
AERES HOGESCHOOL ALMERE
CAÑO PALMA ESTACIÓN BIOLÓGICA


# COASTAL EROSION ON THE CARIBBEAN COAST

*Examining an ever-changing beach in Costa Rica*


**BY RICK VAN DER HAAR**


# An assessment of coastal erosion in Costa Rica

**By Rick van der Haar**
Student No. 3023791

**Commissioned by**

CAÑO PALMA
ESTACIÓN BIOLÓGICA

AERES HOGESCHOOL ALMERE

**University Supervisor**
Danny Merién

**08-06-2020**
**Zwolle, The Netherlands**

**Abstract**
This paper describes an investigation regarding relations between coastal vegetation types and accompanying erosion rates. This study can be interesting for conservation/environmental scientists, or inhabitants of coastal communities. Coastal erosion is a potential threat for ~100 million people that are living within one meter below mean sea level. Furthermore, it poses a threat to wildlife such as marine turtles, and plant communities that are prone to saline stresses. Coastal erosion around the globe has been increasing due to man-made climate change, and so it is very likely to keep increasing in the near future. In order to investigate the relations between vegetation types and their response towards coastal erosion, several surveys have been executed. This has been done on a beach transect of five kilometers on the northeastern Caribbean coast of Costa Rica. Six vegetation types have been determined, namely sandy beach, herbaceous beach, grassland, shrubland, juvenile forest and forest. For a period of three to four weeks, the distance between a fixed point and the nearest eroded cliff was measured. These measurements generated a weekly erosion rate. All data regarding vegetation type and erosion rates was analyzed with an ANOVA and combined into an interactive map. The data shows that the vegetation types with a high plant density provide greater resistance towards erosion, compared to the vegetation types where there is a low plant density or no plants at all. However, the ANOVA suggests that there is no significant difference between the vegetation types in their response towards erosion. Debris from natural and anthropogenic sources has also shown to potentially play a role in slowing down erosion rates. This study had to be terminated early, because of the COVID-19 pandemic. When the shortage of data in this study is considered, it is recommended to repeat this study with a more reliable and more complete datasheet to double-check its findings.

**Samenvatting**
Dit verslag beschrijft een onderzoek naar relaties tussen kustelijke vegetatietypen en bijbehorende erosiesnelheden. Dit onderzoek kan interessant zijn voor wetenschappers binnen het vakgebied van natuurbehoud, milieuwetenschappers of bewoners van kustelijke gebieden. Kustelijke erosie is een potentiële bedreiging voor ~100 miljoen mensen die binnen een meter onder zeeniveau leven. Verder vormt het een bedreiging voor wilde dieren als zeeschildpadden, en plantengemeenschappen die gevoelig zijn voor zoutstress. Kustelijke erosie neemt wereldwijd toe dankzij klimaatverandering veroorzaakt door mensen, en dus is het erg waarschijnlijk dat dit zal blijven toenemen in de nabije toekomst. Om de relaties tussen vegetatietypen en hun rol richting kusterosie te beschrijven, zijn er verschillende onderzoeken uitgevoerd. Dit is gebeurd op een strandgebied van vijf kilometer, die zich bevindt aan de noordoostelijke Caribische kust van Costa Rica. Zes vegetatietypes zijn bepaald, namelijk zandstrand, kruidachtig strand, grasland, struikgewas, jeugdbos en bos. Voor een periode van drie tot vier weken is de afstand tussen vaste punten en de dichtstbijzijnde geërodeerde klif opgemeten. Deze metingen hebben een wekelijkse erosiesnelheid gegenereerd. Alle data met betrekking tot de vegetatietypen en erosiesnelheden zijn geanalyseerd met een ANOVA en gecombineerd tot een interactieve kaart. Deze data laat zien dat de vegetatietypen met een hogere plantdichtheid beter bestand zijn tegen erosie, vergeleken met de vegetatietypen met een lage plantdichtheid of helemaal geen planten. De ANOVA suggereert dat er geen significant verschil is tussen de vegetatietypen en hun erosiesnelheden. Puin uit natuurlijke en menselijke bron hebben ook laten zien een mogelijke rol te spelen in het vertragen van erosiesnelheden. Dit onderzoek moest voortijdig worden stopgezet door de COVID-19 pandemie. Door het tekort aan data, is het aanbevolen om dit onderzoek te herhalen met een meer betrouwbare en meer complete dataset om de gevonden feiten nogmaals te bevestigen.

## Preface & acknowledgements

Before you lies the thesis “Coastal erosion on the Caribbean coast”. It forms the basis of an analysis regarding the first weeks of an ongoing research regarding erosion at playa Norte, a beach located near Tortuguero in northeastern Costa Rica. It has been written to make the first analysis of the first gathered data, gathered between February and April 2020. Unfortunately, due to the global COVID-19 pandemic, the study was cut short with the amount of data collected amounting to 50% of what was originally intended. The project was undertaken at the request of Caño Palma Estación Biológica and Aeres Hogeschool Almere.

My biggest thanks go out to all the people that have stayed at Caño Palma Estación Biológica between February and April 2020. They have helped me in many ways while conducting this research. They have motivated me, thought along throughout my research, and gave me friendship and a home during my time in Costa Rica.

Furthermore, I would like to specially thank Alessandro Franceschini, Charlie Pinceton and Jim Takahashi for helping me with data collection and providing me with advice and feedback. I would also like to thank the station manager Charlotte Foale for her excellent care, hospitality, great meals and positive vibes. My supervisor from Aeres Hogeschool Almere, Danny Merién, deserves praise for the way he guided me through writing this thesis and providing useful feedback when necessary.

Last but not least, I would like to sincerely thank Rebecca Huistra. She motivated me the most to continue my work, came up with great ideas and even broke her leg whilst gathering data for this research. In this study, she played a major role that should not be forgotten.

**Table of contents**

**List of tables and figures**

## 1 Introduction

All terrestrial ecosystems depend on available land mass. In present times, the stability and textures of land masses on which these ecosystems depend are increasingly being threatened by both anthropological influences and natural forces (Meixler, Kennish, & Crowley, 2018). Anthropological influences include activities and processes such as farming, deforestation, pollution, and expansion of urban areas. These factors often parallel human population increase (Hooke, Martín-Duque, & Pedraza, 2012; Houghton, 1994). This makes it very likely that negative anthropological influence on land masses will keep increasing in the near future.

