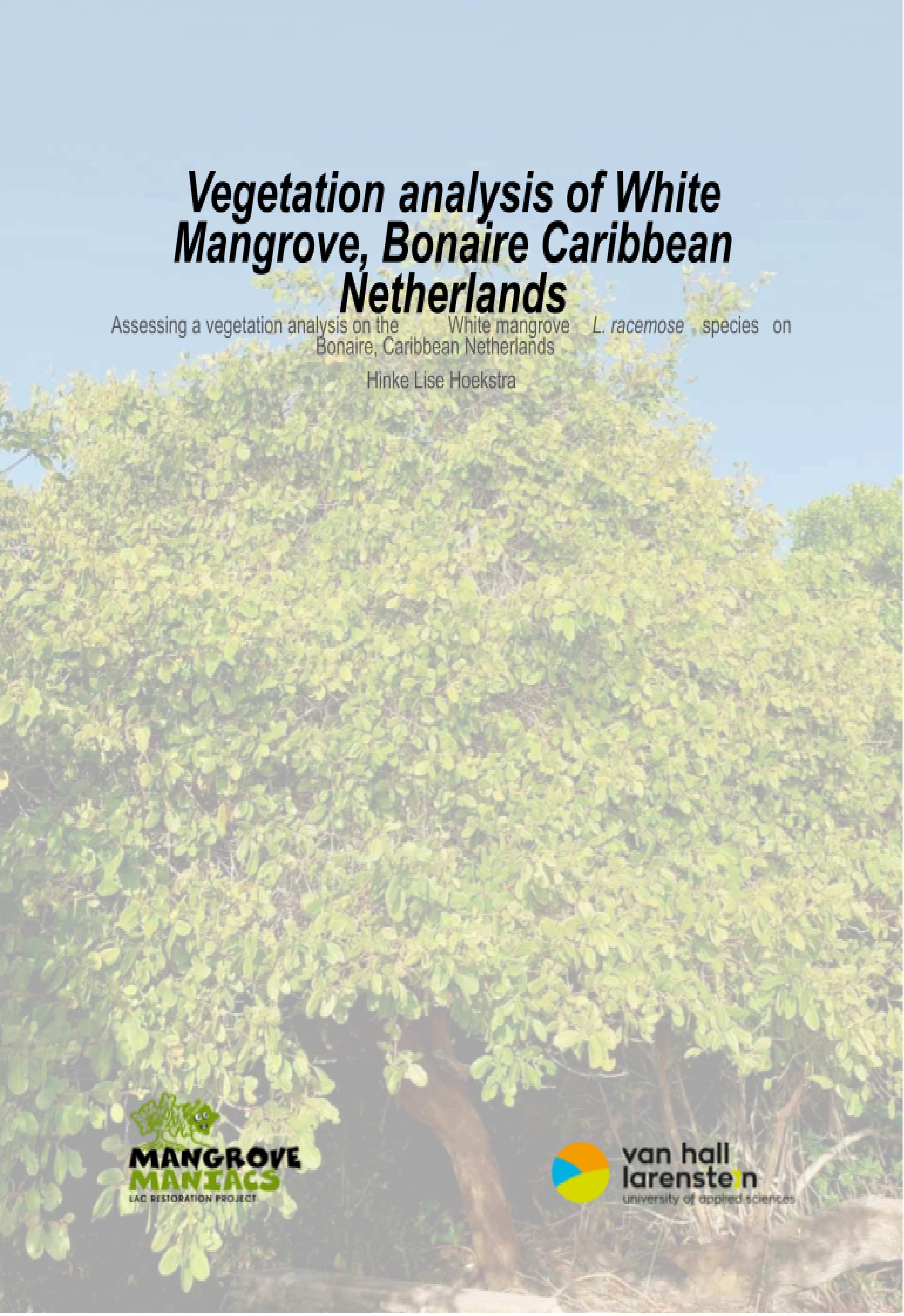

Vegetation analysis of White Mangrove, Bonaire Caribbean Netherlands

Assessing a vegetation analysis on the White mangrove *L. racemose* species on Bonaire, Caribbean Netherlands

Hinke Lise Hoekstra

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14 February – 14 July 2023

Project internship on the occurrence and state of the White mangrove Laguncularia racemosa on Bonaire, Caribbean Netherlands

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University of Applied Scienecs Van Hall Larenstein

Module LKZ360VE

Abstract

A study was conducted on Bonaire, Caribbean Netherlands, focusing on the White mangrove (Laguncularia racemosa) to gather information regarding its abundance and distribution, sediment characteristics, state and herbivory. The distribution range of the White mangrove species is quite extensive on Bonaire, Caribbean Netherlands. The species showed different types of adaptations to their environment, such as root system composition and tree height. The overall sediment composition of the White mangrove species on Bonaire is sand with a limestone foundation underneath. Furthermore, the study on the herbivory brought forth several species that are potentially responsible for the herbivory on the White mangrove. Overall, this study provides a base for filling up the knowledge gap on the White mangrove species on the island of Bonaire and offers a foundation for further research and conservation efforts on the species.

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1. Introduction

Mangroves are one of the world's most productive ecosystems, which are distributed in tropical and sub-tropical coastal regions (Giri et al., 2011). These ecosystems are key in protecting coastal areas and communities and can play a big role in fighting climate change (Intergovernmental Panel on Climate Change, 2022). These forests protect against environmental stressors, including natural disasters such as cyclones, floods, soil erosion, solar UV-B radiation and sea level rise (Intergovernmental Panel on Climate Change, 2022). The systems serve as a barrier to other marine systems, including islands, seaweeds, coral reefs, and seagrass meadows (Debrot et al. 2018). Additionally, these forests are vital in regulating greenhouse gases and act as nutrient sinks and sediment traps that provide support to other coastal ecosystems in the food web (Kathiresan, 2021). Furthermore, they are of ecological importance by providing, feeding, breeding, and nursery ground for numerous marine species (Kathiresan, 2021). According to Kathiresan & Bingham (2001) the recognized number of mangrove species is estimated to be approximately 80, these are classified under 20 distinct plant families. The number of coexisting species within a mangrove forest can vary depending on the geographic location of the forest. Although the IUCN Red List currently categorizes the species as "least concern" on a global level, with the many threats these species have, the overall population size shows a declining trend (IUCN Red List, 2023). Threats that these forests face are for example deforestation and soil and water pollution (Spalding et al., 2016). A threat caused by human activities is climate change. It has caused a global rise of the sea levels (Intergovernmental Panel on Climate Change, 2022). It is known that mangroves are able to adapt to changes in their environment (LópezAngarita et al., 2016). However, to this current extent and taking into account other threats, such as pollution, the mangroves may be more vulnerable to these changes (Goldberg et al.,
2020; Srikanth et al., 2015; Giri et al., 2011). Nevertheless, mangrove forests are fundamental in mitigating climate change by capturing carbon for extended periods of time (Macreadie et al., 2017). Therefore, the protecting of these forest has been globally acknowledged (Intergovernmental Panel on Climate Change, 2022). One of the places the mangroves occur is on Bonaire, an island in the Dutch Caribbean (Debrot et al., 2018). The current state of the mangroves on Bonaire is classified as critically endangered as reported by WWF Neotropical Ecoregion (WWF, 2017). Thus, these mangrove ecosystems are protected by Cartagena Convention and the SPAW protocol (Debrot et al., 2018). Furthermore, the mangrove forests on Bonaire are situated in the protected Ramsar regions (Dutch Caribbean Biodiversity Database, 2023-b). On Bonaire, the identified species are the red mangrove (Rhizophora mangle), the black mangrove (Avicennia germinans) and the White mangrove (Laguncularia racemosa) (Debrot et al., 2018). The mangroves on Bonaire face significant threats, including the pollution of their surrounding soil and water, which ultimately impacts the health of the mangrove forest. Additionally, the silting of the mangroves and the disturbance of foraging bird species by tourism poses as a threat to the ecosystem (Debrot et al., 2018). The White mangrove species tends to be more sensitive to increased tidal heights and saltwater intrusion, therefore the species are expected to become more susceptible to adverse impacts of climate change (Ross et al., 2000; Simpson et al., 2011; Chowdhury et al., 2019). In comparison to the red and black mangrove species, this species distributes further land inwards. The species develops five types of roots to adapt to their environment, which are anchoring roots, cable roots, peg roots (pneumatophores), feeding roots and lateral aerial roots (pneumathodes), see Appendix IV (Angeles et al., 2002). These

specialized roots help the tree species to survive and thrive in waterlogged soil, strong tides and limited nutrient conditions (Kathiresan & Bingham, 2001). Pneumatophore roots are likely to develop in environments with low oxygen levels (Angeles et al., 2002). The species generally occurs on more elevated soils where tidal influx is sporadic (Wooller et al., 2003). Furthermore, the White mangrove species benefits from the burrowing of the fiddler crab (Uca spp.) (Smith et al., 2009). Fiddler crabs help to oxygenate the soil through their burrowing activities, which can create a more favourable environment for the roots of White mangroves to take up oxygen. Their height increased by 27%, trunk diameter by 25% and leaf production by 15% in comparison with crab exclusion (Smith et al., 2009). As stated in Debrot et al. (2018) there is insufficient data available to determine the current cover, distribution and state of the White mangrove species (Laguncularia racemosa) on Bonaire. This finding is supported by the Dutch Caribbean Biodiversity Database as well, as the database shows no data available for the species on Bonaire (Dutch Caribbean Biodiversity Database, 2023-a). Therefore, research is needed in order to better understand the occurrence, cover and state of this species (Debrot et al., 2018). Thus, the objective of this research is to monitor the White mangroves species on Bonaire and give insight on the occurrence, cover and status of the species. Scientific data plays a critical role in informing conservation efforts, and as such, further investigation and monitoring of the White mangrove on Bonaire is necessary to ensure the preservation of this species on Bonaire (Debrot et al., 2018) as mangroves are vital for the preservation of the coastal areas due to the effects of climate change (IPCC, 2022).

