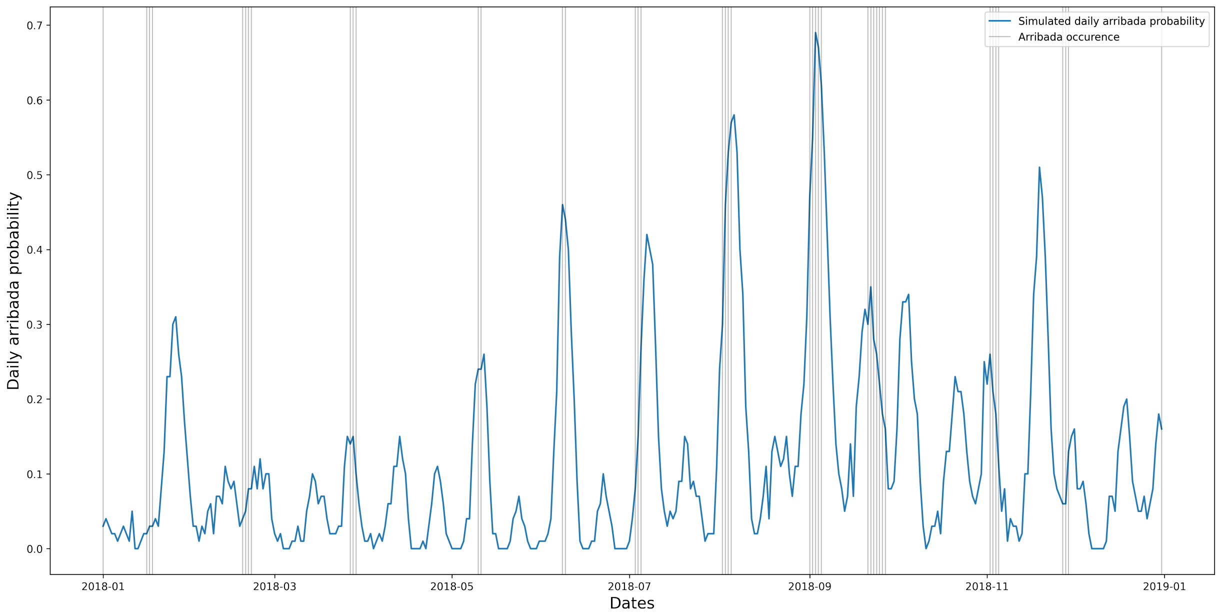


Figure 3.36: Probability using all covariates (conducted in research 2022)

3.2.2 K-fold cross-validation

The k-fold cross-validation resulted in the same scores as the previous research, namely:

- Fold 1: Accuracy score of 0.8976
- Fold 2: Accuracy score of 0.8765
- Fold 3: Accuracy score of 0.8822
- Fold 4: Accuracy score of 0.8822

The resulting mean accuracy score is 0.8846. When the predictions of the different grouped environmental parameters were analysed the results stayed the same, which shouldn't be the case. After further analysis the discovery was made that the k-fold analysis predicted all days without arribada and therefore yielded an average accuracy score of 89 percent. Which is exactly in line with the the percentage of arribada days per year divided by the total amount of days per year. Therefore, the results of k-fold cross-validation remain unchanged regardless of the covariates used in the model, making them unsuitable for further analysis.

3.2.3 Weights and predictions

The predictions and weights of the covariates will be analyzed and presented through plotted results. Appendix figure I.1 shows the probability of arribada occurrence for all years. The ALR model generates reasonable predictions with probabilities of around 50 percent for an arribada event on any given day for all years. Notably, the year 2018 produces the most accurate results and thus was used as a benchmark for comparison in further analysis.

Multiple regression of all covariates

Normally, the fitting process only keeps covariates which improve the current fit. Therefore, other covariates which could have had a positive impact on the arribada probability simulation could not be loaded in. When using over-fitting, the fitting process does assign the covariates a relative weight but does not clear them when they do not improve the fit. Figure 3.37 depicts the results of a simulation of all covariates without clearing after fitting. The relative weights of covariates can be found in the appendix I.2.

The figure shows a clear overview of all weights of covariates. There are 26 covariates which have a bigger relative weight than 0.5, which indicates that it has a notable influence on the arribada. What also stands out is that every group of covariates has multiple covariates that have a significant impact on the prediction of an occurrence of an arribada.

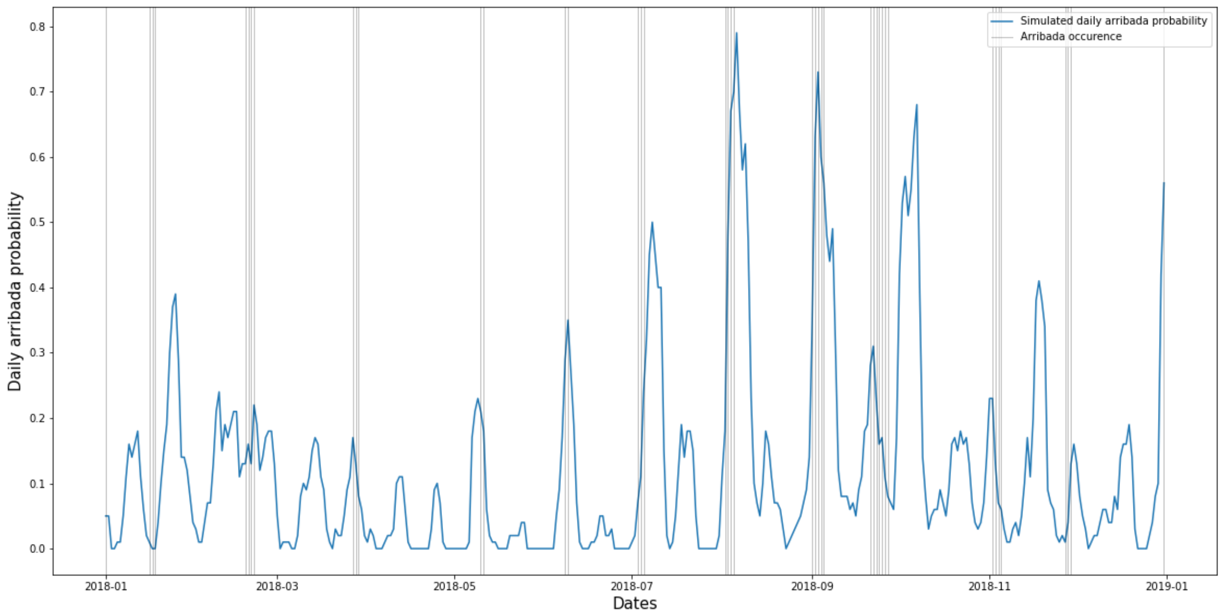
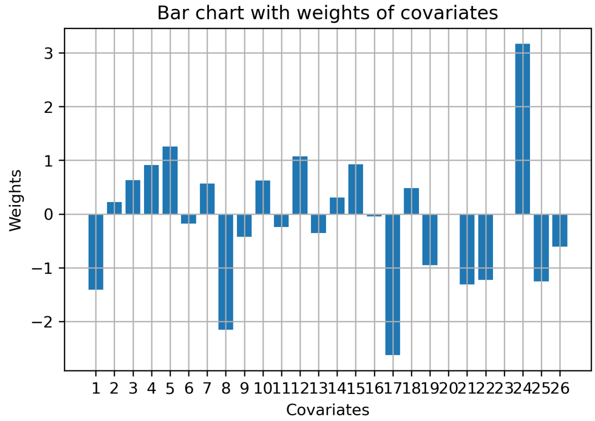


Figure 3.37: Daily probability of all covariates with over-fitting

Figure 3.38 shows the relative weights after fitting all the covariates. The results of most important covariates are partly in line with the over-fitting matrix, see pdTIDE_MF, pdMJO_1 and pdVELOCITY_IHc_rho. However, two of the biggest relative weights 'pdTIDE_tide2N2min and meiv2.data.txt have been cleared after fitting.

Both the figures with fitting (3.35) and over-fitting show notable relative weights in all groups of covariates. The covariates with the most significant impact in figure 3.38 are pdTIDE_MF, pdTIDE_P1, pdVELOCITY_IHc_rho, Moon_v and pdMJO_1. As the over-fitting results indicated a distinct connection between the covariates group and ENSO covariates, it has been decided to include the covariates group in the subsequent analyses. The remaining results will exhibit the daily probability plots and the weights of the most influential parameters for each group listed in 2.2.2, along with a plot of these parameters that incorporates the arribada data.



Number	Covariates
1	constant
2	pdTIDE_K1
3	pdTIDE_K2
4	pdTIDE_M2
5	pdTIDE_MF
6	pdTIDE_MM
7	pdTIDE_O1
8	pdTIDE_P1
9	pdTIDE_P1min
10	pdTIDE_S1
11	pdTIDE_S2
12	pdTIDE_T2min
13	pdTIDE_tidalsignal.csvmin
14	pdVELOCITY_gtsm_phi1
15	pdVELOCITY_gtsm_phi2
16	pdVELOCITY_gtsm_rho1
17	pdVELOCITY_IHc_rho
18	pdVELOCITY_IHc_tide
19	Mooncycle_First
20	Mooncycle_New
21	Moon_v
22	pdMJO_1
23	pdSUNS
24	markov 1
25	markov 2
26	markov 3

Figure 3.38: Relative weight of covariates

Tidal constituents

When all tidal constituents were used combined as input data the model generated a significant probability of 0.6 in September. Also the peaks at arribada occurrences are present during the whole season present over most of the season, still predicting an arribada in the dry months is less accurate. Finally, the model doe create zero's but also a couple of high probabilities when no arribada occurs.

What stands out is the pdTIDE_tidalsignal.csvmin, the calculation of the tide at the location of Playa del Ostional, which has a smaller relative weight than certain individual tidal constituents. This suggests that several tidal constituents together can predict the occurrence of an arribada better than the exact tide at Playa del Ostional.

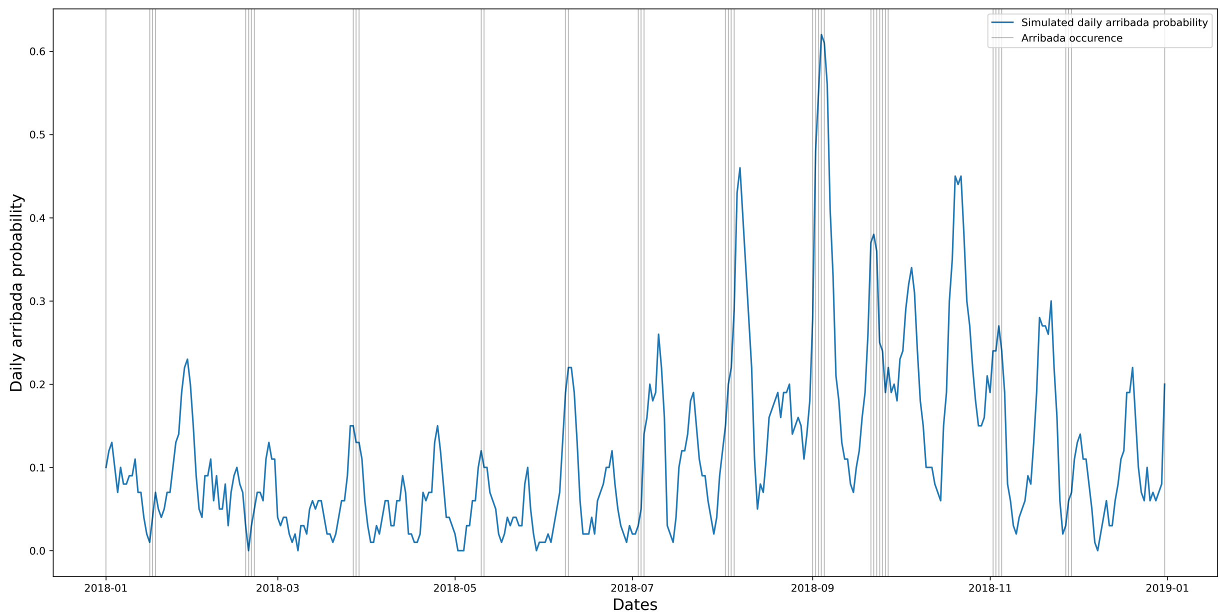
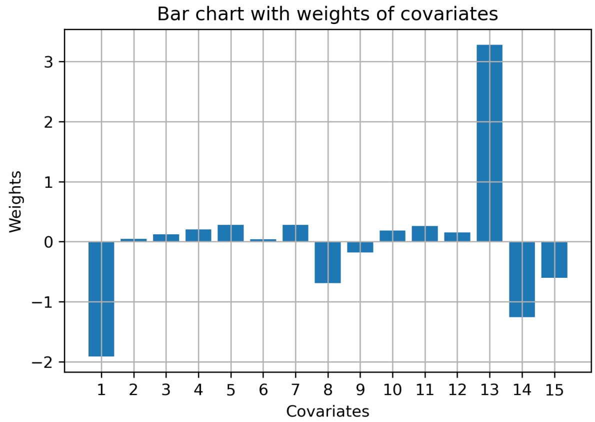


Figure 3.39: Probability of only tidal covariates



Number	Covariates
1	constant
2	pdTIDE_K1
3	pdTIDE_K2
4	pdTIDE_M2
5	pdTIDE_MF
6	pdTIDE_MM
7	pdTIDE_O1
8	pdTIDE_P1
9	pdTIDE_P1min
10	pdTIDE_S1
11	pdTIDE_T2min
12	pdTIDE_tidalsignal.csvmin
13	markov 1
14	markov 2
15	markov 3

Figure 3.40: Relative weight of tidal covariates

The most influential tidal data covariate is pdTIDE_P1 (figure figure 3.41), P1 is one of the EOT20 tidal constituents. This constituent has a seasonal influence as seen in sinusoidal function. More and bigger arribada's occur when P1 is low (nearby 0).

Tidal constituent MF (figure 3.42), O1 (figure 3.43) and T2 (figure 3.44) have a much shorter period than P1. Some of the predictions for an arribada are exactly right, but nearly half of the time these covariates These constituents with a shorter period have a small weights in the ALR model.

It's important to note that tidal analysis typically involves considering not only these tidal constituent, but also many other tidal constituents that have different periods and amplitudes. The combination of these constituents can result in complex and sometimes unpredictable tidal patterns.

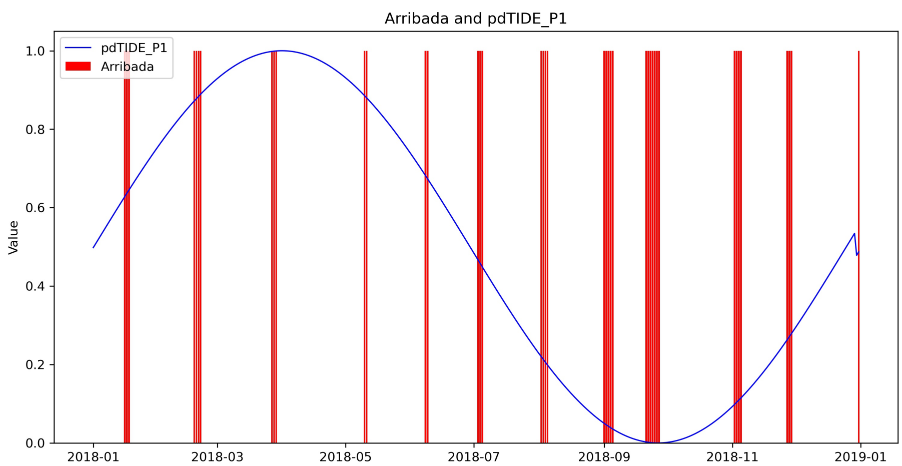


Figure 3.41: pdTIDE_P1 and arribada data

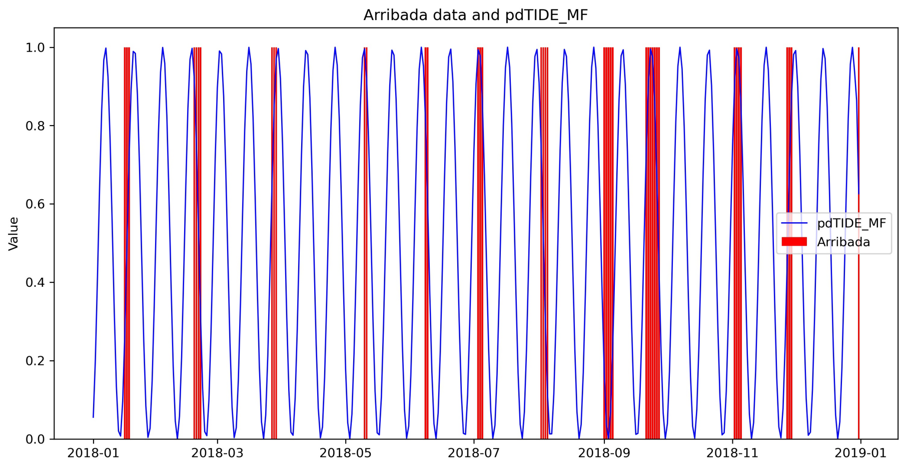


Figure 3.42: pdTIDE_MF and arribada data

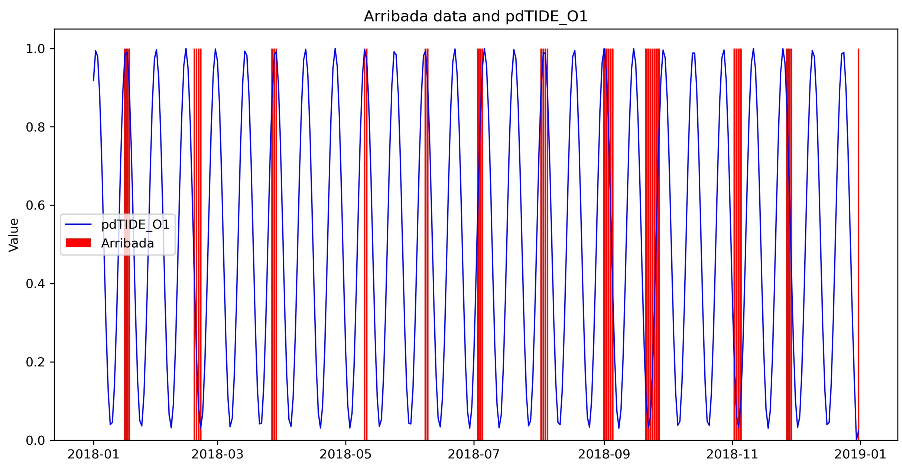


Figure 3.43: pdTIDE_O1 and arribada data

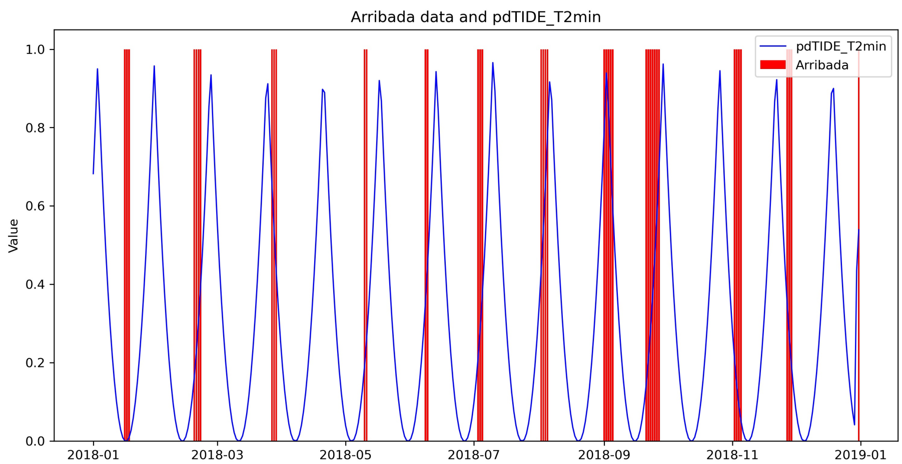


Figure 3.44: pdTIDE_T2min and arribada data

Current direction and velocity covariates

Both the GTSM and IHC model results in three types of covariates: phy (current direction), rho (current magnitude) and tide at the location of the model. In figure 3.46, it can be observed that both the GTSM and IHC model covariates produce significant relative weights, with the IHC model having the highest weight among them. Also, all three types of covariates are used in the model to predict the arribada dates.

pdVELOCITY_gtsm_tide 1,2 and 3 where nearly identical covariates, which resulted in large relative weights of +20 and the -20 (see appendix I.3). Therefore, two were left out of the second simulation, which gave the following relative weights 3.46.

The mentioned covariates produced prediction which predict arribadas with around 40 percent chance. Also the predictions are high during the whole season, which is the only group with this characteristic. Unfortunately, from October till March the predictions are not completely in line with the arribada dates.

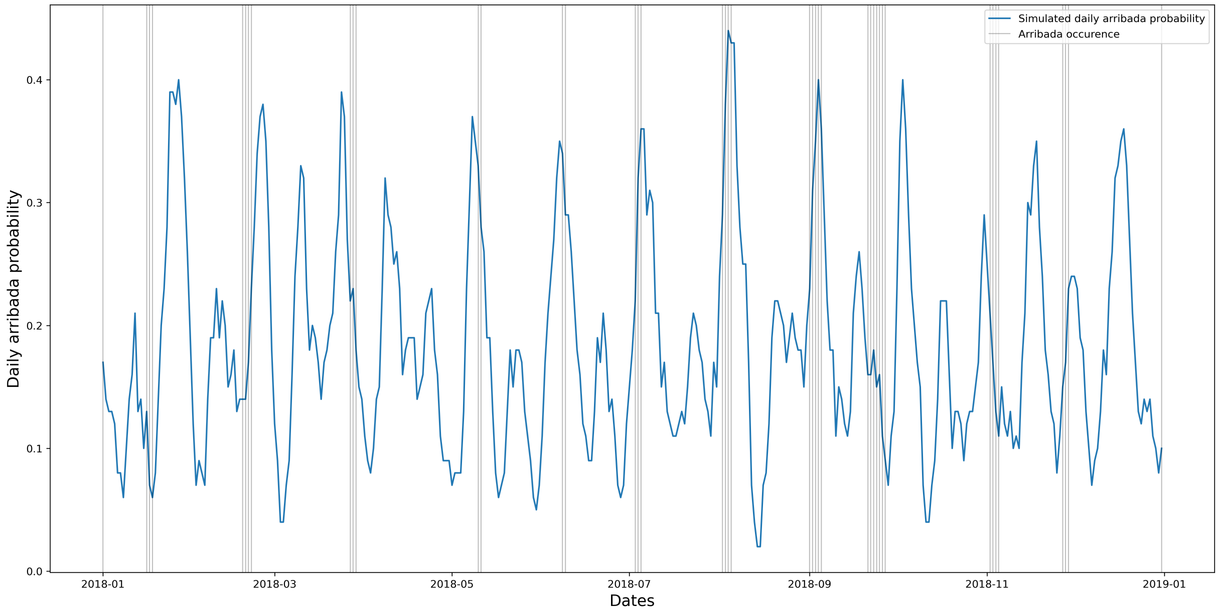
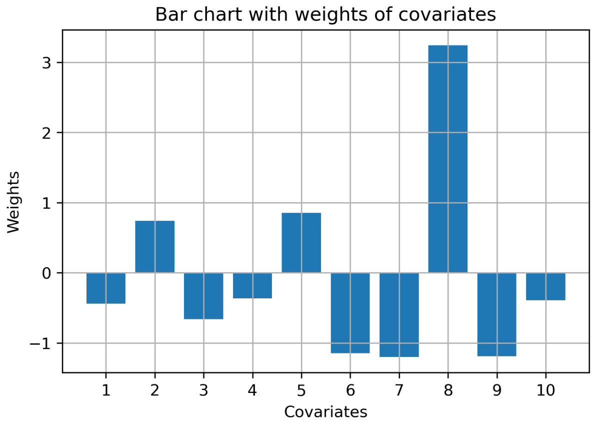


Figure 3.45: Probability plot of current velocity covariates



Number	Covariates
1	constant
2	pdVELOCITY_gtsm_phi2
3	pdVELOCITY_gtsm_phi3
4	pdVELOCITY_gtsm_rho1
5	pdVELOCITY_gtsm_tide3
6	pdVELOCITY_IHc_phi
7	pdVELOCITY_IHc_rho
8	markov 1
9	markov 2
10	markov 3

Figure 3.46: Relative weight of velocity covariates

Figures 3.47, 3.48, 3.49 and 3.50 show the most important GTSM and IHC model covariates with the arribada dates. It is clear that the IHC model generates much clearer results than the GTSM model. The

IHC direction (phy) and velocity (rho) both show good fits with only a couple arribadas where they do not show correlation. Also, multiple times the variables are off for a couple of days.