Since the beginning of time, land masses have been influenced by natural forces as well. The factors that can be considered for having the most impact are plate tectonics and volcanic activity for land mass formation and movement, and erosion for land mass relocation and reduction. (Murphy & Nance, 2004; Stampfli, Hochard, Vérard, & Wilhelm, 2013)

In most coastal areas of the world, land mass reduction by the means of erosion becomes an increasingly severe problem for maintaining land mass. This increase in coastal erosion rates is for a major part a consequence of global warming and climate change, induced by anthropogenic activities (Williams, Rangel-Buitrago, Pranzini & Anfuso, 2018; Zhang, Douglas & Leatherman, 2004). Global warming causes global sea levels to rise, which in its turn increases the rate and severity of sandy beach erosion. It is speculated that the rate of long-term sandy beach erosion is around one hundred times larger than the rate of sea level rise (Zhang et. al, 2004). Climate change is also resulting in more frequent and severe storms, particularly in tropical regions. These storms can speed up sandy beach erosion dramatically, resulting in an even more rapid loss of shoreline (Rivas, Tomillo, Diéguez-Uribeondo, & Marco, 2016). This means that, with the current rates of sea level increase and climate change, shorelines are rapidly decreasing in size.

These facts mean that sea level rise and sandy beach erosion can, and most definitely will, have a major impact on habitats and communities living on or near the shores. If sea levels continue to rise at the current pace, several countries, or island states, could completely disappear (Farbotko, 2010; Lewis, 1989). Sea level rise will also threaten the current manner of existence for people that live on low-altitude areas, most definitely by removal of usable land mass and destroying fixed structures. At least 100 million people are living within one meter below mean sea level, and are very prone to these negative consequences (Zhang et. al, 2004).

Moreover, a variety of organisms that depend on the existence of the shorelines will be affected (Menn, 2002). A good example is the nesting ground of sea turtles. Sea turtles always return to nest on the beaches that they were born on. They do so by using the earth's magnetic field (Brothers & Lohmann, 2015). Once the beaches are eroded, the turtles will not be able to enter the beach and/or find a suitable place for laying their eggs (see Figure 1). This often results in turtles being forced to create a nest in a spot too close to the water, where the nests will eventually flood and the eggs will suffocate. Other animals that are affected include shorebirds, seals and crabs. On top of this, most of these animals are already under constant and increasing threat by plastic pollution and poaching (Reddy, Reddy, Subbaiah, & Subbaiah, 2014).

*Figure 1: Heavily eroded coastline in Costa Rica, on a beach where turtles normally come to nest*

It can be concluded that increasing coastal erosion has a negative influence on populations of animals and humans. On top of that, entire ecosystems can be at risk. This is the case in north-eastern Costa Rica, where big parts of rainforest are threatened by the approaching ocean. The Tortuguero river is the main river of this area and is only protected by a small strip of land, as seen in Figure 2. In addition, the river is directly in contact with a large area of rainforest. The area surrounding the Tortuguero river, including Tortuguero national park, is one of the most biodiverse regions on the planet (Ström, 2013). If the protective strip of land gets removed by erosion, ocean water will enter the Tortuguero river. The salinity of the ocean water can have a drastic impact on biodiversity in this area, to plant and animal species that are not adapted to this (De Herralde et al, 1998; Jouyban, 2012).


*Figure 2: On the left, an aerial photo of the Tortuguero river, protected by the land strip. On the right, Laguna Cuatro, a spot at the end of playa Norte which will be one of the first major fresh water bodies to be in contact with the ocean due to erosion.*

Researchers located in this area have noticed the effects of erosion for several years. In November 2019, the tropical storm Sebastien damaged large parts of the beach located in the northern coastal part of the area, called playa Norte. This initiated a rapid increase in erosion rate, resulting in devastating scenes at the beach as seen in Figure 3.

*Figure 3: The effects of erosion at sites in playa Norte.*

It is hypothesized that plant communities can play a major role in slowing coastal erosion. A study performed in 2013 proved that this is the case in dune landscapes (Kobayashi, Gralher & Do, 2013). However, various studies performed in habitats like wetlands and dunes suggest that plants that are maladjusted to saline stress will disappear at a high rate when exposed to sea water and coastal erosion (Feagan, Sherman & Grant, 2005; Chabreck, 1982). Plant communities can also be drastically altered in composition under influence of coastal erosion (Agir, Kutbay, Surmen & Elmas, 2017). These facts are worth looking into when one considers the vulnerable areas that are present near the Tortuguero river (Figure 2).

As of now, there has been no documentation regarding the erosion in the playa Norte area. To form an indication about the current state of the beach and its area, the main question "What is the relation between erosion rates and various vegetation types at playa Norte?" needs to be answered. To answer this main question, the following sub questions have been formulated:

- What is the current rate of erosion at playa Norte?
- What is the composition of vegetation types in playa Norte?
- How are the different vegetation types responding towards erosion?

This paper describes a qualitative and exploratory research. Prior to this study, there was insufficient data about erosion affecting playa Norte. Furthermore, the area has never been subjected to research concerning the vegetation and the possibility of heavily eroded sites. The results of this study can enable researchers that work with playa Norte to understand at what rate erosion is taking place. Moreover, the data will also be supportive in various surveys taking place i.e. regarding shorebirds and marine turtles. Additionally, by determining where the weakest points on the beach are, precautionary measures can be taken to avoid further erosion in the future.

While the focus of this paper is mainly on playa Norte, storms are also causing similar problems elsewhere in the world. For example in the United States, the tropical storms and hurricanes Irene, Katrina and Sandy caused similar effects along the coastlines (Cornell et. al, 2019). This implies that the findings of this paper will also be useful for areas with similar properties compared to playa Norte. It mainly targets conservation and environmental scientists and inhabitants of coastal communities.

## 2 Materials and methods

### 2.1 About the study

The field work for this study has been conducted between February and April 2020.

#### 2.1.1 Nature of the study

The location where the study has taken place is playa Norte, a transect of five kilometers of beach located approximately eight kilometers north of the village of Tortuguero on the north-eastern coast of Costa Rica. All research equipment has been supplied by Caño Palma Estación Biológica, which is located approximately 300 meters from the investigated area (see Figure 4).

