Reforestation in Bonaire: A Species Suitability Study in Exclosures in the Washington-Slagbaai National Park

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Reforestation in Bonaire: A Species Suitability Study in Exclosures in the Washington-Slagbaai National Park

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Forestry and Nature Management, Major Tropical Forestry

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Front page picture: Adult *Cynophalla flexuosa* in Washington-Slagbaai National Park (by Bram Dicou)

Abbreviations & Definitions

Abbreviation	Description
ANOVA	Analysis Of Variances
DF	Degrees of Freedom
FS	Full Sunlight
IUCN	International Union For Conservation of Nature
MS	Mean Square
PS	Partly in the Sun (around 50%)
S	Shade
SS	Sum of Squares
STINAPA	Stichting Nationale Parken Bonaire

Definition	Description
Ephemeral river	A riverbed that contains water during a short period of time
Exclosure	A fenced off natural area to keep out invasive herbivores
F-Value	Variance of the group means
P-Value	The probability value.
Rooi (plural Rooien)	See Ephemeral river
Xerophytic	Plant species that survive with little liquid water, dry area species

Preface

This is my bachelor thesis for the study Forestry and Nature Management, majoring in Tropical Forestry. I started my thesis project at the 12th of January 2018. I spent 3 months doing research in Bonaire with the parrot organisation Echo and 2 months in the Netherlands. It was an interesting thesis opportunity at Echo, as they have a reforestation program aimed at habitat restoration for the Yellow-Shouldered Amazon parrot. I am very interested in habitat restoration and the fact that they achieve this with such a clear goal is great.

I would like to thank my thesis provider in Bonaire, Quirijn Coolen, for the opportunity to join your team and help me with my research. I would also like the thank the rest of the Echo team, Johan, Roos, Julianka and Nick. And of course I would especially like to thank my fellow volunteers, Nils, Moana, Vera and Wilmar for their invaluable help in the field. Without them it would have taken me twice as long to collect the data.

Also thanks to Anko Stilma, my supervisor, for all his help, especially with excel and statistics.

Lastly thanks to my parents, helping me focus, and letting me study at your house when I needed a lot of concentration.

Bram Dicou

Arnhem, June 2018

Abstract

The nature organisation Echo aims to conserve the Yellow-Shouldered Amazon parrot on Bonaire. They have established two exclosures for reforestation purposes, Washington and Slagbaai (Washington-Slagbaai National park), which increase the habitat of this parrot. Several native Xerophytic tree species were planted in these exclosures. Eleven of these species are chosen for this study. The objective of this study is to establish the suitability of these eleven species by calculating growth and health using the factors (1) distance to the rooi, (2) light and (3) soil. For the first, a special feature of this area is possibly relevant, the presence of an ephemeral river, or rooi, in each of the two exclosures, as well as outside the exclosures in Washington-Slagbaai National park. With limited water availability, a result of a short rainy season (2 months), it only has water with very heavy rains. In a semi-arid tropical climate such as the climate on Bonaire, it seems relevant to investigate the possible influence of an ephemeral river.

Data on pH, distance to rooi, texture, organic matter, vegetation cover and sunlight were collected

- from all planted trees (for vegetation cover and sunlight)
- or trees that occurred within 10*10 plots (for pH, distance to rooi, texture and organic matter).

The data were put in a database, and analysed by creating pivot-tables from the results and performing ANOVA tests on these tables.

For the first question (distance to rooi), the ANOVA calculation did not show a significant difference between plots close to a rooi and further away from the rooi. However*, Bourreria succulenta* did show a significant difference according to the T-Test. For the second question (Light) no significant differences were found. However, there are some large growth differences between some species according to the data. Caesalpinia coriaria and Malpighia emarginata prefer much sunlight, while Quadrella odoratissima prefers the shade. For the third question (Soil) the results showed a significant difference with the relation texture – growth and organic matter growth. The plots with a medium fine texture had better growth. The plots with higher organic matter in the soil (>5%) had better growth. Surrounding vegetation cover did not show a significant difference and pH neither. However for one species there was a significant difference with the pH – growth calculation: *Guaiacum officinale*.

These results allow the conclusion that looking at site suitability for these 11 species, texture and organic matter are important.

For each of the 11 species, best performing values for situational factors (as for growth and health) are put in an overview table.

Differences between the species themselves are used to construct a ranking table: best to least performing trees (again, both for growth and health).

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1. Introduction (general introduction, problem description)

1.1 Introduction

This research is conducted for my bachelor thesis for the study Forestry and Nature Management, major Tropical Forestry, at Van Hall-Larenstein University of Applied Sciences, in Velp, The Netherlands.

For this research I have visited two exclosures in the Washington-Slagbaai National Park in Bonaire. These exclosures are established by the organisation Echo. Echo is an organisation aimed at the conservation of the Yellow-shouldered Amazon parrot. Most trees are removed in colonial times and regeneration of the vegetation is very difficult because of invasive herbivores. The exclosures are established to let trees grow which in their turn provide food and nesting sites for the Yellow-shouldered Amazon parrot. See for more information the information about Echo (1.2) and problem description (1.3).

In early 2017 Echo has done a base inventory at the exclosures in Washington and Slagbaai. All trees in these exclosures have received a physical tag, and a GPS tag. The tree heights were measured as well as coordinates established. For Echo it would be helpful to learn more on growth and health conditions of these planted tree species, as well as the survival chance of these species in the dry environment of the Washington Slagbaai National park. It would also be relevant for the choice of species in future planting in exclosures to be developed in Bonaire. My research objective (2.1) is aimed at gaining this information.

I have researched the suitability of the 11 most planted tree species in the exclosures established in Washington-Slagbaai National Park. The suitability was defined by the factors soil, light and water. For the factor water I have looked at the influence of the local ephemeral river (rooi) on the trees planted close to it. I have analysed growth (since first measurements at base inventory done by Echo), tree mortality, and tree health of these 11 species. I have made calculations to establish if there is a significant difference in growth and health with several variables. See the research questions (2.2.1, 2.2.2 and 2.2.3) and the methodology for these questions (3.2.1, 3.2.2, and 3.2.3).

A description of the study area can be found under 3.1. Here you can find information about the area, as well as information about the 11 tree species used in this study.

The next chapter, results, is divided into general results (such as mortality) and the results per research question (pivot tables and ANOVA results). See chapter 4.

Chapters 5 and 6 show a discussion of these results as well as an conclusion. The report ends with an evaluation and some advice for future research on this topic (chapter 7).

Finally, in the annex you can find the used field forms, the risk analysis and planning, and the full ANOVA result tables (the main information from the ANOVA tables can be found under results).

1.2 Information about Echo

Echo is established in 2010 by Dr Sam Williams. It is an organisation that aims to ensure a stable and growing population of the Yellow-shouldered Amazon parrot in Bonaire (see problem description). They are trying to achieve this by reducing the poaching of chicks, reducing habitat degradation by invasive herbivores and habitat restoration. Echo has a small paid staff (5 people) and works a lot with international volunteers for their projects. They regularly host students who conduct research for Echo as part of their studies (Echo, 2015).

1.3 Problem description

Since the first colonisation of Bonaire by Spain in 1526, and later the Netherlands in 1634, the dry forest in the current Washington-Slagbaai National Park have been mostly culled for its timber and charcoal (Dalhuisen, et al., 2009). The introduction of invasive herbivores such as goats and donkeys for fresh meat production by these Spanish and Dutch colonisers, made regrowth of the trees very difficult (Coolen, 2015) (Geurts, 2015).

The Yellow-shouldered Amazon parrot (*Amazona barbadensis*) has a population of around 900 birds on the island of Bonaire. According to the IUCN Red List of Threatened Species the parrot species *Amazona barbadensis* has the status of vulnerable (Rodriguez, Rojas-Suarez, Sharpe, & Rodriguez-Ferraro, 2016). Currently, it occurs only in the northern mainland of Venezuela, the Venezuelan islands of Margarita and La Blanquilla, and Bonaire (special municipality of the Netherlands) (Sekeris, 2012). The Yellow-shouldered Amazon parrot needs cavities in trees with an adequate height and diameter for its nesting (Cortes, 2011). The Yellow-shouldered Amazon parrot also needs tree species with certain fruits, as they are mostly frugivorous, although they also eat stems, flowers and leaves (Sekeris, 2012).

The need for regrowth of trees for the Yellow-shouldered Amazon parrot, and the lack of tree regeneration caused by invasive herbivores such as goats and donkeys, made Echo decide to create enclosed areas to give the vegetation a chance to grow.

In sum, Echo created exclosures to exclude invasive herbivores and increase the habitat for the Yellow-shouldered Amazon parrot. However, they are not certain which species are growing well, and which locational factors might be the cause of this. They have a lack of knowledge about which species would be best to choose for this project and which factors are most important for a successful growth program.

My research project in the Washington-Slagbaai National park was intended to provide more information on these questions.

This investigation has been done in and outside two exclosures of the Echo tree planting project in this park. I also intend to provide a clear description and to create a map of these areas, using ArcGIS.

The trees planted are all xerophytic dry forest species native to Bonaire. In other dry areas such as in Israel (Ward & Rohner, 1996) and Egypt (Springuel & Mekki, 1994) ephemeral rivers have a positive influence on the growth and mortality of trees. Perhaps the trees in the exclosures could benefit from extra water as well. Some species such as *Bourreria succulenta* and *Crescentia cujete* are very drought tolerant while others might need more water. Some species such as *Melicoccus bijugatus* require a

fertile soil while others such as *Caesalpinia coriaria* also grow on poor soils. (For more information about these species see 3.1.3.

More information was needed on the suitability of these species in order to effectively design plans for future planting by Echo or other reforestation projects on the island of Bonaire. For that, it is necessary to have a clear view on possible relationships between situational factors and tree growth, tree health and mortality, in and around the Washington-Slagbaai National park. Which species is most suitable for which conditions? A research project differentiating for the 11 most planted tree species by Echo would provide useful information on the relative suitability of these species and furthermore provide information on the tree population as a whole. The suitability of the tree species can be measured by investigating:

- tree growth
- tree health

The most probable suitability defining factors are:

- nearness to the local ephemeral rivers for a possible extra water supply (water)
- differences in soil characteristics (soil)
- sunlight or shadow availability (light)

As for the first factor, there is such an ephemeral river, or rooi, in each of the two exclosures, as well as outside the exclosures, in Washington-Slagbaai National park. With limited water availability, a result of a short rainy season (2 months), it only has water with very heavy rains. In a semi-arid tropical climate such as the climate on Bonaire, it seems quite relevant to investigate the possible influence of an ephemeral river. Do the trees at short distance from the rooi profit from it? Are they more healthy and do they grow better? Do they have a higher survival rate? Do some species profit more than others?

Furthermore, it is well known that soil characteristics are an important factor for successfully planting trees. Parts of the areas in and around the exclosures of Washington and Slagbaai may vary in soil characteristics as the capability to retain water, sunlight and vegetation cover. This was expected to be influential. It is helpful to investigate differences in growth and health of the 11 most planted tree species by Echo between plots with different soil conditions as to the capability to retain water.

Another well-known factor is sunlight/shadow conditions and vegetation cover. It would be important to investigate this both for 'all trees' and for the 11 most planted tree species by Echo separately, as effects of sunlight/shadow availability will differ per species. Some species grow best by full sun, others prefer shadow.

This research project investigating tree growth and tree health, and analysing all possible relationships with the discussed situational factors, makes information available on the relative suitability for each of the 11 most planted trees in the exclosures. As a result, Echo is able to make a well-argued decision on the choice of species for future plantations on Bonaire. Moreover, they will have a tool to evaluate the effect of various site conditions for the chosen species.

In this research project I establish, describe and analyse the relationships discussed above. The next section (2.1-2.2) presents my research objectives and research questions.

2. Research objectives and research questions

2.1 Research objective

The objective of this research is to define the species suitability of the planted species in the exclosures created by Echo in the Washington Slagbaai National Park defined by soil, light and water.