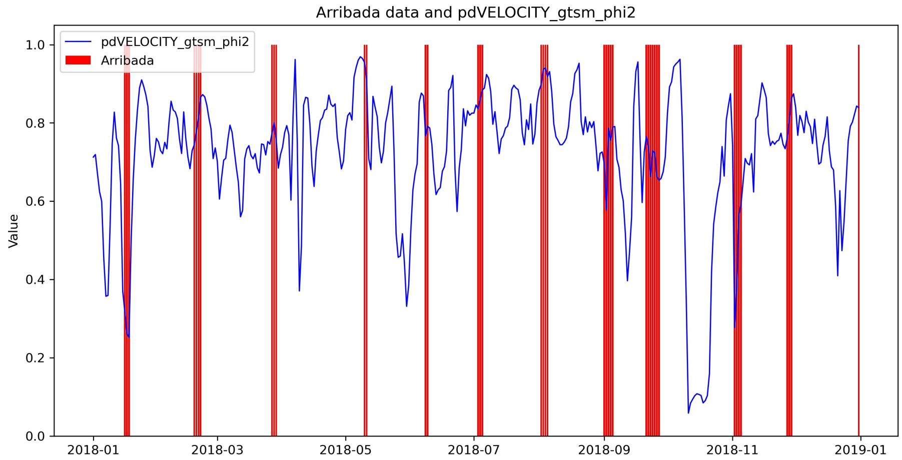


Figure 3.47: pdVELOCITY_gtsm_phi2 and arribada data

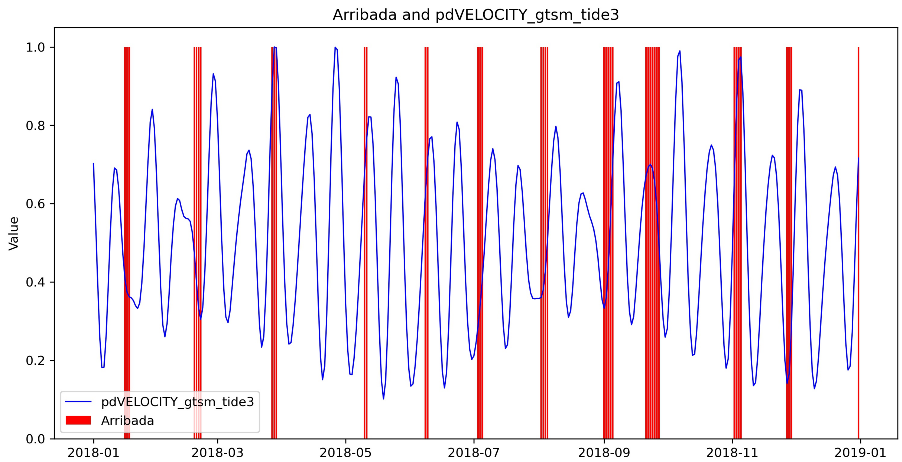


Figure 3.48: pdVELOCITY_gtsm_tide3 and arribada data

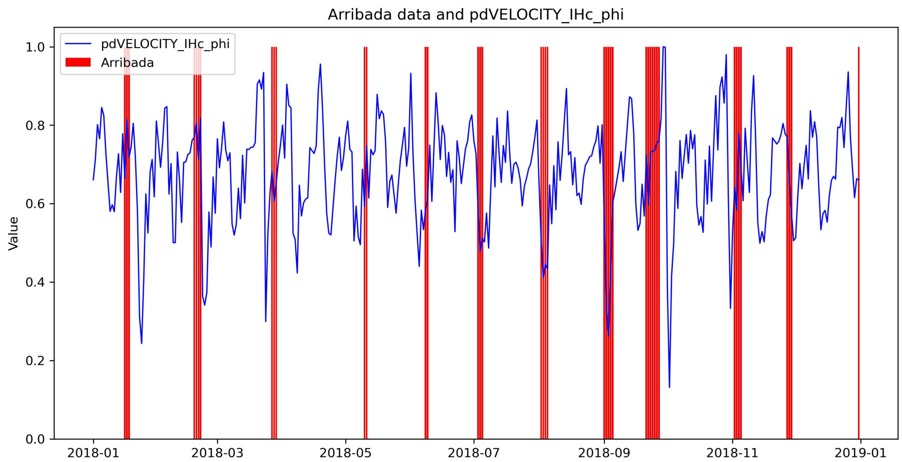


Figure 3.49: pdVELOCITY_IHc_phi and arribada data

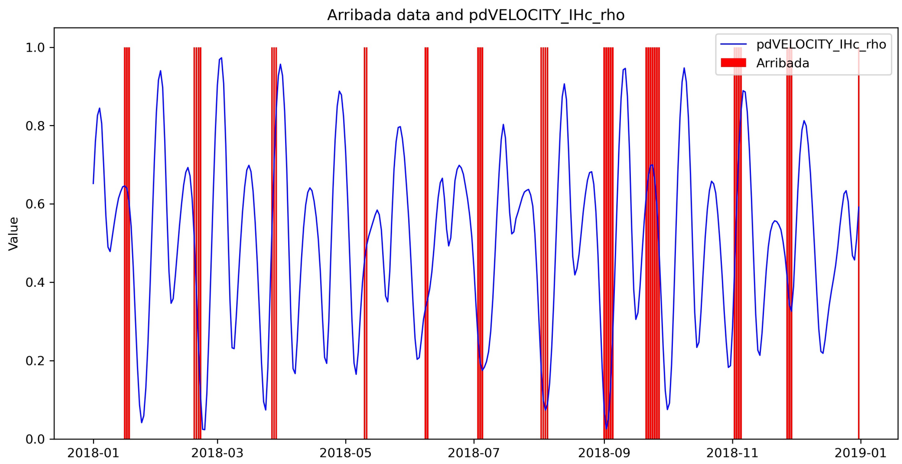


Figure 3.50: pdVELOCITY_IHc_rho and arribada data

Moon cycle covariates
The figure below 3.53 shows the probability plot of only the moon cycle covariates.

The moon cycle covariates alone do not yield satisfactory results, as the maximum probability of an arribada occurring on a single day is only 22.5 percent (as shown in figure 3.51). This is noteworthy, given that both Moon_v and Mooncycle_Third have a significant impact on arribada events in the simulation when all covariates are considered (as shown in the weights analysis presented in Figure 3.38). Furthermore, the probability of an arribada occurring on days without a recorded event deviates numerous times.

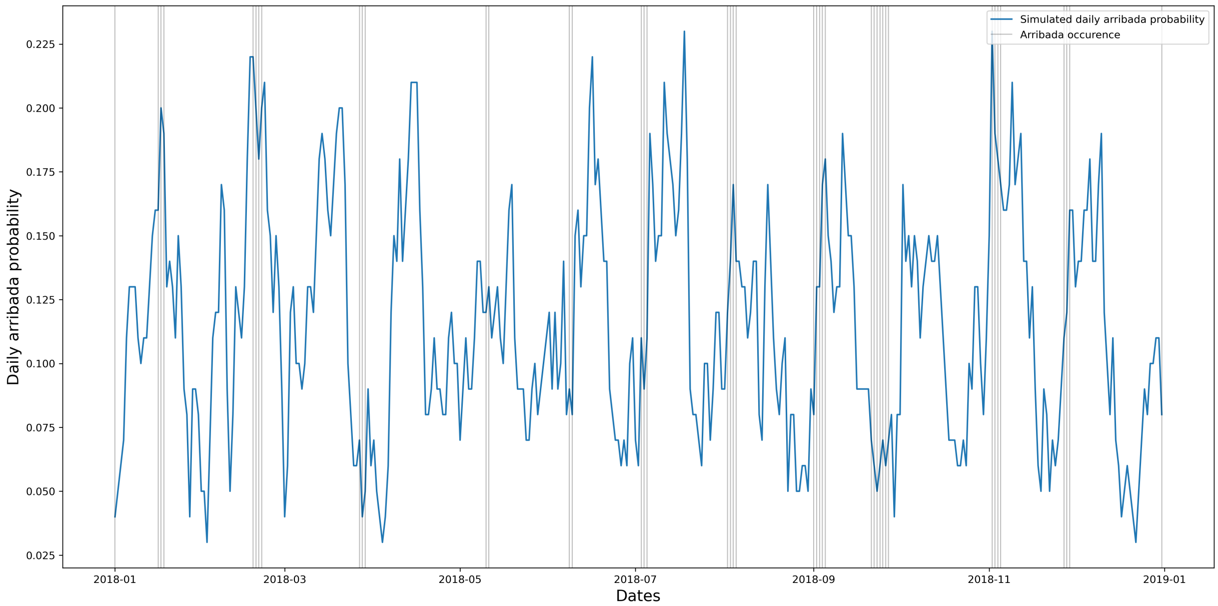
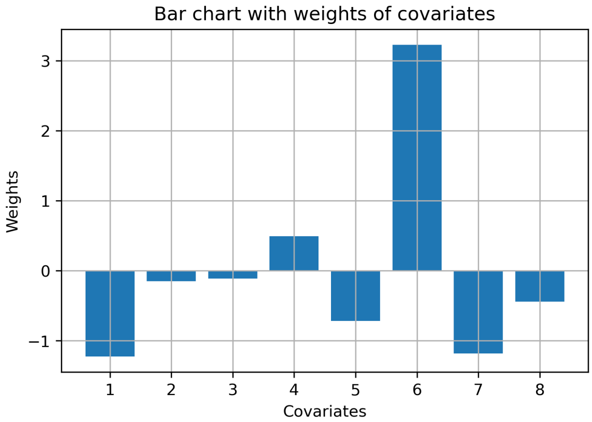


Figure 3.51: Probability plot of moon cycle



Number	Covariates
1	constant
2	Mooncycle_First
3	Mooncycle_Full
4	Mooncycle_Third
5	Moon_v
6	markov 1
7	markov 2
8	markov 3

Figure 3.52: Relative weights of moon cycle covariates

Both figures below (3.53 and 3.54) show a strong correlation between the arribada data for certain dates. The data of the third moon is more aligned with the arribada data; however, since it is binary, the Moon_v data also carries significant weight. Another important observation is that the correlation between the covariates and arribada events markedly decreases during the first four months of the year. Therefore, to better illustrate this relationship, two additional plots of both covariates have been included in Appendix I.0.4. These figures further demonstrate a strong correlation between the third quarter moon and the occurrence of an arribada.

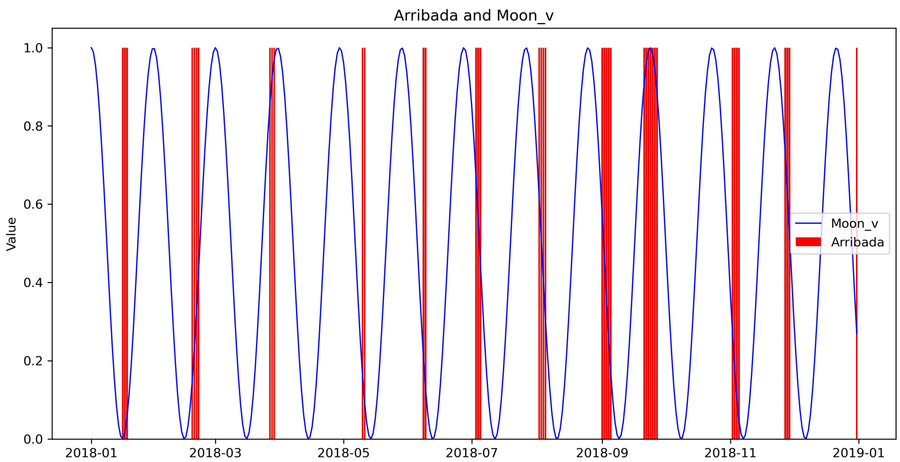


Figure 3.53: Moon_v and arribada data

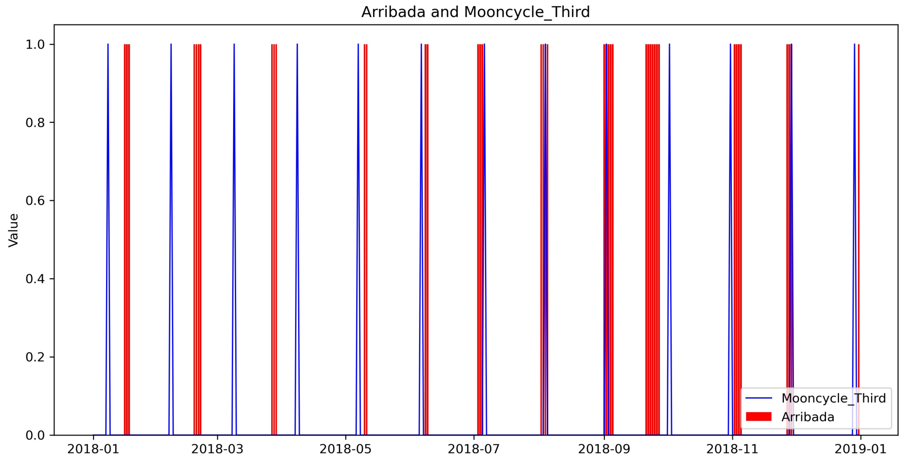


Figure 3.54: Mooncycle_Third and arribada data

MJO covariates

As can be seen in figure 3.55, 3.57 and 3.58, the Madden-Julian Oscillation covariates do not generate significant daily probabilities for arribada occurrence and do not correlate with the daily arribada data.

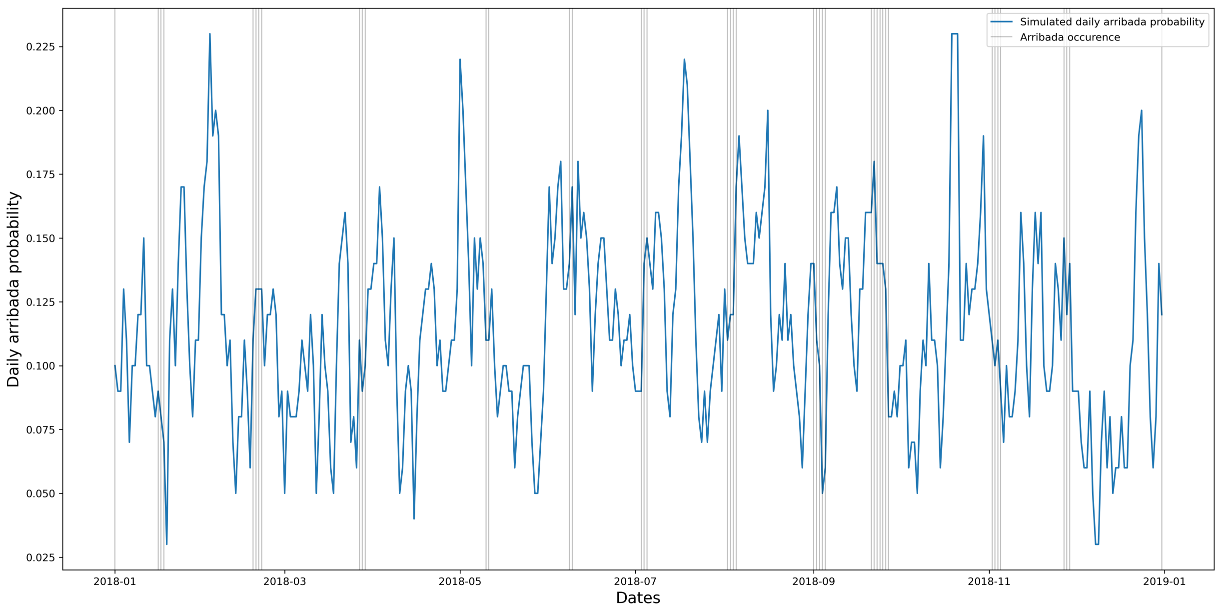
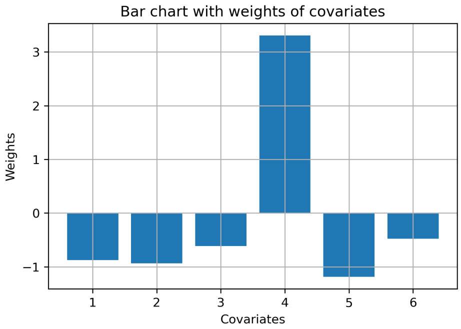


Figure 3.55: Probability plot of tidal covariates



Number	Covariates
1	constant
2	pdMJO_1
3	pdMJO_12
4	markov 1
5	markov 2
6	markov 3

Figure 3.56: Relative weight of Madden-Julian oscillator covariates

Figures 3.57 and 3.58 do not show a clear correlation.

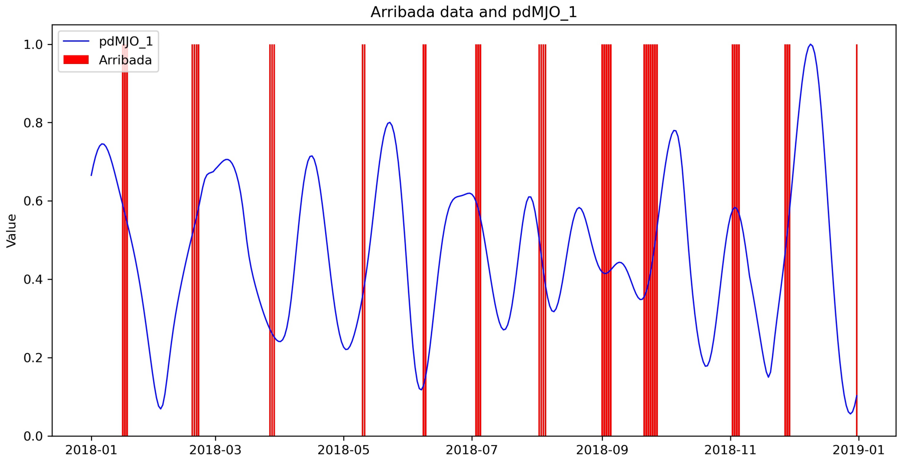


Figure 3.57: pdMJO_1 and arribada data

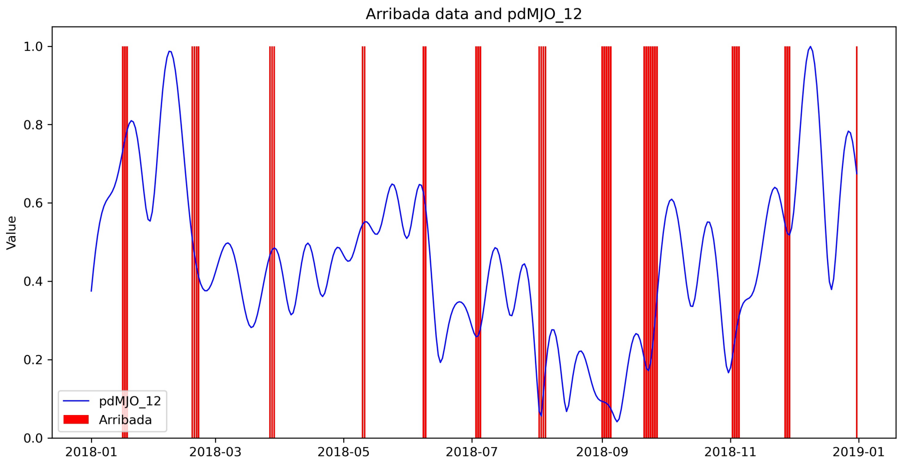


Figure 3.58: pdMJO_12 and arribada data

ENSO covariates
The El Niño-Southern Oscillation frequency is three to seven years as explained in the methodology 2.2.2. The historical data I.11 shows seasonal changes which could impact arribada nesting 3.59. However, with the current dataset it is impossible to draw conclusions.