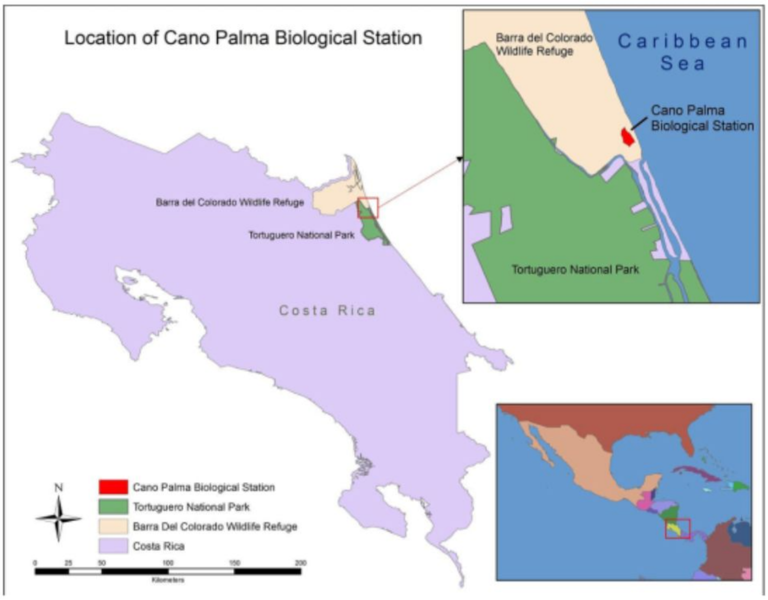


*Figure 4: Location of Caño Palma Estación Biológica (via coterc.org)*

#### 2.1.2 The research area

Playa Norte is a section of beach area that covers five kilometers, with marked trees (or transect posts) placed every 200 meters. This amounts to a total of 26 transect posts, numbered 0-25. These posts were originally constructed to divide the beach up into different sections to assist in surveys regarding marine turtles, and are still used for this purpose. The area starts at 10°35′38.4216″N–83°31′31.2 234″W; and ends at 10°38′2.8536″N–83°32′29.8674″W (visualized in appendix 3). Approximately ten houses can be found on or near the beach area, and the tourist accomodation “Turtle Beach Lodge” can be found between transect posts 19 and 20. This means direct anthropological influences are a factor at some sites. Since 1991, a small research station called Caño Palma Estación Biológica has been performing research in this area on various kinds of topics (coterc.org). Located at approx. 300m to playa Norte, researchers located at this station have noticed the effects of erosion in this area for several years.

### 2.2 Data collection

#### 2.2.1 Monitoring erosion rates

For monitoring the rate at which erosion occured, an entirely new method has been constructed. From a fixed point, the distance to the nearest eroded cliff (at least 20 cm in height) was measured with measurement tape. There are 71 fixed points in total, as can be seen in appendix 1. Starting at transect post 0, at every 100 meters a new fixed point was determined and marked with red plastic tape.

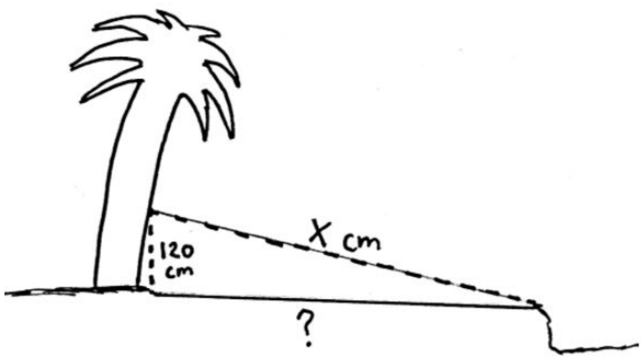


*Figure 5: The method of measuring the erosion illustrated.*

Later, some additional fixed points were added at heavily eroded sites to be able to investigate these areas more thoroughly. The red mark was placed 120cm above the ground at every fixed point. The mark is the starting point of every measurement. This manner of measuring is illustrated in Figure 5. The dotted lines are the lines that are physically measured. They are used to form a triangle which shows the actual distance on the surface, illustrated in Figure 5 as the solid line with the question mark underneath it.

After this measurement, the height of the cliff was also measured and noted together with the estimated percentage of roots found at the cliffside. This was estimated on visual observations. Table 1 shows all the variables that were measured during these surveys.

*Table 1: Datasheet for monitoring erosion*

| Date | Transect post # | GPS coord. | Accuracy | Length in cm (set point → cliff) | Height of cliff (cm) | Root % |
|---|---|---|---|---|---|---|
| | | | | | | |

All measurements, except for the root percentage, were repeated every week on Monday and Thursday. The difference in length over time will display the weekly erosion rate. The detailed protocol for these measurements can be found in appendix 2.

**2.2.2 Determining present vegetation and describing vegetation types**
To give an indication of what the beach area looks like, an assessment of present vegetation and vegetation types was made. To do this, 10x5 plots were created at every transect post. This resulted in 26 measurements. Parallel to the transect post, a stick was placed at the edge of the nearest eroded cliff.* From this point, five meters to both the left and the right of the first stick, other sticks were placed. This formed a 10x5 rectangle. Within this rectangle, all variables seen in table 2 were measured.

*Table 2: Vegetation type plot variable description** & datasheet.*

| Post # | CC | Adult T | T ratio | Dominant T species | Veg. type | GC % | Dominant P species | Hab. descr. | Plastic (Y/N) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |

*If there was no cliff present, the plot was constructed with placing the first stick 5 meters from the transect post.
** CC = canopy cover, T = tree, Veg. = Vegetation, GC = ground cover, P = plant

The canopy cover was measured with a forest densiometer. A forest densiometer is a small bulb-shaped mirror, with a raster with 96 dots on it. To measure the canopy cover, one levels the mirror with the assistance of an air bubble and counts all the dots that are not covered by vegetation. These measurements are done at the left, central and right points of the earlier described plot, from the perspective of the fixed point. The amount of adult trees was determined by counting the present trees taller than 3 meters. The tree ratio is the amount of palm trees compared to other trees. The dominant tree species observation resembles the most occurring tree species inside the plot. The ground cover classifications were determined by six different classes of ground cover. These are classified and further described in table 3. To determine the ground cover percentage, the plot is divided in two squares. An estimation is made about the percentage of ground that is directly covered by living tissue, for both squares. The average of these two squares give the ground cover percentage. The dominant plant species are the most occurring plant species in the plot, which are not trees. The surrounding area description provides a general description of the plot and its surroundings, including any unusualities. Finally, the occurrence of any plastic pollution inside the plot is documented.

*Table 3: All ground cover classifications or vegetation types and their description*

| Vegetation type or GC classification | Description |
|---|---|
| Sandy beach | Mostly deserted beach, no vegetation present at the first 10-20 meters from the ocean |
| Herbaceous beach | First 10-20 meters of beach for the biggest part inhabited by green, non-woody plants besides grass |
| Grassland | The first 10-20 meters of beach is covered by grass by at least 50%. |
| Shrubland | First 10-20 meters for the most part inhabited by shrubs and small woody plants, sometimes young tree species |
| Juvenile forest | First 10-20 meters densely populated with young trees and some shrubs, sporadically some large trees (>3 meter) |
| Forest | First 10-20 meters densely populated with large trees (>3 meter) |

**2.3 Data analysis**

With the data retrieved from the methods described in paragraph 2.2, the following forms of analysis can be made:

**2.3.1 Map of present vegetation types**

To answer the sub-question “What is the composition of vegetation types in playa Norte?”, a map will be created with Google My Maps. This map shows the different vegetation types in the area, as well as representative erosion rates. The displayed erosion rates are the average weekly erosion rates measured at the particular transect posts. The different vegetation types have been explained in paragraph 2.2.2. A table will be added for clarification. The difference between the vegetation types has been made based on the differences in present vegetation, in quality and quantity.