2. Research questions

- How abundant is the White mangrove (*Laguncularia racemosa*) on Bonaire, Caribbean Netherlands, and what is its current distribution?
- What is the state of the White mangrove (Laguncularia racemosa) on Bonaire, Caribbean Netherlands?
- What are the sediment characteristics of the White mangrove (*Laguncularia racemosa*) on Bonaire, Caribbean Netherlands?
- Which insect(s) causes the herbivory on the White mangrove (*Lagunculaira racemosa*) on Bonaire, Caribbean Netherlands?

3. Materials and methods

3.1. Study species

The White mangrove (*Laguncularia racemosa*) can either grow as a shrub or tree. The distribution of the species ranges from North, Central and South America, The Caribbean and Africa (Carol & Rathcke, 2007; Ketner, 2001). The species is also known as Fototi and Mangel on Aruba, Mangel blanku on Bonaire and Curaçao and Romangel on Curaçao (Ketner, 2001). As a pioneer species (Tomlinson, 1986) this mangrove species demonstrates adaptability through five different root types: anchoring roots, cable roots, pneumatophores, feeding roots, and lateral aerial roots known as "pneumathodes" (Jenik, 1970). An interesting characteristic of the species is the ability for self-pollination and self-fertilization. After the flowering period their fruits which are produced all contain one single seed (Baker, 1955). The fruits which are dispersed by water (Carol & Rathcke, 2007). Additionally, according to Baker (1955) these factors may be advantageous for colonization of open habitats.

3.2. Study area

The study area for this research is Bonaire, part of the Dutch Caribbean, see Figure 1. The data collection is conducted at various sites on the island, see Figure 2.

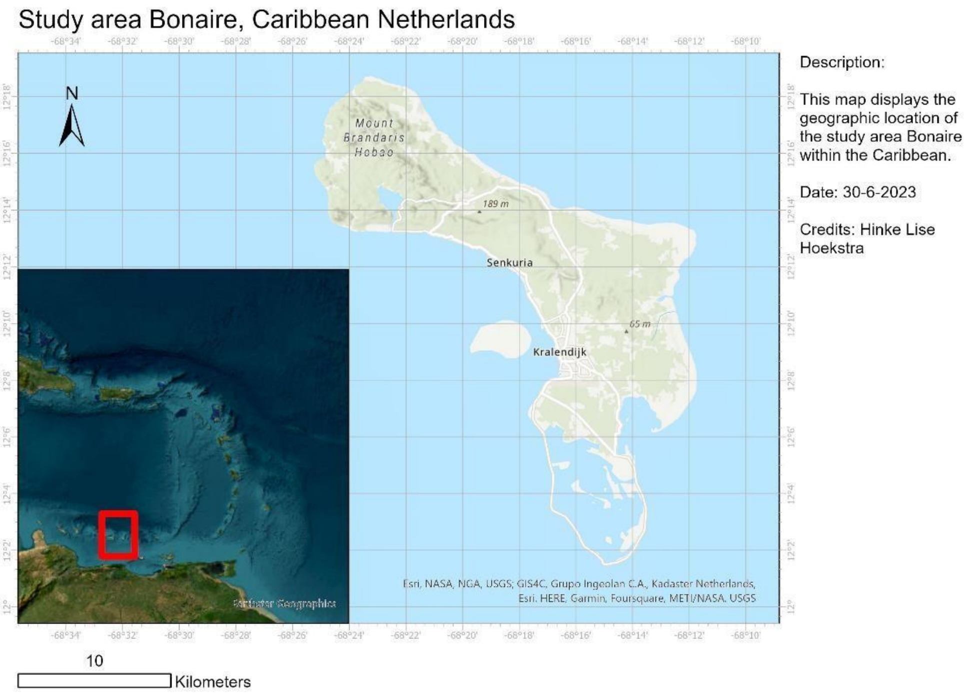

Figure 1: A geographical location map of the study area

3.3. Data collection

Overview conducted plots

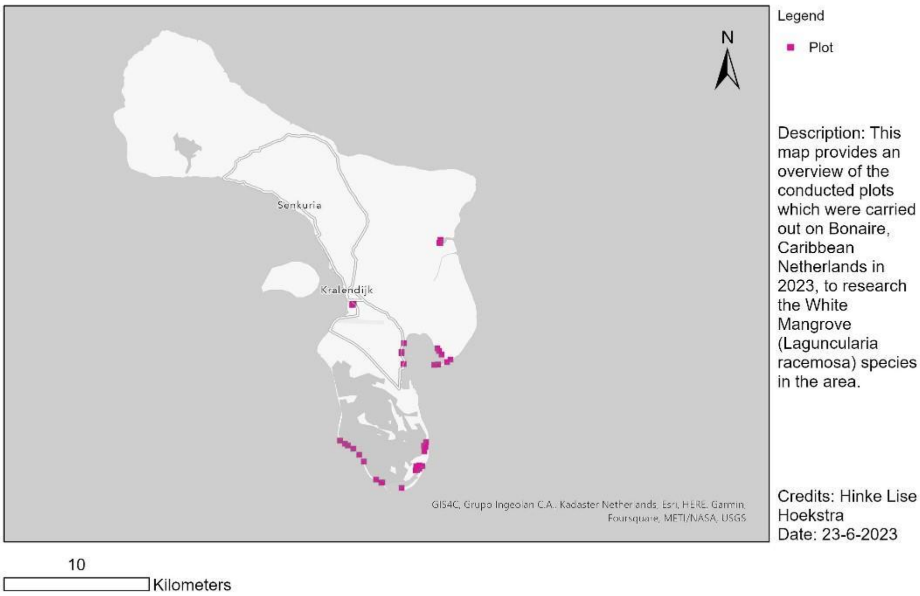

Figure 2: A overview of the conducted plots on Bonaire, Caribbean Netherlands

3.3.1. Data collection vegetation analysis

The data collection process included various measurements and observations. A vegetation analysis was performed, see Appendix I for the full protocol. This analysis involved surveying a 5 by 5 meter plot, within which a smaller 1 by 1 meter plot was examined. The count of White mangrove, red mangrove, black mangrove, and buttonwood individuals was recorded in each plot.

To assess herbivory or predation on the White mangrove species, ten randomly selected leaves were observed, and the presence or absence of herbivory/predation was recorded as "yes" or "no". This provided a percentage indicating the extent of herbivory/predation per plot. Additionally, the presence or absence of peg roots and flowers on the trees was noted using the same "yes" or "no" notation.

The height of randomly selected trees within each plot was measured using different methods depending on their growth form. For shrub-like White mangroves, the height was measured using a measuring tape or measurement tape reel, from the sediment to the highest point of the shrub. Taller trees were assessed using the stick method, as described in the tree height measurement protocol in Appendix III. However, this method is mentioned in the discussion as difficulties with the measurements occurred. The girth of three random trees per plot was measured using a measurement tape at the widest part of the stem.

Each plot and the number of trees within them were registered using the ArcGIS Field Maps App (app version 23.1.0). The collected data from the vegetation analysis was compiled in a Microsoft Excel database (version 2301) and used for further data analysis.

3.3.2. Data collection jar-test

Additionally, a soil sample was taken within each plot and carefully stored in a labelled zip log bag, see Appendix II.

3.3.3. Data collection insect inventory

The beating tray method was employed to gather data for identifying herbivory on the White mangrove species. A detailed protocol for this method can be found in Appendix V. Insects captured during the process were carefully stored in labelled jars. Subsequently, the insects were photographed using a dino-flagellate microscope camera, and additional pictures were taken using a regular camera. The resulting images were organized and stored in a designated folder, labelled with alphanumeric codes (e.g., "2a"), as multiple pictures were taken of each insect. The locations of the insect inventory are illustrated in Figure 3, 4 and 5.

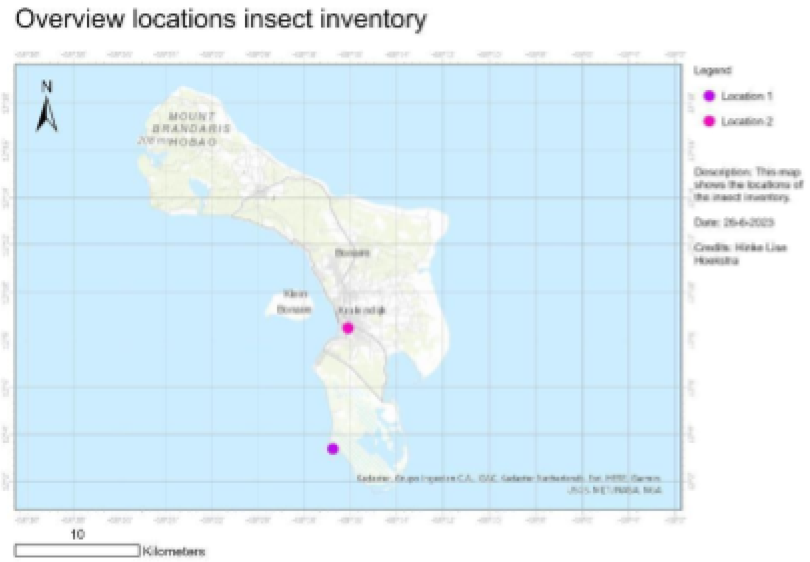

Figure 3: Map of locations of the insect inventory

Figure 4: Map of location 1 of the insect inventory

Figure 5: Map of location 2 of the insect inventory

3.4. Data analysis

Data exploration and analysis were conducted using multiple tools and methods, including Excel, ArcGIS Pro, ArcGIS Field Maps and observations from aerial photographs in Google Earth, and consultations with insect experts through personal communication. These various approaches were employed to thoroughly examine and analyse the collected data.

3.4.1. Data analysis vegetation analysis White mangrove

The data collected from the vegetation analysis has been explored and analysed using pie charts and boxplots to visualize the tree height, tree girth, herbivory percentage, burrow occurrence percentage, peg root occurrence percentage, sediment type overview, seedling occurrence percentage, and flowering state occurrence percentage.

3.4.2. Data analysis jar-test

The jar test is a method used to classify soil types based on their particle size distribution. It involves filling a jar with soil, adding water and detergent, shaking vigorously, and allowing the soil to settle in distinct layers over a period of time. By measuring the heights of the settled layers, the percentages of sand, silt, and clay can be calculated. These percentages help determine the soil type using a classification triangle, see Figure 6. The jar test provides a simple and effective way to analyse soil composition and understand its characteristics, see Appendix II for the protocol of the jar-test.