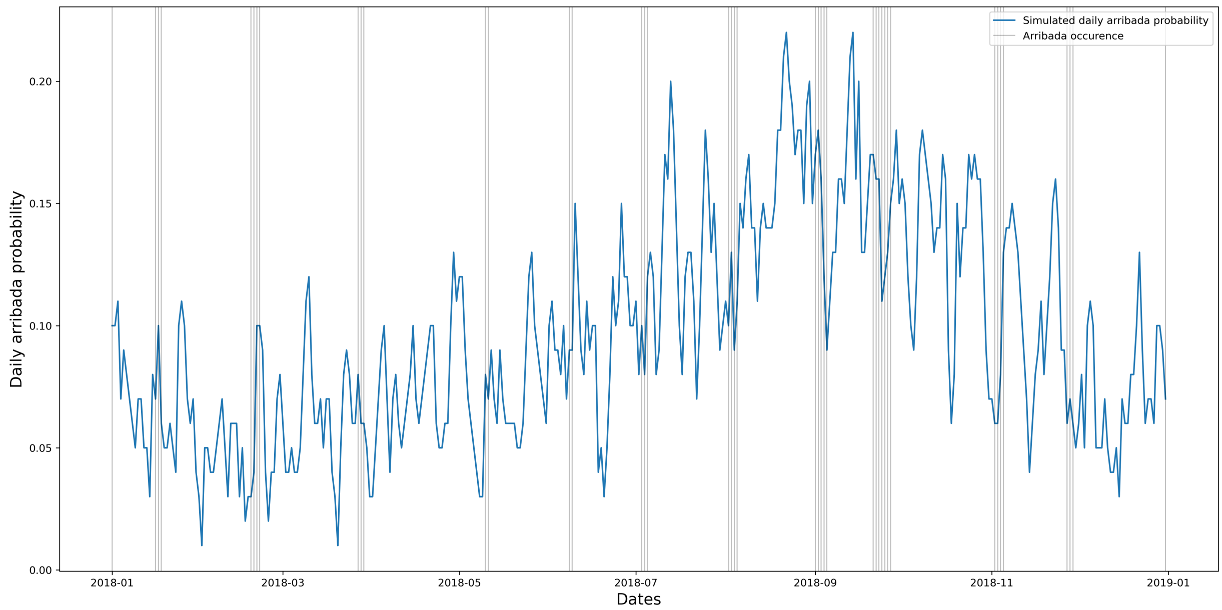
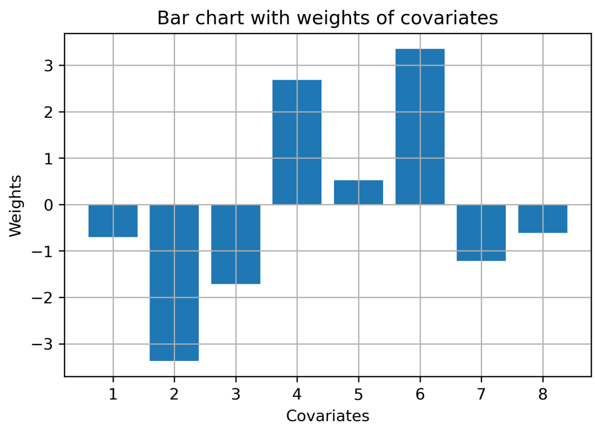


Figure 3.59: Probability plot of ENSO covariates



Number	Covariates
1	constant
2	data_correlation_soi.data.txt
3	nino12.long.data.txt
4	soi.long.data.txt
5	tni.had.long.data.txt
6	markov 1
7	markov 2
8	markov 3

Figure 3.60: Relative weight of ENSO covariates

Figures 3.61, 3.62, 3.63 show no clear correlation between the arribada dates and their values.

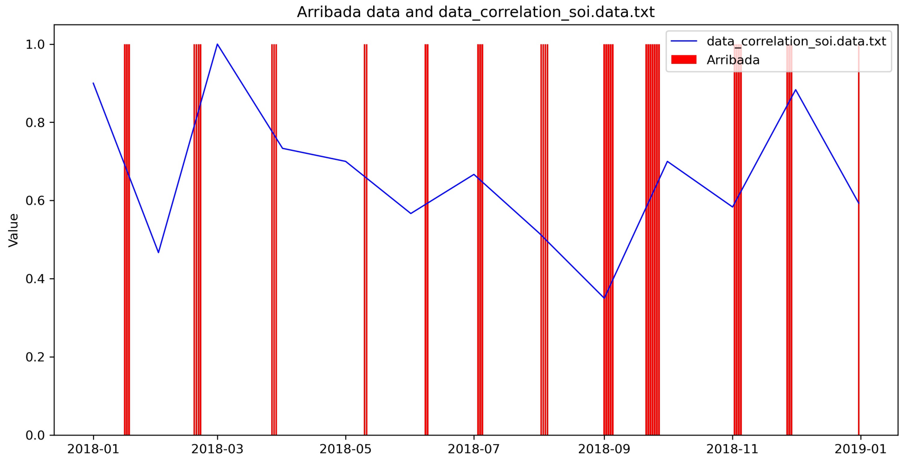


Figure 3.61: data_correlation_soi.data.txt and arribada data

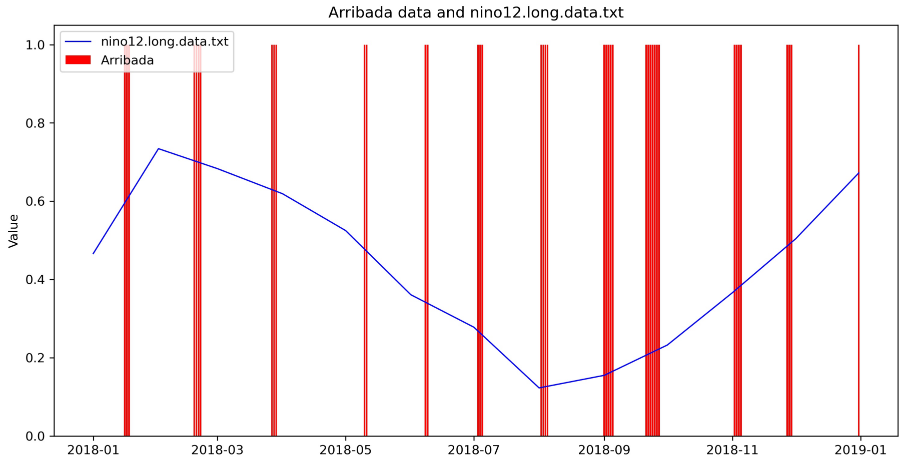


Figure 3.62: nino12.long.data.txt and arribada data

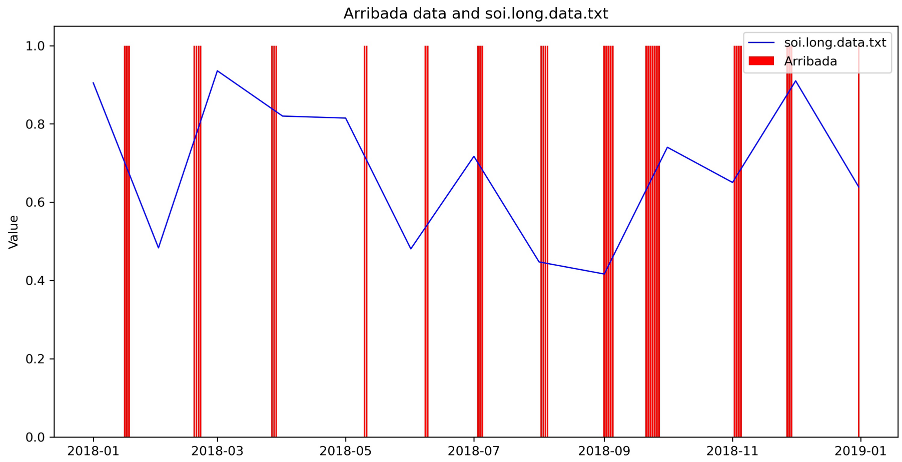


Figure 3.63: soi.long.data.txt and arribada data

3.3 Stakeholder analysis

3.3.1 Stakeholder exploration

The following stakeholders were identified at Ostional:

- Refugio Nacional de Vida Silvestre Ostional
- Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)
- Ministerio del Ambiente y Energía (MINAE)
- Sistema Nacional de Áreas de Conservación (SINAC)
- Asociacion de Desarollo Integral Ostional (ADIO)
- Asociacion de Guias Locales de Ostional (AGLO)
- Guías Independientes de Ostional
- Hospitality such as hotels, restaurants, cafes and bars

Refugio Nacional de Vida Silvestre Ostional is a natural conservation area that protects the nesting of various species of sea turtles from the Pacific Ocean, particularly the Olive Ridley. The Refuge was established in 1983 and is co-managed by a number of different groups and institutions: the Ministry of the Environment and Energy (MINAE), the University of Costa Rica (UCR), the Ostional Development Association (ADIO), and representatives from the local community [10]. Their activities include cleaning the beach from dirt and plastics, as well as making room for the turtles to come ashore by creating wooden piles from the wood on the beach. This is done in collaboration with a volunteering program. Besides this, the solitary turtles and arribadas are monitored, and when a female lays eggs, the eggs are measured, labeled and counted. This data is saved and send to CITES.

CITES is an international agreement between governments. Its aim is to ensure that international trade in specimens of wild animals and plants does not threaten the survival of the species. Organizations need to receive a CITES reviewed permit in order to legally import and export protected species, in Ostional concerning the harvesting and selling of olive ridley turtle's eggs.

MINAE is the Ministry of Environment and Energy.

SINAC is the National System of Conservation Areas, a department working with the MINAE.

ADIO is the association in charge of harvesting turtle eggs. Once the Arribada is declared by the Regent Biologist of the association (this is done when there are more than 1000 turtles on beach), the members of the association have 3 days to harvest eggs during the morning (usually from 6am to 9am). The eggs are harvested by hand, cleaned, dried and packed in labeled bags with the mark of ADIO [10]. The eggs are sold all around the country, since this is the only legal sea turtle eggs to buy and eat in Costa Rica. ADIO obtains an annual permit from CITES that allows them to legally declare the harvesting and sale of turtle eggs.

AGLO is the collective noun for a group of local guides in Ostional, working during the arribadas to guide tourists safely onto the beach. There are 32 guides in total.

Guías Independientes de Ostional are independant beach guides for arribadas that do not work for the organization AGLO, but do have a certification to work at Playa del Ostional.

3.3.2 Stakeholder Map

The results of the stakeholder mapping are visualized in figure 3.64, to map out the important stakeholders involved, concerning protection and preservation of arribadas at Playa del Ostional and possible future research. The stakeholders are grouped in 4 different segments on the stakeholder map, using a matrix with two axes: on the y-axis Power (Low/High) and on the x-axis Interest (Low/High).

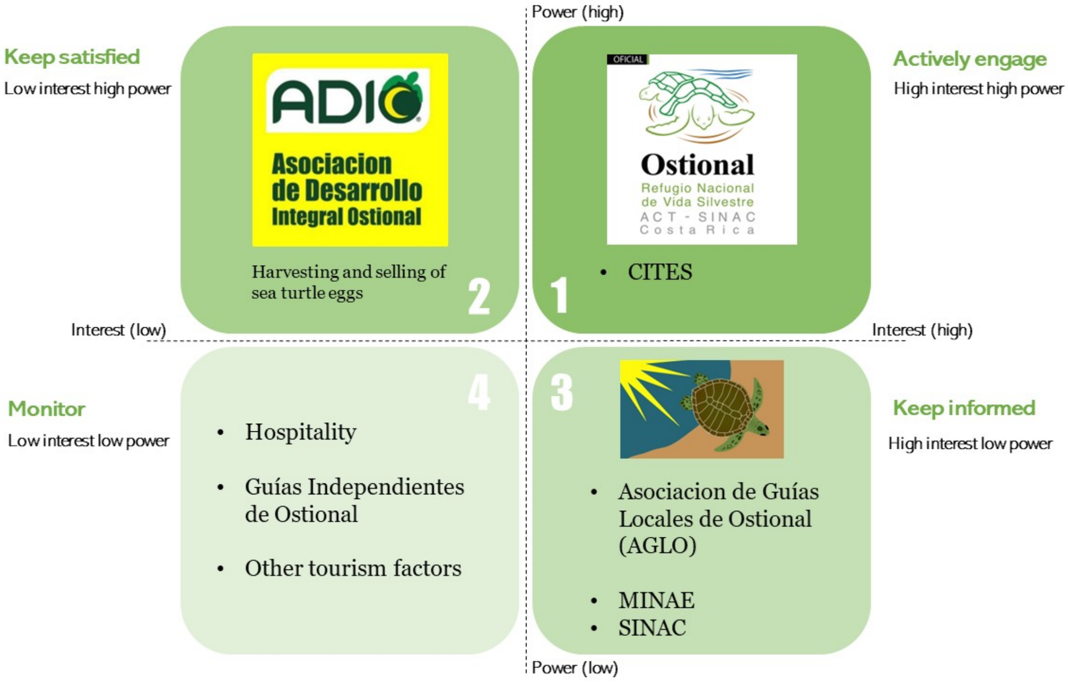


Figure 3.64: Stakeholder map, dividing the stakeholders in four segments

3.3.3 Interviews

A total of 7 participants were interviewed for this study in a total of 6 interviews. All participants are adults living in Guanacaste, Costa Rica. 6 out of 7 participants are local residents of Ostional, 1 out of 7 participants lives in the adjacent village Guiones. 5 out of 7 participants are male, 2 out of 7 are female.

The following people were interviewed: two workers in maintenance and turtle nesting, a restaurant owner, a surf teacher, two workers in the Ostional refuge and a biologist of the University of Costa Rica.

The main themes that emerged from the interviews were related to the participants' attitudes towards climate change at Playa del Ostional and the effects it has on the arribadas and the nesting behaviour of the sea turtles.

Quantitative data showed that 100% of participants mentioned to be aware of the climate change in Costa Rica. 83,3% of the participants mentioned to see changes on the beach of Ostional, due to climate change: *"We see changes, such as more heat and higher sea level and hot sand at the beach." - participant 2.*

Besides that, 100% of the participants mentioned to be aware of the negative effects climate change can have on the amount of arribadas and the amount of tourism in Ostional: *"When there are less arribadas, there are less turtles born and I'm afraid that the tourism drops when there are less turtles." - participant 1.*

In addition, the interviews provided extra information about the different organizations and stakeholders involved in sea turtle conservation in Ostional. Two of the participants mentioned their affiliation with local initiatives, such as the Refugio Nacional de Vida Silvestre Ostional. All the interview notes can be found in Appendix H.

4 Conclusion

The first goal of this research was to map the specific morpho- and hydrodynamic conditions of Playa del Ostional, and therefore to answer the following research question:

1. *How does the morpho- and hydrodynamics of Playa del Ostional vary between the wet and dry season?*

In order to answer this research question, the morpho- and hydrodynamic characterization of the beach was based on different components: the beach profile, the sediment composition, hydrodynamical properties and other general environmental characteristics.

During the dry and wet seasons, the beach profiles of Playa del Ostional exhibit slight variations. Specifically, the slopes of all beaches are more gradual during the dry season than the wet season, with a mean slope that is 0.5 degrees steeper during dry season. Additionally, the beach plateau on top of the slope at the stretches of Playa del Ostional and Playa Nosara is 3.0 m wider. However, crossing rivers have no discernible effect on the bottom part of the slope during the dry season, and the difference in beach width between the two seasons can be considered small.

The sediment composition on the beach shows significant differences between the dry and wet seasons. A significant difference is present in D_{50} values between the dry and wet season for almost all sediment samples. The sediment of all distinct stretches at Playa del Ostional, Main Nesting Beach and Playa Nosara, is generally coarser in the wet season than in the dry season. Moreover, in the dry season, coarser sediment is found on top of the slope, while in the wet season the coarser sediment is found at the waterline. This suggests that coarse sediment may relocate from areas near the waterline to the submerged part of the slope over time, indicating that sediment transport is influenced by seasonal changes in incoming wave energy. At Main Nesting Beach, the difference in D_{50} between sediment samples taken from the waterline and slope is greater than those taken from above the high tide waterline. Furthermore, sediment samples from the waterline at Main Nesting Beach exhibit a significant difference in particle size distribution compared to samples from other locations on the shore face. The same holds for the sediment samples located at the waterline at Playa del Ostional and Playa Nosara. Collectively, these results suggest that seasonal changes have a significant impact on the sediment composition at Playa del Ostional, particularly at Main Nesting Beach, extending from the low tide waterline up to the end of the high waterline at the top of the slope, but specifically around the low tide waterline.

Although the wave climate near Playa del Ostional is expected to be calmer with lower wave energy during the dry season, the precise differences in wave climate, as well as tidal environment, between the two seasons cannot be determined due to a lack of available data. Playa del Ostional is likely to be characterized as a reflective or intermediate beach during the dry season, mainly due to the presence of plunging waves and rip currents. However, a conclusive determination about the beach's state during this season cannot be made as the available data is also insufficient. Regarding sediment transport, the coastal zone of Playa del Ostional experiences a decline in sediment deposition during the dry season compared to the wet season. This is because the rivers and estuaries that usually carry fine sediment to the beach during the wet season do not flow out to the sea during the dry season.

Further, the distinct stretches of Playa del Ostional exhibit significant variation in environmental characteristics between wet and dry seasons. Vegetation bounds most of the beach in both seasons, with similar grass and trees present. However, a beach scarp appears during the dry season in a portion of the beach that is absent during the wet season. An estuary was observed in the dry season at transect 77 at Main Nesting Beach but was not reported during the wet season research. Most rivers that flow out during the wet season are absent during the dry season. Playa Nosara features numerous small stacked stone piles during the dry season but not in the wet season. No significant difference in wildlife presence was observed between the dry and wet seasons at Playa del Ostional.

The second goal of the research was to determine the environmental parameters that exert the greatest influence on the occurrence of an arribada at Playa del Ostional, and therefore to answer the following research question:

2. *Which environmental parameters have the greatest influence on the occurrence of an arribada?*

Firstly, the results of the data analysis are improved and can predict an arribada on a certain day with a certainty of 80%. This improvement is caused by several factors including, fixing the second and third order markov chain, adding the moon visibility parameter and normalisation of parameters. Also, the simulation duration was significantly reduced by 50%.

Following, splitting the covariates into groups allowed for detailed analysis of their influence on the occurrence of an arribada. The maximum probability predicted of an arribada happening on a certain day per group is listed below from high to low:

1. Tidal covariates 60%
2. Current velocity covariates 40%
3. MJO covariates 22.5%
4. Moon cycle covariates 22.5%
5. ENSO covariates 20%

Several conclusion can be drawn out of the weight analysis: several covariates, especially the tidal constituents, together yield higher predictions even though the individual covariates did not correlate with the arribada data. The prediction of all grouped covariates, except for the current direction and velocity, was significantly worse for the months December till April. The best performing parameters, as described in the next paragraph, appear to be effective in predicting arribada events, although they may deviate slightly on certain days.

Parameters pdTIDE_P1, pdVELOCITY_IHC_phi, pdVELOCITY_IHC_rho, Mooncycle_third and Moon_v are expected have most influence on the occurrence of an arribada. The word expected is used because it is still not possible to conclude if these parameters really have a direct influence, influence another parameter or have coincidence. For example, pdTIDE_P1 has a seasonal influence on the occurrence of an arribada. There are probably more than one environmental parameters which also have a seasonal characteristics.

It is notable that the pdTIDE_tidalsignal.csvmin, the calculation of the tide at the location of Playa del Ostional, which has a smaller relative weight than certain individual tidal constituents. This suggests that several tidal constituents together can predict the occurrence of an arribada better than the calculated exact tide at Playa del Ostional. Futhermore, Mooncycle_third has one of the best fits of all data but is combined with Moon_v because it exists of binary data. Although, the moon cycle covariates together do not generate a 25 percent probability on a certain day.

The third goal of the research was to identify and map out the stakeholders who are involved in the occurrence of arribada at Playa del Ostional, and therefore to answer the following research question:

3. *How do the current stakeholders involved in the arribadas at Playa del Ostional envision the future of the site in the context of climate change, and what are their interests in this regard?*

In order to answer the first part of this research question, the results of the interviews are discussed. It was found that all interviewees are aware of the climate changes at Playa del Ostional and the negative effects this might have on the tourism stimulated by the arribadas. These results suggest that the local residents are willing to engage in the protection of the arribadas at their beaches, if that is necessary in the future due to climate change effects.

The interviews also provided more information about the organizations involved in the protection of the turtles. This confirms the level of engagement of the residents of Ostional in order to learn more about the species, as well as their interests in finding solutions for malfunctions in the behaviour of the sea turtles and the climate change. To conclude, local residents approach the future of Playa del Ostional with a realistic outlook regarding climate change, of which they are aware, but maintain a positive attitude towards finding solutions for potential problems.

In order to answer the second part of the third research question, the results of the stakeholder analysis are discussed.

The stakeholder map (figure 3.64) indicates that 'Refugio Nacional de Vida Silvestre Ostional' is the most important stakeholder to actively engage together with CITES, if any potential changes need to be made to the beach in order to continue protecting the turtles. As they have a strong vested engagement in safeguarding the turtles, their level of interest is high. Furthermore, they receive substantial support from the ministry (MINAE) and CITES. Overall, this is granting them significant power in the decisions being made concerning the protection of the sea turtles. A suggestion would be to include CITES as a second important stakeholder as possessor of the legal data on the arribadas in further collaboration with the refuge.

Furthermore, the results indicate that ADIO is an important stakeholder, with relative low interest but high power. The association has a strong market position in the selling and harvesting of eggs and high power. In addition, the interviews show that the association is engaged with the wealth of the turtles, meaning this is a stakeholder to keep satisfied during further possible steps.

There are three organizations that exhibit a high level of interest but relatively low power: AGLO, MINAE, and SINAC. While MINAE and SINAC, both governmental organizations 3, have strong interest and engagement in protecting the arribadas, they lack specialized knowledge required to move the process forward. In contrast, AGLO has extensive knowledge about the turtles and is deeply engaged with the arribadas and the community, making them a highly interested party. However, as a small organization, they do not possess significant power to make changes when necessary. Based on these findings, it is recommended to keep the three parties informed and welcome their support, but recognize that they do not hold key stakeholder status for this research objective.

Finally, there are three stakeholders in the realm of hospitality, Guías Independientes de Ostional, and other forms of tourism. They possess low power and interest due to the presence of other, more pressing interests such as tourism income and financial status. Hospitality captures 19 percent of the livelihood activities incurred by the village of Ostional, where tourism covered only 11 percent. This indicates that these are not stakeholders with significant power. Ultimately, all three stakeholders have an interest in preserving the protection of sea turtles; however, this is a long-term concern and not a high priority for them. Nonetheless, they do qualify as stakeholders that should be monitored given their potential impact on the issue at hand.

5
Discussion and recommendations

This section scrutinizes some points of discussion regarding the research, as well as possible improvements on the executed practices during this study, and potential future directions for further research into arribadas at Playa del Ostional.

5.1 Discussion points on the current practices

During the field investigation, sediment samples were collected using two basic hand shovels of varying sizes. Moreover, the depth at which the samples were collected was not precisely defined, resulting in variations in the size of the sediment samples. This discrepancy in sediment sample size could potentially affect the particle size distribution, as one sample may contain more sediment than the other. Regarding the sieving of the sediment samples, there is always a small amount of sediment residue that remains in the dry sediment bag and does not pass through the sieves. In addition, the sieves were tightly attached to each other, making it difficult to separate them, which may have caused some grains to escape from the sieve. The loss of sediment during sieving could have resulted in a slightly lower percentage of sediment being collected, which in turn may have had an impact on the particle size distribution.

In addition to the measurements carried out using the RTK-GPS equipment, a drone was used to obtain a more comprehensive characterization of the beach. This drone flew over the stretches of Playa del Ostional, Main Nesting Beach and Playa Nosara. The drone captured aerial images of sections of the beach every few seconds. Subsequently, these images were processed using photogrammetry software, resulting in an orthophoto of the designated area. However, this orthophoto is not further analyzed or used in this research. Such an orthophoto could be used to facilitate the construction of a Digital Elevation Model that can provide even more insight into the terrain. In addition to capturing aerial images, the drone was used to record several videos of incoming waves which makes it possible to map the bathymetry of the beach. These videos are not further processed or analyzed during this research.