**2.3.2 Erosion rates**

A diagram will be created which shows how the different areas of playa Norte are responding to erosion. This will answer the sub-question “What is the current rate of erosion?” for all the fixed points within the transect.

### 2.3.3 Comparison between vegetation type and average weekly erosion rate

A comparison can be made between the different vegetation types and the accompanying rate of erosion. This will answer the sub-question “How are the different vegetation types responding towards erosion?”

With the weekly measurements of the distance between the fixed points and the nearest cliffs, a weekly erosion rate can be determined. First, the real erosion rate at ground level (the “?” value in Figure 5) is determined. To do this, the pythagorean theorem is used ($a^2+b^2=c^2$). This shows the true distance between the fixed point and the eroded site. This is used to calculate the average and median erosion rate over the three or four weeks of measurements.

When the median value accounts for two numbers (i.e. for the numbers 1-10, the two middle numbers are 5 and 6), the average of those two numbers (5+6/2=5,5) is determined as the median value.

### 2.3.4 Erosion rates per vegetation type

The data of 2.3.1 and 2.3.2 can be compared to see if there is a correlation between vegetation types and erosion rates. This will be done with an analysis of variance (ANOVA), with a standard of 0.05. This approach is done with the assumption that the erosion measurements throughout time are independent (unpaired) of one another. This will answer the sub-question “How are the different vegetation types behaving towards erosion?” This method will give a clear idea about which vegetation type is most prone to erosion, and can indicate which areas of the beach are most likely to heavily erode in the near future.

## 3 Results

This chapter displays the results of all measurements that were made according to paragraph 2.2 of chapter 2, sorted by the sub-questions. The raw data for chapter 3 can be found in appendix 4.

### 3.1 Erosion rates

Figure 6 shows the average weekly erosion rates, measured per fixed point at the playa Norte beach transect. The most severe erosion rates were measured at fixed points 1, 13.25 and 22.5. These fixed points show an average erosion rate of more than 200 cm per week. The lowest erosion rates have been measured between fixed points 5.5 and 8.75, where the average erosion rates are only once measured above 8 cm per week at fixed point 8. The other measurements within this range are all under 5 cm per week. The remaining rates differ a lot, ranging from 0,3 to 149,4 cm per week. The colour codes from Table 4 are used in Figure 6. The total average of all measurements comes down to an erosion rate of 40,0 cm per week.

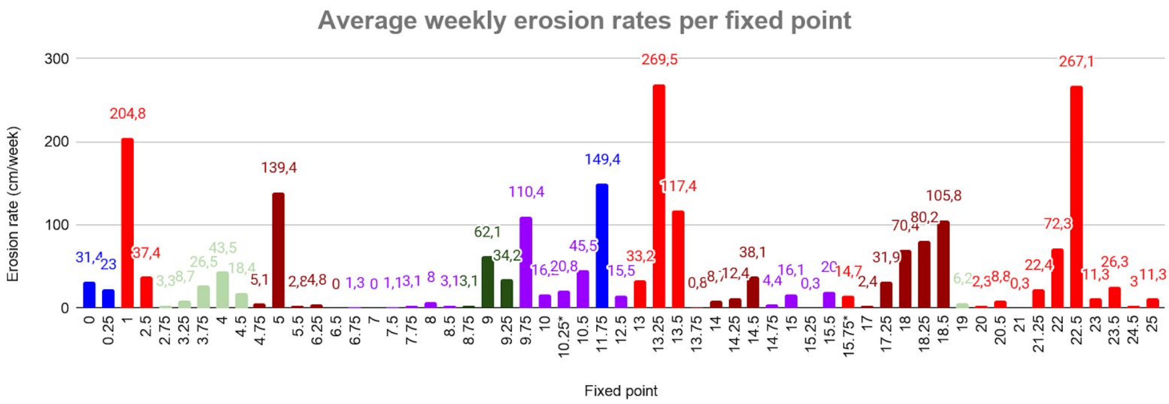


*Figure 6: Average weekly erosion rates in cm per week per fixed point at the 5 km transect of playa Norte beach.*

### 3.2 Vegetation types

Table 4 shows all observed vegetation types, their locations and the frequency in which they occur. It shows that the Sandy beach vegetation type is the most common (38,5%) followed by Herbaceous beach and Shrubland (19,2%), Juvenile forest (11,5%), Grassland (7,7%) and finally Forest (3,8%). The locations of the vegetation types have been processed into an interactive map, and can be accessed through Figure 7. The map shows the estimated locations of the vegetation types, based on the transect posts where they were observed.

*Table 4: The observed vegetation types, their locations and their occurance*

| Colour | Vegetation type | Amount | % |
|---|---|---|---|
| | Sandy beach | 10 | 38.5 |
| | Herbaceous beach | 5 | 19.2 |
| | Grassland | 2 | 7.7 |
| | Shrubland | 5 | 19.2 |
| | Juvenile forest | 3 | 11.5 |
| | Forest | 1 | 3.8 |

*Figure 7: QR code link to interactive vegetation type map*

### 3.3 Response of vegetation types towards erosion

Comparisons have been made between the vegetation types and their accompanying erosion rates. Shown in Figure 8 is the median weekly erosion rate per vegetation type. This shows that the highest median erosion rates can be found in the grasslands (31,4 cm/week) and the forests (34,2 cm/week). The lowest rates can be found in the shrublands (6,2 cm/week) and the herbaceous beaches (6,9 cm/week). The sandy beaches (18,95 cm/week) and the juvenile forests (18,4 cm/week) score rather average.

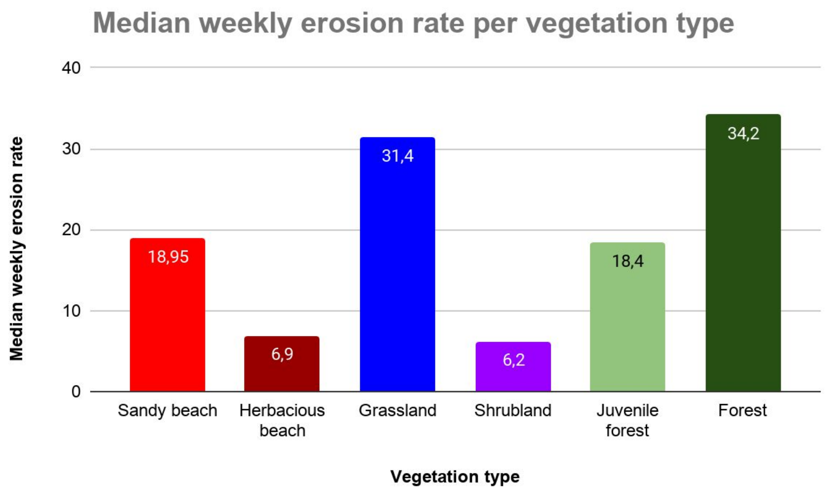


*Figure 8: Median weekly erosion rate per vegetation type*

The ANOVA shows an F-statistic value (F-stat) of 0,68. A standard of 0,05 is chosen. Therefore, it can be concluded that there are no differences found in weekly erosion rate between the vegetation types. To support these findings, Table 5 shows all the found results.