2.2 Research questions

2.2.1 Question 1

Is there a significant difference in growth and health of the planted trees close to the ephemeral river compared to the growth and health of the planted trees further away from the ephemeral river in the Washington-Slagbaai National Park?

The hypothesis to be tested is that the ephemeral river has a relevant positive influence on the growth and health on the trees planted closer to the river compared to those that are planted further away. In other arid regions such as Egypt (Springuel & Mekki, 1994) and Israel (Ward & Rohner, 1996) trees benefit from the influence of an ephemeral river. The statistical null hypothesis (H_0) is that there is no significant difference in growth and health rating near or further away from the river. The alternative hypothesis (H_1) is that there is a significant difference in growth and health rating.

The hypothesis is tested both for the group 'all trees' and for every of the involved 11 species. This because the results might differ per tree species as some are very drought resistant and might not need the extra water, while others might benefit from it.

2.2.2 Question 2

Does the amount of sunlight have a significant difference on the growth and health of the eleven most occurring tree species in Washington study area and Slagbaai study area?

The hypothesis to be tested is that the amount of sunlight shows a significant difference between growth and health of trees in sunlight and growth and health of trees in the shade, or trees partly in the shade. This might differ per tree species.

The statistical null hypothesis (H_0) is that there is no significant difference in growth and health rating. The alternative hypothesis (H_1) is that there is a significant difference in growth and health rating.

The hypothesis is tested both for the group 'all trees' and for every of the involved 11 species.

2.2.3 Question 3

Do differences in soil characteristics (organic matter, acidity, texture and surrounding vegetation) have a significant influence on tree growth and health of the eleven most occurring tree species in Washington study area and Slagbaai study area?

The four hypotheses to be tested maintain that:

1. percentage of organic matter
2. soil acidity
3. texture
4. percentage of vegetation on the soil around the tree

result in significant differences in growth and health of the trees. The statistical null hypothesis (H_0) is that there is no significant difference in growth and health rating. The alternative hypothesis (H_1) is that there is a significant difference in growth and health rating. The hypothesis is tested both for the group 'all trees' and for every of the involved 11 species.

Figure 1: Caesalpinia coriaria (Bram Dicou)

3. Methodology

3.1 Study area

3.1.1 Brief history

Between 1634 and 1648 the Dutch West-India Company (West-Indische Compagnie, or WIC) conquered several islands from Spain which later came to be known as the Netherlands Antilles. Aruba, Bonaire and Curacao are part of the Leeward Antilles (Benedenwindse eilanden). Bonaire (see figure 2 for a satellite image) was used for its timber, limestone and salt, first by the WIC and later by the Dutch Government (although Bonaire was temporarily occupied by the British). Since 1815 the islands became an official part of the kingdom of the Netherlands. In 1948 the islands were known as the Netherlands Antilles. Since 2010 the Netherlands Antilles no longer exist, and Bonaire became a special municipality of the Netherlands (along with Sint Eustasius and Saba). (Dalhuisen, et al., 2009)

Figure 2: Google Earth Image of Bonaire (Google)

The Washington-Slagbaai national park used to be two separate slave plantations. The Washington and Slagbaai plantations were used for salt, goats, timber, charcoal and divi-divi pods (used for leather tanning). Since 1969 these two former slave plantations were established as national park Washington-Slagbaai. The national park has an area of 5643 hectares (56,4 km^2). The National park is divided into two separate areas separated by a gate. (Stinapa, 2017).

The exclosures established by Echo within the Washington-Slagbaai national park have the size of 1.5 hectare (Washington) and 0,85 hectare (Slagbaai). They were established in 2016. An ephemeral river, or rooi, flows within these exclosures in the rainy season (see figure 3 and 4).

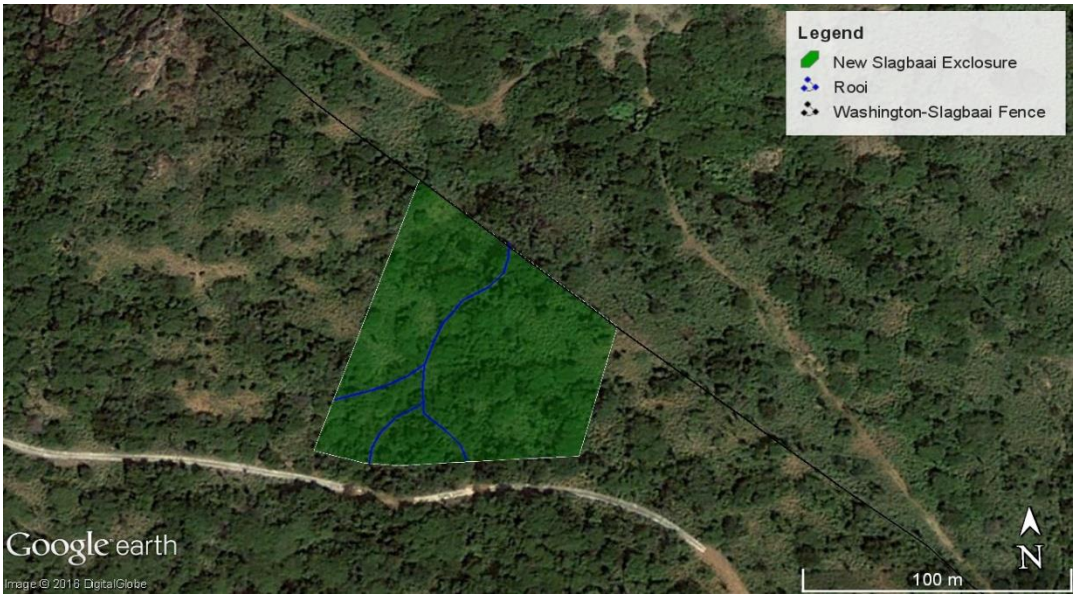

Figure 3: Slagbaai exclosure (Coolen, Slagbaai exclosure, 2016)

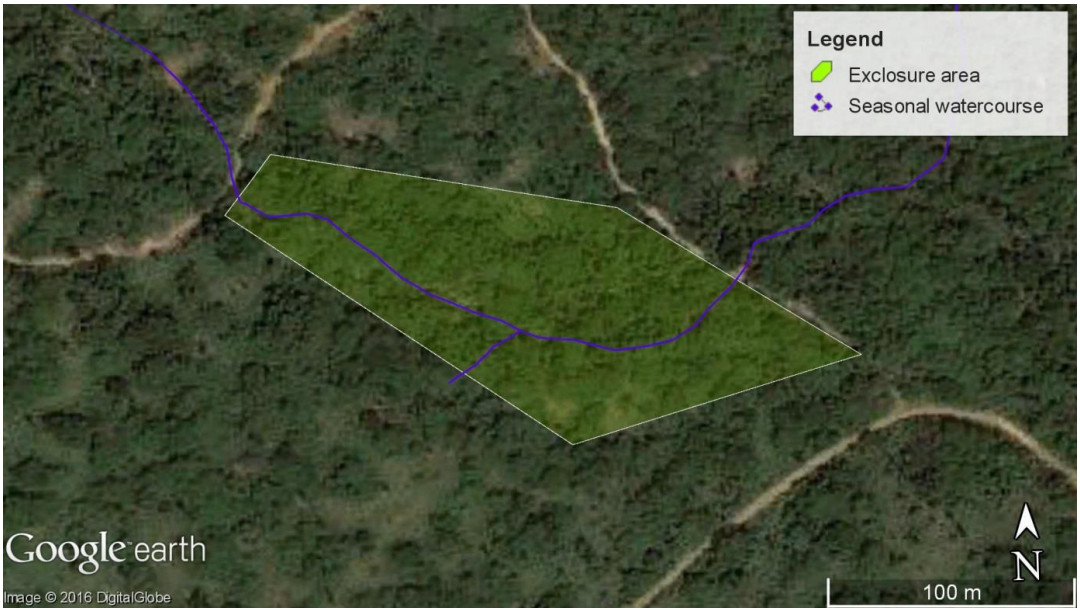

Figure 4: Washington exclosure (Coolen, Washington Exclosure, 2016)

3.1.2 Geology and climate

Bonaire has an area of 288 km^2 (Dalhuisen, et al., 2009). The oldest rocks on Bonaire are of volcanic origin from the Washikemba formation. Limestone sediments among the volcanic rocks show that the geological formation is a marine deposit. The highest mountain top is Brandaris (241 m) (Pijpers, 1933). Bonaire is surrounded by coral reefs and mangroves. All water surrounding Bonaire are included in the Bonaire national marine park (Stinapa, 2018).

Bonaire has a semi-arid climate according to the Köppen climate classification. Bonaire has an average rainfall of 500 mm per year. The rainy season usually happens from October to December. (Dalhuisen, et al., 2009).

3.1.3 Tree species

The following tree species are being researched for research question 2 (see 2.2.2). Eleven species are chosen instead of ten because the 10th most planted species which occurs in Washington and Slagbaai in nearly the same amount as the 11th .

Bourreria succulenta:

*Bourreria succulenta (Boraginaceae) (*figure 12) local name Watakeli, is an evergreen shrub or small tree which can grow to 7,5 meters (Fern, Useful Tropical Plants, 2014). *Bourreria succulenta* requires an animal pollinator for flowering. It flowers 2 days a year, with white flowers on the first day and beige on the second day (Ratchke, 2001). *Bourreria succulenta* requires a calcareous soil (high pH), is very drought resistant and is moderately salt tolerant (Florida Native Plant Society, 2013).

Caesalpinia coriaria:

Caesalpinia coriaria (Fabaceae) local name Divi-Divi (figure 1) , is a small tree with a rounded, spreading grown usually growing up to 10 meters tall, although sometimes taller. It is susceptible to wind in exposed areas giving it strange crowns and leaning trunks (Fern, Useful Tropical Plants, 2014) (see figure 5). Divi-Divi pods were used for leather tanning in Europe. Traders used to pay a high price for Divi-Divi pods from Bonaire as they were known to be of superior quality (Stinapa, 2017). Divi-Divi tolerates a wide range of soil types and climates. It can grow on nutrient rich soils as well as poor soils. It tolerates a pH of 4.5 – 8.7. It grows in warm dry climates as well as in wet tropical climates. However, divi-divi has a higher yield under drier conditions (Jansen, 2005).

Figure 5: Divi-Divi Tree (Wikimedia)

Cordia dentata:

Cordia dentata (Boraginaceae) local name Kohara, is a shrub or small tree species growing up to 15 meters tall. Its trunk is usually short and often crooked. Is has a very slow germination. It prefers a moist but freely draining loam soil (Fern, Useful Tropical Plants, 2014).

Crescentia cujete:

Crescentia cujete (Bignoniaceae) local name Kalbas, is a small to medium sized tree usually growing up to 10 meters. The fruits of these trees are very large and used for making several materials such as spoons, containers, cups and maracas (musical instruments). The Kalbas fruit is also used for several medicinal uses and is excellent parrot food. *Crescentia cujete* prefers a fertile, moist soil in a sunny position. Once established it is very drought tolerant. (Fern, Useful Tropical Plants, 2014).

Cynophalla flexuosa:

Cynophalla flexuosa (Capparaceae), local name Stoki, is a 2 – 4-meter-high shrub, sometimes growing into a small tree. It flowers from early to mid-summer. The flowers are white or pink. Its fruits are green and cylindrical (Encyclopedia of Life, 2013). Stoki requires moist, well drained sandy or limestone soils. It requires full sunlight and is very drought tolerant once established (NFYN, 2018).

Guaiacum officinale:

Guaiacum officinale (Zygophyllaceae) (figure 13), local name Wayaká, is a small tree species growing up to 10 meters. It has been listed as an endangered species by the IUCN. Regeneration of this species is good, but the growth is very slow. It is threatened because of overexploitation through the years (IUCN, 1998). Its flowers are blue and its trunk often crooked (Grieve, 1931). It is drought tolerant and requires a well-drained soil with a pH of 5 – 7,5. It prefers a sunny position (Fern, Useful Tropical Plants, 2014).