The results from the K-fold analysis did not provide an accurate measure of the model's performance. Therefore, alternative methods for quantifying the accuracy of the model should be explored in order to draw more reliable conclusions and validate the ALR model.

5.2 Recommendations for future research

A recommendation for further research is to compare the beach characteristics of Playa del Ostional to a beach that does not experience arribada, such as Playa Guiones. Several sediment samples have already been collected, and the beach has been observed during the fieldwork of this study. Gathering more data, such as bathymetry and sand transport offshore, to get more knowledge on the behavior of the local estuaries (especially in the wet season) can be valuable in the seasonal increase of size of arribadas. Also, calibration of the orthophoto made by the drone can be very useful for comparing the obtained elevation maps between the wet and dry season. This would facilitate a more comprehensive characterization and comparison of the beach.

Currently, there is insufficient accurate data available on the hydrodynamic environment near the research site at Playa del Ostional, making a comparison between the beach's hydrodynamic properties during the dry and wet seasons practically impossible. To develop accurate models, more precise information on waves and water levels in these coastal areas is crucial. By gathering detailed wave data that captures seasonal variations in wave height, period, and other relevant characteristics, simulations on phenomena like sea level rise can be conducted, enabling a meaningful comparison of hydrodynamic conditions between the dry and rainy seasons.

Moreover, aerial videos of a wave field can provide information on wave directions, celerity, and near-surface currents, as well as on coastal bathymetry [7]. A recommendation for further research is therefore to analyze and process the aerial videos of the incoming waves that are obtained with the drone during this research, and to obtain and analyze such videos during the wet season. Also the calibrated drone elevation map can be used for a more accurate estimation of slope and plateaus.

To enhance the accuracy and comprehensiveness of the arribada event model for olive ridley sea turtles, several recommendations are provided. Adding additional parameters such as salinity, wave direction, and surface temperature to the model, and adding memory in covariates to see if they have a delayed impact on triggering an arribada, could provide more nuanced understanding. Adapting the arribada data based on the number of nesting females and improving the validation process of the model could also be beneficial. Moreover, separating the seasonal arribada data from 'non-seasonal' data could provide a better understanding of which covariates trigger an arribada and which ones have an impact on its size. Finally, finding the correlation between the covariates which have an impact on the prediction of arribadas could help to answer the second research question.

Regarding the stakeholder analysis, conducting interviews with a more diverse range of people, including different age groups, professions, and ethnic backgrounds, could provide more valuable data. Additionally, asking more detailed questions in a follow-up research about potential necessary modifications to the beach to safeguard the olive ridley sea turtles and the arribadas could enhance the understanding of the stakeholders' perspectives and their willingness to work together in future projects.

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A
Interview questions

Questions in English

The set-up of the interview is to first ask some more general questions about how they’re doing or some background information

Introduction about our project, ask if we can ask them some questions

1. How are you doing?
2. Do you live or work here at Playa del Ostional/Nosara? What kind of work do you do?
3. How big is the tourism that Playa del Ostional gets, in this village?
    a. How many jobs are linked to the turtle nesting?
2. Is the tourism the main source of income?
    a. How many people does it affect?
    b. How many people come visit the turtle nesting beaches every month/year?
3. Are you aware of the climate change that might have effect on the beach?
    a. If yes, is there a plan B?
        i. What will they do for a living?
    b. If yes, how do you feel about it?

Do you want anything else to change in the village?

    c. In the tourism, maybe the tourists are effecting their privacy/nature
    d. Or, are they happy with how it is?
    e. Struggles/Needs

Spanish

Introduction about our project, ask if we can ask them some questions

1. Hola, vives en Playa del Ostional? Y trabajas aquí?
    a. ¿que tipo de trabajo haces aquí? ¿y Cuánto tiempo llevas haciendo este trabajo?
    b. ¿te gusta vivir y trabajar aquí? Por qué?
2. ¿Qué tan grande es el turismo que recibe Playa del Ostional, en este pueblo?
    a. ¿Cuántos trabajos están vinculados a la anidación de tortugas?
3. ¿Es el turismo la principal fuente de ingresos?
    a. ¿A cuántas personas afecta?
4. ¿Cuántas personas vienen a visitar las playas de anidación de tortugas cada mes/año?
5. ¿Ves cambios en la playa como consecuencia del cambio climático?
    a. Por ejemplo en la playa, o en la cantidad de arribadas?
    b. ¿Eres consciente del cambio climático que puede afectar a la playa?
6. ¿Qué opinas sobre el cambio climático?
7. ¿Tienes miedo de que algo cambie en el número de arribadas en la playa del ostional?
    a. Por ejemplo, Tienes miedo de que haya menos turismo?