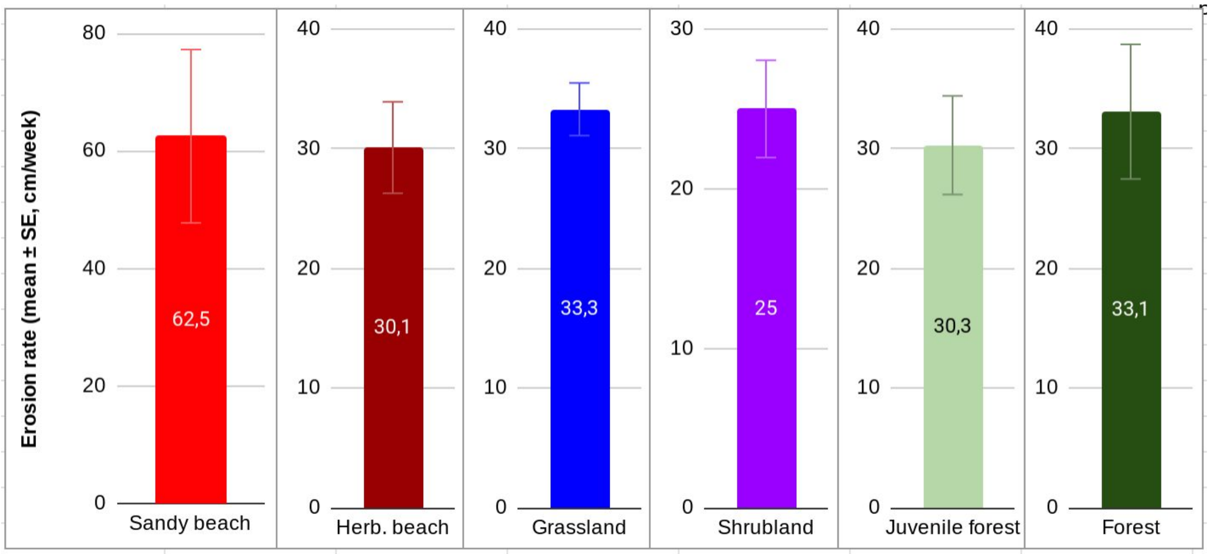


*Figure 9: The mean erosion rates for all vegetation types in cm per week, displayed in the centers. The error bars display the found standard errors.*

*Table 5: The results that were found with the ANOVA.*

| Variable | Value |
|---|---|
| K (amount of groups) | 6 |
| N | 55 |
| Sum of squares (SS) between groups | 71,05 |
| SS within groups | 22,07 |
| Degrees of freedom (dF) between groups | 5 |
| dF within groups | 49 |
| F-statistical value | 0,68 |
| P-value | 1,34 |
| F-critical value | -2,45 |

Table 5 displays all information that is used in the calculation of the ANOVA. The outcomes are the F-statistic value of 0,68, the P-value of 1,34 and the F-critical value of -2,45.

## 4 Discussion

In this chapter all results will be interpreted and reflected on, to create a better understanding of the data in chapter 3 and the paper as a whole.

### 4.1 Low erosion rates

The results (in this case Figures 6 and 8) show that, in general, the vegetation types ‘Herbaceous beach’ and ‘Shrubland’ experience the lowest average and median weekly erosion rates. This is most likely related to the plant density. Other studies have shown that the decrease of water-caused erosion is exponential in relation to an increasing vegetation density (Gyssels & Poesen, 2003). Herbaceous beach, grassland and shrubland have the most dense vegetation of all the vegetation types. The reason that grasslands has not reported a low erosion rate, can be due to the lack of measurements and the lack of occurrence of grasslands within the transect. This may have resulted in unreliable data for this part. Furthermore, the density and types of roots can play a potentially large role in combating erosion. For example, plants with fibrous root structures are able to hold more sediment compared to plants with tap roots.

### 4.2 High erosion rates

The data collected at the Forest and Sandy beach vegetation types do not show consistent reliable high erosion rates. This should be the case when one considers the logic explained in the previous paragraph, as the plant density in these areas is in general significantly lower. A reason for this might be the extreme amounts of debris, mainly in the form of plastic pollution and big tree stems. This debris was especially abundant between transect posts 20 and 25, where simultaneously a lot of the sandy beach vegetation type has been found. Measurements at areas with sandy beach outside the 20-25 range often did result in high erosion rates, for example fixed points 1, 13.25 and 13.5. These all show an average weekly erosion rate of more than 100 cm per week. This was only found once between transect posts 20-25, at fixed point 22.5. The high amounts of debris might have protected the sandy beach from erosion, while it had already been washed away in the other (less polluted) parts of the beach transect. It has been suggested that large woody debris like tree stems can hold enough sand to form sand dunes over time, which negatively affects the erosion rate (Eamer & Walker, 2010). Also, it was not possible during this study to consider the shapes and forms found under the water surface. There might be something below the water surface like a sudden increase/decrease in depth at the areas where less severe erosion was measured. The flow of the currents was also not considered and might play a role.

### 4.3 Analysis of variance and shortage of data

However, when the results of the ANOVA are considered, it becomes clear that there is no significant variation observed between vegetation types and their response towards erosion. This result should mean that conservation scientists should not focus on vegetation type composition if their means are to prevent or reduce coastal erosion. However, several studies have found that destroying plant communities like coastal forests increases the vulnerability of the coasts. This is seen in many countries, including Thailand (Thampanya, Vermaat, Sinsakul, & Panapittukul, 2006), India (Gopinath & Seralathan, 2005), Sri Lanka (Samarayanke, 2003) and Vietnam (Cat, Tien, Sam, & Bien, 2006). The demand and interest for using forests and trees for coastal protection is growing as a result of these findings (Prasetya, 2006). This can be a reason to doubt the reliability of the outcome of the ANOVA in this study. This particular result may be caused by the unreliability of the dataset due to the lack of plentiful and consistent data, as the result is contradicting expectations (which were along the lines of the described matter in paragraphs 4.1 and 4.2). The datasheet that was used for this study was planned to contain more information. The total time for data collection was set beforehand at eleven weeks. However, due to the outbreak of the COVID-19 pandemic in March (2020), the data collection had to be terminated early. This resulted in four or even three weeks of measurements, which was not enough to ensure a reliable datasheet. In paragraph 3.3, in figures 8 and 9, examples can be found which show the significant presence of outliers in the dataset. The early termination of this study has also limited the ability to gain additional information on the field, and to take more precise pictures to support this paper.