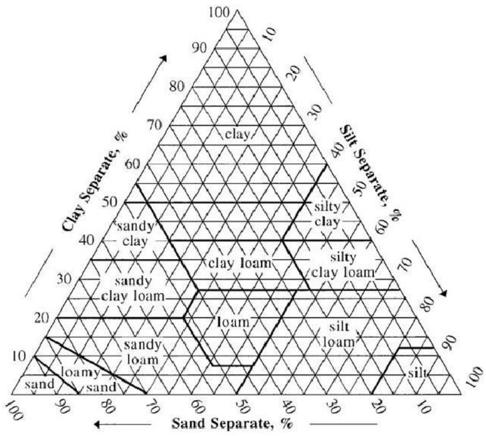

Figure 6: USDA soil texture triangle (University of Nebraska-Lincoln Extension, n.d)

3.4.3. Data analysis insect inventory

To analyse the herbivory on the leaves of the White mangrove, the Dino-Lite Microscope Premier AM7013MT was used to capture detailed images of the herbivory damage as well as the collected insects, see Figure 7. Species identification was carried out by referring to the Dutch Caribbean Species Register website, which offers comprehensive information on various species. This online resource served as a valuable reference for obtaining general species information during the analysis process.

Figure 7: Dino-Lite Microscope Premier AM7013MT (AnMo Electronics Corporation, 2016)

4. Results

4.1. Distribution White mangrove (Laguncularia racemosa) on Bonaire, Caribbean Netherlands

The distribution map provides an overview of the recorded occurrences of the White mangrove species, Laguncularia racemosa. It includes locations identified through vegetation analysis, quick scans, and predicted areas where the presence of White mangrove is expected. The locations collected through the vegetation analysis are named as “data point site” in the legend of Figure 8. Additionally, data points from other locations where the White mangrove is present were collected, but were not included in the final dataset. These locations are referred to as “quick scan site” in the legend. Thirdly, the legend of Figure 8 includes “potential site”. These are locations were the White mangrove species could occur. However, further research and investigation is needed to gain knowledge about these sites. The overall map shows a schematic distribution of the White mangrove on Bonaire. The species occurs around almost all the southern part of the island as shown in Figure 8. Also around and on the islands within Lac Cai the species is present.

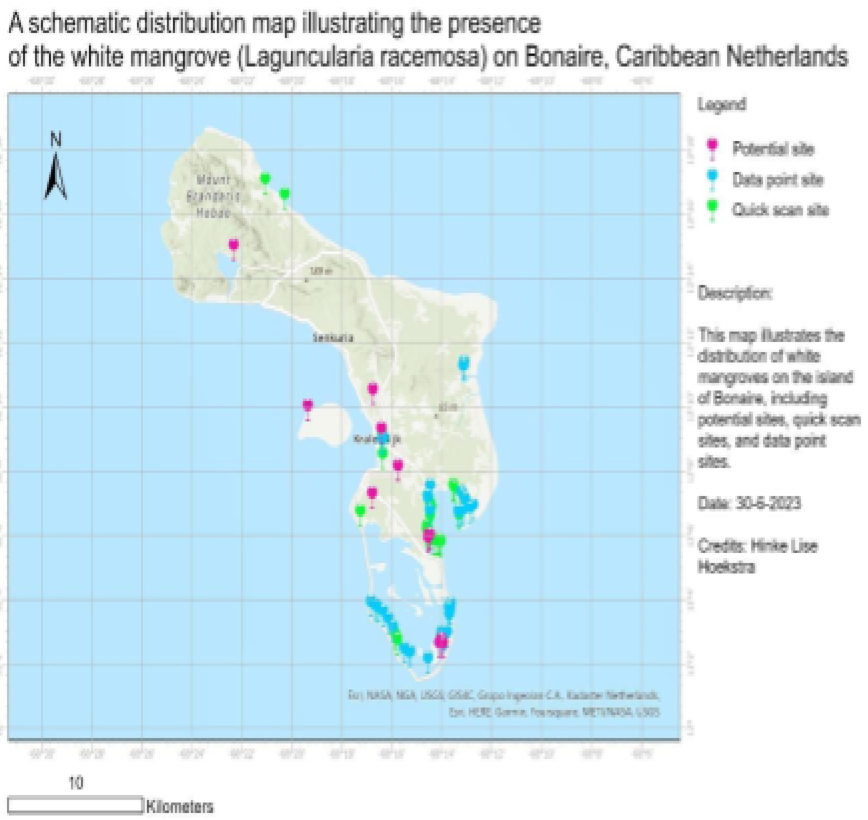

Figure 8: A schematic distribution map of white mangrove presence on Bonaire, Caribbean Netherlands including potential sites, data point sites and quick scan sites.

4.2. Results jar-test analysis

According to the findings from the jar-tests, it was observed that the White mangroves within the surveyed plots predominantly thrive in sandy substrates, as illustrated in Figure 9.

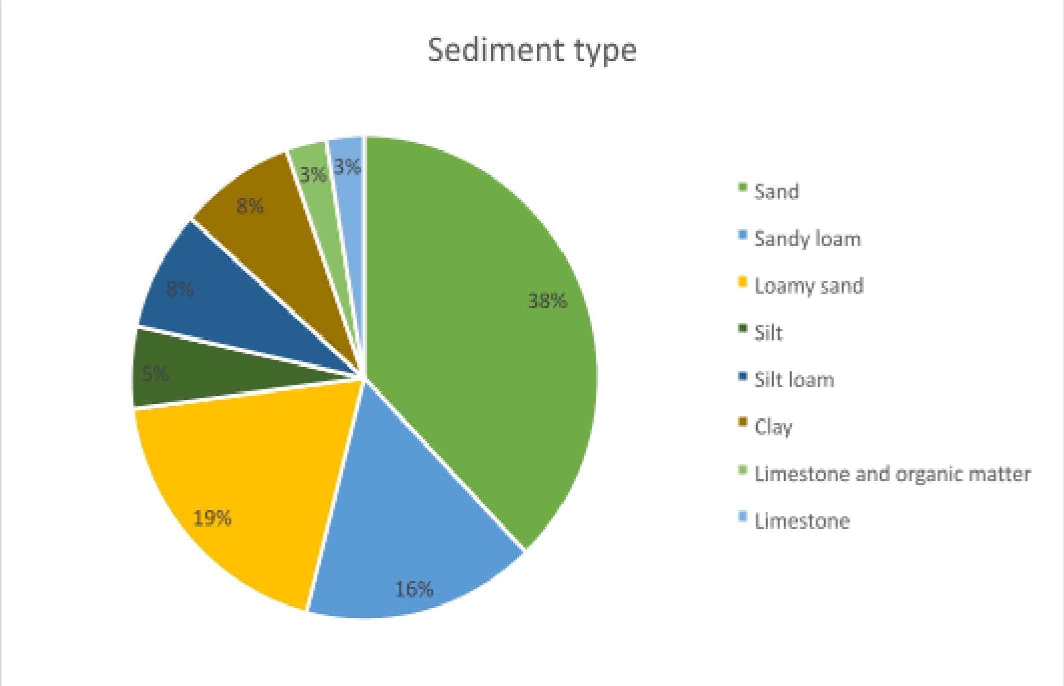

Figure 9: Results of jar-test analysis

4.3. Results Google Earth analysis

The investigation of clay sediments brought forward that clay is almost exclusively present in Kralendijk. To determine the timeframe of White mangrove growth in this area, I examined aerial images from Google Earth, see Appendix IV Figures 24, 25, 26 and 27. Based on observations, it can be inferred that the White mangroves included in my vegetation analysis have been growing at this location for approximately twenty years. Based on these observations it can be concluded that the distribution of the species has still been expanding in this area the last twenty years. Additionally, this observation suggests that clay sediment serves as a favourable substrate for the thriving of White mangroves, see Figure 10 and 11.