B
Particle size distributions

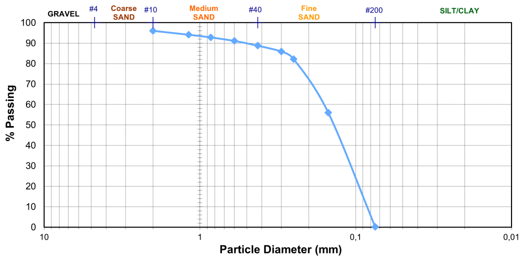


Figure B.1: Particle size distribution of sample 1

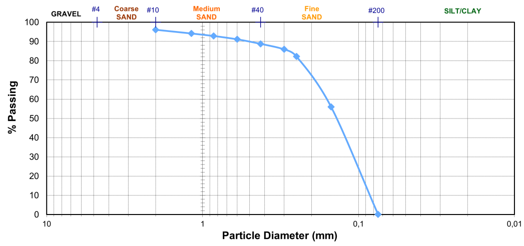


Figure B.2: Particle size distribution of sample 2

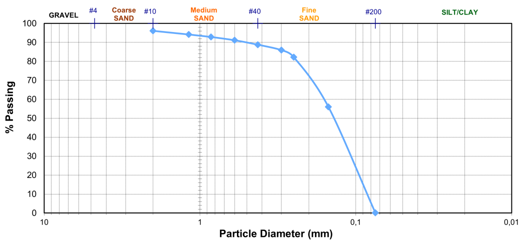


Figure B.3: Particle size distribution of sample 3

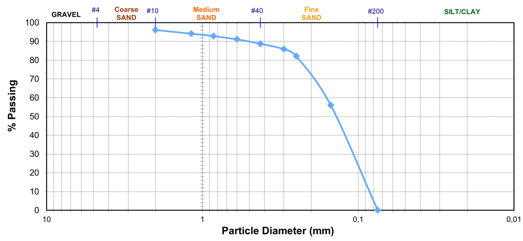


Figure B.4: Particle size distribution of sample 5

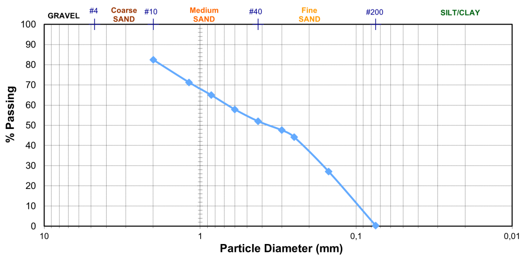


Figure B.5: Particle size distribution of sample 6

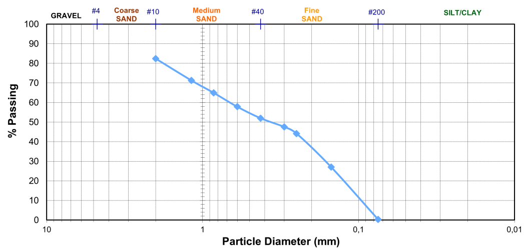


Figure B.6: Particle size distribution of sample 7

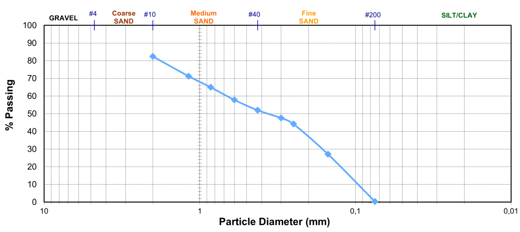


Figure B.7: Particle size distribution of sample 8

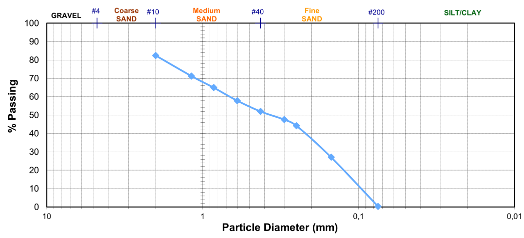


Figure B.8: Particle size distribution of sample 9

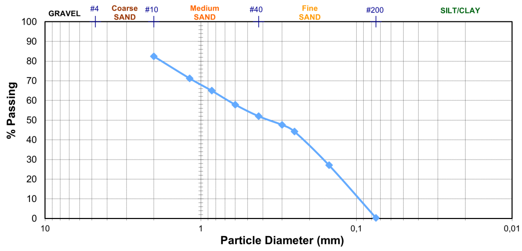


Figure B.9: Particle size distribution of sample 10

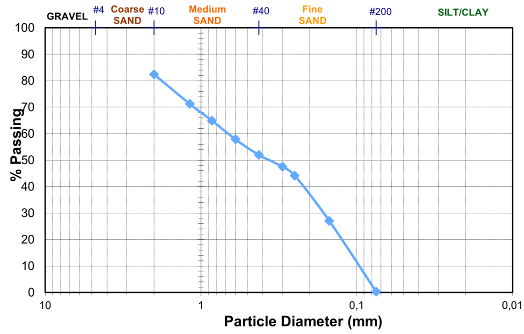


Figure B.10: Particle size distribution of sample 11

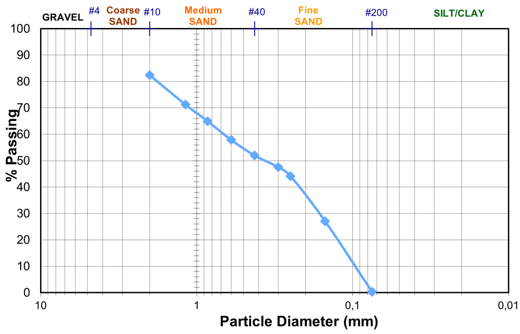


Figure B.11: Particle size distribution of sample 12

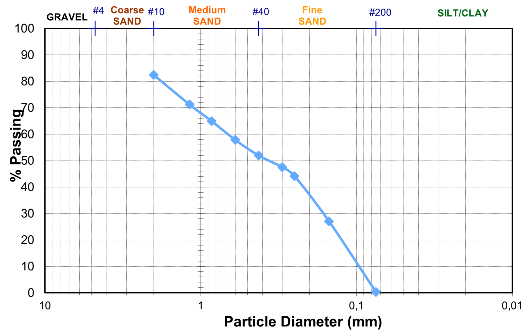


Figure B.12: Particle size distribution of sample 13

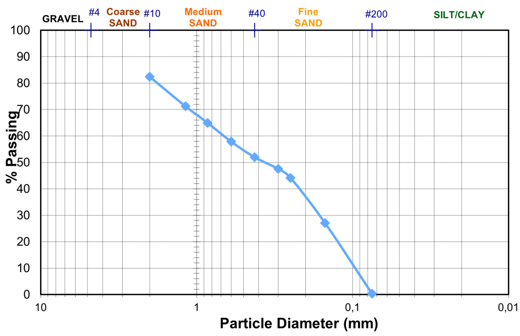


Figure B.13: Particle size distribution of sample 14

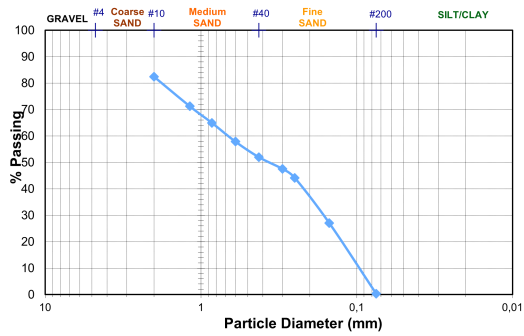


Figure B.14: Particle size distribution of sample 15

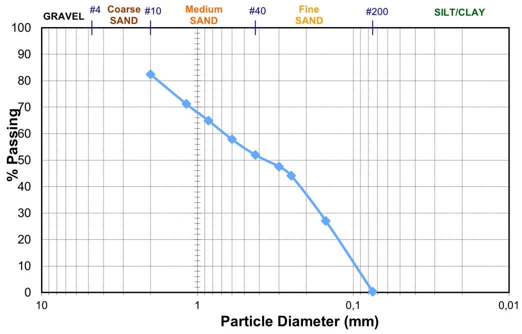


Figure B.15: Particle size distribution of sample 16

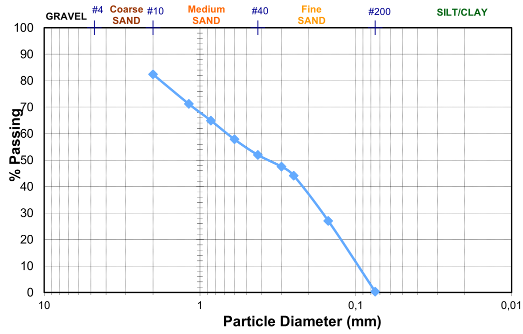


Figure B.16: Particle size distribution of sample 17

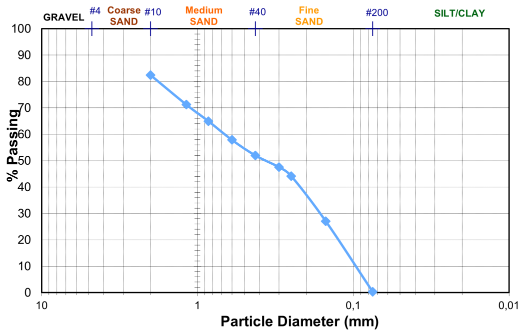


Figure B.17: Particle size distribution of sample 18

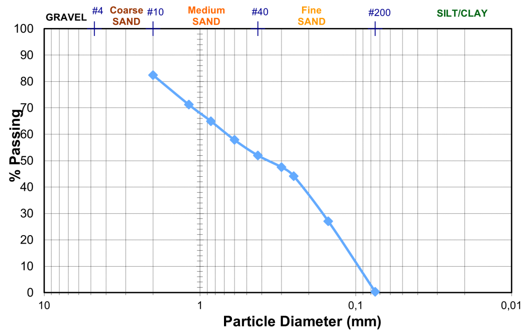


Figure B.18: Particle size distribution of sample 19

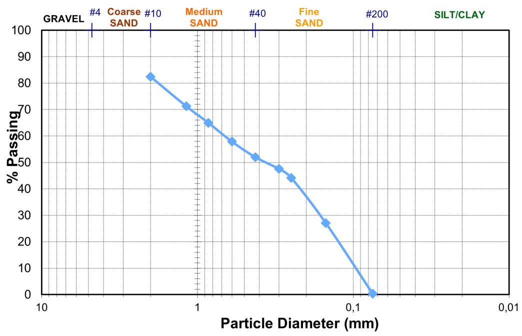


Figure B.19: Particle size distribution of sample 20

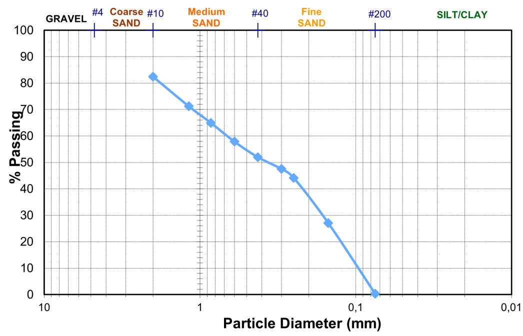


Figure B.20: Particle size distribution of sample 21

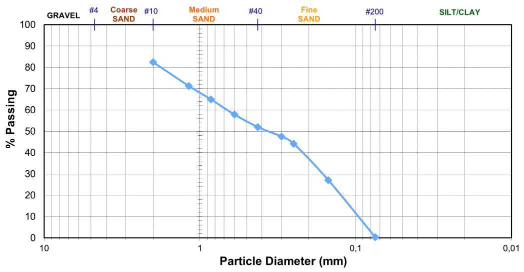


Figure B.21: Particle size distribution of sample 22

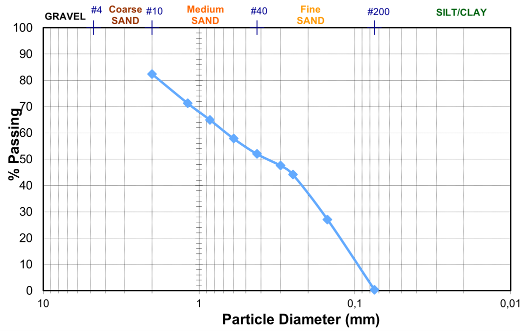


Figure B.22: Particle size distribution of sample 23

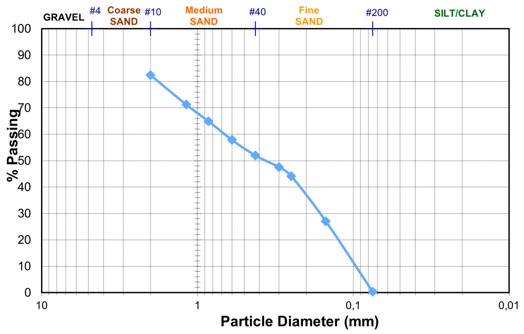


Figure B.23: Particle size distribution of sample 24

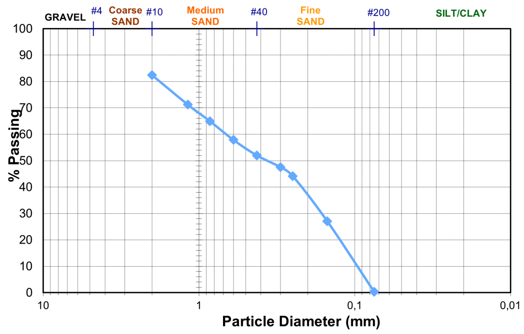


Figure B.24: Particle size distribution of sample 25

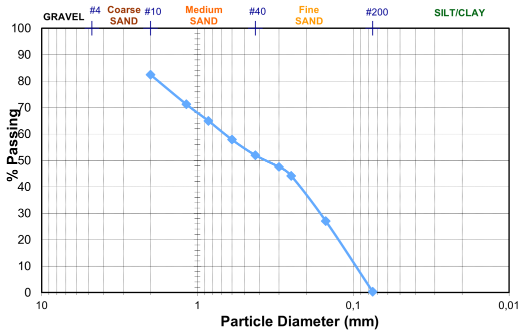


Figure B.25: Particle size distribution of sample 26

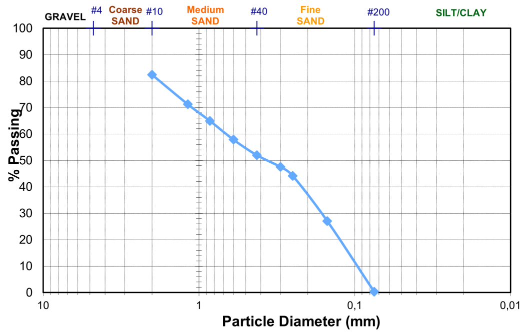


Figure B.26: Particle size distribution of sample 27

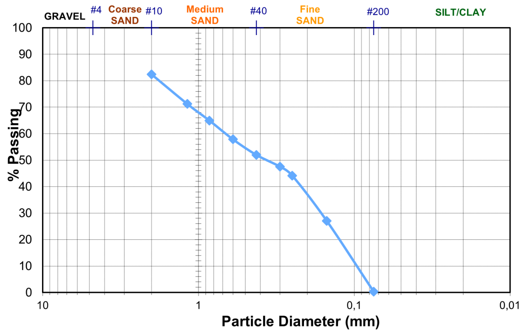


Figure B.27: Particle size distribution of sample 28

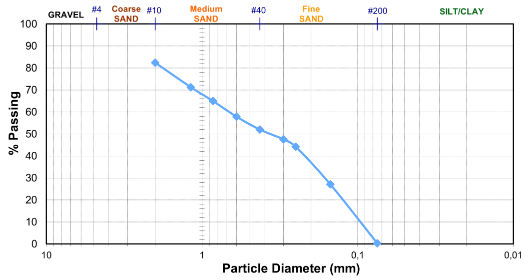


Figure B.28: Particle size distribution of sample 29

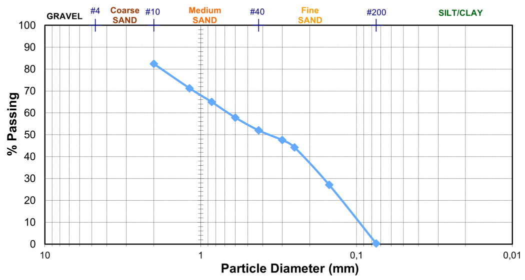


Figure B.29: Particle size distribution of sample 30

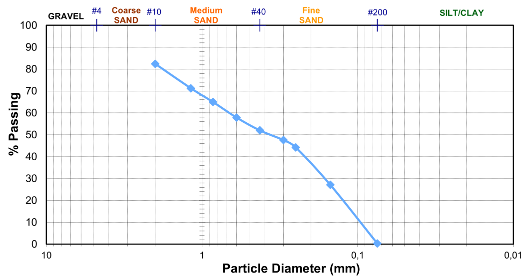


Figure B.30: Particle size distribution of sample 31

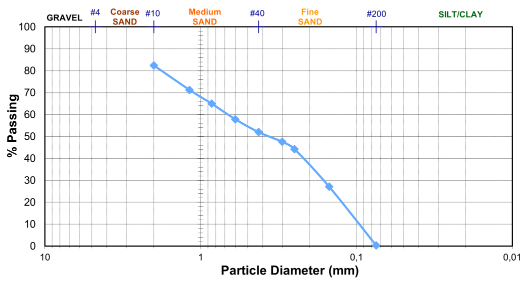


Figure B.31: Particle size distribution of sample 32

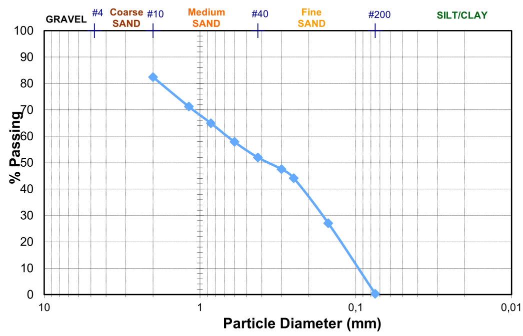


Figure B.32: Particle size distribution of sample 33

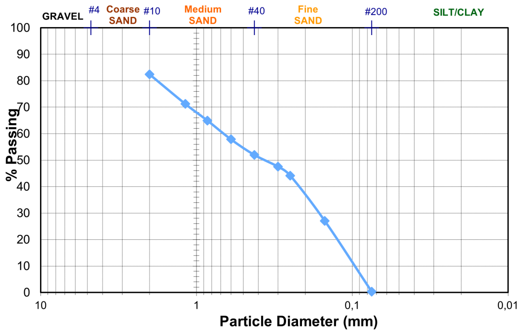


Figure B.33: Particle size distribution of sample 34

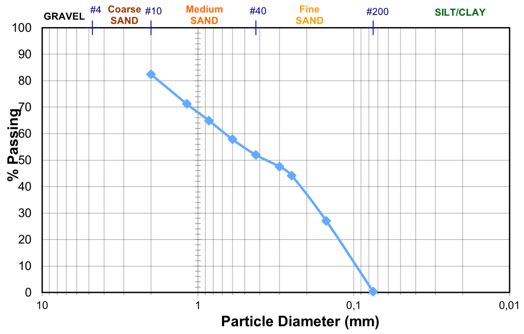


Figure B.34: Particle size distribution of sample 35

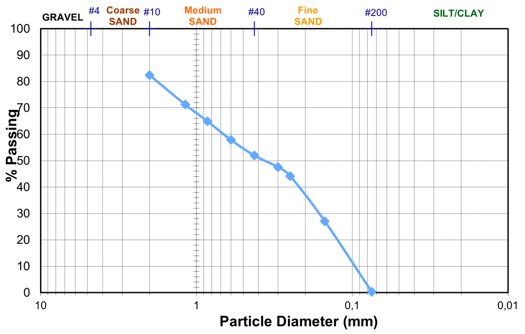


Figure B.35: Particle size distribution of sample 36

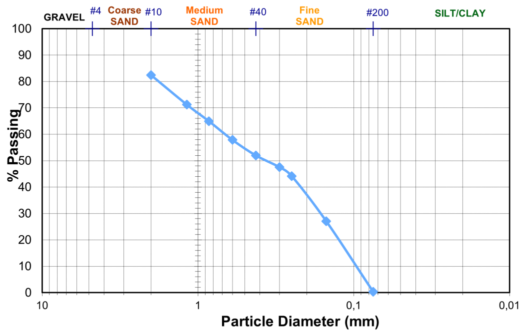


Figure B.36: Particle size distribution of sample 37

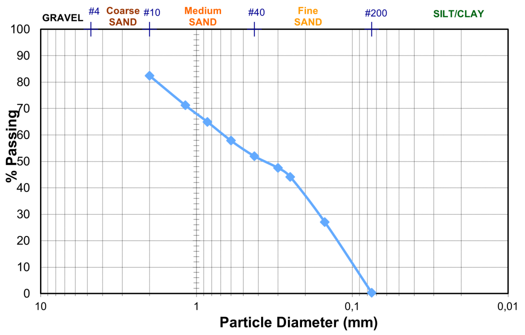


Figure B.37: Particle size distribution of sample 38

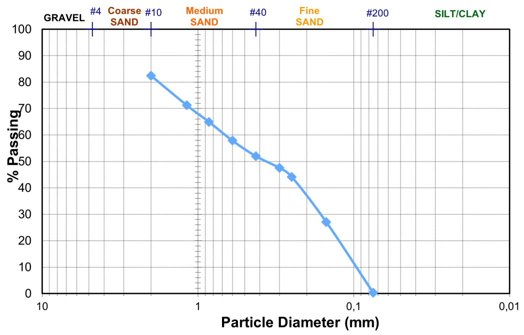


Figure B.38: Particle size distribution of sample 39

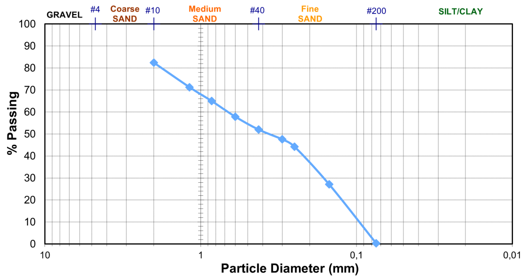


Figure B.39: Particle size distribution of sample 40

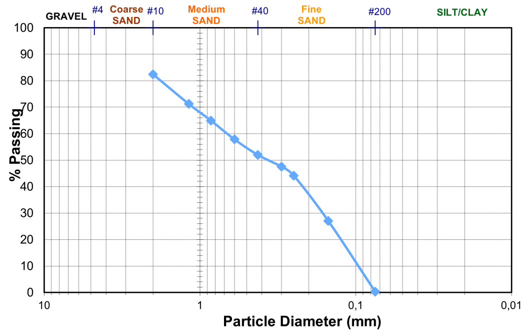


Figure B.40: Particle size distribution of sample 41

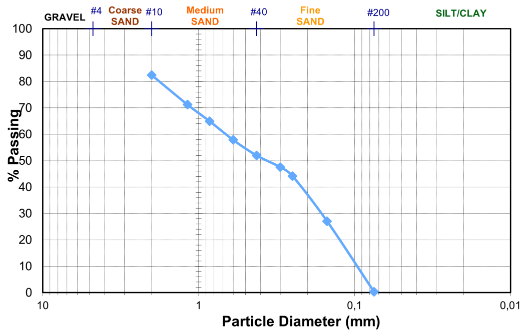


Figure B.41: Particle size distribution of sample 42

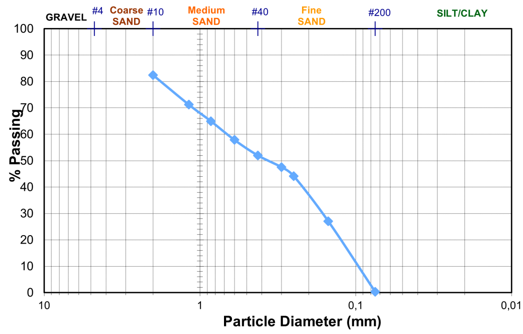


Figure B.42: Particle size distribution of sample 43

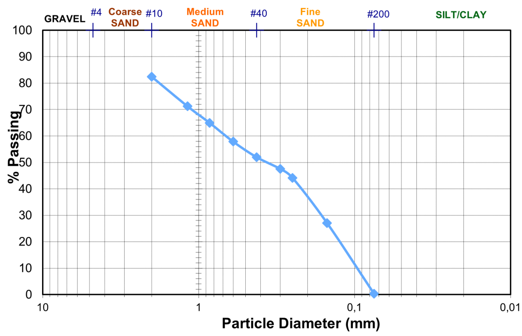


Figure B.43: Particle size distribution of sample 44

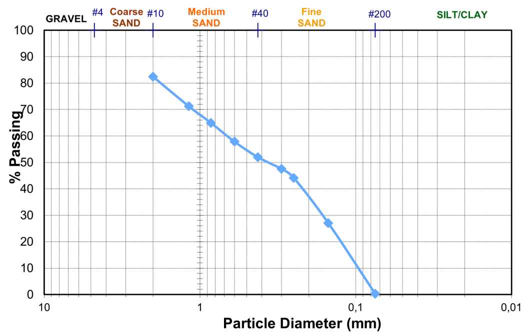


Figure B.44: Particle size distribution of sample 45

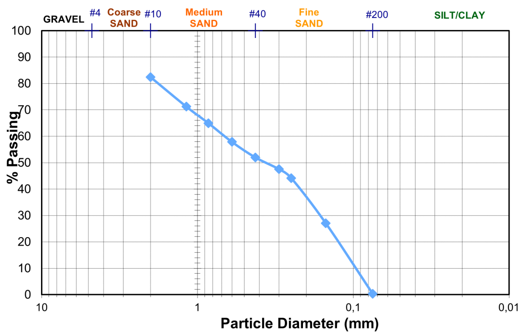


Figure B.45: Particle size distribution of sample 46

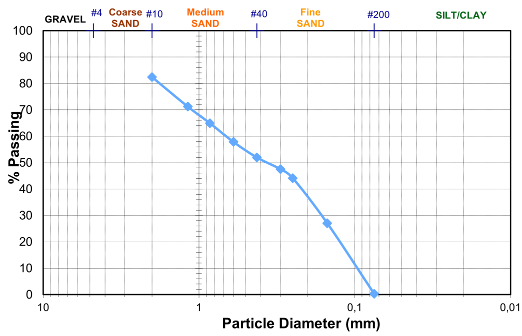


Figure B.46: Particle size distribution of sample 47

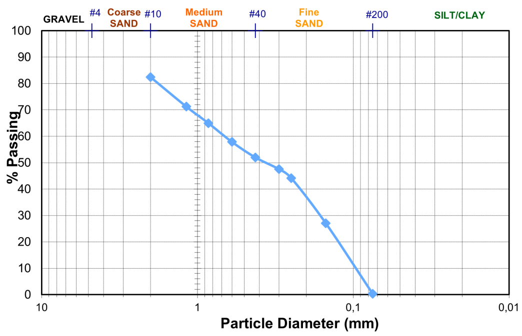


Figure B.47: Particle size distribution of sample 48

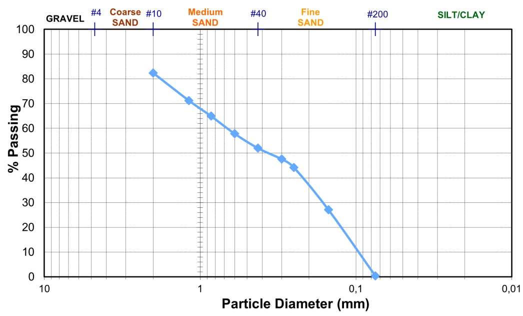


Figure B.48: Particle size distribution of sample 49

C
Locations sediment samples

Table C.1: Overview specific locations and D_{50} of obtained sediment samples in 2023 and 2022

ID 2023	ID 2022	Transect	Location on slope	Date and time	Latitude	Longitude	D_{50} 2023	D_{50} 2022
1	**31**	**6**	**At the waterline**	26/02/23 13:04	10,0103803	-85,7188779	0,142	1,137
2	**32**	**6**	**1/3rd of the slope**	26/02/23 12:19	10,0105236	-85,7186881	0,547	0,533
3	**33**	**6**	**2/3rd of the slope**	26/02/23 12:24	10,0106468	-85,7185373	0,393	0,290
5	**34**	**24**	**At the waterline**	26/02/23 13:34	10,0049727	-85,7127447	0,267	0,622
6	**35**	**24**	**1/3rd of the slope**	26/02/23 12:40	10,0050576	-85,7126632	0,369	0,651
7	**36**	**24**	**2/3rd of the slope**	26/02/23 12:44	10,0051276	-85,7125737	0,250	0,469
8	**37**	**24**	**Above the waterline**	26/02/23 12:46	10,0052263	-85,7124436	0,277	0,289
9	**10**	**50**	**At the waterline**	26/02/23 13:20	9,9967911	-85,7043283	0,127	0,751
10	**20**	**50**	**1/3rd of the slope**	26/02/23 12:07	9,9968133	-85,7042276	0,201	0,524
11	**30**	**50**	**2/3rd of the slope**	26/02/23 12:12	9,9969166	-85,7040725	0,237	0,258
12	**38**	**50**	**Above the waterline**	26/02/23 13:30	9,9970886	-85,703933	0,215	0,252
13	**9**	**56**	**At the waterline**	26/02/23 13:15	9,9947724	-85,7024873	0,150	5,412
14	**19**	**56**	**1/3rd of the slope**	26/02/23 12:05	9,994844	-85,7023585	0,271	0,710
15	**29**	**56**	**2/3rd of the slope**	26/02/23 12:17	9,9949497	-85,7022066	0,248	0,315
16	**39**	**56**	**Above the waterline**	26/02/23 13:40	9,995052	-85,7021114	0,258	0,248
17	**8**	**59**	**At the waterline**	26/02/23 13:11	9,9936375	-85,7017034	2,784	1,443
18	**18**	**59**	**1/3rd of the slope**	26/02/23 12:00	9,9937478	-85,7015415	0,724	0,526
19	**28**	**59**	**2/3rd of the slope**	26/02/23 12:30	9,9938059	-85,7014174	0,450	0,367
20	**40**	**59**	**Above the waterline**	26/02/23 13:45	9,9939842	-85,7012766	0,226	0,225
21	**7**	**64**	**At the waterline**	26/02/23 13:05	9,9917564	-85,7000113	0,121	0,233
22	**17**	**64**	**1/3rd of the slope**	26/02/23 12:42	9,9919245	-85,6998805	0,266	0,815
23	**27**	**64**	**2/3rd of the slope**	26/02/23 12:45	9,9920318	-85,6997595	0,196	0,197
24	**48**	**64**	**Above the waterline**	26/02/23 13:50	9,9921253	-85,6995885	0,275	0,266
25	**6**	**66**	**At the waterline**	26/02/23 13:00	9,9912899	-85,6994389	0,128	5,878
26	**16**	**66**	**1/3rd of the slope**	26/02/23 12:47	9,9914292	-85,6993142	0,275	0,615
27	**26**	**66**	**2/3rd of the slope**	26/02/23 12:49	9,9915015	-85,6991513	0,152	0,369
28	**47**	**66**	**Above the waterline**	26/02/23 13:56	9,9917244	-85,6990027	0,251	0,276
29	**5**	**69**	**At the waterline**	27/02/23 14:00	9,9903425	-85,6987469	0,166	2,199
30	**15**	**69**	**1/3rd of the slope**	27/02/23 15:08	9,9904393	-85,6985437	0,136	0,775
31	**25**	**69**	**2/3rd of the slope**	27/02/23 15:06	9,9905172	-85,6983691	0,243	0,325
32	**43**	**69**	**Above the waterline**	27/02/23 15:05	9,9906318	-85,6982658	0,260	0,264
33	**4**	**73**	**At the waterline**	27/02/23 14:06	9,9888227	-85,6978004	0,117	1,245
34	**14**	**73**	**1/3rd of the slope**	27/02/23 14:46	9,9888464	-85,6976506	0,143	0,493
35	**24**	**73**	**2/3rd of the slope**	27/02/23 14:50	9,9889263	-85,6974786	0,128	0,280
36	**42**	**73**	**Above the waterline**	27/02/23 14:55	9,9890634	-85,6972566	0,316	0,321
37	**3**	**76**	**At the waterline**	27/02/23 14:13	9,9876921	-85,6972385	0,121	2,620
38	**13**	**76**	**1/3rd of the slope**	27/02/23 14:41	9,9878195	-85,6970484	0,151	0,532
39	**23**	**76**	**2/3rd of the slope**	27/02/23 14:35	9,9878714	-85,6969213	0,183	0,318
40	**41**	**76**	**Above the waterline**	27/02/23 14:30	9,9878139	-85,6967155	0,486	0,420
41	**2**	**82**	**At the waterline**	27/02/23 14:10	9,9850168	-85,6958273	0,120	0,161
42	**12**	**82**	**1/3rd of the slope**	27/02/23 13:41	9,9852721	-85,6956275	2,776	0,836
43	**22**	**82**	**2/3rd of the slope**	27/02/23 13:40	9,9853777	-85,69554	2,360	0,472
44	**1**	**86**	**At the waterline**	27/02/23 14:03	9,9838096	0,99999871	0,122	0,167
45	**11**	**86**	**1/3rd of the slope**	27/02/23 13:49	9,9840844	-85,6942841	0,864	0,712
46	**21**	**86**	**2/3rd of the slope**	27/02/23 13:47	9,98416	-85,6941188	1,963	0,353
47	**46**	**128**	**At the waterline**	28/02/23 15:04	9,9690299	-85,682313	0,131	0,147
48	**45**	**128**	**1/3rd of the slope**	28/02/23 15:08	9,9691587	-85,6820747	0,127	0,850
49	**44**	**128**	**2/3rd of the slope**	28/02/23 15:10	9,9692323	-85,6819472	0,260	0,387

D

D_{50} values of sediment samples in both seasons

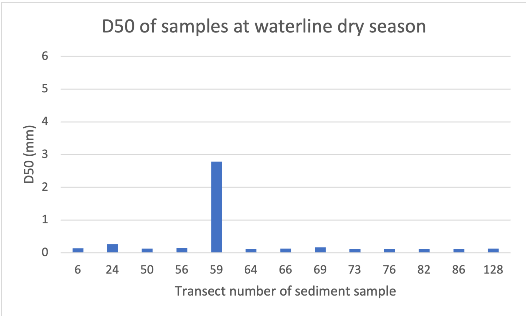


Figure D.1: D_{50} of samples of dry season situated at the waterline

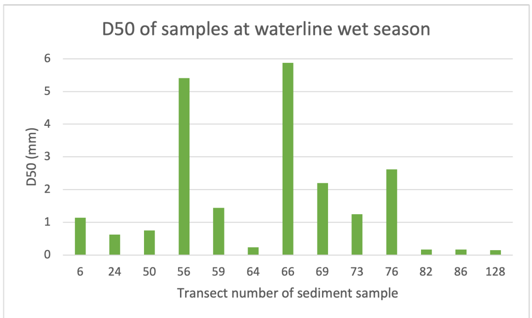


Figure D.2: D_{50} of samples of wet season situated at the waterline

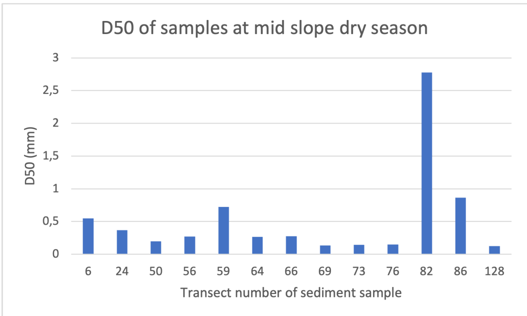


Figure D.3: D_{50} of samples dry season situated at middle of the slope

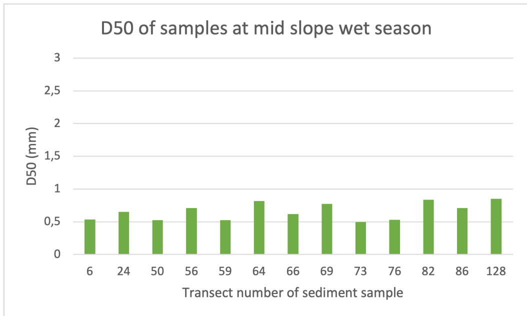


Figure D.4: D_{50} of samples wet season situated at middle of the slope

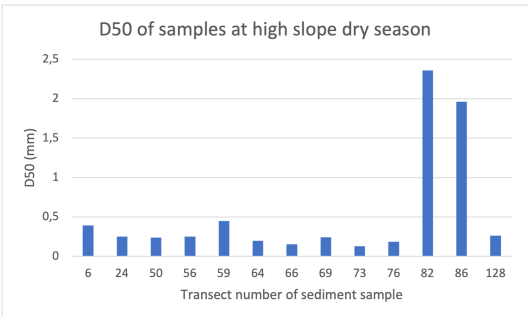


Figure D.5: D_{50} of samples dry season situated at the high part of the slope

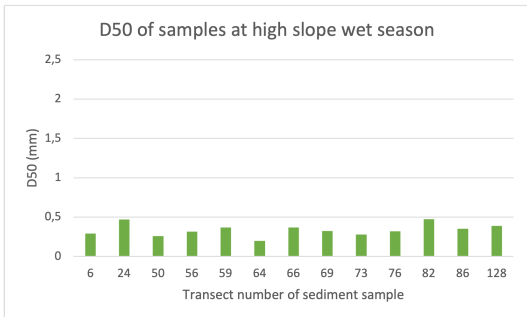


Figure D.6: D_{50} of samples wet season situated at the high part of the slope

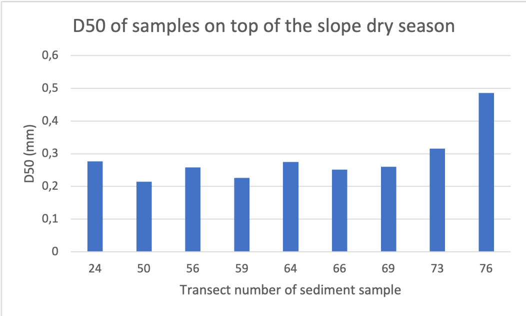


Figure D.7: D_{50} of samples dry season situated at the top of the slope

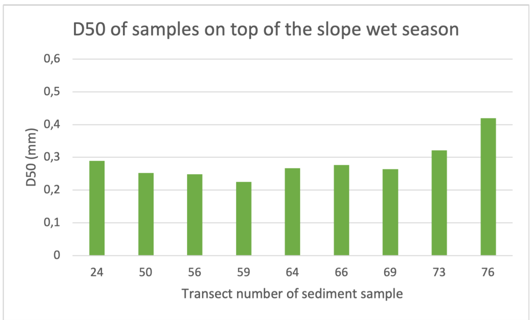


Figure D.8: D_{50} of samples wet season situated at the top of the slope

E

Histograms of particle size distributions of sediment samples at Main Nesting Beach

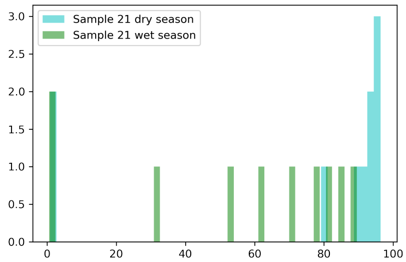


Figure E.1: Histogram of the PSDs of sediment sample 21

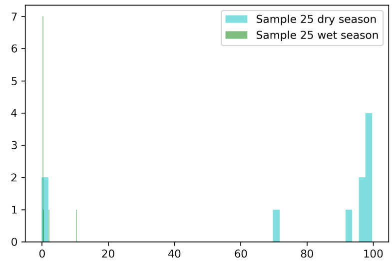


Figure E.2: Histogram of the PSDs of sediment sample 25

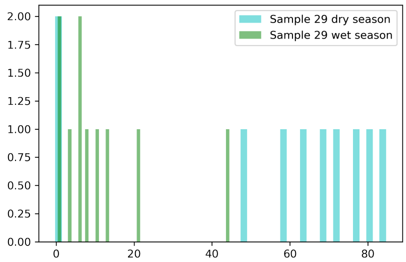


Figure E.3: Histogram of the PSDs of sediment sample 29

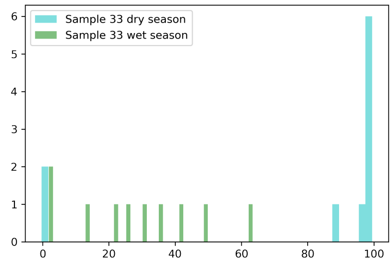


Figure E.4: Histogram of the PSDs of sediment sample 33

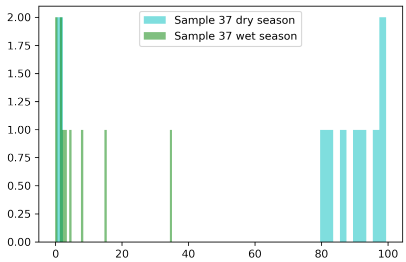


Figure E.5: Histogram of the PSDs of sediment sample 37

F
Results t-tests and two sample K-S tests

F.0.1 Playa del Ostional

Table F.1: Results of the t-tests performed on average D_{50} of sediment samples at Playa del Ostional