**4.4 Potential errors in the erosion measurements**

The method used for the data collection might not have been completely identical for every measurement. The direction of each measurement was always pointed at 60 degrees from the fixed point, with the goal of always measuring the same area of the eroded cliff. The GPS has proven to be not completely accurate in other surveys, but there was no alternative available. Also, it was very hard to consistently find the same measurement spot as the week before, because the measured cliff was often eroded in the meantime and thus changed shape. Furthermore, for the measurements of long slopes of beach, strong winds might have influenced the measurements. In some scenarios it was impossible to completely straighten the measurement tape, which most likely resulted in inconsistent measurements. The measurements were also not always done by the same two people, which also might have affected the measurements.

**4.5 Potential errors in vegetation type determination**

The goal for determining the vegetation types was to complete the entire beach transect in one day, with the same group of people, to ensure a consistent manner of determination. Unfortunately, during the first session of measurements, one of the group members had an accident and broke her leg. This resulted in a forced change in the group composition, as the injured group member could not continue the determination. This might have influenced the manner in which several variables were perceived. An example for this are the measurements for the ground cover percentage, which were done by estimation. Different people might estimate the same thing differently.

## 5 Conclusions and recommendations

Coastal erosion is in its essence a natural process. However, due to human induced climate change, sea levels are rising which increases the severity of coastal erosion all around the globe. This fact provides a potential threat for 100 million people that are living within one meter below mean sea level. Plant communities close to the ocean will not be able to handle the dramatic increase in salinity in their environment, once the coastal erosion reaches them. This puts these plant communities themselves at risk, but also humans and organisms that rely on them. Finally, there are also direct consequences for wildlife, with most obviously the marine sea turtles that are losing their ancestral nesting grounds due to coastal erosion.

This paper has investigated the relation between different coastal vegetation types and their response towards erosion. If a difference was to be found, this could provide valuable information on which vegetation types or plant communities can be used to prevent or slow coastal erosion. The study has taken place on a beach transect of 5 km in northeastern Costa Rica, called playa Norte. The main question for this study was “What is the relation between erosion rates and various vegetation types at playa Norte?”

### 5.1 Sub questions

To answer the main question, it is necessary to first evaluate the answers to the subquestions.

<u>Sub question one: What is the current rate of erosion?</u>
The measured rates of erosion per fixed point are very fluctuating. The lowest average weekly erosion rate is measured at fixed point 6.5 at 0 cm/week, while the highest average weekly erosion rate is measured at fixed point 13.25, at 269,5 cm per week. The total average of all measurements can be concluded at an erosion rate of 40,0 cm per week.

<u>Sub question two: What is the composition of vegetation types in playa Norte?</u>
Six coastal vegetation types can be observed at playa Norte: sandy beach, herbaceous beach, grassland, shrubland, juvenile forest and forest. They are distributed unevenly, with sandy beach as the most common (38,5%), followed by herbaceous beach (19,2%), shrubland (19,2%), juvenile forest (11,5%), grassland (7,7%) and finally forest (3,8%).
The last 1000 meters of transect entirely exists out of the sandy beach vegetation type, which is most likely due to the high amount of debris found there.

<u>Sub question three: How are the different vegetation types responding towards erosion?</u>
When one considers the measured average weekly erosion rates, it seems that the vegetation types with more dense plant communities, namely herbaceous beach and shrubland, experience the lowest erosion rates. When the median erosion rates are reviewed, the same conclusion can be drawn as herbaceous beach (6,9 cm/week) and shrubland (6,2 cm/week) score lower compared to the least dense vegetated sandy beach (18,95 cm/week) and forest (34,2 cm/week). However, an analysis of variance with a standard of 0,05 shows a F-statistic value of 0,68 and a P-value of 1,34. This concludes that there are no statistically significant differences found in (response to) weekly erosion rates between the vegetation types.

## 5.2 General conclusion

This study can not conclude that there is any significant relation present between vegetation types and their response towards erosion. However, as explained in paragraph 4.3, this might be questionable because of the shortcomings of the used dataset. Also, other studies have concluded that a relation between vegetation and erosion can exist.

## 5.3 Recommendations

It is recommended that this study is repeated with more abundant and reliable data, to double-check its findings.

It can be useful to further investigate the precise role that debris plays regarding coastal erosion. The difference between the role of debris coming from anthropogenic pollution and debris coming from natural sources can also be interesting. This might enable conservation scientists or inhabitants of coastal communities to understand how to create man-made structures to combat coastal erosion.

This study does, to some extent, show that it is useful to fortify coastal regions with dense plant growth in vulnerable locations in order to slow down or prevent coastal erosion. This is also shown in earlier mentioned studies. Therefore, it is still recommended to future conservation scientists and/or inhabitants of coastal communities to provide their erosion-experiencing shores with a high plant and root density to combat the occurrence or progression of erosion.

## References


Agır, S. U., Kutbay, H. G., Surmen, B., & Elmas, E. (2017). The effects of erosion and accretion on plant communities in coastal dunes in north of Turkey. *Rendiconti Lincei*, *28*(1), 203-224.

Brothers, J. R., & Lohmann, K. J. (2015). Evidence for geomagnetic imprinting and magnetic navigation in the natal homing of sea turtles. *Current Biology*, *25*(3), 392-396.

Cat, N.N., Tien, P.H., Sam, D.D. & N.N. Bien. 2006. Status of coastal erosion of Viet Nam and proposed measures for protection. This volume (abstract).

Caño Palma Biological Station official website - via http://www.coterc.org/cantildeo-palma-overview.html (consulted at 06/04/2020 & 09/04/2020)

Chabreck, R. H. (1982). The effect of coastal alteration on marsh plants. In *Proceedings of the Conference on Coastal Erosion and Wetland Modification in Louisiana: Causes, Consequences and Options. US Fish and Wildlife Service, Office of Biological Services, FWS/OBS-82* (pp. 92-98).

Cornell, S., Fitzgerald D., Frey, N., Georgiou, I., Hanegan, K.C., Hung, L.S., Kulp, M., Maygarden, D., Retchless, D. & Yarnal, B. (2019). Shoreline effect of Storms. *Earth 107: Coastal processes, Hazards, and Society.* - article via https://www.e-education.psu.edu/earth107/node/1519 (consulted at 05/05/2020)

Eamer, J. B., & Walker, I. J. (2010). Quantifying sand storage capacity of large woody debris on beaches using LiDAR. *Geomorphology*, *118*(1-2), 33-47.