Haematoxylum brasiletto:

Haematoxylum brasiletto (Fabaceae), local name Brasia or Brasil, is usually a shrub growing around 2 – 3 meters tall, although sometimes it can grow into a tree with a maximum height of 9 meter. Its branches are armed with spines up to 2 cm. The wood is used for its dye (Fern, Useful Tropical Plants, 2014). It grows in a mildly acidic to mildly alkaline soils. It is drought tolerant, although it needs consistent moist in the growing season. Brasia is a nitrogen fixing species (Campus Arboretum, 2013).

Malpighia emarginata:

Malpighia emarginata (Malpighiaceae), local name Shimaruku, is a shrub of small tree growing around 4 meters tall. It has edible fruits with very high vitamin C contents. Its requires a sunny position and is drought tolerant (Fern, Useful Tropical Plants, 2014).

Melicoccus bijugatus:

Melicoccus bijugatus (*Saponaceous)* local name Kenepa, is a tree which can reach a height of 25 meters. Its fruit its edible and tasty. The trunk grows up to 170 cm. The bark is used for medicinal purposes. It is a slow growing species but with a high germination rate, high seedling establishment and high survival rate (CABI, 2017). Kenepa prefers a fertile, well-drained soil in a sunny position with a pH of 5,5 – 7. Once established Kenepa is very drought tolerant (Fern, Useful Tropical Plants, 2014).

Pithecellobium unguis-cati:

Pithecellobium unguis-cati (Fabaceae) local name Unagatu, is a shrub or small tree with multiple stems. Often its armed with spines up to 5 mm. It can grow into 8 meters tall. More commonly however it grows around 3 meters tall. Its fruit is edible and collected in the wild. It grows on arid limestone soils. Unagatu has a symbiotic relationship with a soil bacteria. This bacteria forms nodules on the stem which can fix nitrogen for the plant itself and other plants around it (Fern, Useful Tropical Plants, 2014).

Quadrella odoratissima:

Quadrella odoratissima (Capparaceae) (figure 6), has the local name Oliba, extra information about soil requirements are not found online.

Figure 6: Quadrella odoratissima (Bram Dicou)

3.2 Data collection and analysis

3.2.1 Method question 1

As stated in the chapter research questions, the first factor to be analysed is water, and the first research question is:
Is there a significant difference in growth and health of the planted trees close to the ephemeral river compared to the growth and health of the planted trees further away from the ephemeral river in the Washington-Slagbaai National Park?

As stated above this research questions focusses on the following 11 species:

- Bourreria succulenta
- Caesalpinia coriaria (synonym of Libidibia coriaria)
- Cordia dentata
- Crescentia cujete
- Cynophalla flexuosa
- Guaiacum officinale
- Haematoxylum brasiletto
- Malpighia emarginata
- Melicoccus bijugatus
- Pithecellobium unguis-cati
- Quadrella odoratissima (synonym of Caparis odoratissima)

Before fieldwork for this question actually started, it took several weeks of learning to recognise the health of these species by tree tagging for Echo in other exclosures.

For this research question, two rooi areas were investigated in the Washington and Slagbaai exclosures. Plots with a size of 10*10 meter were established. Five of these plots were established along the rooi on the left side and another five at the right side. They were established at equal distance of each other – at about 0, 20, 40, 60 and 80 meters along the side of the rooi. Another ten plots were established near the fence on both sides of the exclosure. This means a total of 20 plots per exclosure (see figure 7 and 8). As an extra control, distance to the rooi was calculated by using the GPS points in ArcGIS and excluding all points not in the vicinity of the rooi.
For an overview of the rooi's in Washington-Slagbaai, see figure 9.

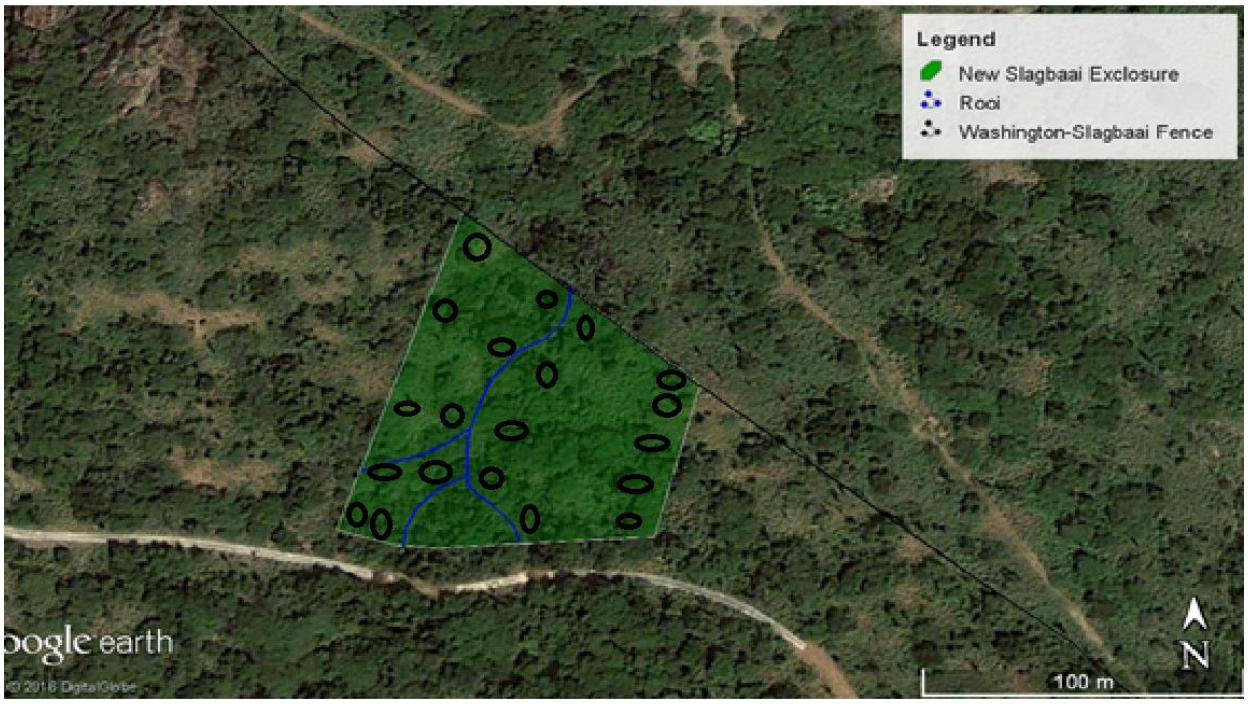

Figure 7: Points of the plots in the Slagbaai Exclosure

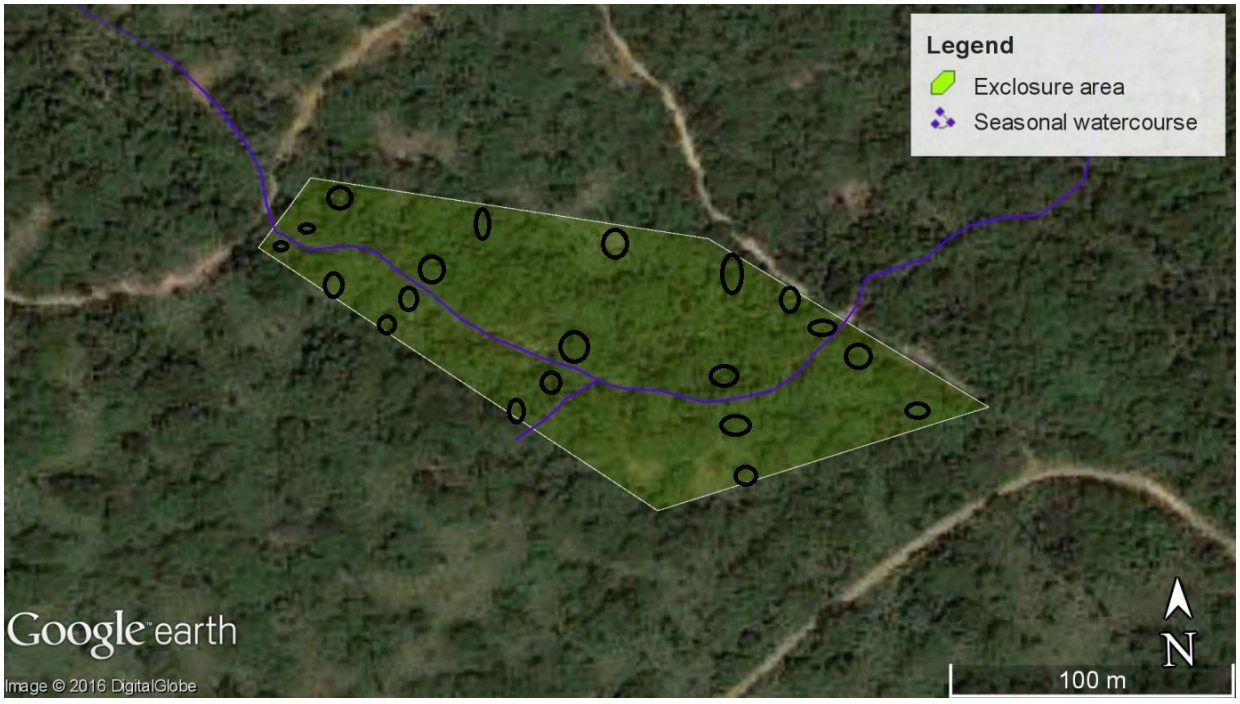

Figure 8: Points of the plots in the Washington exclosure

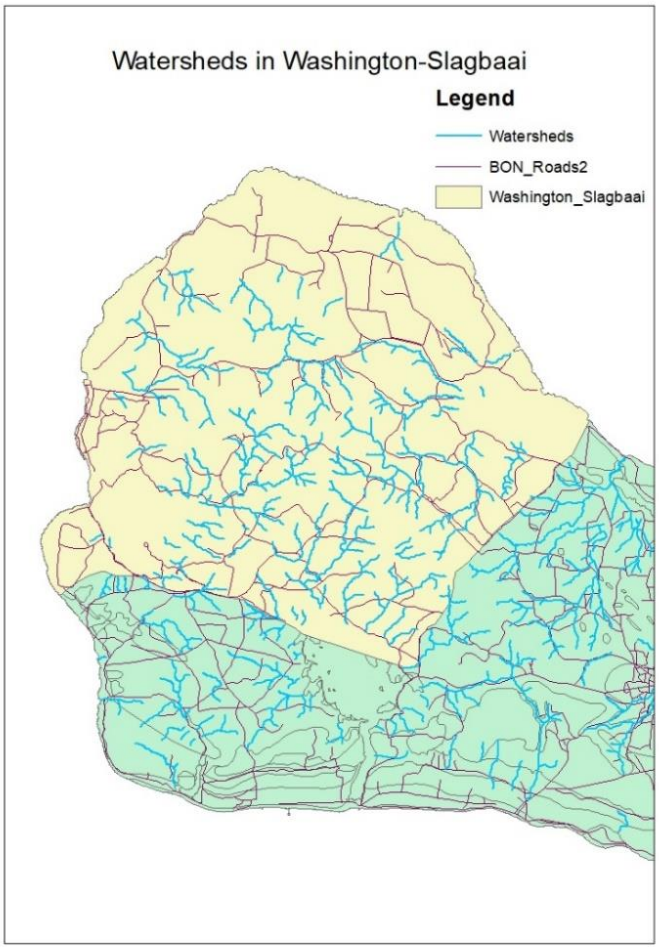

Figure 9: Rooi's in Washington-Slagbaai National park

Within the plots, the following response variables were measured on the planted trees:

A. Growth. For growth I used the new height measurements from February – March 2018 and subtract the height measurements from base inventory done by Echo (late 2016). The average of these new heights is calculated with the explanatory variables (for the total number of trees, per species and per plot).
B. Health: The general health of the tree is divided into four parameters:
   A. Very healthy (many branches, standing straight, good colour of the leaves).
   B. Healthy (somewhat less branches or shorter branches, still good colour of leaves)
   C. Neutral (somewhat crooked stem, pale leave colours)
   D. Unhealthy (no leaves, nearly dead, very crooked stem)
   Each explanatory variable is calculated with the number of trees within a category.