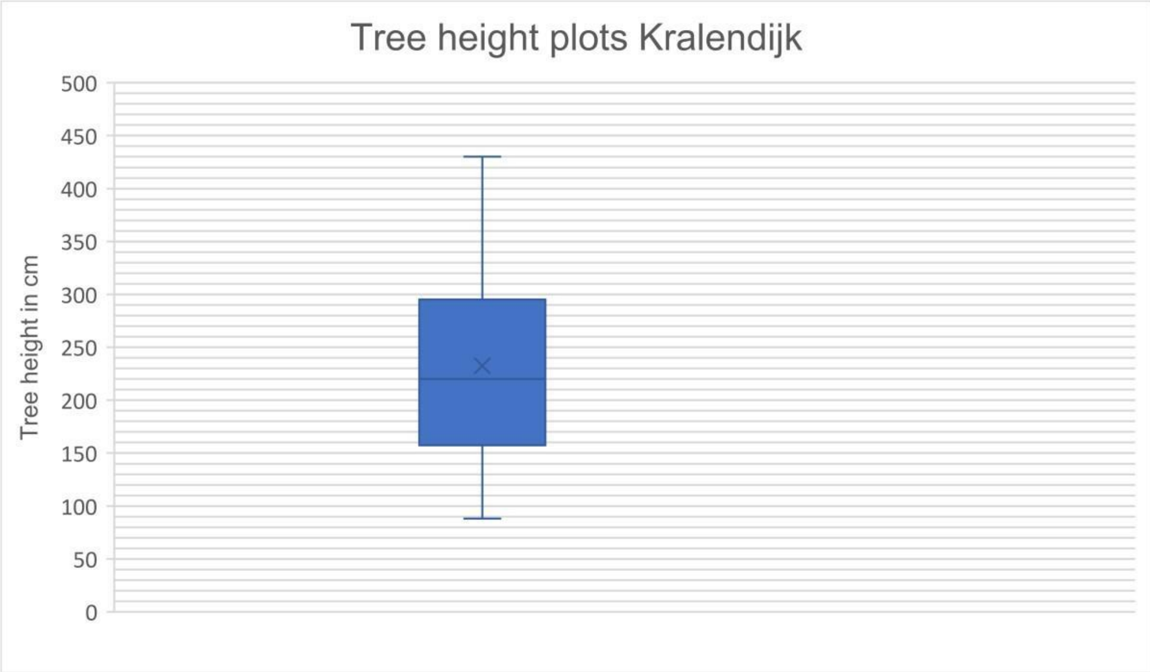

Figure 10: Tree height of the White mangrove in Kralendijk

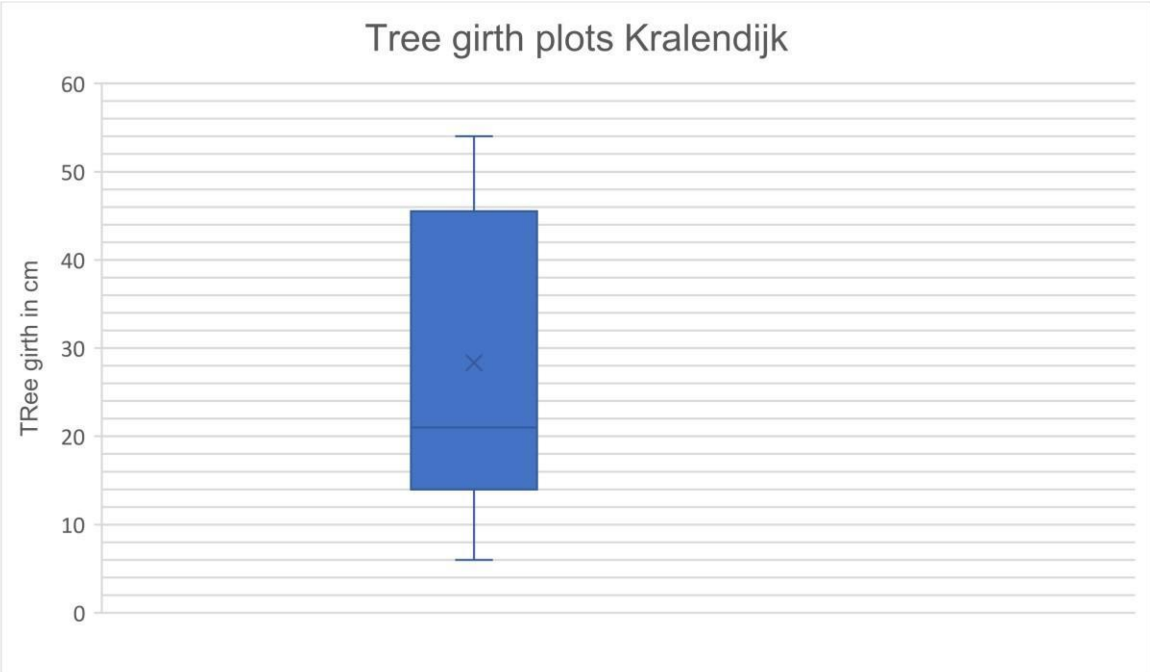

Figure 11: Tree girth boxplot of the White mangroves in Kralendijk

4.4. Results vegetation analysis White mangrove (Laguncularia racemosa)

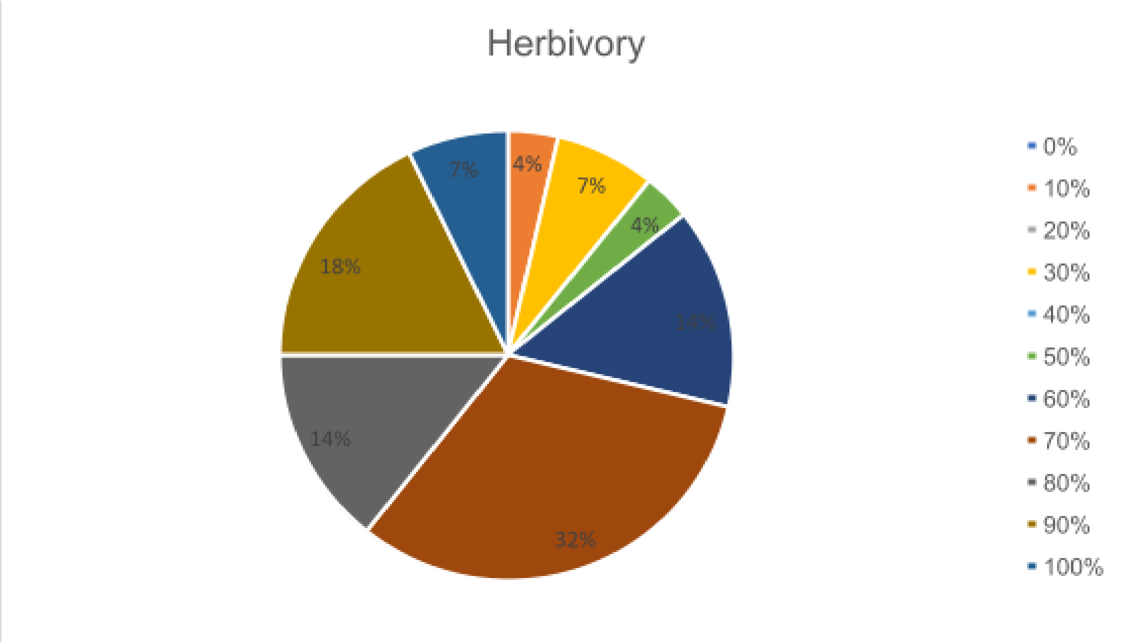

Figure 12: Percentage of herbivory within the plots

Herbivory on the White mangrove was observed in all of the surveyed plots, as shown in Figure 12. In Appendix VIII the Figures 45, 46 and 47 illustrate what the herbivory looks like. The legend on the right side of Figure 12 displays the varying percentages of herbivory on the trees within a plot, ranging from 0% till 100%. The circle diagram presents the distribution of herbivory percentages, with each percentage represented by a different colour. The extent of herbivory varied across the plots, but was present in all the surveyed plots.

Furthermore, Figure 41 in Appendix VIII presents a circle diagram illustrating that peg roots were present in 44% of the surveyed plots. Figure 42 in Appendix VIII displays another circle diagram showing that 18% of the plots exhibited a flowering state. Additionally, Figure 43 in Appendix VIII also displays a circle diagram which indicates that burrow presence was observed in 46% of the surveyed plots. Furthermore, it was observed that seedlings were present in 22% of the surveyed plots, as illustrated in Figure 44 in Appendix VIII.

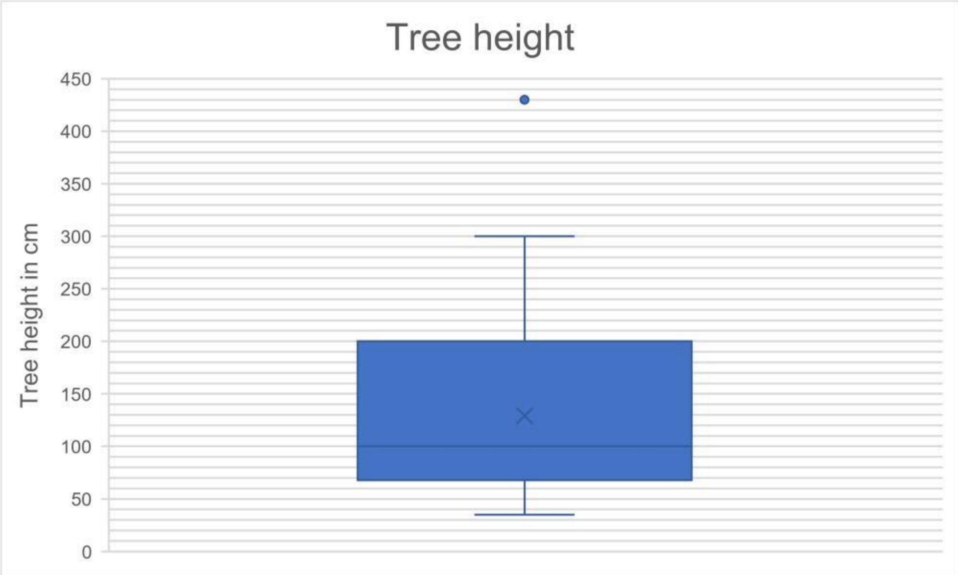

Figure 13: Tree height White mangrove

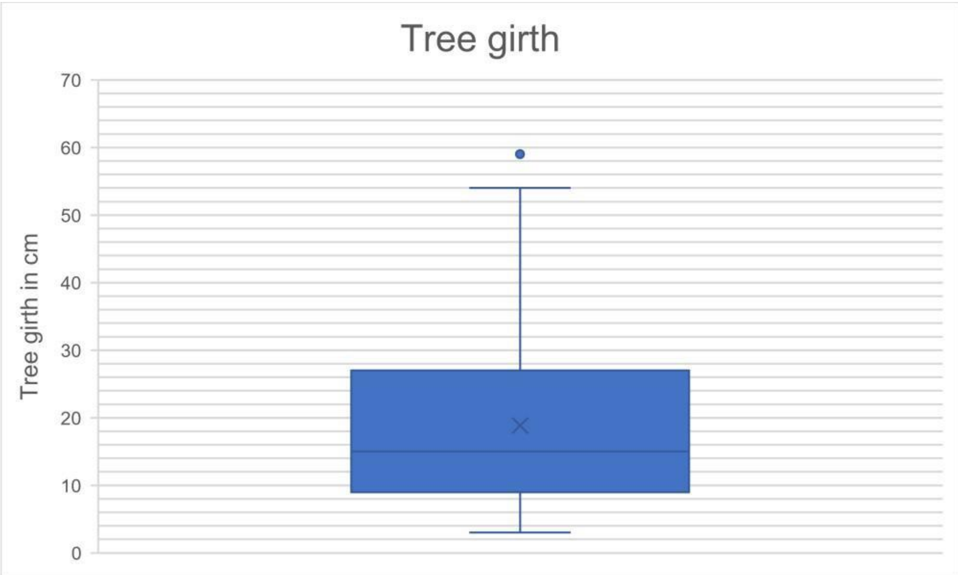

Figure 14: Tree girth White mangrove

The boxplot, Figure 13, illustrates that the total height distribution of White mangrove trees within the surveyed plots is ranging from approximately 40 centimetres (cm) to 5.9 meter (m). The mean within the surveyed plots is 1.80 meter (m). The population of White mangrove species displays a notable presence of young trees as evident from the girth graph, see Figure 14. The total tree girth within the surveyed plots ranges from approximately 4 centimetres (cm) till 58 centimetres (cm). The mean tree girth is approximately 19 centimetres (cm) see Figure 14. Moreover, there are observations of trees with significant tree girth, suggesting a considerable number of mature individuals within the population.