Farbotko, C. (2010). 'The global warming clock is ticking so see these places while you can': Voyeuristic tourism and model environmental citizens on Tuvalu's disappearing islands. *Singapore Journal of Tropical Geography*, *31*(2), 224-238.

Feagin, R. A., Sherman, D. J., & Grant, W. E. (2005). Coastal erosion, global sea-level rise, and the loss of sand dune plant habitats. *Frontiers in Ecology and the Environment*, *3*(7), 359-364.

Gopinath, G. & P. Seralathan. 2005. Rapid erosion of the coast of Sagar island, West Bengal – India. Environment Geology, 48: 1058–1067

Green SXM - via http://greensxm.com/seashore-plants-in-sxm/ (consulted at 19/05/2020)

Gyssels, G., & Poesen, J. (2003). The importance of plant root characteristics in controlling concentrated flow erosion rates. *Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group*, *28*(4), 371-384.

Herralde De, F., Biel, C., Savé, R., Morales, M. A., Torrecillas, A., Alarcón, J. J., & Sánchez-Blanco, M. J. (1998). Effect of water and salt stresses on the growth, gas exchange and water relations in Argyranthemum coronopifolium plants. Plant Science, 139(1), 9-17.

Hooke, R. L., Martín-Duque, J. F., & Pedraza, J. (2012). Land transformation by humans: a review. *GSA today*, *22*(12), 4-10.

Houghton, R. A. (1994). The worldwide extent of land-use change. *BioScience*, *44*(5), 305-313.

Jouyban, Z. (2012). The effects of salt stress on plant growth. *Technical Journal of Engineering and Applied Sciences*, *2*(1), 7-10.

Kobayashi, N., Gralher, C., & Do, K. (2013). Effects of woody plants on dune erosion and overwash. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, *139*(6), 466-472.

Lewis, J. (1989). Sea level rise: some implications for Tuvalu. *Environmentalist*, *9*(4), 269-275.

Meixler, M. S., Kennish, M. J., & Crowley, K. F. (2018). Assessment of plant community characteristics in natural and human-altered coastal marsh ecosystems. *Estuaries and coasts*, *41*(1), 52-64.

Menn, I. (2002). Beach morphology and food web structure: comparison of an eroding and an accreting sandy shore in the North Sea. *Helgoland Marine Research*, *56*(3), 177-189.

Murphy, J. B., & Nance, R. D. (2004). How Do Supercontinents Assemble? One theory prefers an accordion model; another has the continents travel the globe to reunite. *American Scientist*, *92*(4), 324-333.

National Department of Agriculture South Africa (1999). Soil erosion. - via https://www.nda.agric.za/docs/erosion/erosion.htm (consulted at 05/05/2020)

Prasetya, G. (2006, August). Protection from coastal erosion. In *Proceedings of the Regional Technical Workshop, Khao Lak, Thailand* (pp. 28-31).

Reddy, M. S., Reddy, P. S., Subbaiah, G. V., & Subbaiah, H. V. (2014). Effect of plastic pollution on environment. *J Chemic Pharm Sci*, 28-9.

Rivas, M. L., Tomillo, P. S., Diéguez-Uribeondo, J., & Marco, A. (2016). Potential effects of dune scarps caused by beach erosion on the nesting behavior of leatherback turtles. *Marine Ecology Progress Series*, *551*, 239-248.

Stampfli, G. M., Hochard, C., Vérard, C., & Wilhem, C. (2013). The formation of Pangea. *Tectonophysics*, *593*, 1-19.

Ström, C. (2013). Rapid biodiversity assessment of a Neotropical rainforest using soundscape recordings. *Umea Universitet. Suecia*.

Thampanya, U., Vermaat, J.E., Sinsakul, S. & N. Panapitukkul. 2006. Coastal erosion and mangrove progradation of Southern Thailand. Estuarine, Coastal and Shelf Science, 68: 75–85.

Useful Tropical Plants - via http://tropical.theferns.info/viewtropical.php?id=Ipomoea+pes-caprae (consulted at 24/05/2020)

Williams, A. T., Rangel-Buitrago, N., Pranzini, E., & Anfuso, G. (2018). The management of coastal erosion. *Ocean & Coastal Management*, *156*, 4-20.

Zhang, K., Douglas, B. C., & Leatherman, S. P. (2004). Global warming and coastal erosion. *Climatic change*, *64*(1-2), 41.

## Appendix 1 - Locations of all fixed points

| Measurement # | GPS Coord. | Accuracy |
|---|---|---|
| 0 | 3704/2114 | 3m |
| 0.25 | 3712/2179 | 3m |
| 0.5 | 3711/2215 | 4m |
| 0.75 | 3712/2278 | 2m |
| 1 | 3707/2302 | 2m |
| 1.5 | 3677/2403 | 3m |
| 2 | 3614/2514 | 4m |
| 2.5 | 3580/2606 | 4m |
| 2.75 | 3555/2663 | 5m |
| 3 | 3548/2680 | 6m |
| 3.25 | 3518/2768 | 8m |
| 3.5 | 3501/2334 | 6m |
| 3.75 | 3488/2823 | 9m |
| 4 | 3465/2888 | 4m |
| 4.5 | 3413/2985 | 4m |
| 4.75 | 3389/3036 | 7m |
| 5 | 3382/3070 | 6m |
| 5.5 | 3341/3181 | 6m |
| 6 | 3313/3262 | 4m |
| 6.25 | 3274/3324 | 11m |
| 6.5 | 3260/3360 | 4m |
| 6.75 | 3240/3410 | 9m |
| 7 | 3239/3451 | 4m |
| 7.5 | 3183/3551 | 3m |
| 7.75 | 3167/3604 | 8m |
| 8 | 3146/3627 | 3m |
| 8.5 | 3123/3714 | 6m |
| 8.75 | 3096/3764 | 8m |
| 9 | 3076/3812 | 4m |
| 9.25 | 3049/3876 | 9m |
| 9.5 | 3026/3922 | 7m |
| 9.75 | 3018/3952 | 5m |
| 10 | 2997/3988 | 5m |
| 10.25 | 2973/4035 | 9m |
| 10.5 | 2965/4081 | 4m |
| 11 | 2944/4145 | 4m |
| 11.5 | 2882/4260 | 3m |
| 11.75 | 2873/3414 | 2m |
| 12 | 2855/4366 | 3m |
| 12.5 | 2796/4475 | 5m |
| 13 | 2769/4551 | 4m |
| 13.25 | 2754/4583 | 4m |
| 13.5 | 2730/4674 | 4m |
| 13.75 | 2716/4703 | 6m |
| 14 | 2705/4740 | 3m |
| 14.25 | 2684/4791 | 3m |
| 14.5 | 2671/4827 | 3m |
| 14.75 | 2632/4904 | 9m |
| 15 | 2615/4937 | 3m |
| 15.25 | 2607/4958 | 7m |
| 15.5 | 2573/5045 | 3m |
| 15.75 | 2570/5061 | 5m |
| 16 | 2546/5112 | 5m |
| 16.5 | 2553/5130 | 8m |
| 17 | 2496/5230 | 8m |
| 17.25 | 2460/5325 | 5m |
| 17.5 | 2432/5404 | 5m |
| 18 | 2403/5474 | 5m |
| 18.25 | 2382/5542 | 3m |
| 18.5 | 2365/5580 | 4m |
| 19 | 2335/5650 | 5m |
| 19.5 | Turtle beach lod | |
| 20 | 2256/5869 | 3m |
| 20.5 | 2206/5980 | 3m |
| 21 | 2166/6043 | 4m |
| 21.25 | 2156/6071 | 3m |
| 21.5 | 2137/6149 | 3m |
| 22 | 2096/6203 | 6m |
| 22.5 | 2060/6329 | 3m |
| 23 | 2022/6415 | 4m |
| 23.5 | 2005/6482 | 3m |
| 24 | no tree/cliff | - |
| 24.5 | 1894/6709 | 3m |
| 25 | 1870/6780 | 3m |