This results in the description and analysis of the following relations:

- *Average of health rating in plots close to rooi compared with percentage of trees with an A health rating in far away from rooi. (per plot type and per species)*
- *Average growth in plots close to rooi compared with average growth in faraway plots (per plot type and per species)*

The relations are analysed by ANOVA tests. The tests will determine if there is a significant difference between the means of the collected data on growth and health, per species. The ANOVA test is chosen because every factor is analysed for these 11 species together. ANOVA compares (for those 11 species) several categories of that factor. In some cases T-Tests may be added to analyse possibly significant differences between 2 factor categories for 1 species.

3.2.2 Method question 2

As stated in the chapter research questions the second factor to be analysed is light, and the second research question is:
Does the amount of sunlight have a significant difference on the growth and health of the eleven most occurring tree species in Washington study area and Slagbaai study area?

For the second research question all 2174 planted trees (11 chosen species) were located with their GPS tag. The amount of sunlight received was noted down on the form (full sunlight, partly in the sun, full shade).

The following response variables were measured for question 2:

A. Growth. For growth I used the new height measurements from February – March 2018 and subtract the height measurements from base inventory done by Echo (late 2016). The average of these new heights is calculated with the explanatory variables (for the total number of trees, per species).
B. Health: The general health of the tree is divided into four parameters:
   A. Very healthy (many branches, standing straight, good colour of the leaves).
   B. Healthy (somewhat less branches or shorter branches, still good colour of leaves)
   C. Neutral (somewhat crooked stem, pale leave colours)
   D. Unhealthy (no leaves, nearly dead, very crooked stem)
   Each explanatory variable is calculated with the number of trees within a category.

For this question I calculate with the following categories: ***fully in the sun, partly in the sun, full shade.***

This results in the description and analysis of the following relations:

- *Relation of sunlight with growth (per species)*
- *Relation of sunlight with health (per species)*

The relations are analysed by ANOVA tests. The tests will determine if there is a significant difference between the means of the collected data on growth and health, per species. The ANOVA test is chosen because every factor is analysed for these 11 species together. ANOVA compares (for those 11 species) several categories of that factor. In some cases T-Tests may be added to analyse possibly significant differences between 2 factor categories for 1 species.

3.2.3 Method question 3

As stated in the chapter research questions the third factor to be analysed is soil, and the third research question is:

Do differences in soil characteristics (organic matter, acidity, texture and surrounding vegetation) have a significant influence on tree growth and health of the eleven most occurring tree species in Washington study area and Slagbaai study area?

For the third research question the same plots as in with question 1 are used (see page 16-17) as well as the same tree species. Moreover, soil samples were collected near other rooi areas within the Washington-Slagbaai National Park. For every soil sample taken near a rooi, another soil sample was taken ca. 50 meters away from this sample and the rooi. The texture is divided according to the official sand classification groups (Eijkelkamp, 2009). For instance, a soil sample with a texture of 150 falls under group B very fine.
The rooi areas for the soil samples were selected locally, as many of them are inaccessible because of a thick growth of several cactus species. When a rooi was chosen, the coordinates were entered in GPS.

In every other plot (1,3,5 etc) a soil sample was taken to do a soil analysis. I used the Analog Forestry method (Faries, 2012). Holes were dug of 30 cm wide and deep. Deeper than 30 cm is not useful since after c.a. 30 cm rock is encountered. I analysed texture with a sand ruler. The texture in the soil gives information about the rate of water consumption, water accumulation and fertility. Next, I measured acidity by measuring pH with pH strips. Finally, I analysed the upper layer of soil for organic matter. The percentage of organic matter in the upper layer gives more information on fertility and soil stability.
Additionally, all 2174 trees are analysed for the vegetation cover around the tree. For all 2174 trees the percentage of soil covered by vegetation in a circle 2 meters around the tree was written down on the forms, as well the type of vegetation (grass, cactus, sage for example). This to have a clear view on possible causes for lack of growth or health caused by competition with other plants.

The following response variables were measured for question 3:

A. Growth. For growth I used the new height measurements from February – March 2018 and subtract the height measurements from base inventory done by Echo (late 2016). The average of these new heights is calculated with the explanatory variables (for the total number of trees, per species and per plot).
B. Health: The general health of the tree is divided into four parameters:
   A. Very healthy (many branches, standing straight, good colour of the leaves).
   B. Healthy (somewhat less branches or shorter branches, still good colour of leaves)
   C. Neutral (somewhat crooked stem, pale leave colours)
   D. Unhealthy (no leaves, nearly dead, very crooked stem)
   Each explanatory variable is calculated with the number of trees within a category.

I calculate with the following explanatory variables: *Soil Texture, Soil Acidity, Soil Organic Matter and Percentage of surrounding vegetation on the soil*

This results in the description and analysis of the following relations:

- *Relation of texture with growth plots (per plot and per species)*
- *Relation of texture with health plots (per plots and per species)*
- *Relation of organic matter percentage with growth plots (per plot and per species)*
- *Relation of organic matter percentage with health plots (per plot and per species)*
- *Relation of pH with growth plots (per plot and per species)*
- *Relation of pH with health plots (per plot and per species)*
- *Relation of vegetation cover with growth (per species)*

- *Relation of vegetation cover with health (per species)*

The relations are analysed by ANOVA tests. The tests will determine if there is a significant difference between the means of the collected data on growth and health, per species. The ANOVA test is chosen because every factor is analysed for these 11 species together. ANOVA compares (for those 11 species) several categories of that factor. In some cases T-Tests may be added to analyse possibly significant differences between 2 factor categories for 1 species.

Figure 10: A Plot (Bram Dicou)

4. Results

In this chapter the main results of the pivot-tables and ANOVA tests made in the Excel database belonging to this research project are shown, as well as several graphs based on these results, separate for each research question. Note: the factors texture and organic matter apply for both water and soil. This chapter starts with some general results from the database such as number of alive trees per species and number of trees per exclosure (4.1). Then follow the results on research questions 1 (4.2, distance to rooi), question 2 (4.3, light) and question 3 (4.4, soil). The larger versions of the ANOVA results can be found in the annex.

4.1 General results

The table and bar chart below (table 1) show the number of trees, from the 11 choses species, in the exclosures in Washington-Slagbaai National Park.

Row Labels	Count of Species
Guaiacum officinale	284
Crescentia cujete	261
Cordia dentata	197
Cynophalla flexuosa	176
Haematoxylum brasiletto	164
Caesalpinia coriaria	149
Bourreria succulenta	146
Quadrella odoratissima	136
Pithecellobium unguis-cati	115
Malpighia emarginata	68
Melicoccus bijugatus	68
Grand Total	**1764**

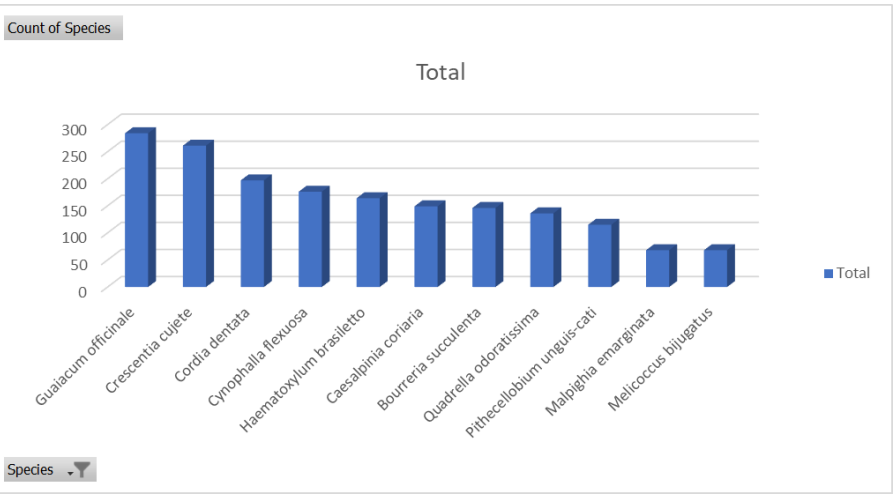

Table 1: Number of trees in Washington-Slagbaai National Park

The table and bar chart below (table 2) show the number of trees from the 11 chosen species per exclosure.

Count of Species	Column Labels		
Row Labels	Slagbaai	Washington	Grand Total
Guaiacum officinale	99	185	284
Crescentia cujete	113	148	261
Cordia dentata	111	86	197
Cynophalla flexuosa	50	126	176
Haematoxylum brasiletto	105	59	164
Caesalpinia coriaria	87	62	149
Bourreria succulenta	90	56	146
Quadrella odoratissima	43	93	136
Pithecellobium unguis-cati	44	71	115
Malpighia emarginata	30	38	68
Melicoccus bijugatus	25	43	68
Grand Total	**797**	**967**	**1764**

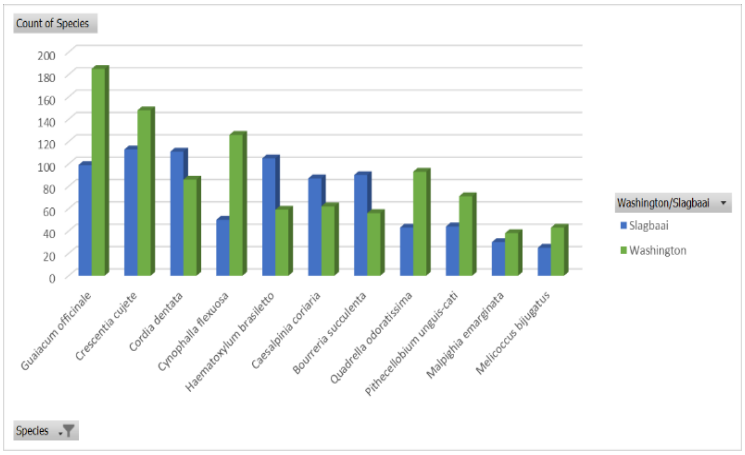

Table 2: Number of trees in Washington and Slagbaai Exclosures

The table and bar chart below (table 3) show the average growth per species from best to worst.

Row Labels	Average of Growth (in cm)
Bourreria succulenta	87.07092199
Cynophalla flexuosa	68.37931034
Haematoxylum brasiletto	57.89506173
Cordia dentata	49.65816327
Pithecellobium unguis-cati	45.80701754
Quadrella odoratissima	45.16296296
Caesalpinia coriaria	37.62837838
Crescentia cujete	31.8828125
Malpighia emarginata	29
Guaiacum officinale	27.20070423
Melicoccus bijugatus	26.06060606
Grand Total	**45.74010327**

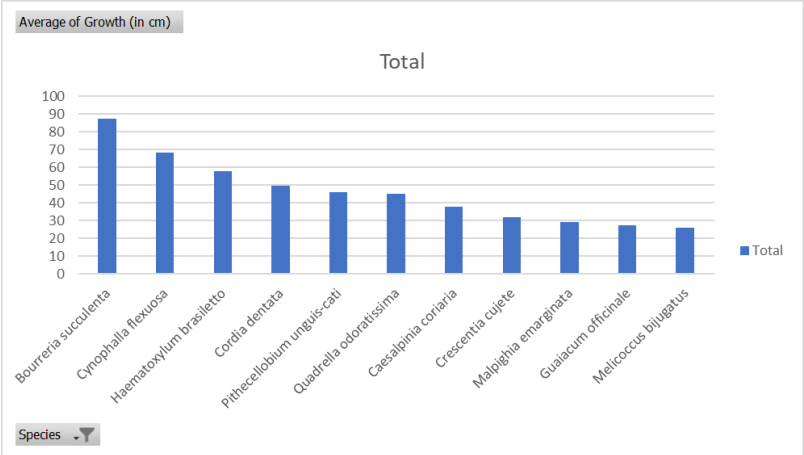

Table 3: Average Growth

The table and bar chart (table 4) show the average health per species from best to worst.