The graphs provide an overview of the observed trends within the surveyed plots, and provide insight into the herbivory, peg root presence, flowering state, burrow presence, seedlings presence, tree height and tree girth of the White mangrove population.

4.5. Results insect inventory

As mentioned in Chapter 4.4. all the White mangroves showed signs of herbivory. The insect inventory provided information about the species living on the White mangrove and the possible insects that could cause the herbivory on the species.

In total four out of the seventeen collected species have been identified, see Table 1 and 2. Two of the idenified species are illustrated in Appendix VII Figure 38, 39 and 40. During the insect inventory two caterpillar species have been found, see Figure 15, 16, 17 and 18. The Figures 19, 20 and 21 show the locations of where the caterpillars were observed.

Common name	Latin name
European Honey Bee	Apis mellifera
Umbrella Paper Wasp	Polistes myersi
Juniper Shield Bug	Cyphostethus tristriatus
Quick Silver Spider	Argyrodes argentatus

Table 1: Identified insect species

Common name	Latin name
Caribbean Land Hermit Crab	Coenobita clypaetus
Mangrove Periwinkle	Littoraria angulifera

Table 2: Other identified species

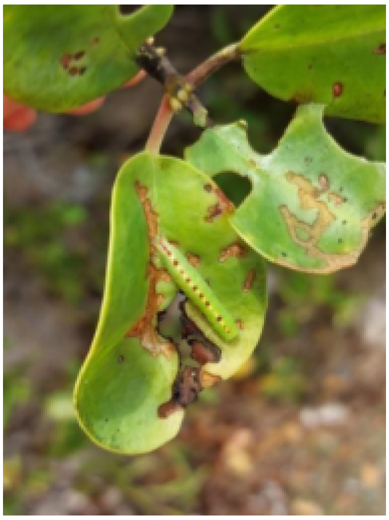

Figure 15: Caterpillar B

Figure 16: Faeces of caterpillar B

Figure 17: Caterpillar B

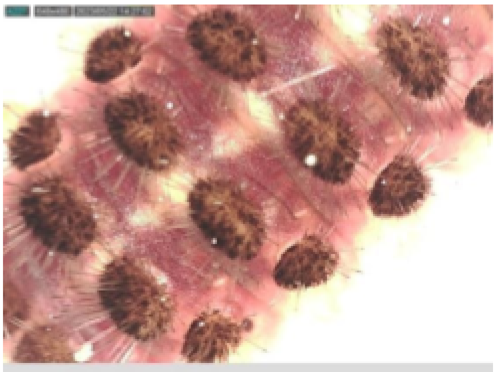

Figure 18: Caterpillar B

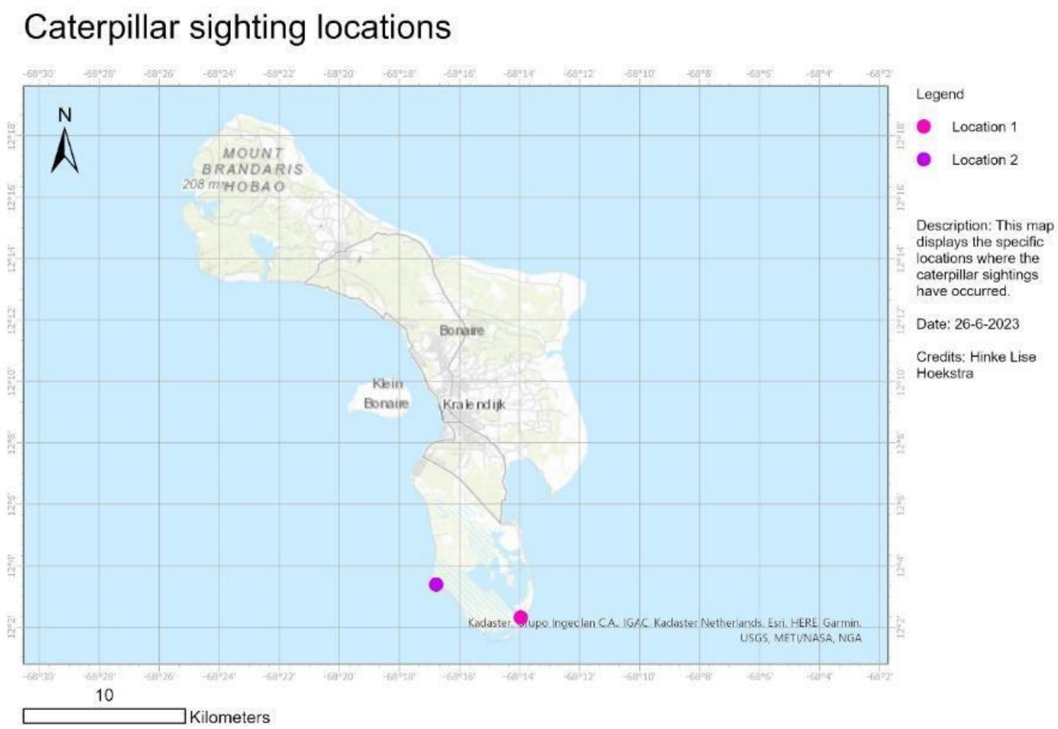

Figure 19: A map of the locations of the caterpillar sighting on the white mangrove locations

Figure 20: A geographical location map of location 1 of the caterpillar sighting

Figure 21: A geographical location map of location 2 of the caterpillar sighting

5. Discussion

The aim of this study was to gain knowledge about the abundance and distribution, state, sediment characteristics and herbivory of the White mangrove species on Bonaire, Caribbean Netherlands. To gather relevant data and insights for the mentioned aspects of the White mangrove population several methods were employed. The methods used for this were a vegetation analysis, jar-tests, the beating tray method and Google Earth imagery analysis.

This study, which included a vegetation analysis of the White mangrove species on Bonaire, showed that the distribution range of the White mangrove species on the island is quite extensive, see Figure 8. The distribution range includes areas in Lac Bay. A previous study of Smith et al. (2011) mentioned the occurrence of the White mangrove (Laguncularia racemosa) on Bonaire. However, Davaasuren & Meesters (2011) does not mention the White mangrove species in Lac Bay. The study of Davaasuren & Meesters researched the extent and health of mangroves in Lac Bay using satellite data.. Additionally, in the map of Freitas et al. (2005) illustrates the ecological vegetation map of the island of Bonaire areas . When comparing the results of this study and the study of Freitas et al. (2005) the White mangrove distribution overlaps with the buttonwood (Conocarpus erectus) distribution.

In Chapter 4.4 Figure 13 illustrates the results of the height observations and measurements. However, it is important to note that there were larger trees observed that were not included during the surveying. Therefore, the recorded tree heights do not fully represent the maximum height that White mangroves can attain on Bonaire. Thus, Figure 13 exclusively represents the tree height of the White mangrove within the surveyed plots. As for the tree girth this is also an representation of the White mangroves within the surveyed plots.

In Chapter 4.5 only the species that were able to be identified are mentioned in Table 1. During the insect inventory more species were collected. However, due to time limitations the other species have not yet been identified. Additionally, it has to be mentioned that the insect inventory was only done at two locations. A more comprehensive inventory could give a better insight into the all the insects on the White mangrove.

According to the results of the jar-tests the overall sediment type in which the White mangrove occurs on Bonaire is sand. However, underneath the sand layer a base of limestone is present (Dutch Caribbean Biodiversity Database, 2023-c).

To ensure a more comprehensive representation of tree heights, the decision was made to include trees located at the back of the plots in addition to the original protocol. However, when it came to taller trees, implementing the protocol became challenging due to obstructing trees in front, which made it impossible to accurately measure the distances required. This had as consequence that the accuracy of the higher trees is less precise. However, the estimate of the trees was done with human size height and discussing the estimate.

The jar-test method has been an effective way. This simple yet efficient technique offers a quick and concise evaluation of sediment types, providing a clear understanding of the specific sediment environments where White mangroves thrive. The jar-test method is a cost-effective approach that offers a preliminary assessment of sediment type and was recommended by my internship supervisor at Mangrove Maniacs.

Due to the occurrence of the studied species as both a shrub and vegetation, some adjustments had to be made to the vegetation analysis protocol. These adjustments resulted in a delay in the research progress. To prevent such issues, it would have been beneficial to conduct a thorough literature study prior to the fieldwork instead of attempting it concurrently. This approach would have helped me anticipate the presence of the studied species as a shrub and make the necessary adjustments in advance, thus avoiding any delays in future research.

Some complications with the understanding of notations by the volunteers who assisted me. This miscommunication resulted in incomplete data, necessitating revisiting the same locations. Despite providing a protocol and conducting an example plot, it was still unclear to the volunteers about the tasks they were required to perform.

The beating tray method, which was acquired through personal communication with Naturalis, proved to be highly effective for conducting the insect inventory. This method is widely employed in the field of entomology and has been extensively utilized by researchers. Its reliability and success rate make it a commonly adopted technique for insect sampling.