Location on transect	p-value t-test	Significant difference
At the waterline	0.29643	no
At the middle of the slope	0.16331	no
At the high part of the slope	0.68341	no
On top of the slope	0.64338	no

Table F.2: Results of the two-sample K-S tests performed on the PSDs of the sediment samples at Playa del Ostional

Sediment sample ID	Location on transect	K-S test statistic	p-value	p-value < 0.05?
1	At the waterline	0.7	0.012	yes
2	1/3rd of the slope	0.3	0.787	no
3	2/3rd of the slope	0.2	0.994	no
4	At the waterline	0.4	0.418	no
5	1/3rd of the slope	0.3	0.787	no
6	2/3rd of the slope	0.3	0.787	no
7	Above the waterline	0.2	0.994	no
8	At the waterline	0.7	0.012	yes
9	1/3rd of the slope	0.4	0.418	no
10	2/3rd of the slope	0.2	0.994	no
11	Above the waterline	0.1	1.000	no
12	At the waterline	0.8	0.002	yes
13	1/3rd of the slope	0.4	0.418	no
14	2/3rd of the slope	0.2	0.994	no
15	Above the waterline	0.2	0.994	no
16	At the waterline	0.4	0.418	no
17	1/3rd of the slope	0.2	0.994	no
18	2/3rd of the slope	0.2	0.994	no
19	Above the waterline	0.1	1.000	no

F.0.2 Playa Nosara

Table F.3: Results of the t-tests performed on average D_{50} of sediment samples at Playa Nosara

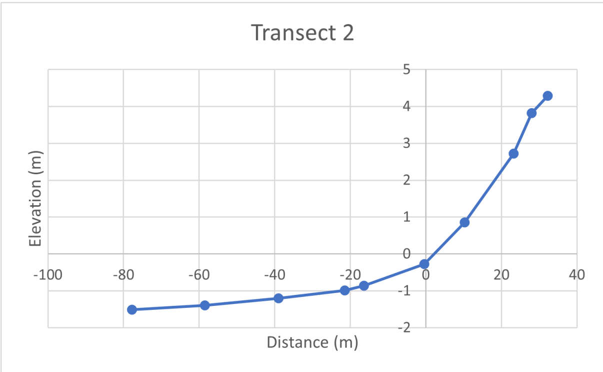
Location on transect	p-value t-test	Significant difference
At the waterline	0.01166	yes
At the middle of the slope	0.62190	no
At the high part of the slope	0.22292	no

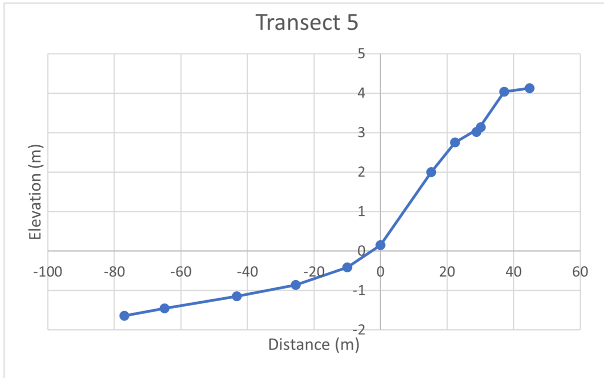
Table F.4: Results of the two-sample K-S tests performed on the PSDs of the sediment samples at Playa Nosara

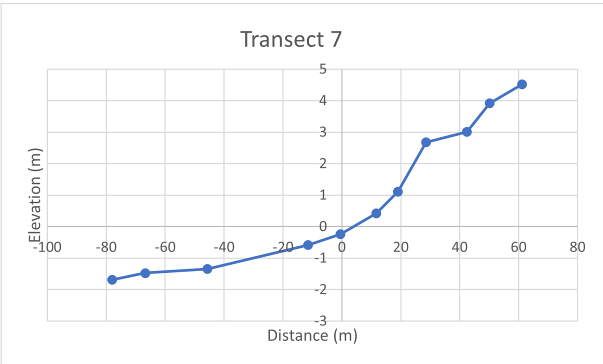
Sediment sample ID	Location on transect	K-S test statistic	p-value	p-value < 0.05?
41	At the waterline	0.6	0.05	yes
42	1/3rd of the slope	0.4	0.42	no
43	2/3rd of the slope	0.6	0.05	yes
44	At the waterline	0.7	0.012	yes
45	1/3rd of the slope	0.4	0.42	no
46	2/3rd of the slope	0.5	0.17	no
47	At the waterline	0.6	0.05	yes
48	1/3rd of the slope	0.7	0.012	yes
49	2/3rd of the slope	0.3	0.787	no

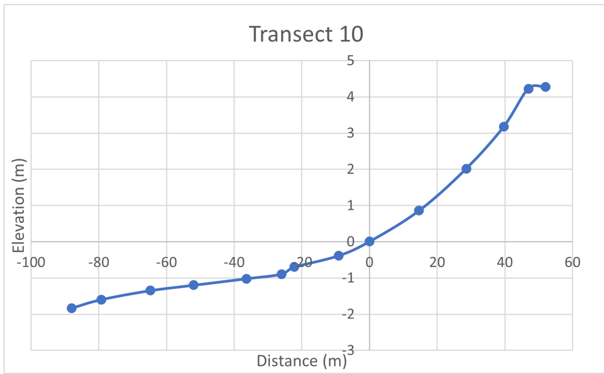
G

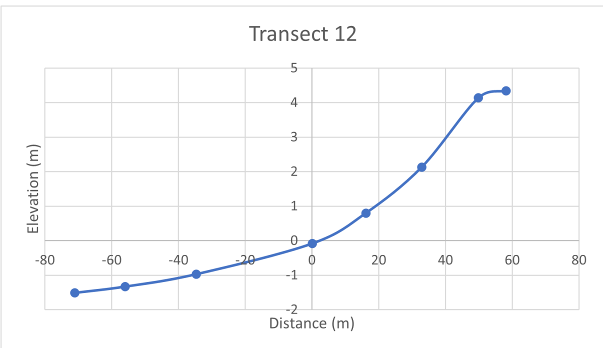
GPS transects

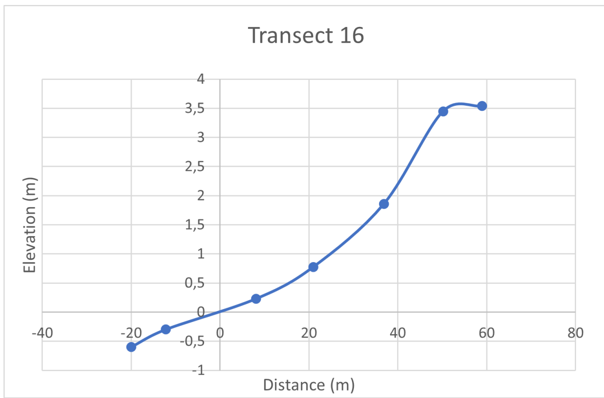


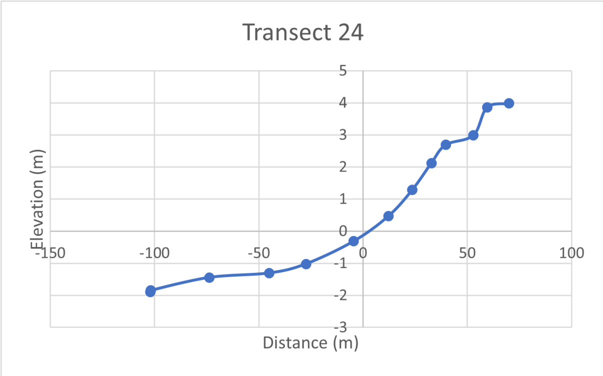











Transect 24
Elevation (m)
Distance (m)
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4
3
2
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0
-1
-2
-3
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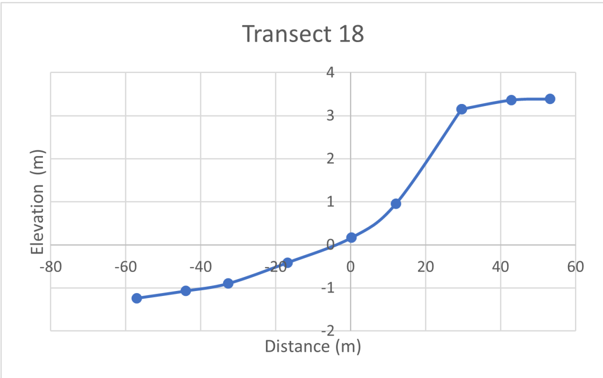
-100
-50
0
50
100


Transect 18
Elevation (m)
Distance (m)
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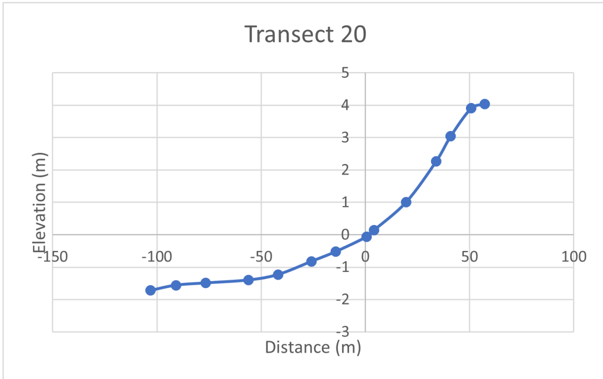
3
2
1
0
-1
-2
-80
-60
-40
-20
0
20
40
60


Transect 20
Elevation (m)
Distance (m)
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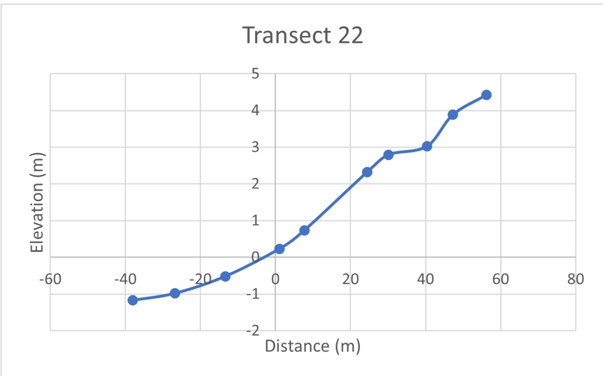
3
2
1
0
-1
-2
-3
-150
-100
-50
0
50
100


Transect 22
Elevation (m)
Distance (m)
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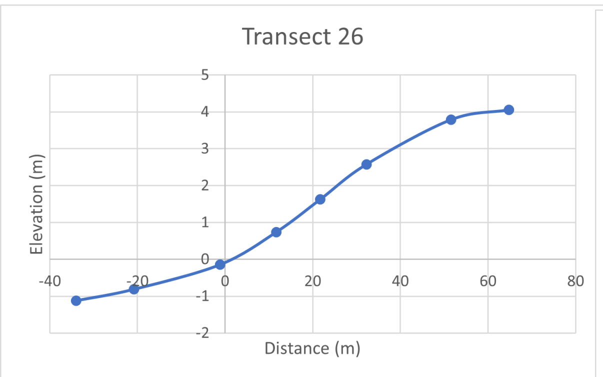
3
2
1
0
-1
-2
-60
-40
-20
0
20
40
60
80


Transect 26
Elevation (m)
Distance (m)
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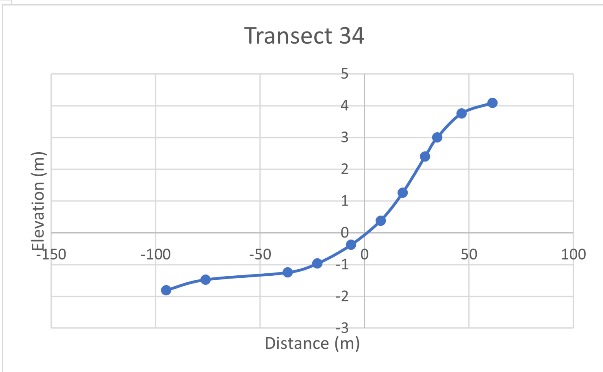
4
3
2
1
0
-1
-2
-40
-20
0
20
40
60
80


Transect 34
Elevation (m)
Distance (m)
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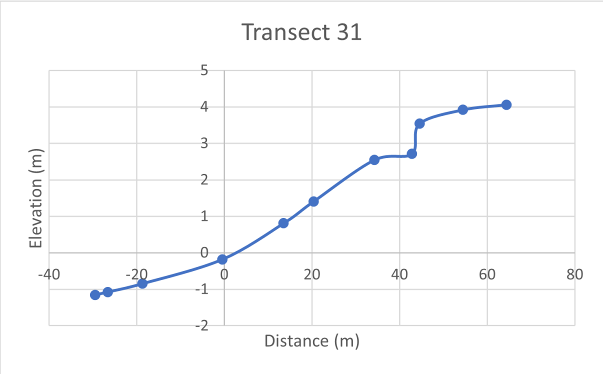
4
3
2
1
0
-1
-2
-3
-150
-100
-50
0
50
100


Transect 31
Elevation (m)
Distance (m)
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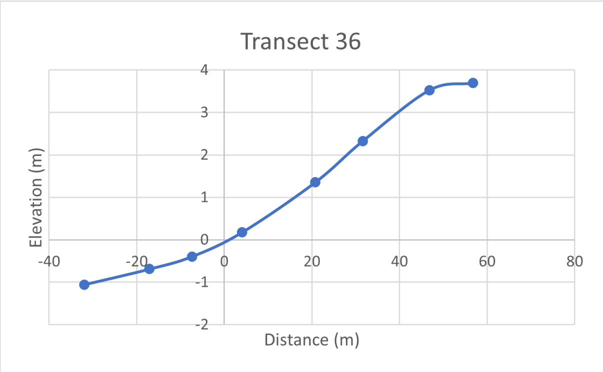
4
3
2
1
0
-1
-2
-40
-20
0
20
40
60
80


Transect 36
Elevation (m)
Distance (m)
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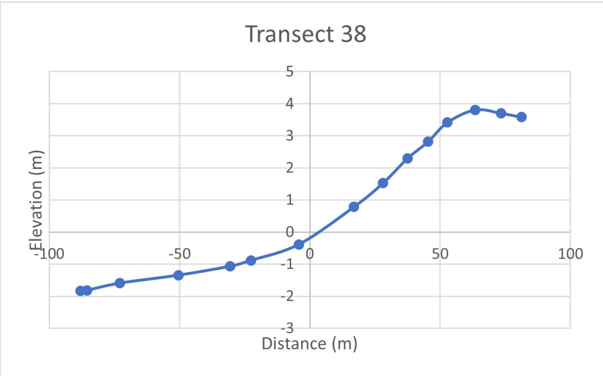
3
2
1
0
-1
-2
-40
-20
0
20
40
60
80


Transect 38
Elevation (m)
Distance (m)
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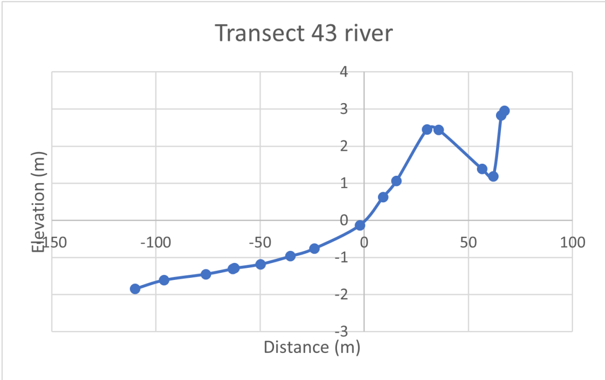
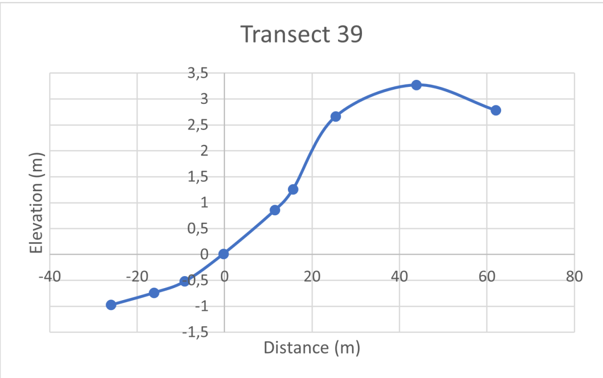
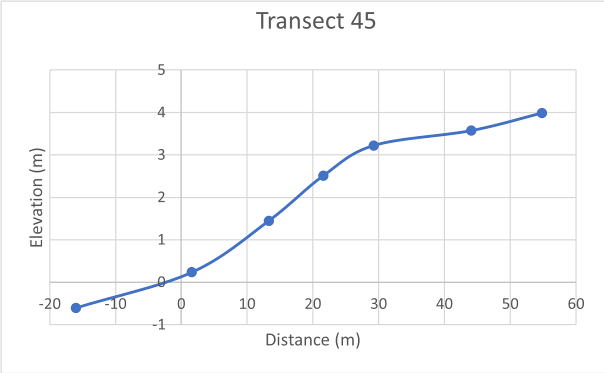
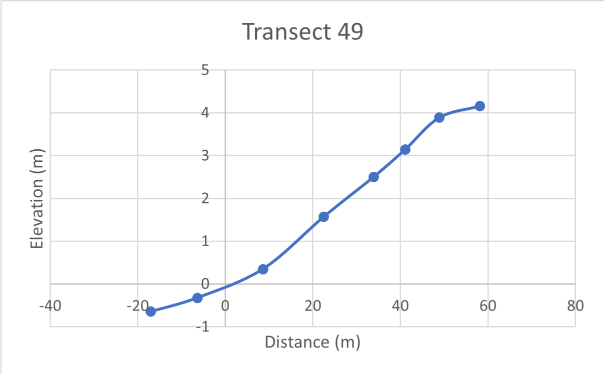
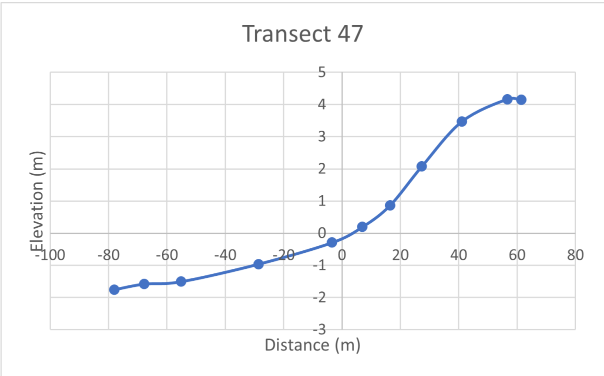
4
3
2
1
0
-1
-2
-3
-100
-50
0
50
100

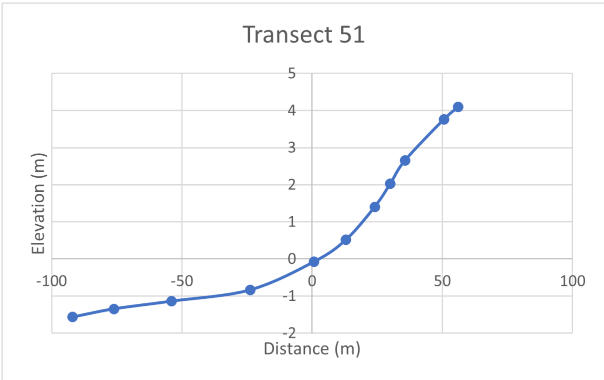

Transect 43 river
Elevation (m)
Distance (m)
4
3
2
1
0
-1
-2
-3
-150
-100
-50
0
50
100

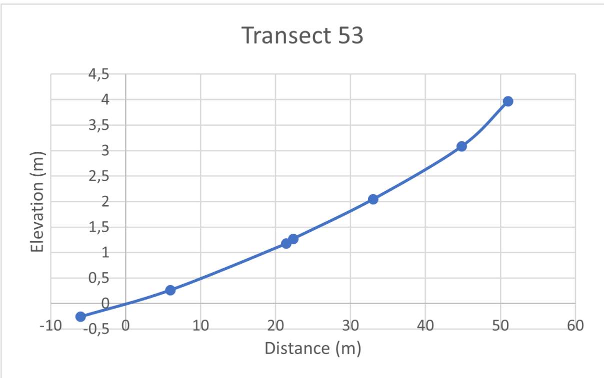

Transect 39
Elevation (m)
Distance (m)
3,5
3
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
-40
-20
0
20
40
60
80

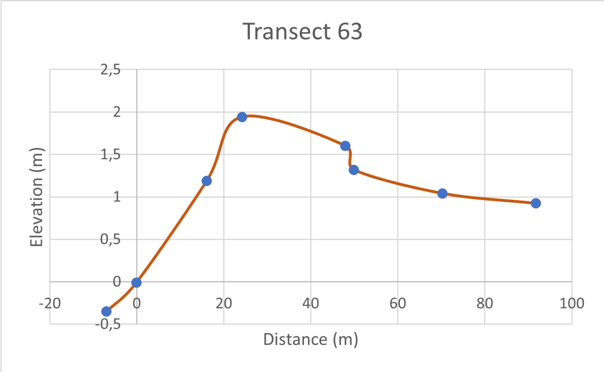

Transect 45
Elevation (m)
Distance (m)

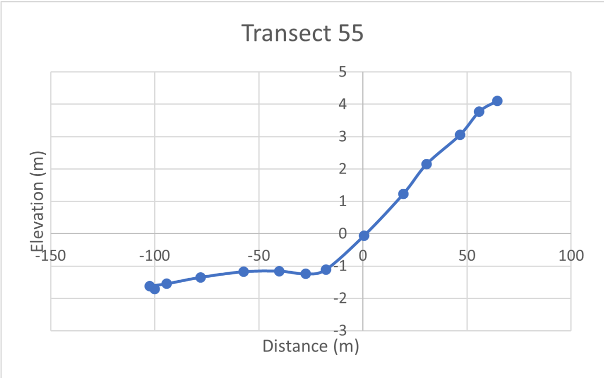

Transect 49
Elevation (m)
Distance (m)