Row Labels	Average of Health Rating in Numbers (for mean calculations)
Bourreria succulenta	3.746478873
Haematoxylum brasiletto	3.62962963
Melicoccus bijugatus	3.597014925
Pithecellobium unguis-cati	3.417391304
Guaiacum officinale	3.375451264
Cynophalla flexuosa	3.16091954
Caesalpinia coriaria	3.081632653
Cordia dentata	3.056410256
Quadrella odoratissima	3.053030303
Malpighia emarginata	3.044776119
Crescentia cujete	2.979919679
Grand Total	**3.264041691**

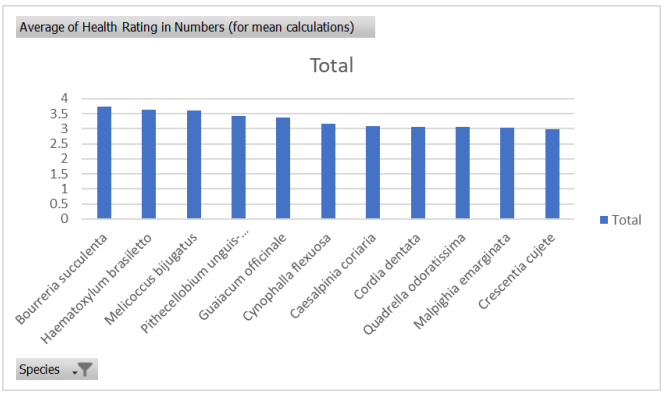

Table 4: Average Health

The table below show the mortality of trees between base inventory and new measurements from this research.

Number of (alive) trees per species	Late 2016 (Base Inventory)	Early 2018 (New Measurements by BD)	Mortality
Bourreria succulenta	144	142	2
Caesalpinia coriaria	150	148	2
Cordia dentata	199	197	2
Crescentia cujete	261	259	2
Cynophalla flexuosa	176	174	2
Guaiacum officinale	284	282	2
Haematoxylum brasiletto	163	162	1
Malpighia emarginata	67	67	0
Melicoccus bijugatus	68	67	1
Pithecellobium unguis-cati	115	115	0
Quadrella odoratissima	135	135	0

Table 5: Mortality

It is noteworthy that from these results, the growth data appear to be more interesting, as the health ratings are all relatively similar, while the growth show some interesting differences between species. The health generally seems quite good for all 11 species researched. The differences between growth are much larger which gives us more interesting results.

4.2 Results question 1 (distance to rooi)

Below you can find the results of research question 1, which is (as mentioned before):
Is there a significant difference in growth and health of the planted trees close to the ephemeral river compared to the growth and health of the planted trees further away from the ephemeral river in the Washington-Slagbaai National Park?

The following relation are to be analysed:

- *Average of health rating in plots close to rooi compared with percentage of trees with an A health rating in far away from rooi. (per plot type and per species)*
- *Average growth in plots close to rooi compared with average growth in faraway plots (per plot type and per species)*

Distance to rooi – Health

Average of Health Rating in Numbers (for mean calculations)	Column Labels		
Row Labels	Close to rooi	Far Away	Grand Total
Bourreria succulenta	3.894736842	3.692307692	3.777777778
Caesalpinia coriaria	2.92	3.411764706	3.119047619
Cordia dentata	3.236842105	3.24137931	3.23880597
Crescentia cujete	2.871794872	3.096774194	2.971428571
Cynophalla flexuosa	3.131578947	3.294117647	3.181818182
Guaiacum officinale	3.490566038	3.326086957	3.414141414
Haematoxylum brasiletto	3.571428571	3.821428571	3.696428571
Malpighia emarginata	2.923076923	3	2.947368421
Melicoccus bijugatus	3.647058824	3.25	3.571428571
Pithecellobium unguis-cati	3.571428571	3.235294118	3.387096774
Quadrella odoratissima	3.6	3.078947368	3.1875
Grand Total	**3.306122449**	**3.332046332**	**3.318264014**

Table 6: Distance to rooi - health

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	1.357864773	10	0.135786477	2.765054893	0.062105	2.978237
Columns	0.007656241	1	0.007656241	0.155905995	0.701245	4.964603
Error	0.491080584	10	0.049108058			
Total	1.856601598	21				

Table 7: ANOVA distance to rooi - health

These distance to rooi calculations involve 559 trees from the database. **The distance to the rooi does not show a significant difference in both the rows section (species) as a significant difference in the column section.** The distance to the rooi does not seem very important for the health of the planted species according to this statistical calculation.

Distance to rooi – Growth

Average of Growth (in cm)	**Column Labels**		
Row Labels	**Close to rooi**	**Far Away**	**Grand Total**
Bourreria succulenta	114.1111111	68.26923077	87.02272727
Caesalpinia coriaria	49.48	39.70588235	45.52380952
Cordia dentata	41.41025641	49.4137931	44.82352941
Crescentia cujete	26.60465116	33.2	29.31506849
Cynophalla flexuosa	73.15789474	68.11764706	71.6
Guaiacum officinale	27.43396226	25.41304348	26.49494949
Haematoxylum brasiletto	45.85714286	55.21428571	50.53571429
Malpighia emarginata	32.30769231	65.16666667	42.68421053
Melicoccus bijugatus	16.125	13.5	15.6
Pithecellobium unguis-cati	54.21428571	52.52941176	53.29032258
Quadrella odoratissima	43.9	57.47368421	54.64583333
Grand Total	**45.26599327**	**47.57364341**	**46.33873874**

Table 8: Distance to rooi - growth

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	8666.867421	10	866.6867421	4.692090641	0.011253	2.978237
Columns	0.525964222	1	0.525964222	0.002847478	0.958495	4.964603
Error	1847.122761	10	184.7122761			
Total	10514.51615	21				

Table 9: ANOVA distance to rooi - growth

These distance to rooi calculations involve 559 trees from the database. The difference in growth between species shows a significant difference (like with most growth calculations) while the distance to the rooi does not show a significant difference. If you look at the table above, *Bourreria succulenta, Malpighia emarginata* and *Quadrella odoratissima,* do seem to have some different growth differences between distances. Therefore, some T-Test were executed to calculate a possible statistical significant difference for these separate species.

For Bourreria succulenta, the t-test (table 10) showed a statistical significant difference (p value 0.000678*).* *Bourreria succulenta* grows significantly better near the rooi compared to other *Bourreria succulenta* growing further away. In the case of *Malpighia emarginata* (p value 0.263256) and *Quadrella odoratissima* (p value 0.132785) no statistical significant difference was found.

t-Test: Two-Sample Assuming Equal Variances			
	Variable 1	*Variable 2*	
Mean	114.1111	68.26923	
Variance	1604.34	1696.765	
Observations	18	26	
Pooled Variance	1659.355		
Hypothesized Mean Difference	0		
df	42		
t Stat	3.670197		
P(T<=t) one-tail	0.000339		
t Critical one-tail	1.681952		
P(T<=t) two-tail	0.000678		
t Critical two-tail	2.018082		

Table 10: T-Test Bourreria succulenta

As an additional investigation, I have counted the number of wild seedlings within the plots. This was done to look at a possible relation between the distance to the rooi and wild seedling germination. However, the main factor for the number of seedlings appeared to be a different one. Most of them were coming from an adult tree in the vicinity of the plot. If a plot happened to have an adult *Haematoxylum brasiletto* for example, seedlings of this species would occur in the plot. Plots with no adult trees in the vicinity would have no seedlings. The relation between distance to the rooi and seedlings is therefore too dependent on this other factor. Therefore no calculations were made.

Finally, I have taken a look at a possible relationship between distance to the rooi and soil characteristics. This to see if there is a correlation between the distance to the rooi and pH (Pie Chart 1), Organic matter (Pie chart 2) and Texture (Pie Chart 3). There appear to be slight differences, but not significant (see figure 11).

Row Labels	Average of Ph
Close to rooi	5.815319149
Far Away	5.089542484
Grand Total	**5.529123711**

Row Labels	Average of Organic Matter (%)
Close to rooi	5.259574468
Far Away	4.712418301
Grand Total	**5.043814433**

Row Labels	Average of Texture
Close to rooi	165.5744681
Far Away	174.4117647
Grand Total	**169.0592784**

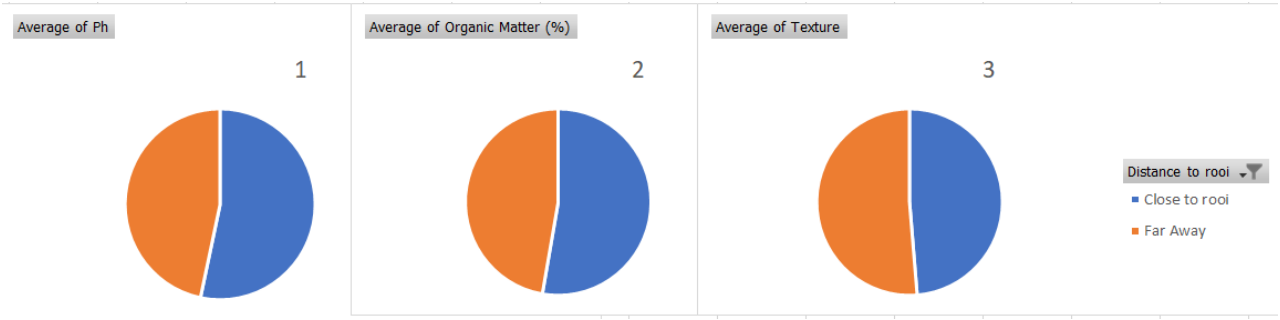

Figure 11: Pie charts of distance to rooi - soil characteristics

4.3 Results question 2 (light)

Below you can find the results of research question 2, which is (as mentioned before):
Does the amount of sunlight have a significant difference on the growth and health of the eleven most occurring tree species in Washington study area and Slagbaai study area?

The following relation are to be analysed:

- *Relation of sunlight with growth (per species)*
- *Relation of sunlight with health (per species)*

Sunlight - Health

Average of Health Rating in Numbers (for mean calculations)	**Column Labels**			
Row Labels	**FS**	**PS**	**S**	**Grand Total**
Bourreria succulenta	3.744680851	3.744680851	4	3.746478873
Caesalpinia coriaria	3.145454545	3.129411765	2	3.081632653
Cordia dentata	3.395833333	2.957446809	2.666666667	3.056410256
Crescentia cujete	3.183673469	2.861111111	2.571428571	2.979919679
Cynophalla flexuosa	2.473684211	3.248275862	3.2	3.16091954
Guaiacum officinale	3.36	3.373271889	3.5	3.375451264
Haematoxylum brasiletto	3.677083333	3.516666667	4	3.62962963
Malpighia emarginata	2.714285714	3.070175439	3.333333333	3.044776119
Melicoccus bijugatus	3.555555556	3.596491228	4	3.597014925
Pithecellobium unguis-cati	3.526315789	3.321428571	3	3.417391304
Quadrella odoratissima	2.794871795	3.163043478	3	3.053030303
Grand Total	**3.339047619**	**3.238675958**	**3.074074074**	**3.264041691**

Table 11: sunlight - health

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	4.336468483	10	0.433646848	3.655830901	0.006563	2.347878
Columns	0.02313596	2	0.01156798	0.097523084	0.90751	3.492828
Error	2.372357257	20	0.118617863			
Total	6.731961699	32				

Table 12: ANOVA sunlight - health

The sunlight calculations involve 1727 trees from the database. The p value shows a significant difference in health between rows (species). However for this calculation we are trying to determine is the is the relation between sunlight and health of the species, **which does not show a statistically significant difference with a P value of 0.0976 and a f value that is smaller than the f critical**. The amount of sunlight does not seem to have a large impact on the health of the species. PS shows the best result in Health. This is also the case for Growth.