6. Recommendations

1. A pilot study could be conducted to do several outplant pilot locations along the coast in the south alongside EEG Boulevard. This area is located within the distribution of the White mangrove species as illustrated in Figure 8. Additionally, the girth of the White mangrove species in the south is relatively high, which indicates the species to thrive in this area. Furthermore, observations during the fieldwork showed that the White mangrove species tends to grow better when growing simultaneously with other mangrove and plant species, see Appendix IX. It is therefore important to take into account when a pilot study for the outplant will be conducted. An outplant could include planting the White mangrove seedlings with Buttonwood and/or Red mangrove and/or Sesuvium-Lithophila.
2. As mentioned in Appendix IX Sesuvium-Lithophila has been an frequently observed plant species around the seedlings. It is hypothesized that the species helps the growth of the seedlings by protecting them against heat stress by keeping the soil more moist.
3. Based on the results of the jar-test and the Google Earth Imagery it can be suggested that clay is a very nutritious soil type for the White mangrove species to grow. This observation presents an opportunity for future studies on cultivating White mangrove seedlings, specifically by investigating whether clay improves the growth in cultivation environments.
4. Google Earth imagery can be a way to see the changes in the distribution of the White mangrove. An example is given in Chapter 4.3. Additionally, this information can be useful to locate suitable outplant sites. Places where they naturally spread out can be looked at to see what they're preferred environments are.
5. As for the insect inventory a more comprehensive study on the White mangrove could be conducted as the insect inventory of this study showed already 17 different insect species. More information about the insects living on this mangrove species could be valuable to give an better understanding of the ecological role of the species.
6. Employing drones can be an useful instrument to gain a comprehensive understanding of the distribution of the White mangrove species on Bonaire. This approach has advantageous in areas that are otherwise inaccessible. Additionally, a digital record of the distribution will be documented and thereby could be of use for future analysis.
7. As mentioned in Appendix VI, personal observations showed that the White mangrove appears to have a tree-like growth form and thrives well when coexisting with other mangrove species., a study could be conducted to investigate the frequency of White mangrove's occurrence in coexistence with the Red mangrove, Black mangrove and Buttonwood species. The vegetation analysis also included an inventory of the coexistence of the White mangrove with the Red mangrove, Black mangrove, and Buttonwood species. However, the available data is insufficient to draw definitive conclusions from this analysis.

7. Conclusion

In conclusion, the research conducted on Bonaire, Caribbean Netherlands addressed the main research question of assessing the abundance and distribution of the White mangrove (Laguncularia racemosa) species. The vegetation analysis revealed that the White mangrove is a common species on the island, with an extensive distribution range, see Figure 8. This highlights the significance of the White mangrove as an ecological species on Bonaire.

Based on the findings of the insect inventory it can be concluded that the herbivory is not caused by one species only, but a combination of different species as there are different herbivory patterns present. This is amplified by the different kinds of herbivory on the leaves of the White mangrove species, see Appendix VIII. Additionally, the insect inventory further emphasised the ecological importance of the White mangrove. It serves as a habitat for numerous insect species, highlighting its role in supporting insect biodiversity and ecological interactions.

Overall, these findings contribute to help filling the knowledge gap regarding the White mangrove (Laguncularia racemosa) species on Bonaire. The study results provides insights into the abundance, distribution, state and ecological significance of this mangrove species, which contributes to a better understanding of the local ecosystem and aiding in conservation efforts. However, further research is needed to get a more sufficient understanding of the distribution of the White mangrove species on Bonaire.

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Appendix

Appendix I: Vegetation analysis protocol

The vegetation analysis consists of plots of 5x5 meter and 1x1 meter. The plots will be conducted on several sites on Bonaire, Caribbean Netherlands, see Appendix I. The ArcGIS Field Maps app will be used to mark where plots of the vegetation analysis are located. The collected data can be stored in the app and will be written manually in a notebook.

Within the 5x5 meter plots the amount of adult white, red and black mangrove trees will be counted. Additionally, an estimate of the tree height will be made by random selection of three trees within the 5x5 meter plot, see Table 1 for more details. The 1x1 meter plot will be randomly selected within the 5x5 meter plot. In the plot the herbivory, seedling presence, peg roots presence, flower presence, burrow presence and sediment type will be notated.

Table 3: 5x5 plot

Variable	Measurement scale	Note
Adult White mangrove	Amount	The counted trees can be marked to avoid a counting bias when density is high
Adult Red mangrove	Amount	The counted trees can be marked to avoid a counting bias when density is high
Adult Black mangrove	Amount	The counted trees can be marked to avoid a counting bias when density is high
Adult Buttonwood	Amount	The counted trees can be marked to avoid a counting bias when density is high
Tree height White mangrove	Cm/m	Average tree height of three random trees within the 5x5 m plot, see Appendix III for more details on the tree height measurement.
Tree girth White mangrove	Cm	Average of tree random trees within 5x5 m plot.

Herbivory White mangrove	Amount	Ten random selected leaves will be taken as a representative for the herbivory. For example: 4 of the 10 leaves has herbivory. This will result in a 1 to 10 scale or approximately 40% herbivory within the plot.
Sediment type	Limestone (1) – sand (2) – (loam) soil (3)	Take a sample of the sediment when other than limestone.
Peg roots White mangrove	yes (1) – no (2)	
Flower presence White mangrove	yes (1) – no (2)	

Table 4: 1x1 meter plot within the 5x5 meter plot

Variable	Measurement scale	Note
Seedling presence White mangrove	Amount	A seedling is defined by its non-wooden bark and an adult tree by its wooden bark (see Appendix II). The seedlings will only be counted in the 1x1 meter plot. Optionally, note how many small (<15 cm), medium (15-25 cm) and large (>25 cm)
Burrows	Amount	The burrows will only be counted in the 1x1 meter plot.

The data is stored in an excel document. The data points will be stored in the ArcGIS Field Maps App.

NOTE: For the vegetation analysis proper shoes or booties, a hat and enough water and sunscreen/UV clothes are advised. As we will be out in the sun for the quite some of the analyses

Appendix II: Jar-test protocol

The jar-test is used to classify the different soil types based on their particle size distribution. The following protocol is derived from University of Nebraska-Lincoln Extension (n.d.)

1. Using a mesh sieve or old colander, sift the soil to remove any debris, rocks, and large organic matter (leaves, sticks, roots, etc.).
2. Fill the jar ⅓ full of the soil to be tested
3. Fill the remainder of the jar with clean water, but leave some space at the top.
4. Add 1 tablespoon of powdered dishwashing detergent
5. Cap the jar and shake vigorously until the soil turns into a uniform slurry.
6. Set on a level surface and time for one minute.
7. Place a mark the outside of the jar, showing the coarse sand layer settled at the bottom of the jar. Jar showing the silt layer.
8. Leave the jar in a level spot for 2 hours.
9. Mark the top of the next settled layer with the permanent marker. This is the silt layer.
10. Leave the jar on a level spot for 48 hours.
11. Mark the top of the next settled layer with the permanent marker. This is the clay layer that has settled on top of the silt layer.
12. Using a ruler, measure and record the height of each layer, and the total height of all three layers.
13. To calculate the proportions (percentages) of sand, silt, and clay use the formulas below. The 'total' height of mixture is the same as the clay layer.

% Sand = (height of sand) / (total height of mixture)

% Silt = [(height of silt) – (height of sand)] / (total height of mixture)

% Clay = 1 – %Sand – % silt

14. Determine the soil type using the pyramid from USDA, see Figure 22.

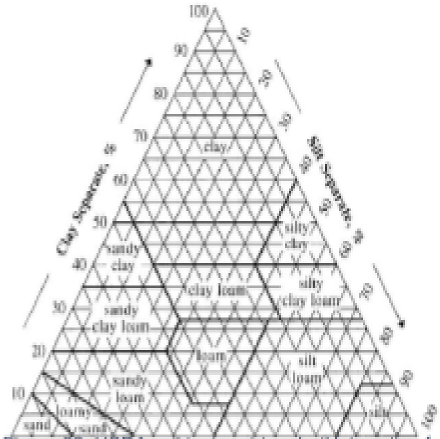

Figure 22: USDA soil texture triangle (University of Nebraska-Lincoln Extension, n.d)

Appendix III: Tree height measurement protocol

The White mangrove species grows in shrub like form and as a tree. Therefore two different methods are used to determine the height within a plot based on its form. Within each plot the height of tree random selected trees are determined. The average of the three trees represents the estimate height of the plot.

The smaller shrubs and trees are measured by using a measuring tape, see Figure 23. The shrub or tree will be measured from the stem or sediment of the tree till the highest part of the shrub or tree.

The taller trees are measured by means of trigonometry, see Figure 23. This method only works on level ground. It requires a stick and a distance measuring tape.

1. The stick must be the same length as your arm or grasped at a point where the length of the stick above your hand equals that of your arm.
2. The stick is held pointing straight up, at 90 degrees to your outstretched, straight arm.
3. Carefully walk backwards until the top of the tree lines up with the top of your stick.
4. Mark where your feet are.
5. The distance between your feet and the tree is roughly equivalent to the height of the tree. (University of British Columbia, n.d.).