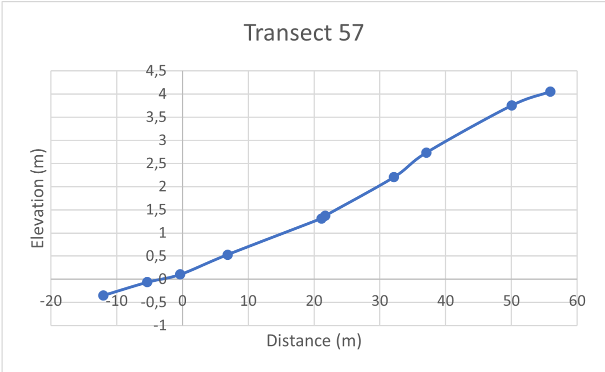

Transect 47
Elevation (m)
Distance (m)

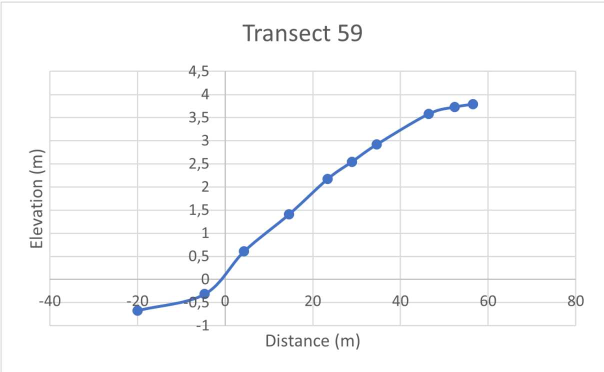

Transect 51
Elevation (m)
Distance (m)

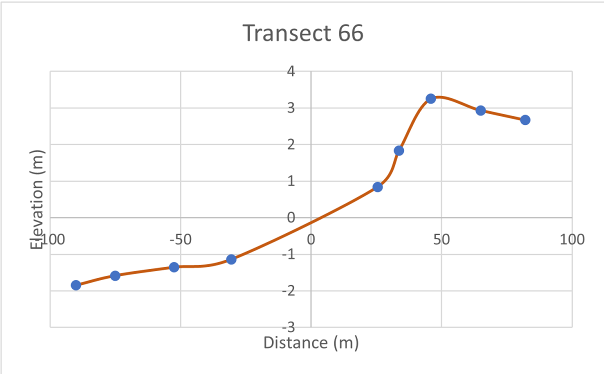

Transect 53
Elevation (m)
Distance (m)

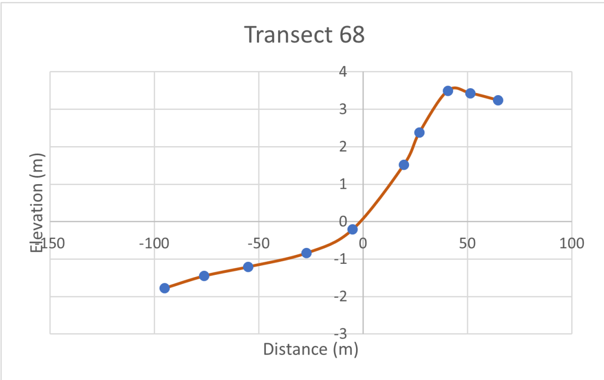

Transect 63
Elevation (m)
Distance (m)

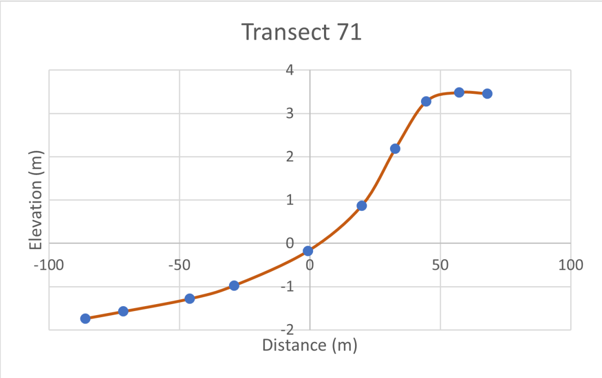

Transect 55
Elevation (m)
Distance (m)

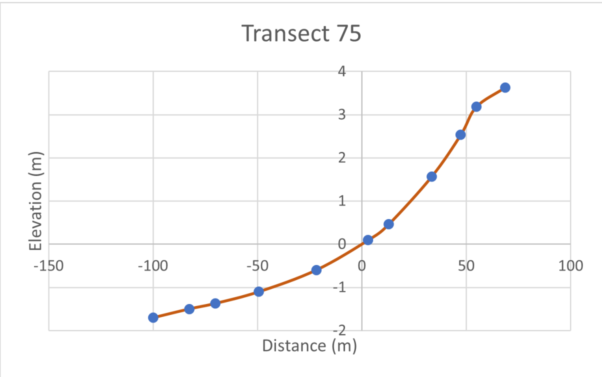

Transect 57
Elevation (m)
Distance (m)


Transect 59
Elevation (m)
Distance (m)


Transect 66
Elevation (m)
Distance (m)


Transect 68
Elevation (m)
Distance (m)


Transect 71
Elevation (m)
Distance (m)
4
3
2
1
0
-1
-2
-100
-50
0
50
100


Transect 75
Elevation (m)
Distance (m)
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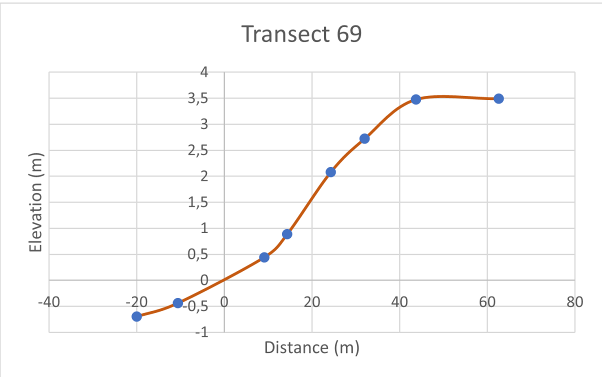
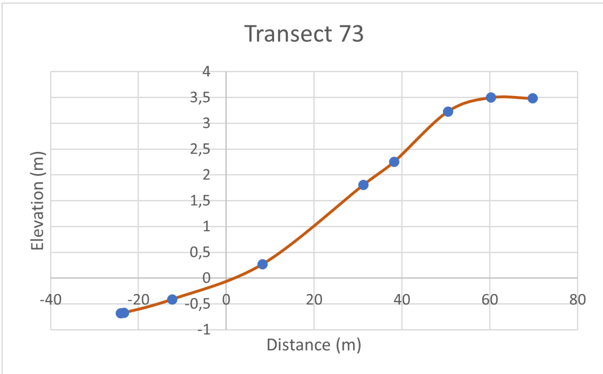
1
0
-1
-2
-150
-100
-50
0
50
100


Transect 69
Elevation (m)
Distance (m)
4
3,5
3
2,5
2
1,5
1
0,5
0
-0,5
-1
-40
-20
0
20
40
60
80


Transect 73
Elevation (m)
Distance (m)
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3,5
3
2,5
2
1,5
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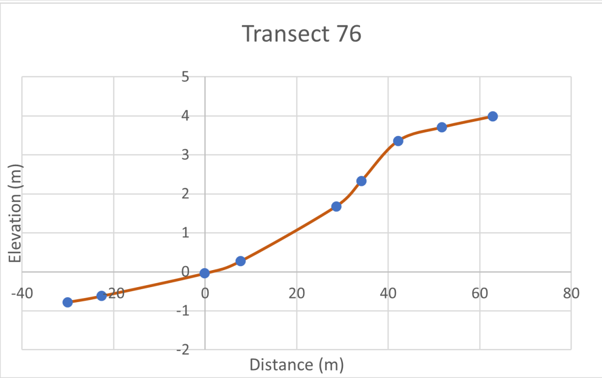
0,5
0
-0,5
-1
-40
-20
0
20
40
60
80


Transect 76
Elevation (m)
Distance (m)
5
4
3
2
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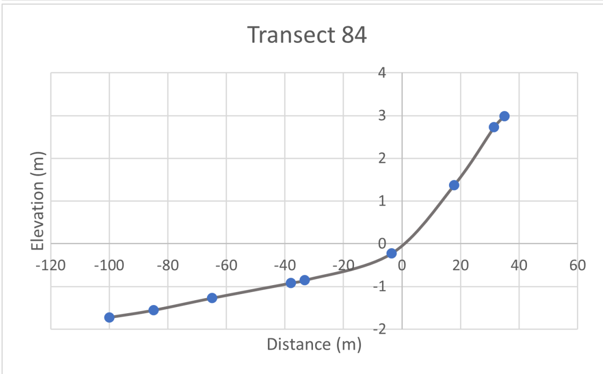
-1
-2
-40
-20
0
20
40
60
80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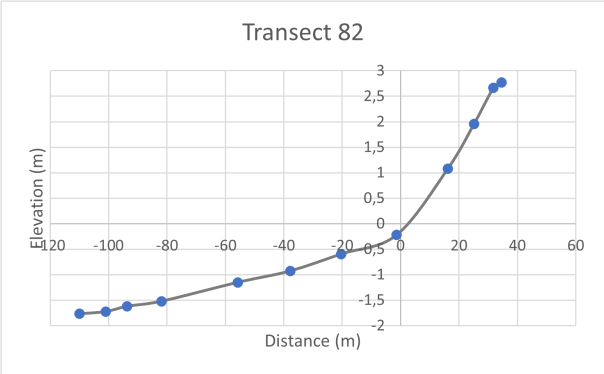
20
40
60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-2
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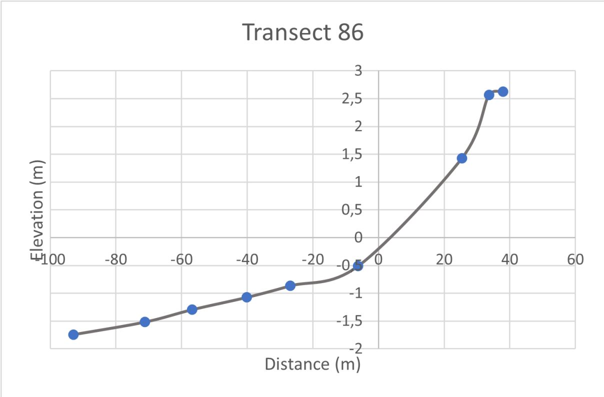
-100
-80
-60
-40
-20
0
20
40
60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Distance (m)
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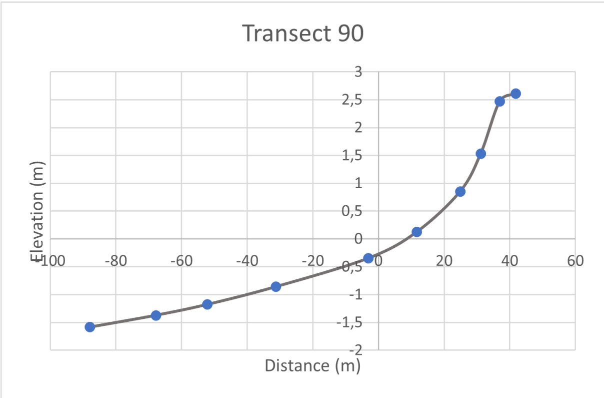
-80
-60
-40
-20
0
20
40
60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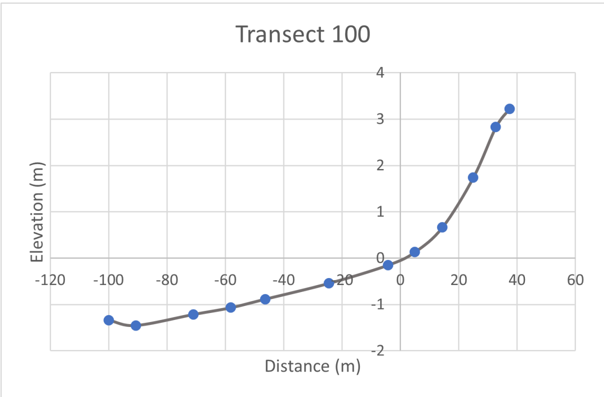
-60
-40
-20
0
20
40
60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0
20
40
60

H Interview notes

H.0.1 Interview 1

	Fecha: 28/02 Nombre: Jesus Anchia Villogas	*Date: 28/02* *Interviewee 1*
1. Hola ¿como estás?, vives en Playa Ostional? Y trabajas aquí?	Si vivo en Ostional, si trabajo aquí UCR	*Yes, live and work in Ostional, here at UCR (university)*
a. ¿que tipo de trabajo haces aquí? ¿y Cuánto tiempo llevas haciendo este trabajo?	Mantenimiento, y investigación con tortugas 10 anos	*I work in the maintenance and investigation of sea turtles for 10 years*
b. ¿te gusta vivir y trabajar aquí? Por qué?	Sí	*Yes i like working here*
2. ¿Qué tanto turismo recibe Playa Ostional?	En 2022 nos visitaron 9600 turista nacionales y extranjeros	*In 2022 9600 tourists visit us, as wel national tourists as foreigners*
a. ¿Cuántos trabajos tienen que ver con la anidación de tortugas?	6 trabajos	*There are 6 organizations working with the nesting of the turtles*
3. ¿Es el turismo la principal fuente de ingresos del pueblo? a. ¿A cuántas personas beneficia el turismo en Ostional?	El turismo no es la principal fuerte de ingreso al pueblo pero hay algunas familias que se beneficias al 100% del turismo, a mas 70 personas	*The tourism is not the biggest income of the town, but there are some families that rely 100% on the tourism. This is about 70 people.*
4. ¿Cuántas personas vienen a visitar las playas de anidación de tortugas cada mes/año?	promedio 800 personas por mas bonorcian y por años 9600.	*About 800 people per month come visit Ostional because of the turtles, yearly that's 9600*
5. ¿Ves cambios en la playa como consecuencia del cambio climático? Por ejemplo en la playa, o en la cantidad de arribadas?	Si hoy hau cambios climáticos en playa muy caliente la arena y mareos muy altas en el comportamiento de las arribadas	*Yes there are changes in the climate, at the beach the sand is very warm. And the sea level is very high during the coming of the arribadas. (Sea level rise)*

H.0.2 Interview 2

	fecha: 28/02	*Interviewee 2*
1. Hola ¿como estás?, vives en Playa Ostional? Y trabajas aquí?	Si vivo en ostional y si trabaja aquí UCR	*Yes I live and work in Ostional, here at UCR*
a. ¿que tipo de trabajo haces aquí? ¿y Cuánto tiempo llevas haciendo este trabajo?	Mantenimiento y trabajo de investigación con torgtugas 5 años	*I work in the maintenance and investigation of sea turtles for 5 years*
b. ¿te gusta vivir y trabajar aquí? Por qué?	Si es muy tranquilo	*Yes, it's very relaxed*
2. ¿Qué tanto turismo recibe Playa Ostional?	2022 nos visitaron 9600 nacionales y extranjeros	*In 2022 9600 people came to visit us, national and foreign tourists*
a. ¿Cuántos trabajos tienen que ver con la anidación de tortugas?	6	*There are 6 organizations that work with the turtles*
3. ¿Es el turismo la principal fuente de ingresos del pueblo? a. ¿A cuántas personas beneficia el turismo en Ostional?	No pero si es una gran ayuda para el publo Pero si hay algunas familias si se benefician al 100% (70 personas)	*No, the tourism is not the main income, but it is a big help for the village* *But there are some families that depend 100% on it, thats 70 people*
4. ¿Cuántas personas vienen a visitar las playas de anidación de tortugas cada mes/año?	Pro medio 800 personas por mes Por años 9600	*On average, 800 people visit Ostional beach per month. Thats 9600 per year*
5. ¿Ves cambios en la playa como consecuencia del cambio climático? Por ejemplo en la playa, o en la cantidad de arribadas?	Si vemos cambio como mas caliente y morea altos arena muy caliente Si a veces la arribada no salen todos los mese, hay meses que no sale.	*Yes, we see changes such as more heat and high sea level and hot sand at the beach.* *Yes sometimes the arribadas do not come during every month, there are months that there is no arribada.*

H.0.3 Interview 3

Interview 28/02 *Interviewee 3*

What kind of work do you do at the UCR?

I am a professor at UCR and I am starting some projects in Ostional. But we are having some issues with the hatchlings because we have some malformation, some of them. What I'm trying to check first, is to understand how important is that effect on the whole population. What I'm doing is just counting and checking all the hatchling in each nest, from all the years. To check how many hatchlings have malformation or any kind of misbehaviour, because there are some that have some neurological malformation and they don't behave regurarly. They start like turning and rolling and rolling and they never go towards the sea.

But we have several projects, also a project about the solitary turtle. Between one arribada and the other, there are some turtles that prefer to go on their own during the night to lay the eggs. We monitor each morning to see the traces, we go along the whole beach to see if they lay their eggs or if they didn't. Because sometimes they come to the beach but still not lay their eggs and go back to the sea.

We are monitoring who is eating the eggs, we have humans, dogs, raccoons, the birds, the vultures.

Do you also monitor the seperate harvestery?

That is from Minae, exclusively the most endangered species. For example for the leatherback turtles, they come only 4-6 per year. So if that turtle is spotted on the beach and lays her eggs, those eggs are exstracted immediately and placed on the hatchery. To be sure that no one steals them or eats them.

More limited then the olive ridley species? Yes

When do the turtles come to land?

The highest intensity during night, but during day could also be possible.

Are the arribadas usually during rain season?

Yes biggest arribiadas are from august to november, sometimes december also. Still all year round, 13 march more or less probably will one occur. There was one not too long ago, expecting next one 13 of march, not exact.

When hatchlings will appear?

Expecting they hatch after 45-50 days, around the end of next week, and totally next week entirely. Only problem this month is worst month for hatchlings, temperature is too high, most eggs will die. So there will be very few hatchlings or none. We are expecting to work with arribada, we can let you know when arribada starts. Between 3-5 days, sometimes less longer. Work with hatchlings, after rainy season starts (now density long because of dryness and temperature sand).

How do people feel about the climate change in Ostional?

H.0.4 Interview 4

	fecha: 7-3-2023	Date: 7-3-2023 *Interviewee 4*
1. Hola ¿como estás?, vives en Playa Ostional? Y trabajas aquí?	*Hola, si vivo en y trabajo en Ostional*	*Hi, yes i live and work in Ostional*
a. ¿que tipo de trabajo haces aquí? ¿y Cuánto tiempo llevas haciendo este trabajo?	*I'm owner of Basilico Ostional. It's a restaurant around 7 months ago*	*I'm owner of Basilico Ostional. It's a restaurant since 7 months ago*
b. ¿te gusta vivir y trabajar aquí? Por qué?	*Claro es tranquilo y bello pueblo*	*I like working here because its relaxed and the vilage is beautiful*
2. ¿Qué tanto turismo recibe Playa Ostional?	*Estimo que al rededar de 600 a 700 personas par mes*	*I think about 600 to 700 people come here every month*
a. ¿Cuántos trabajos tienen que ver con la anidación de tortugas?	*Estimo que al rededar de 5 trabajas son designados para eso*	*I think there are 5 organizations designated for the turtle nesting*
3. ¿Es el turismo la principal fuente de ingresos del pueblo? a. ¿A cuántas personas beneficia el turismo en Ostional?	*Consider que sí, debido al inuducramiento de la comunidad y beneficia cerca de 300 personas*	*I consider the tourism is the main income, due to the introduction of the community and it benefits about 300 people*
4. ¿Cuántas personas vienen a visitar las playas de anidación de tortugas cada mes/año?	*Around 600 a 700 people per month so around 6900 fair*	*Around 600 a 700 people per month come here because of the turtles, so around 6900 fair*
5. ¿Ves cambios en la playa como consecuencia del cambio climático? Por ejemplo en la playa, o en la cantidad de arribadas?	*I think the beach doesn't have any change*	*I think the beach doesn't have any change*

H.0.5 Interview 5

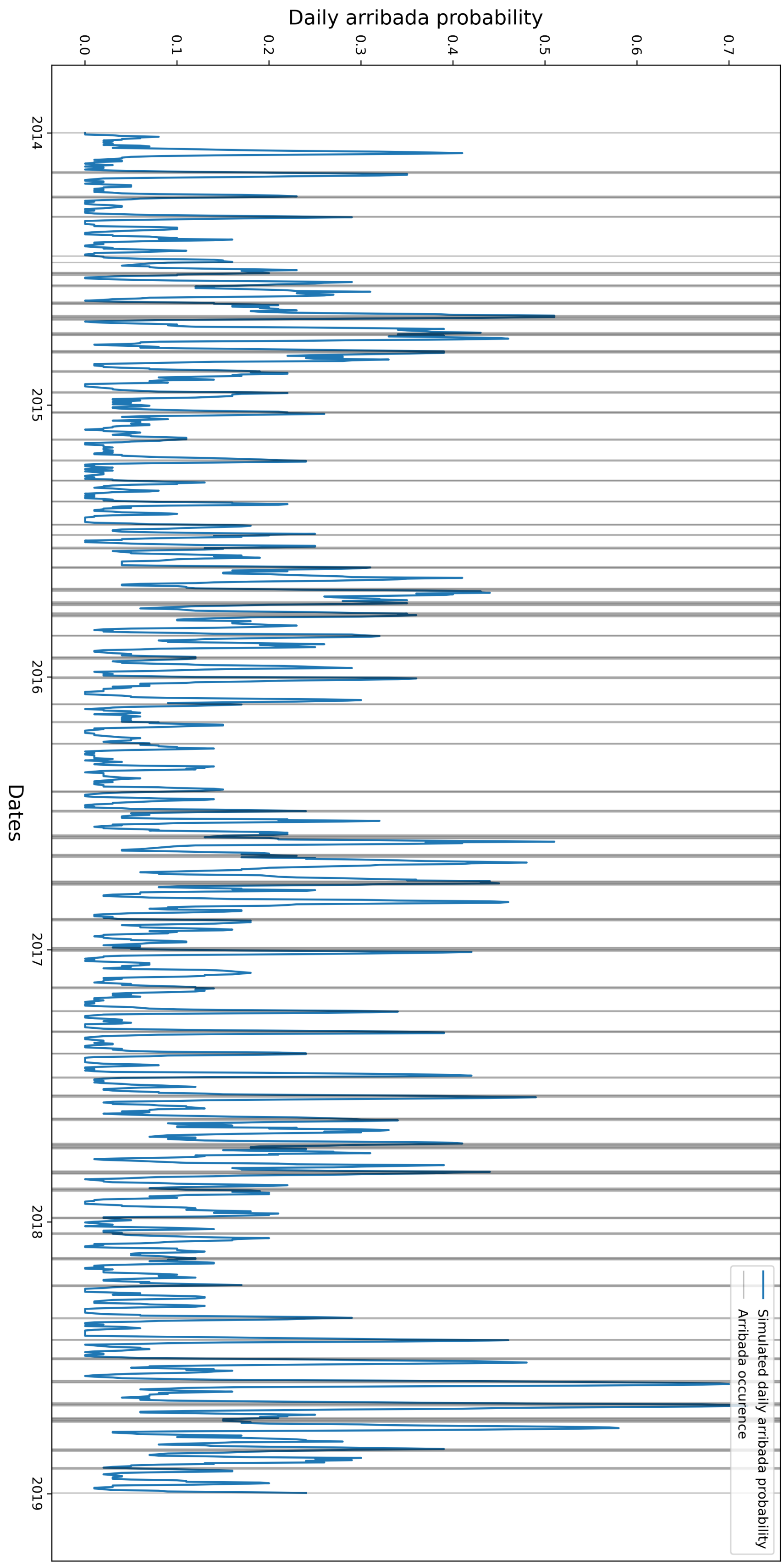
Interview de universidad de Costa Rica	Date: 9-3-2023 Names: *Interviewee 5*
1. Hola ¿como estás?, vives en Playa Ostional? Y trabajas aquí?	*Yes, we live and work here at Refugio Nacional de vida silvestre Ostional*
a. ¿que tipo de trabajo haces aquí? ¿y Cuánto tiempo llevas haciendo este trabajo? b. What are the activities that you do and how does that work?	*There are 4 activities that we do:* *1) Night patrols, 4 hour walks at night depending on the tides when that is* *2) Exclavations, 45 days after incubation of arribadas, we dig the holes and get the best density rates: how many eggs, how many new or old nests. We count the hatching success rate and see why they did not hatch* *3) Beach clean ups, we divide this in plastic and trash and wooden piles to make sure the mothers and babys have room to walk the beach and no obstacles.* *4) Hatchery for greens and leatherbacks. This is a square meter, with clean treated sand got from the waterline. They replace the sand when a new egg is harvested. They count the eggs and right now the hatching rate is 80% withing the hatchery, which has improved a lot since the beginning. They weigh and measure the eggs, take temperature of the nests to see if its too hot and to determine the gender of the egg. Above 29 degrees its mostly female, below is male.*
2. Where does the data go to? Is this in collaboration with UCR?	*The data gives insights in the population of olive ridley sea turtles, this goes to CITES to analyze the numbers whether its dropping or changing.*
a. What do they do with the data?	*Every year our permit has to be renewed and checked, whether we can still harvest and sell the eggs from Playa del Ostional. This is the only beach where its allowed in the world, so every year they check the data whether its dropping or changing.*
b. What does CITES do?	*CITES is monitoring the illegal trafficking of animals.*
3. How many volunteers do you have here?	*We have 12 volunteers right now, the maximum is 26 to sleep in the dorms. So we usually have 12-20 people here.* *During the arribadas, we stop our 'normal' activities and focus fully on walking transects and counting the turtles and eggs. We got a*