Sunlight – Growth

Average of Growth (in cm)	Column Labels			
Row Labels	FS	PS	S	Grand Total
Bourreria succulenta	91.0212766	84.77419355	115	87.07092199
Caesalpinia coriaria	40.30909091	37.71764706	20.71428571	37.87755102
Cordia dentata	52.20833333	49.17021277	50	49.94358974
Crescentia cujete	30.54639175	33.30985915	25.85714286	32.00813008
Cynophalla flexuosa	45.94736842	72.49655172	51.3	68.37931034
Guaiacum officinale	28.18	27.44239631	23.4	27.42960289
Haematoxylum brasiletto	53.9375	63.65	63.66666667	57.89506173
Malpighia emarginata	52.57142857	26.71929825	17.33333333	29
Melicoccus bijugatus	11.66666667	28.39285714	25	26.06060606
Pithecellobium unguis-cati	43.12280702	49.8	12.5	45.80701754
Quadrella odoratissima	33.38461538	50.16304348	68	45.34090909
Grand Total	**45.14694656**	**46.81189851**	**37.77777778**	**46.02149913**

Table 13: Sunlight - growth

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	13965.40772	10	1396.540772	8.411031376	3.18684E-05	2.347878
Columns	131.8030905	2	65.90154523	0.39690926	0.67757514	3.492828
Error	3320.736089	20	166.0368045			
Total	17417.9469	32				

Table 14: ANOVA Sunlight - growth

The sunlight calculations involve 1727 trees from the database. The p factor shows a significant difference in growth between species. However this calculation is trying to determine the relation between sunlight and growth, which does not show a significant difference between the sunlight categories. Partly in the sun shows the best result in health in general. The influence of sunlight on both health and growth is not statistically significant different. However, there are some large growth differences between some species according to this data. Caesalpinia coriaria and Malpighia emarginata prefer much sunlight, while Quadrella odoratissima prefers the shade. The f value is also smaller than the f critical value.

4.4 Results question 3 (soil)

Below you can find the results of research question 3, which is (as mentioned before):
Do differences in soil characteristics (organic matter, acidity, texture and surrounding vegetation) have a significant influence on tree growth and health of the eleven most occurring tree species in Washington study area and Slagbaai study area?

The following relations are analysed:

- *Relation of texture with growth plots (per plot and per species)*
- *Relation of texture with health plots (per plots and per species)*
- *Relation of organic matter percentage with growth plots (per plot and per species)*
- *Relation of organic matter percentage with health plots (per plot and per species)*

- *Relation of pH with growth plots (per plot and per species)*
- *Relation of pH with health plots (per plot and per species)*
- *Relation of vegetation cover with growth (per species)*
- *Relation of vegetation cover with health (per species)*

Texture – Health

Average of Health Rating in Numbers (for mean calculations)	Column Labels			
Row Labels	**A. Extreme Fine**	**B. Very Fine**	**C. Medium Fine**	**Grand Total**
Bourreria succulenta	4	3.5	3.833333333	3.818181818
Caesalpinia coriaria	3.857142857	2	3	3.076923077
Cordia dentata	3.055555556	3.529411765	3	3.227272727
Crescentia cujete	3.090909091	3.052631579	2.823529412	2.978723404
Cynophalla flexuosa	3.333333333	3.75	3.230769231	3.416666667
Guaiacum officinale	4	3.259259259	3.37037037	3.393442623
Haematoxylum brasiletto	3.75	3.625	3.714285714	3.703703704
Malpighia emarginata	2.75	3.166666667	3	3
Melicoccus bijugatus	4	3.75	3.5	3.6875
Pithecellobium unguis-cati	3.5	3.4	3.357142857	3.391304348
Quadrella odoratissima	3.5	2.666666667	3.230769231	3
Grand Total	**3.460526316**	**3.262711864**	**3.266666667**	**3.310030395**

Table 15: Texture health

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	3.045891	10	0.304589	2.345784	0.050174	2.347878
Columns	0.535848	2	0.267924	2.063408	0.153215	3.492828
Error	2.596907	20	0.129845			
Total	6.178646	32				

Table 16: ANOVA texture - health

The texture calculations involve 329 trees from the database. The p value between species does not show a significant difference. The p value between texture groups does not show a significant difference either. This means that according to these calculations, texture does not have a large impact on the health of the species planted in the exclosures.

Texture - Growth

Average of Growth (in cm)	Column Labels			
Row Labels	A. Extreme Fine	B. Very Fine	C. Medium Fine	Grand Total
Bourreria succulenta	37.83333333	83	113.0833333	87.09090909
Caesalpinia coriaria	25.14285714	47.25	64.4	51.19230769
Cordia dentata	26.77777778	43.52941176	57.22222222	39.47727273
Crescentia cujete	21.45454545	20.22222222	39.58823529	27.67391304
Cynophalla flexuosa	81	81.875	62.38461538	71.20833333
Guaiacum officinale	28.42857143	25.2962963	26.44444444	26.16393443
Haematoxylum brasiletto	27.08333333	68.5	66.71428571	49.62962963
Malpighia emarginata	22.75	30	36	28.58333333
Melicoccus bijugatus	11	23.85714286	14.66666667	18.46666667
Pithecellobium unguis-cati	20	55.2	59.5	51.69565217
Quadrella odoratissima	22	57.33333333	78.46153846	64.88888889
Grand Total	**27.96052632**	**41.56896552**	**55.67407407**	**44.2293578**

Table 17: Texture - growth

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	11529.94	10	1152.994186	5.466971438	0.000626	2.347878
Columns	4212.359	2	2106.179728	9.986541609	0.000983	3.492828
Error	4218.036	20	210.9018127			
Total	19960.34	32				

Table 18: ANOVA texture - growth

The texture calculations involve 329 trees from the database. The texture growth relation ANOVA calculation shows a significant difference in growth between species in general and as well as a statistically significant difference between the texture groups. This shows that texture is quite an important factor for the growth of the 11 planted species in the exclosures. The growth average is highest in category C medium Fine, and lowest in A extreme fine.

Organic Matter – Health

Average of Health Rating in Numbers (for mean calculations)	Column Labels			
Row Labels	>5	0 - 2.5	2.5 - 5	Grand Total
Bourreria succulenta	3.75	4	3.857142857	3.818181818
Caesalpinia coriaria	2.454545455	3.125	4	3.076923077
Cordia dentata	2.5	3.615384615	3.2	3.227272727
Crescentia cujete	2.470588235	3.181818182	3.315789474	2.978723404
Cynophalla flexuosa	3.416666667	3.222222222	4	3.416666667
Guaiacum officinale	3.47826087	3	3.40625	3.393442623
Haematoxylum brasiletto	4	3.5	3.785714286	3.703703704
Malpighia emarginata	3	3	3	3
Melicoccus bijugatus	3.8	3.666666667	3.5	3.6875
Pithecellobium unguis-cati	3.25	3.666666667	3.333333333	3.391304348
Quadrella odoratissima	3.666666667	3	2.909090909	3
Grand Total	**3.176470588**	**3.382716049**	**3.363013699**	**3.310030395**

Table 19: Organic matter - health

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	2.81336	10	0.28133595	1.83701949	0.118578	2.347878
Columns	0.289081	2	0.14454059	0.943796483	0.405807	3.492828
Error	3.062961	20	0.153148049			
Total	6.165402	32				

Table 20: ANOVA organic matter - health

The organic matter calculations involve 329 trees from the database. The p value between species does not show a significant difference. **The p value between organic matter groups does not show a significant difference either.** This means that according to these calculations, organic matter does not have a large impact on the health of the species planted in the exclosures.

Organic Matter – Growth

Average of Growth (in cm)	**Column Labels**			
Row Labels	**>5**	**0 - 2.5**	**2.5 - 5**	**Grand Total**
Bourreria succulenta	112.5833333	87.66666667	43.14285714	87.09090909
Caesalpinia coriaria	71.45454545	19.125	56	51.19230769
Cordia dentata	72.16666667	28.61538462	37.28	39.47727273
Crescentia cujete	33.23529412	20.45454545	26.83333333	27.67391304
Cynophalla flexuosa	62	83.33333333	71.66666667	71.20833333
Guaiacum officinale	31.65217391	16	24.125	26.16393443
Haematoxylum brasiletto	95	32.9	51.85714286	49.62962963
Malpighia emarginata	36	18.75	32.66666667	28.58333333
Melicoccus bijugatus	26	16.25	8.5	18.46666667
Pithecellobium unguis-cati	69.75	34	47.44444444	51.69565217
Quadrella odoratissima	74.66666667	26	67.09090909	64.88888889
Grand Total	**57.60784314**	**33.1125**	**40.95172414**	**44.2293578**

Table 21: Organic matter - growth

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	12687.30913	10	1268.730913	4.713475134	0.001569	2.347878
Columns	4403.201556	2	2201.600778	8.179189467	0.002537	3.492828
Error	5383.420416	20	269.1710208			
Total	22473.93111	32				

Table 22: ANOVA organic matter - growth

The organic matter calculations involve 329 trees from the database. The organic matter growth relation ANOVA calculation shows a **significant difference in growth between species in general and as well as a statistically significant difference between the organic matter groups**. This shows that organic matter, just like texture, is quite an important factor for the growth of the 11 planted species in the exclosures. The highest average is found at an organic matter level of more than 5%.

pH – Health

Average of Health Rating in Numbers (for mean calculations)	Column Labels		
Row Labels	**4.7 - 5.5**	**5.8 - 7.0**	**Grand Total**
Bourreria succulenta	3.789473684	4	3.818181818
Caesalpinia coriaria	3.058823529	3.111111111	3.076923077
Cordia dentata	3.227272727	3.227272727	3.227272727
Crescentia cujete	3.027777778	2.818181818	2.978723404
Cynophalla flexuosa	3.444444444	3.4	3.416666667
Guaiacum officinale	3.342105263	3.47826087	3.393442623
Haematoxylum brasiletto	3.666666667	3.75	3.703703704
Malpighia emarginata	3	3	3
Melicoccus bijugatus	3.6	3.833333333	3.6875
Pithecellobium unguis-cati	3.35	3.666666667	3.391304348
Quadrella odoratissima	3.105263158	2.571428571	2.961538462
Grand Total	**3.303317536**	**3.316239316**	**3.307926829**

Table 23: pH - health

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	2.488422	10	0.24884221	9.004373261	0.000889	2.978237
Columns	0.002716	1	0.002715681	0.098267096	0.76036	4.964603
Error	0.276357	10	0.027635706			
Total	2.767495	21				

Table 24: ANOVA pH - health

The pH calculations involve 329 trees from the database. The p value of between species is (again) significant. However, the factor calculated here is the relation between pH and health. This calculation does not show a statistically significant difference for pH – Health.

pH – Growth

Average of Growth (in cm)	Column Labels		
Row Labels	**4.7 - 5.5**	**5.8 - 7.0**	**Grand Total**
Bourreria succulenta	92.05263158	55.66666667	87.09090909
Caesalpinia coriaria	50.17647059	53.11111111	51.19230769
Cordia dentata	43.59090909	35.36363636	39.47727273
Crescentia cujete	31.11428571	16.72727273	27.67391304
Cynophalla flexuosa	78.22222222	67	71.20833333
Guaiacum officinale	23.05263158	31.30434783	26.16393443
Haematoxylum brasiletto	45.53333333	54.75	49.62962963
Malpighia emarginata	36.66666667	20.5	28.58333333
Melicoccus bijugatus	16.3	22.8	18.46666667
Pithecellobium unguis-cati	53.55	39.33333333	51.69565217
Quadrella odoratissima	71	46.85714286	64.5
Grand Total	**46.26666667**	**40.27586207**	**44.13496933**

Table 25: pH - growth

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	7141.835458	10	714.1835458	6.787331864	0.002805	2.978237
Columns	435.1713293	1	435.1713293	4.135704676	0.069381	4.964603
Error	1052.230184	10	105.2230184			
Total	8629.236971	21				

Table 26: ANOVA pH - growth

The pH calculations involve 329 trees from the database. Again, the differences between species is statistically significant, while the researched factor, **in this case pH is not statistically significant.** Guaiacum grows better with a higher pH while Malpighia and Quadrella are growing less. On these three species a T-Test was performed. Quadrella odoratissima and Malpighia emarginata do not show a significant difference. **Guaiacum officinale however does show a significant difference between lower and higher pH groups.** See below for the result.