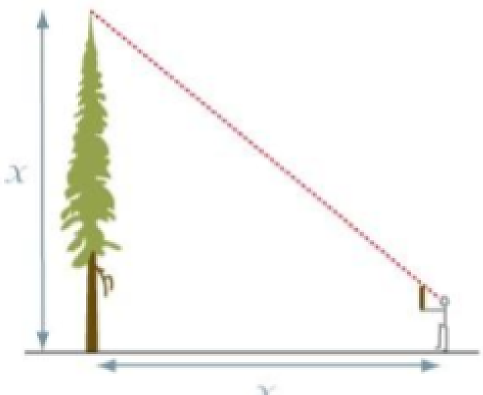

Figure 23: Stick method for tree height measurement

Appendix IV: Google Earth

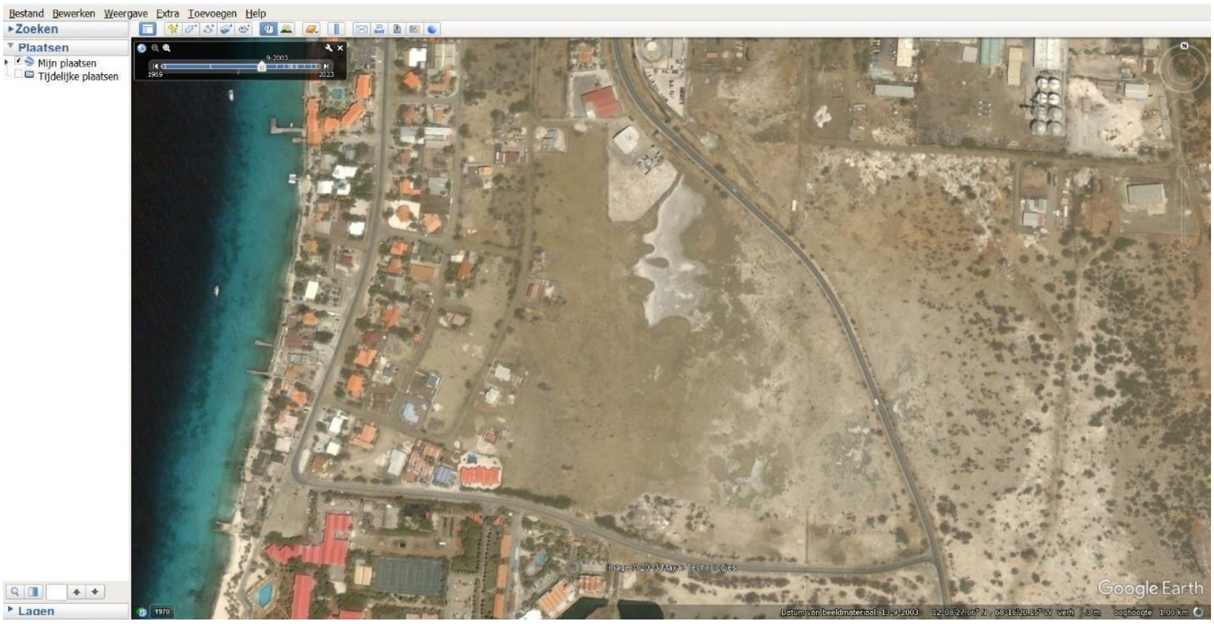

Figure 24: Google Earth image 2003

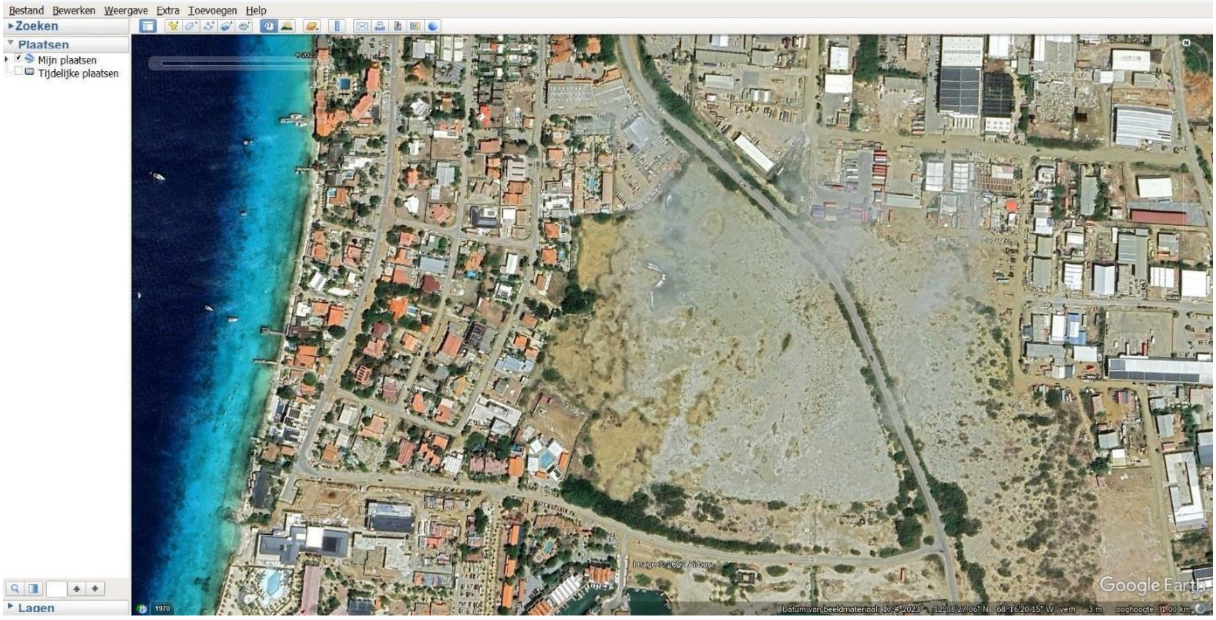

Figure 25: Google Earth image 2023

Figure 26: Google Earth image 2023

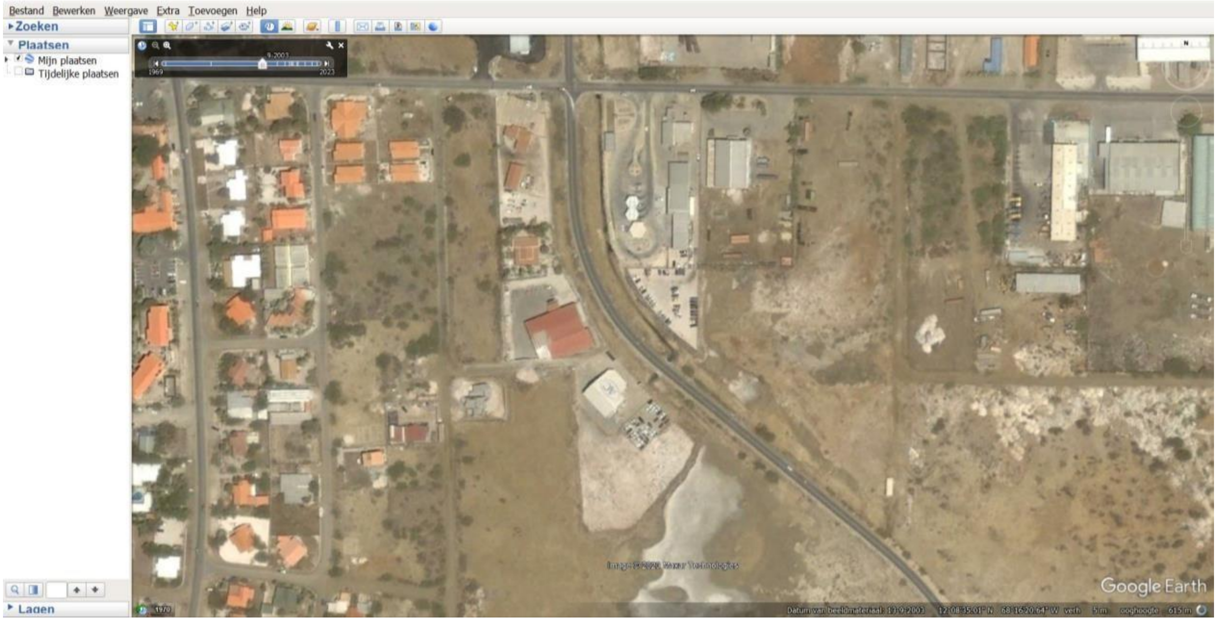

Figure 27: Google Earth image 2003

Appendix V: Beating tray method protocol

To gain insight on the insect living on the White mangrove the beating tray method is used to collect insects. This protocol is received from personal communication with Naturalis.

1. Prepare a large, sturdy, preferably white umbrella and small containers with lids. Place a label in each container to record the sampling location.
2. Find a suitable mangrove area to conduct the sampling. Ensure you have permission if needed and consider any ethical guidelines or environmental regulations.
3. Hold the umbrella upside down beneath the mangrove canopy, positioning it to catch any falling insects.
4. Take a sturdy stick and strike the mangrove leaves and branches forcefully. This action, known as "beating," dislodges the insects, causing them to fall into the open umbrella.
5. After beating, wait for a moment near the umbrella to allow the insects to start moving again. This allows for better visibility and collection.

6. Observe the collected insects in the umbrella. Note that flying insects may quickly fly away, so focus on the ones that have fallen into the umbrella.
7. Carefully transfer the collected insects into the labelled containers using small brushes, forceps, or by gently shaking them into the containers.
8. To euthanize the insects for preservation, place a piece of toilet paper soaked in ethyl acetate-based nail polish remover (avoiding acetone-based removers) in each container. The fumes will immobilize and euthanize the insects. Ensure the lid is tightly closed to prevent leaks.
9. Store the containers in a cool and dry place until further analysis or identification.

Appendix VI: Personal observations

Based on the numerous sites which have been visited, it appears that the White mangrove grows bigger and higher and thus thrives better alongside the Red mangrove, Black mangrove and Buttonwood. It is hypothesized that this is due to the competition for light. Additionally, several root systems were found during the fieldwork, as illustrated in the Figures 29, 30, 31 and 32. Another observation was the growth of fruits of the White mangrove as illustrated in Figure 37 and 38. As described in Chapter 4.4 the White mangrove species is a habitat for several insect species. One of the insect findings is the ant and aphid relation which was observed at location 2 of the insect inventory, see Figure 35 and 36. During the fieldwork, the presence of spiders on the White mangrove was observed, along with frequent sightings of spider nests, see Figure 35 and 36. A plant species that is frequently present next to White mangrove seedlings is Sesuvium-Lithophila. It is hypothesized that the presence of Sesuvium-Lithophila enhances soil's water retention capabilities and provides protection against heat stress as the soil was less dry compared to sites without the plant species.