H.0.6 Interview 6

		fecha: 10-03-2023 *Interviewee 6*
1. Hola ¿como estás?, vives en Playa Ostional? Y trabajas aquí?	*Trabajo en playa guiones*	*I work at Playa Guiones (Another beach closeby)*
a. ¿que tipo de trabajo haces aquí? ¿y Cuánto tiempo llevas haciendo este trabajo?	*Soy maestro de surf*	*I am a surf teacher*
b. ¿te gusta vivir y trabajar aquí? Por qué?	*Me gusta porque es muy tranquilo*	*I like this work because it is relaxed*
2. ¿Qué tanto turismo recibe Playa Ostional?	*Mucho en tiempos de arribadas*	*A lot of tourism comes to Ostional during the arribadas*
a. ¿Cuántos trabajos tienen que ver con la anidación de tortugas?	*ADIO*	*The ADIO works with the nesting of the sea turtles*
3. ¿Es el turismo la principal fuente de ingresos del pueblo? a. ¿A cuántas personas beneficia el turismo en Ostional?	*No es la principal fuente*	*The tourism is not the main income for the village*
4. ¿Cuántas personas vienen a visitar las playas de anidación de tortugas cada mes/año?	*400 a 1000 por mes*	*400 to 1000 people visit Ostional for the sea turtles*
5. ¿Ves cambios en la playa como consecuencia del cambio climático? Por ejemplo en la playa, o en la cantidad de arribadas?	*Si hay en cambio*	*I see a difference in the beach because of climate change*

Data analysis

I.0.1 All years



I.0.2 Overfitting

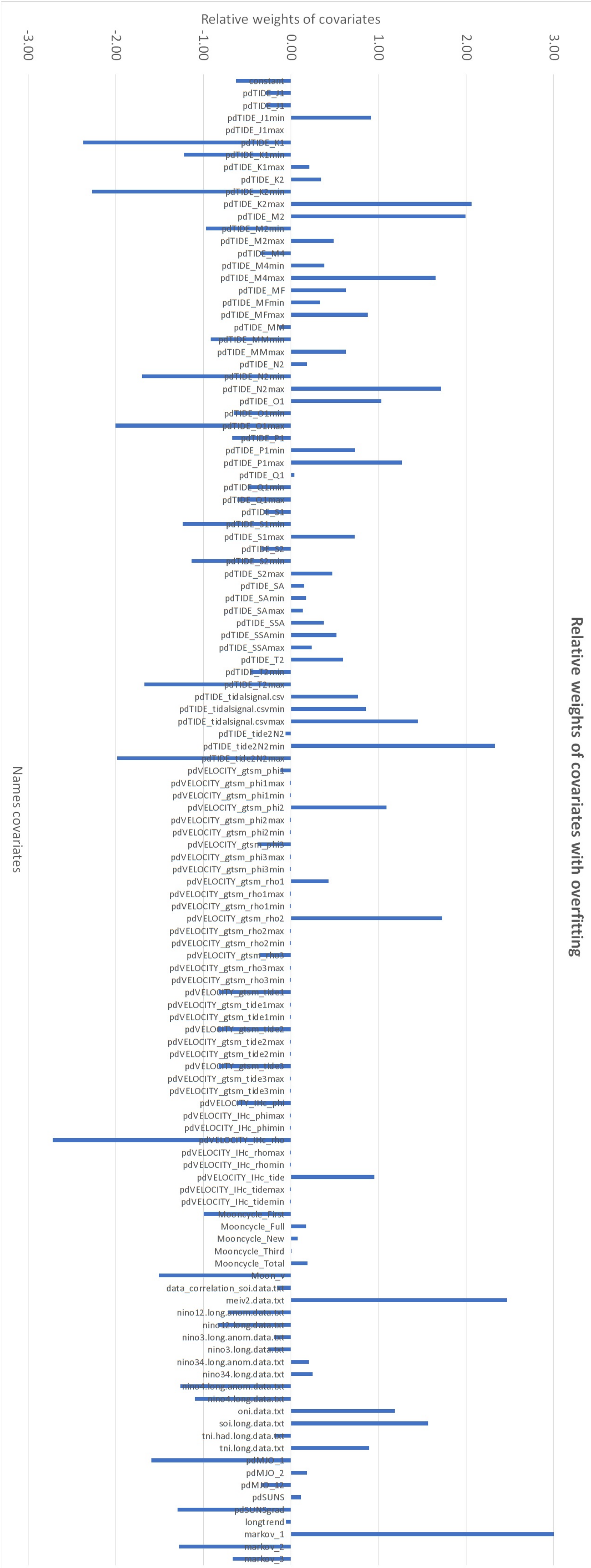
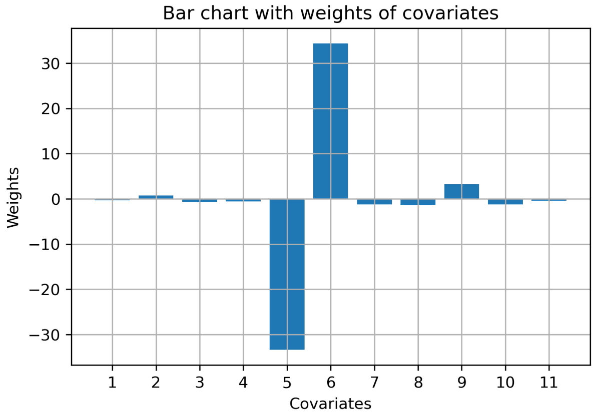


Figure I.2: Relative weight of all covariates during over-fitting

I.0.3 Velocities



Number	Covariates
1	constant
2	pdVELOCITY_gtsm_phi2
3	pdVELOCITY_gtsm_phi3
4	pdVELOCITY_gtsm_rho1
5	pdVELOCITY_gtsm_tide1
6	pdVELOCITY_gtsm_tide3
7	pdVELOCITY_IHc_phi
8	pdVELOCITY_IHc_rho
9	markov 1
10	markov 2
11	markov 3

Figure I.3: Relative weight of all current velocity covariates

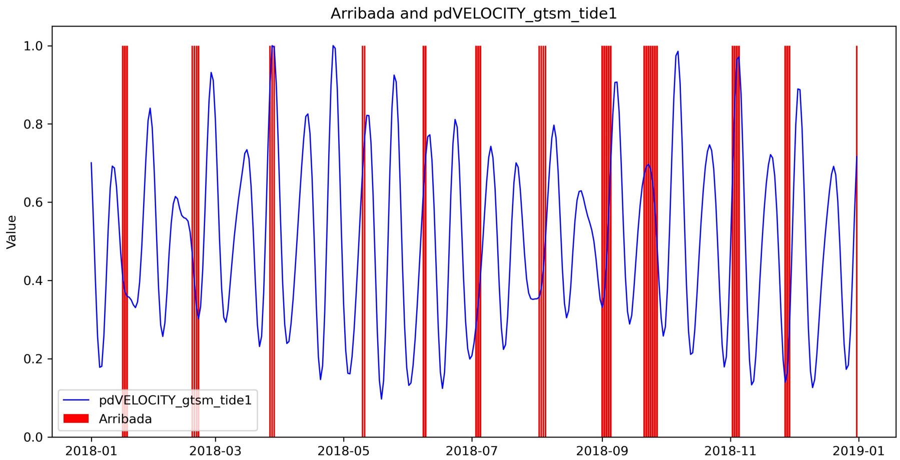


Figure I.4: pdVELOCITY_gtsm_tide1

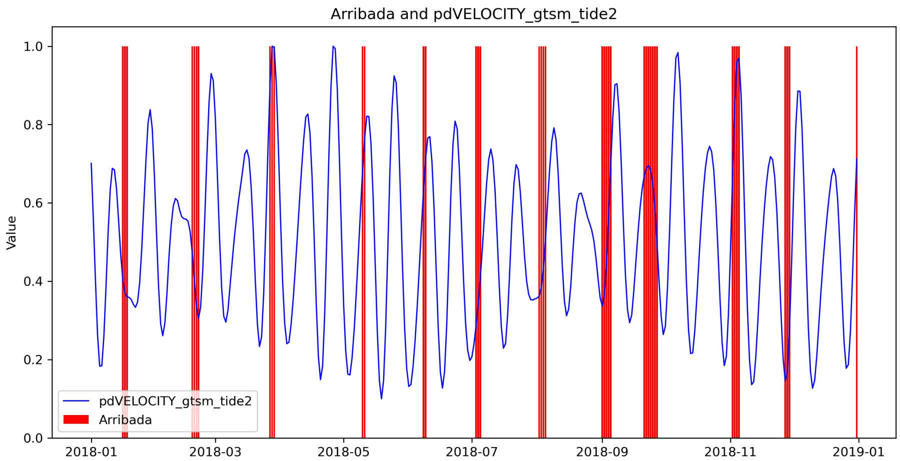


Figure I.5: pdVELOCITY_gtsm_tide2

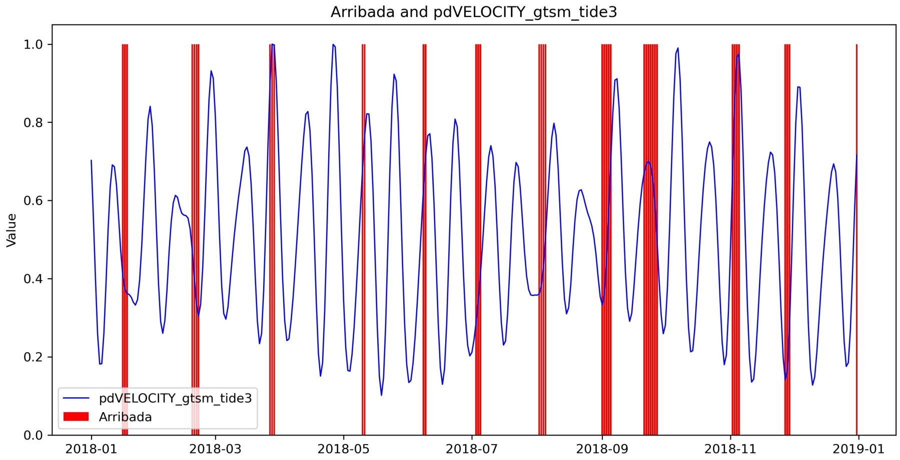


Figure I.6: pdVELOCITY_gtsm_tide3

I.0.4 Moon cycle

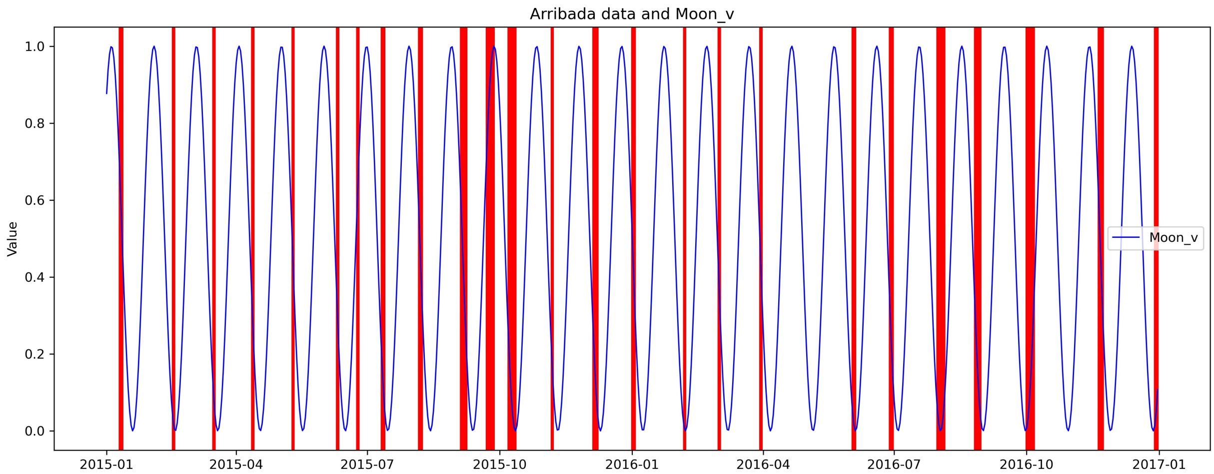


Figure I.7: Moon_v and arribada data 2015-2016

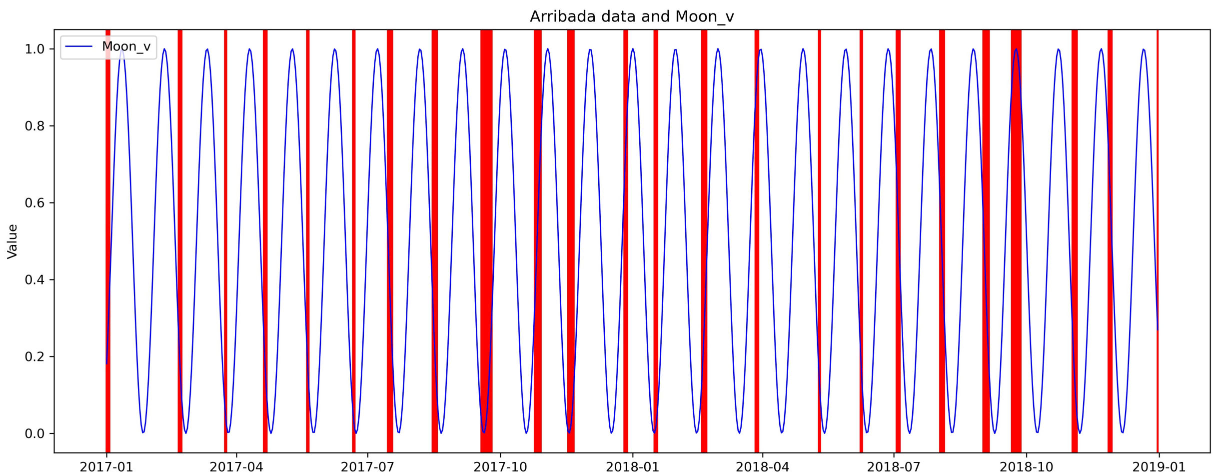


Figure I.8: Moon_v and arribada data 2017-2018

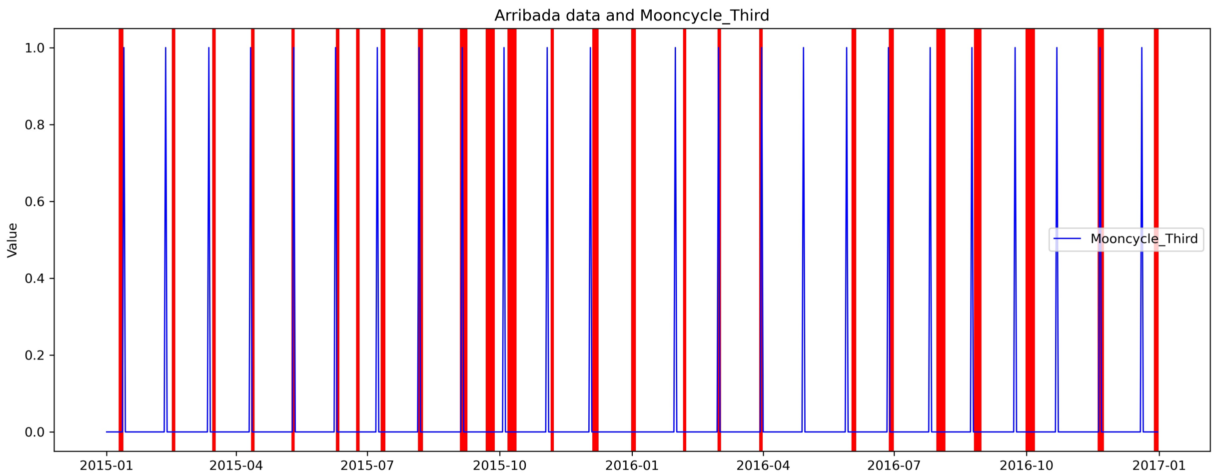


Figure I.9: Quarter moon and arribada data 2015-2016

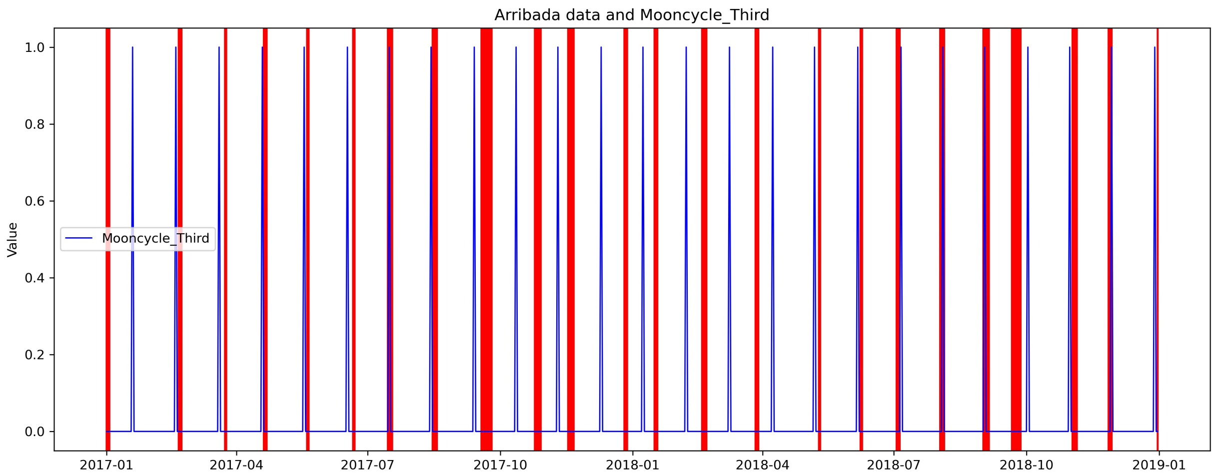


Figure I.10: Quarter moon and arribada data 2017-2018

I.0.5 ENSO

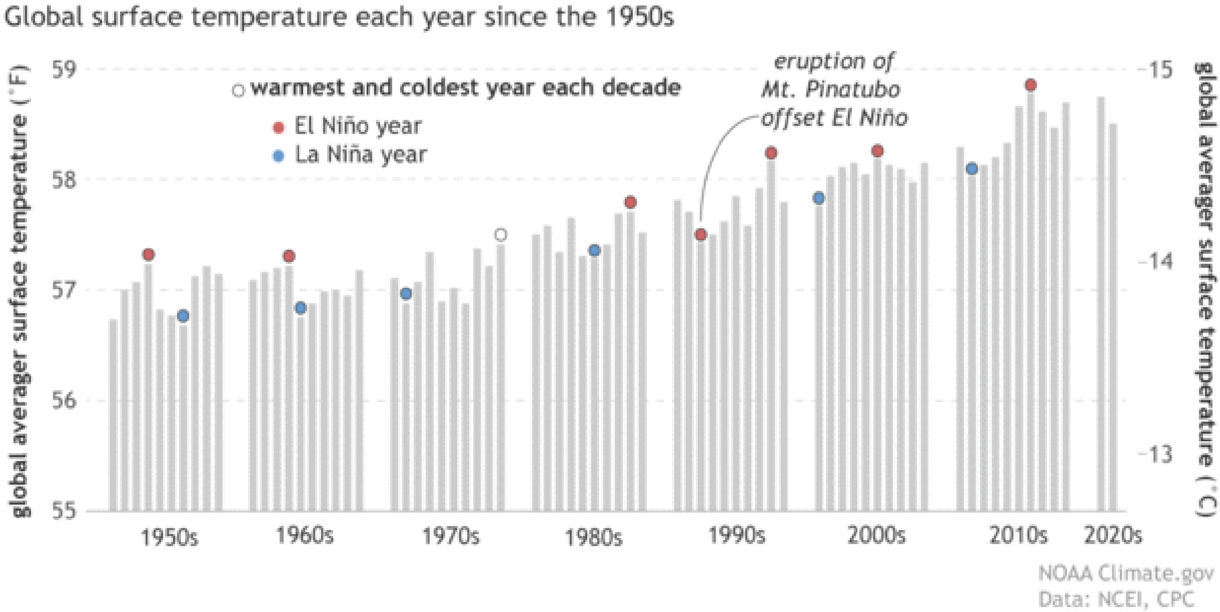


Figure I.11: Historical data ENSO [**Climate.gov**]