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	23.05263	31.30435
Variance	192.6458	132.8577
Observations	38	23
Pooled Variance	170.3519	
Hypothesized Mean Difference	0	
df	59	
t Stat	-2.3931	
P(T<=t) one-tail	0.009954	
t Critical one-tail	1.671093	
P(T<=t) two-tail	0.019907	
t Critical two-tail	2.000995	

Table 27: T - Test Guaiacum officinale pH - growth

Vegetation Cover – Health

Average of Health Rating in Numbers (for mean calculations)	**Column Labels**					
Row Labels	**>50%**	**0 - 15%**	**16 - 30%**	**16- 30%**	**31 - 50%**	**Grand Total**
Bourreria succulenta	3.52	3.882352941	3.8125	3.789473684	3.677419355	3.744680851
Caesalpinia coriaria	3.444444444	3.125	2.947368421	2.888888889	3	3.081632653
Cordia dentata	3.105263158	3.142857143	2.857142857	2.888888889	3.233333333	3.056410256
Crescentia cujete	2.829268293	2.906666667	2.960784314	3.1	3.163934426	2.983870968
Cynophalla flexuosa	3.222222222	3.175438596	3.108108108	3.111111111	3.147058824	3.156069364
Guaiacum officinale	3.341463415	3.288659794	3.5	3.357142857	3.422222222	3.375451264
Haematoxylum brasiletto	3.527777778	3.62	3.653846154	3.684210526	3.709677419	3.62962963
Malpighia emarginata	2.666666667	3.304347826	3.153846154	3.125	2.714285714	3.044776119
Melicoccus bijugatus	3.545454545	3.64	3.636363636	3.625	3.5	3.597014925
Pithecellobium unguis-cati	3.785714286	3.451612903	3.323529412	3.142857143	3.476190476	3.421052632
Quadrella odoratissima	3.285714286	3.047619048	3.083333333	2.75	3.083333333	3.053030303
Grand Total	**3.28627451**	**3.262786596**	**3.245989305**	**3.225806452**	**3.290322581**	**3.264074289**

Table 28: Vegetation cover - health

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	3.982785367	10	0.398278537	13.67584682	5E-10	2.077248
Columns	0.061461932	4	0.015365483	0.527610639	0.716046	2.605975
Error	1.164910786	40	0.02912277			
Total	5.209158086	54				

Table 29: ANOVA vegetation cover - health

The vegetation cover calculations involve 1723 trees from the database. The p value of the rows section of vegetation cover – health shows an statistically significant difference **while the differences in vegetation cover do not show a significant difference.**

Vegetation Cover – Growth

Average of Growth (in cm)	**Column Labels**					
Row Labels	**>50%**	**0 - 15%**	**16 - 30%**	**16- 30%**	**31 - 50%**	**Grand Total**
Bourreria succulenta	99.29166667	87	95	71.05263158	79.4516129	87.1
Caesalpinia coriaria	31.5	32.21428571	45.76315789	38.55555556	42.73076923	37.87755102
Cordia dentata	54.94736842	43.35064935	53.19047619	55.66666667	54	49.94358974
Crescentia cujete	44.36585366	23.17808219	31.96	23.55	37.03278689	31.99591837
Cynophalla flexuosa	89.07407407	68.35087719	60.7027027	59.27777778	64.29411765	68.20809249
Guaiacum officinale	30.70731707	24.95876289	26.33333333	26.92857143	31.68888889	27.42960289
Haematoxylum brasiletto	53.11111111	49.6	61.65384615	69.05263158	66.83870968	57.89506173
Malpighia emarginata	47.55555556	24.73913043	43.30769231	25.25	12.92857143	29
Melicoccus bijugatus	24	18.08	36.54545455	46.625	20.81818182	26.06060606
Pithecellobium unguis-cati	64.14285714	45.53333333	41.26470588	30	51.57142857	45.75221239
Quadrella odoratissima	39.28571429	44.57142857	57.375	42.875	41.66666667	45.34090909
Grand Total	**53.26377953**	**40.5106383**	**48.10455764**	**45.61827957**	**47.44117647**	**45.97262667**

Table 30: Vegetation cover- growth

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	17225.90602	10	1722.590602	20.05149881	1.4E-12	2.077248
Columns	825.6480928	4	206.4120232	2.40270116	0.065706	2.605975
Error	3436.332851	40	85.90832128			
Total	21487.88697	54				

Table 31: ANOVA vegetation cover - growth

The vegetation cover calculations involve 1723 trees from the database. The p value of the rows section of vegetation cover – growth shows again a statistically significant difference **while the differences in vegetation cover do not show a significant difference in growth**.

5. Discussion of results

5.1 Questions 1, 2 and 3: Hypotheses tested

Question 1: *Is there a significant difference in growth and health of the planted trees close to the ephemeral river compared to the growth and health of the planted trees further away from the ephemeral river in the Washington-Slagbaai National Park?*
The statistical null hypothesis (H_0) is to be accepted: there is no significant difference in growth and health rating near or further away from the river.

Question 2: *Does the amount of sunlight have a significant difference on the growth and health of the eleven most occurring tree species in Washington study area and Slagbaai study area?*
The statistical null hypothesis (H_0) is to be accepted: there is no significant difference.

Question 3: *Do differences in soil characteristics (organic matter, acidity, texture and surrounding vegetation) have a significant influence on tree growth and health of the eleven most occurring tree species in Washington study area and Slagbaai study area?*
The statistical null hypothesis (H_0) is to be rejected for the relations texture-growth and organic matter-growth. There is a statistically significant difference.
H_0 is to be accepted for all other relations: there is no significant difference in these relations.

5.2 Research objective: Overview tables

As mentioned (2.1), the objective of this research is to define the species suitability of the planted species in the exclosures created by Echo in the Washington Slagbaai National Park defined by soil, light and water.

I have put the results of the pivot-tables as created from the database in two overview tables for the most suitable results per factor, first for health, then for growth. See below. These results are found by looking at the highest average per species for health and growth. For health (see below) this shows some interesting results. Most tree species prefer an Extreme Fine soil texture (75-150 μm). pH varies, as well as the need for organic matter and light requirements.

Compared to the information on the tree species found in literature (3.1.3) some things can be confirmed while others are different. Not all species are mentioned as I do not have information from literature on the researched factors from some species. *Bourreria succulenta* requires a calcareous soil which is confirmed by the higher pH preference in the results (although the pH is still below 7 meaning it is not calcareous). *Cordia dentate* prefers a sunny which is also confirmed by the results (FS). According to literature *Cynophalla flexuosa* requires a sunny position as well. This does not completely match with the results. The health rating is highest in the PS (partly sun) instead of FS (full sun) category. Interestingly *Malpighia emarginata* requires a sunny position according to literature, but has the best health in the shade. *Melicoccus bijugatus* requires a sunny position and a pH between 5.5 – 7. The pH result matches with the literature, the sun requirements differ as Melicoccus prefers the shade according to the table.

Advice Table Health	Distance To Rooi	Texture	Organic Matter	Light	pH	Vegetation Cover
Bourreria succulenta	Close To Rooi	A. Extreme Fine	0 - 2.5	S	5.8 - 7.0	0 - 15%
Caesalpinia coriaria	Far Away	A. Extreme Fine	2.5 - 5	FS	5.8 - 7.0	>50%
Cordia dentata	Far Away	B. Very Fine	0 - 2.5	FS	ALL	31 - 50%
Crescentia cujete	Far Away	A. Extreme Fine	2.5 - 5	FS	4.7 - 5.5	31 - 50%
Cynophalla flexuosa	Far Away	B. Very Fine	2.5 - 5	PS	4.7 - 5.5	>50%
Guaiacum officinale	Close To Rooi	A. Extreme Fine	>5	PS	5.8 - 7.0	16 - 30%
Haematoxylum brasiletto	Far Away	A. Extreme Fine	>5	S	5.8 - 7.0	31 - 50%
Malpighia emarginata	Far Away	B. Very Fine	All	S	ALL	0 - 15%
Melicoccus bijugatus	Close To Rooi	A. Extreme Fine	>5	S	5.8 - 7.0	0 - 15%
Pithecellobium unguis-cati	Close To Rooi	A. Extreme Fine	0 - 2.5	FS	5.8 - 7.0	>50%
Quadrella odoratissima	Close To Rooi	A. Extreme Fine	>5	PS	4.7 - 5.5	>50%

Table 32: Advice table health

Figure 12: Healthy Bourreria succulenta (Bram Dicou)

The overview table for growth (see below) shows different results. For growth most species prefer a Medium Fine soil texture (210 - 300 µm), a much larger grain size compared to the health requirements. Also the organic matter requirements are higher for most species. The vegetation cover is an interesting factor to look at. It seems some surrounding vegetation on the soil, or in the cases of *Bourreria, Crescentia, Cynophalla, Malpighia* and *Pithecellobium* a lot of vegetation, is positive to the growth of the species.

Compared to the literature again, *Bourreria succulenta* requires a calcareous soil, which does not match with the results from the table. As stated above, *Cordia dentate* requires a sunny position which does match with the result in the table. Again, *Cynophalla flexuosa* prefers PS according to the table, while preferring a sunny position according to literature. *Malpighia emarginata* is interesting, according to literature it prefers a sunny position, which concurs with the results in this table. The results at the health table however show a preference for shade. The pH results for *Melicoccus bijugatus* are the same as the health table.

Advice Table Growth	Distance To Rooi	Texture	Organic Matter	Light	pH	Vegetation Cover
Bourreria succulenta	Close To Rooi	C. Medium Fine	>5	S	4.7 - 5.5	>50%
Caesalpinia coriaria	Close To Rooi	C. Medium Fine	>5	FS	5.8 - 7.0	16 - 30%
Cordia dentata	Far Away	C. Medium Fine	>5	FS	4.7 - 5.5	16- 30%
Crescentia cujete	Close To Rooi	C. Medium Fine	>5	PS	4.7 - 5.5	>50%
Cynophalla flexuosa	Close To Rooi	B. Very Fine	0 - 2.5	PS	4.7 - 5.5	>50%
Guaiacum officinale	Close To Rooi	A. Extreme Fine	>5	FS	5.8 - 7.0	31 - 50%
Haematoxylum brasiletto	Far Away	B. Very Fine	>5	S	5.8 - 7.0	16- 30%
Malpighia emarginata	Far Away	C. Medium Fine	>5	FS	4.7 - 5.5	>50%
Melicoccus bijugatus	Close To Rooi	B. Very Fine	>5	PS	5.8 - 7.0	16- 30%
Pithecellobium unguis-cati	Close To Rooi	C. Medium Fine	>5	PS	4.7 - 5.5	>50%
Quadrella odoratissima	Far Away	C. Medium Fine	>5	S	4.7 - 5.5	16 - 30%

Table 33: Advice table growth

Figure 13: Guaiacum officinale

6. Conclusion

In conclusion, the suitability has been defined by several variables, divided under the factors distance to rooi (question 1), light (question 2) and soil (question 3).

For the first question (distance to rooi), the ANOVA calculation from the distance to the rooi did not show a significant difference between plots close to a rooi and further away from the rooi. However, *Bourreria succulenta* did show a significant difference according to the T-Test.

For the second question (light) no significant differences were found. However, there are some large growth differences between some species according to the data. Caesalpinia coriaria and Malpighia emarginata prefer much sunlight, while Quadrella odoratissima prefers the shade.