Figure 28: Root system 1

Figure 29: Root system 2

Figure 30: Root system 3.a

Figure 31: Root system 3.b

Figure 32: Fruit growth 1

Figure 33: Fruit growth 2

Figure 34: Spider web

Figure 35: Spider web

Figure 36: Aphid on White mangrove

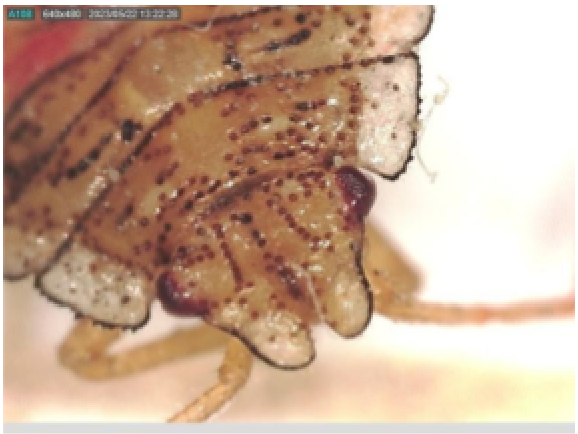

Figure 37: Aphid

Appendix VII: Images of insects

Figure 38: Juniper Shield Bug Cyphostethus tristriatus

Figure 39: Quick Silver Spider Argyrodes argentatus

Figure 40: Mite species on white mangrove

Appendix VIII: Results of vegetation analysis illustrated in circle diagrams

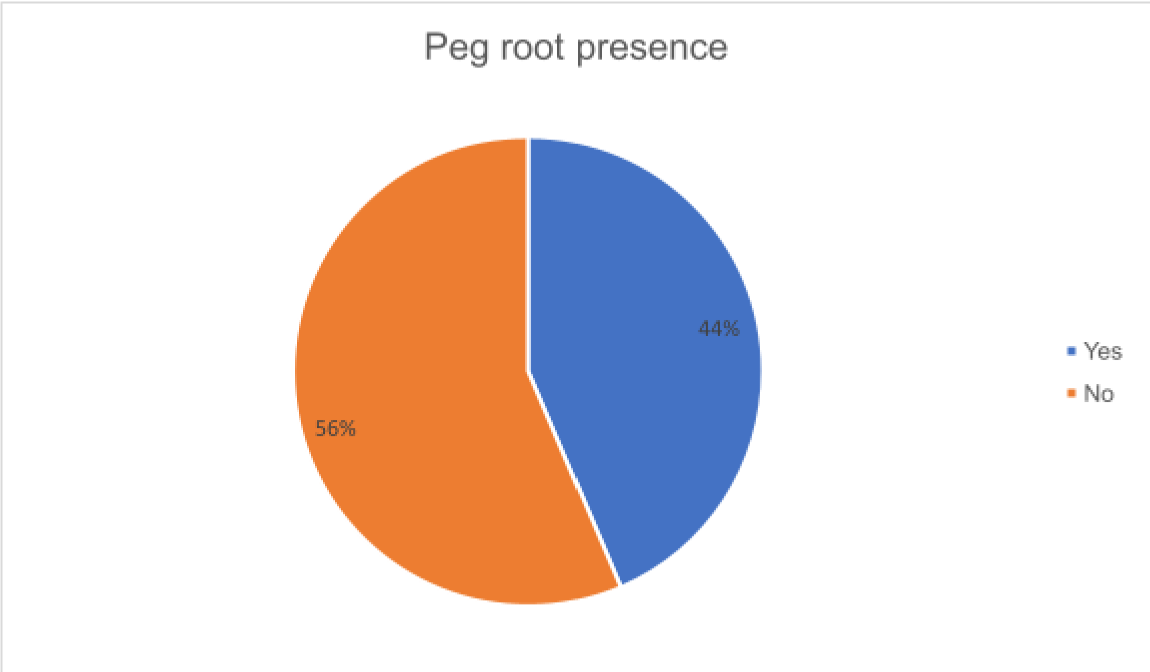

Figure 41: Peg root presence within the surveyed plots

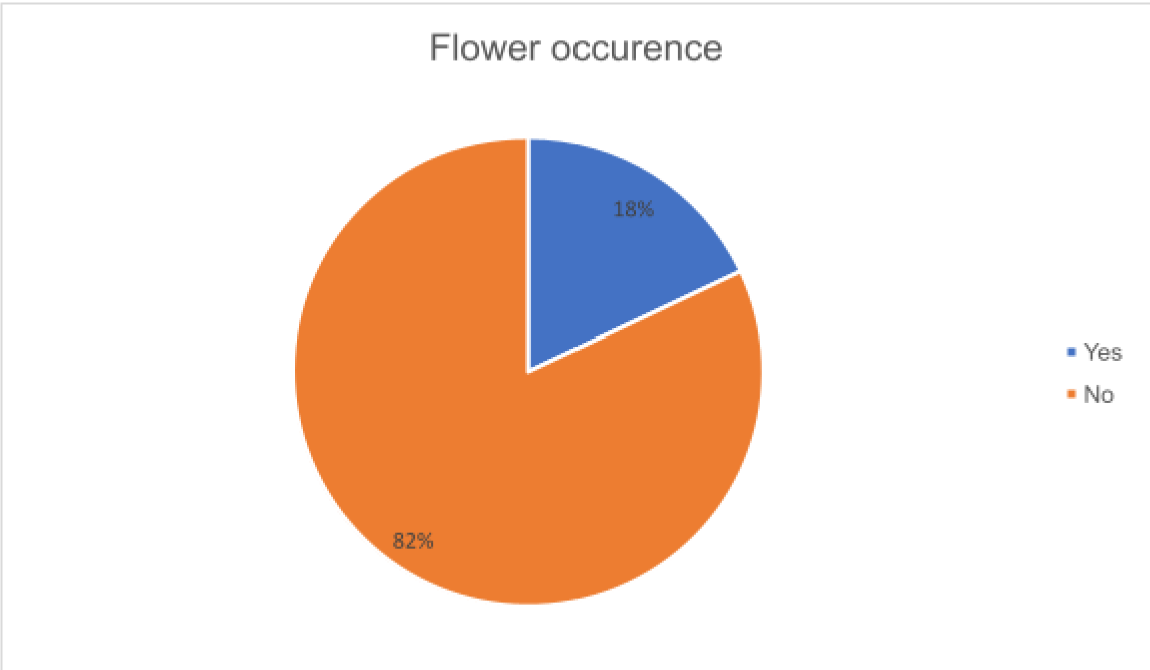

Figure 42: Flowering state of the White mangrove within the surveyed plots

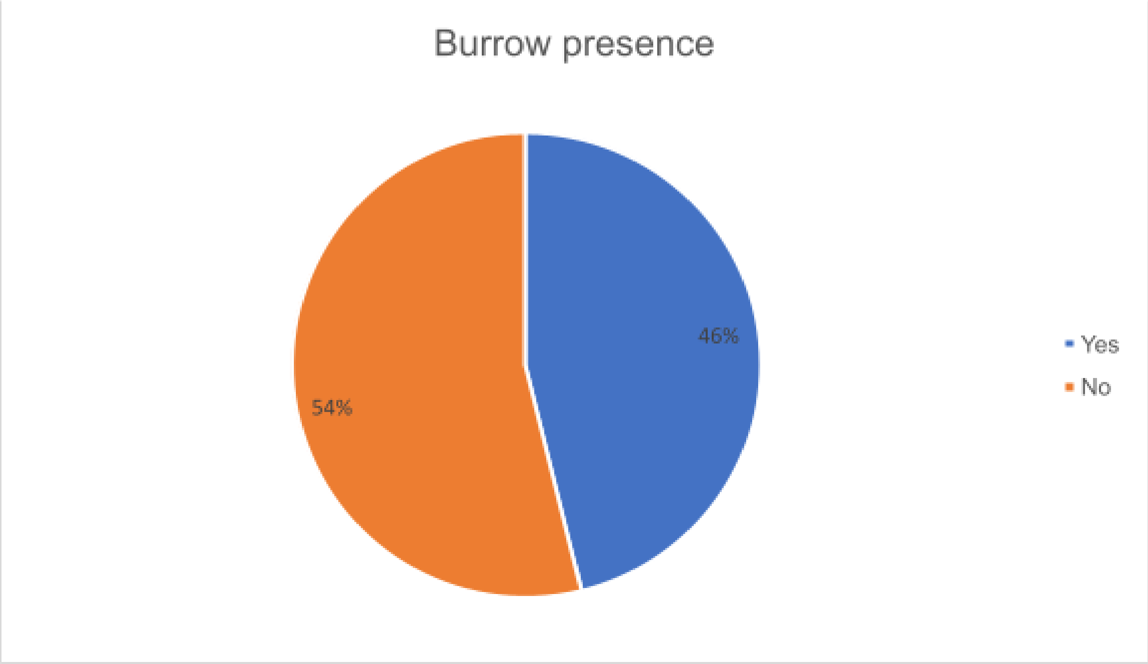

Figure 43: Burrow presence within the surveyed plots

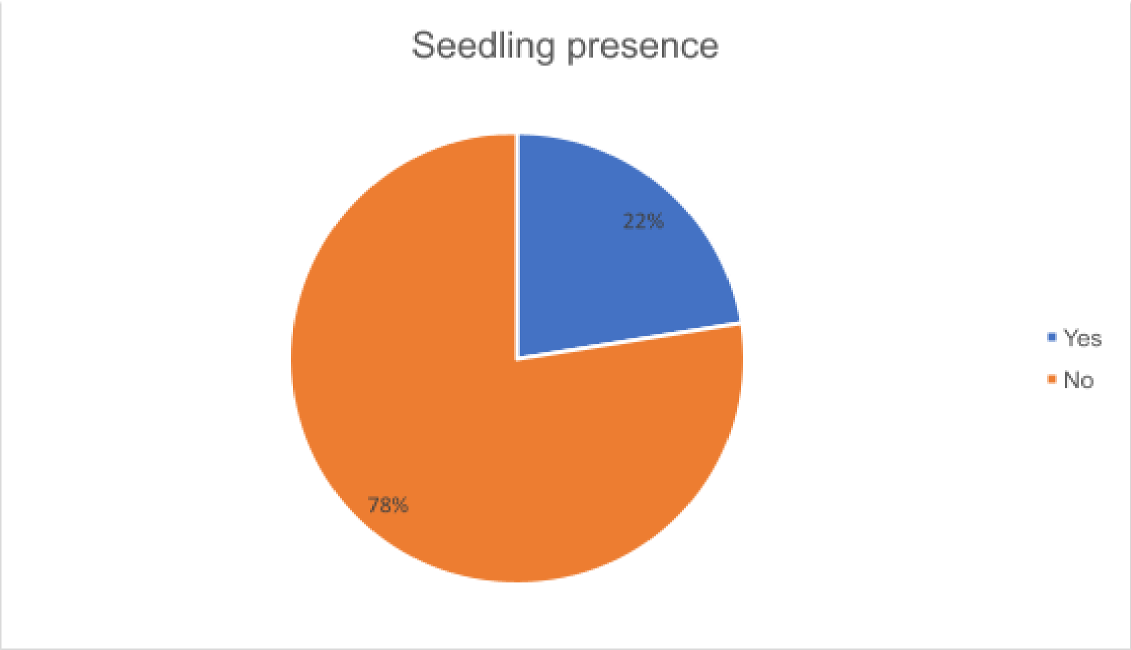

Figure 44: Seedling presence within the surveyed plots

Appendix VIII: Herbivory on White mangrove (Laguncularia racemosa)

Figure 45: Herbivory leaf 1

Figure 46: Herbivory leaf 2.a

Figure 47: Herbivory leaf 2.b