**Appendix 2 - Protocol for measuring erosion (M&M)**

## Beach erosion rate protocol

*Rick van der Haar* *May 2020* *Caño Palma Estación Biológica*

### Materials & methods

**Materials**

To do the measurements, the standard survey equipment (radio, GPS, first aid kit, notepad, pencils) should be brought. Next to this, it is necessary to bring a compass/phone, measuring tape (50m), plastic red tape and two straight sticks. The measurements should be done by no less than two persons.

**Methods**

Method for determining and marking fixed points (FPs)

Starting at transect post 0, which is the most southern post of the playa Norte transect (marked with an "0"), GPS coordinates are used to determine the fixed points. Every 50 meters northwards, a tree is marked with plastic red tape. The GPS coordinates should be written down. The red plastic marker is placed ideally at 1.20m height, but if this is not possible it should be noted. A back-up marker is placed directly under the 1.20m marker. **Important:** 120cm has to be measured from the ground up, to create a straight line from the ground. This should give an angle of ~90°, which is important for later calculations. The fixed points can be used as an anchor point for weekly measurements.

Method for measuring FPs - cliff distance

**[OLD METHOD, used for this thesis**] The **ring** of the measuring tape should be held against the marker on the FP. With the compass/mobile phone, the direction of 60 degrees is determined. At the cliff side, the second person hold the measuring tape and reads the distance. The distance should be measured at the highest point on the absolute edge of the cliff.

[NEW METHOD] The **ring** of the measuring tape should be held against the marker on the FP. A straight line perpendicular to the sea and cliff is set using the measuring tape. A marked stick is planted on the ground at a suitable point along the line, functioning as a reference for future measurements or in order to make it possible to construct the same line. The distance between the FP and the cliff can now be measured. If there is more than one cliff, both cliffs should be measured, but this should be limited to a maximum of two cliffs/measurements. More cliffs will potentially give different measurements each week, which can cause confusion.

Method for measuring cliff height

The measuring tape should be lain on the ground, and measurements start from the **0cm** mark. The distance between the ground and the highest point should be measured. The stick is used to make it easier to measure the cliff height, it should be placed at the highest point of the cliff so that the measurement tape can be held against it, so the height can be read. If it occurs that the cliff has a big angle and a second smaller cliff is formed at a lower level, they are both measured. However, the amount of cliff height measurements should be at maximum two measurements to avoid confusion.

When all of the above has been considered, the datasheet in Table 1 can be used. Please note that the GPS coordinates only have to be documented once, since there is no point in writing down the GPS coordinates every time. The coordinates can be used to locate a missing fixed point if this is necessary. The most practical way to measure is to start at transect post 0, and move up to the north measuring all the points you encounter. Or, if preferred, one can start at transect post 25 and do the same but then walking towards the south.

*Table 1: Datasheet for monitoring erosion rates*

**Date: xx-xx-xxxx** **Team: XX, XX**

| Measurement # | GPS Coordinates | Accuracy | Slope length | Cliff height | Notes |
|---|---|---|---|---|---|
| | | | | | |

**Analysis**

When the datasheet from Table 1 has been filled in, the distance between the tree and the eroded site on ground level can be calculated. The value at the "?" in Figure 1 is what needs to be determined. This is why it is important to always create a 90° angle when creating the fixed points.

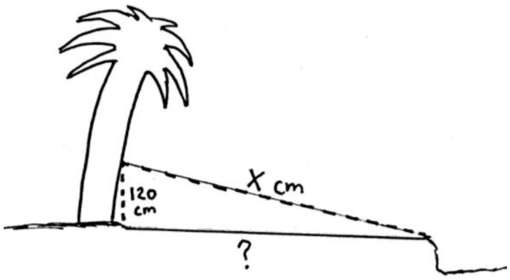


*Figure 3: The method of measuring the erosion illustrated.*

To calculate the "?" value from Figure 1, the Pythagorean theorem is used. This translates to

$$a^2 + b^2 = c^2 .$$

An example:

For the X value in Figure 1, we'll fill in 400cm. This will give the following values:

| | |
|---|---|
| a = 120 | $a^2 = 120^2$ |
| b = ? | $b^2$ = ? |
| c = 400 | $c^2 = 400^2$ |

To determine $b^2$, it is necessary to reformulate the Pythagorean theorem to $b^2 = c^2 - a^2$. When the values are filled in, this gives $b^2 = 400^2 - 120^2 \rightarrow b^2 = 145600 \rightarrow b = \sqrt{145600} \rightarrow$ **b = 381,58 cm**. This shows the true distance between the fixed point and the eroded site.

## Appendix 3 - Playa norte and its transect posts

Locations of all the transect posts can be found in the interactive map behind this QR code:

Or this link:

https://www.google.com/maps/d/drive?state=%7B%22ids%22%3A%5B%221S3AggkRXXqnpd-mU3BNGwgSS0g_cOvR8%22%5D%2C%22action%22%3A%22open%22%2C%22userId%22%3A%22105611451460545542688%22%7D&usp=sharing

## Appendix 4 - Datasheets

https://docs.google.com/spreadsheets/d/1WhLEHa8DhkC4_PsESHJu4YDZoRfiMYet6D6I7UNnrCs/edit?usp=sharing