For the third question (soil) some significant differences were found. These are the statistically significant ANOVA results of the relations texture – growth and organic matter - growth. This is important for texture gives information on the rate of water consumption and water accumulation. Organic matter – growth is important for the same reason.
Not only for water consumption and water accumulation these factors are important, but also for nutrient availability.
Surrounding vegetation cover did not show a significant difference and pH neither. However for one species there was a significant difference with the pH – growth calculation: *Guaiacum officinale*. The T-Test performed on this species shows a significant difference between the two pH groups.

These results allow the conclusion that looking at site suitability for these 11 species, texture and organic matter are important. The other factors, including the location of the rooi, are not important, or at least not when analysing the statistics. There are significant differences between the species itself however. For that reason a ranking table was created of the best performing trees. The tree with the highest health average got, 11 points, the number 2 10 points, etc. The same counts for growth. This resulted in Bourreria succulenta as best performing tree (see below).

Tree ranking	Species	Points Health	Points Growth	Point Total
1	Bourreria succulenta	11	11	22
2	Haematoxylum brasiletto	10	9	19
3	Cynophalla flexuosa	6	10	16
4	Pithecellobium unguis-cati	8	7	15
5	Cordia dentata	4	8	12
6	Caesalpinia coriaria	5	5	10
6	Melicoccus bijugatus	9	1	10
7	Guaiacum officinale	7	2	9
7	Quadrella odoratissima	3	6	9
8	Crescentia cujete	1	4	5
8	Malpighia emarginata	2	3	5

Table 34: Tree ranking table

Next, when looking at the pivot tables created using the database, an overview of the ideal requirements for health and growth was created for each species. This showed some interesting results discussed in chapter 5.

7. Evaluation and advice

For advice on species suitability in future plantations, see section 5 (Discussion of results).

For future research on this subject I recommend to study the species for a longer period of time. For this study the trees have been studied c.a. 1,5 years after planting. It would be interesting to see which species survive in 5, 10 or 20 years. I would recommend taking the data on water, light and soil after these years to have more information on the effects of these factors on the growth, health and possible mortality.

Soil research can be extended by taking the soil nutrients into consideration. When soil samples are examined in a laboratory more nutrient information can be gathered.

The main problem during fieldwork was the abundance of cactus growing everywhere, which made setting out plots difficult and sometimes impossible. This was countered by moving the plots a bit further away. I did however, manage to examine all planted trees in the exclosures. Another problem was the rocky soil, which made digging holes in some cases impossible. Both these problems were addressed beforehand in the risk analysis (see annex).

In general a study like this could benefit from engaging a (local) expert on these species. I took several weeks learning to recognise the species in their various health stages by tagging the same species in other exclosures. Someone with more experience may have added a more detailed way of looking, taking in account other health details as well. So this I would recommend for future research.

Obviously, more plots, more trees and more locations would be beneficial for a more accurate statistical calculation. However, I did manage to collect all data I planned to collect within the given timeframe (see annex).

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Annex

In the annex you can find the forms used during fieldwork. The conditions, risk analysis and organisation and planning can also be found here. The used to be in the main part of the research proposal. Lastly the full versions of the ANOVA result tables are in the annex. The most import part of these results can already be found in chapter 4.

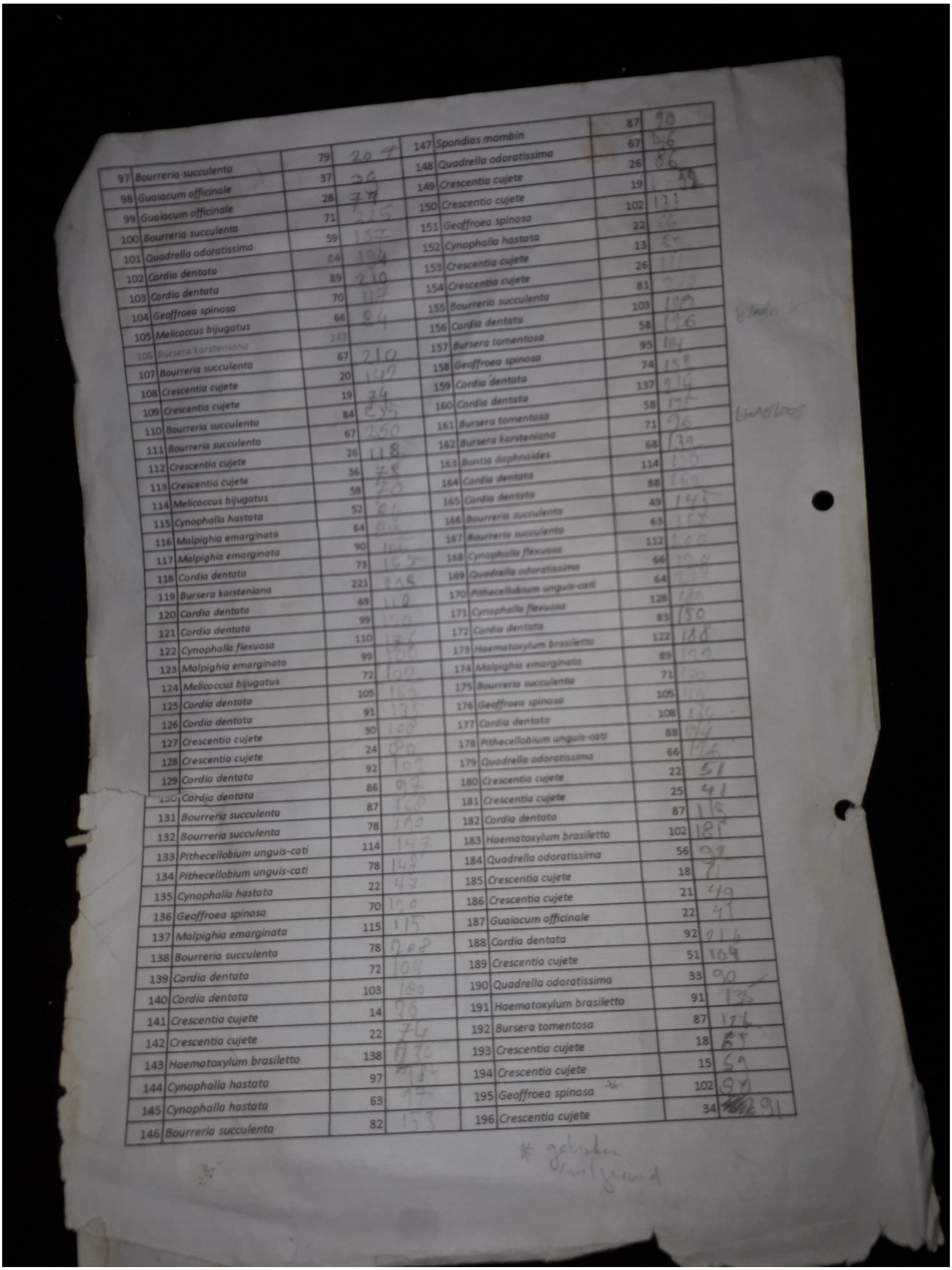
On this page you can find an example of the form used for research question 2. Height is measured on a separate form.

	A	B	C	D	E	F	G
1	**Tag**	**Name**	**Dead?**	**Health (A,B,C OR D)**	**Surrounding vegetation**	**Full Sun (FS), partly in the Sun (PS), Shade (S)**	**Comments**
119	118	*Cordia dentata*					
120	119	*Bursera karsteniana*					
121	120	*Cordia dentata*					
122	121	*Cordia dentata*					
123	122	*Cynophalla flexuosa*					
124	123	*Malpighia emarginata*					
125	124	*Melicoccus bijugatus*					
126	125	*Cordia dentata*					
127	126	*Cordia dentata*					
128	127	*Crescentia cujete*					
129	128	*Crescentia cujete*					
130	129	*Cordia dentata*					
131	130	*Cordia dentata*					
132	131	*Bourreria succulenta*					
133	132	*Bourreria succulenta*					
134	133	*Pithecellobium unguis-cati*					
135	134	*Pithecellobium unguis-cati*					
136	135	*Cynophalla hastata*					
137	136	*Geoffroea spinosa*					
138	137	*Malpighia emarginata*					
139	138	*Bourreria succulenta*					
140	139	*Cordia dentata*					
141	140	*Cordia dentata*					
142	141	*Crescentia cujete*					
143	142	*Crescentia cujete*					
144	143	*Haematoxylum brasiletto*					
145	144	*Cynophalla hastata*					
146	145	*Cynophalla hastata*					
147	146	*Bourreria succulenta*					
148	147	*Spondias mombin*					
149	148	*Quadrella odoratissima*					
150	149	*Crescentia cujete*					
151	150	*Crescentia cujete*					
152	151	*Geoffroea spinosa*					
153	152	*Cynophalla hastata*					
154	153	*Crescentia cujete*					
155	154	*Crescentia cujete*					
156	155	*Bourreria succulenta*					
157	156	*Cordia dentata*					

This is the form for research question 1.

Plot Nr	Tree tag	Dead?	Health (A,B,C OR D)	Height	pH	Organic matter	Texture

This is the (used) form for the height measurements at research question 2.



97	Bourreria succulenta	79	207	147	Spondias mombin	87	90
98	Guaiacum officinale	37	30	148	Quadrella odoratissima	67	46
99	Guaiacum officinale	28	77	149	Crescentia cujete	26	86
100	Bourreria succulenta	71	225	150	Crescentia cujete	19	46
101	Quadrella odoratissima	59	157	151	Geoffroea spinosa	102	123
102	Cordia dentata	84	194	152	Cynophalla hastata	22	66
103	Cordia dentata	89	210	153	Crescentia cujete	13	57
104	Geoffroea spinosa	70	117	154	Crescentia cujete	26	111
105	Melicoccus bijugatus	66	84	155	Bourreria succulenta	81	77
106	Bursera karsteniana	243		156	Cordia dentata	103	130
107	Bourreria succulenta	67	210	157	Bursera tomentosa	58	126
108	Crescentia cujete	20	107	158	Geoffroea spinosa	95	164
109	Crescentia cujete	19	74	159	Cordia dentata	74	158
110	Bourreria succulenta	84	235	160	Cordia dentata	137	216
111	Bourreria succulenta	67	250	161	Bursera tomentosa	58	197
112	Crescentia cujete	26	118	162	Bursera karsteniana	71	96
113	Crescentia cujete	36	78	163	Bontia daphnoides	68	139
114	Melicoccus bijugatus	59	70	164	Cordia dentata	114	170
115	Cynophalla hastata	52	86	165	Cordia dentata	88	164
116	Malpighia emarginata	64	83	166	Bourreria succulenta	49	145
117	Malpighia emarginata	90	106	167	Bourreria succulenta	63	157
118	Cordia dentata	73	162	168	Cynophalla flexuosa	112	160
119	Bursera karsteniana	221	258	169	Quadrella odoratissima	66	124
120	Cordia dentata	69	112	170	Pithecellobium unguis-cati	64	98
121	Cordia dentata	99	150	171	Cynophalla flexuosa	128	181
122	Cynophalla flexuosa	110	176	172	Cordia dentata	83	150
123	Malpighia emarginata	99	168	173	Haematoxylum brasiletto	122	118
124	Melicoccus bijugatus	72	102	174	Malpighia emarginata	89	109
125	Cordia dentata	105	153	175	Bourreria succulenta	71	120
126	Cordia dentata	91	138	176	Geoffroea spinosa	105	118
127	Crescentia cujete	30	100	177	Cordia dentata	108	146
128	Crescentia cujete	24	90	178	Pithecellobium unguis-cati	88	124
129	Cordia dentata	92	109	179	Quadrella odoratissima	66	126
130	Cordia dentata	86	92	180	Crescentia cujete	22	51
131	Bourreria succulenta	87	150	181	Crescentia cujete	25	41
132	Bourreria succulenta	78	140	182	Cordia dentata	87	118
133	Pithecellobium unguis-cati	114	147	183	Haematoxylum brasiletto	102	181
134	Pithecellobium unguis-cati	78	143	184	Quadrella odoratissima	56	99
135	Cynophalla hastata	22	42	185	Crescentia cujete	18	71
136	Geoffroea spinosa	70	100	186	Crescentia cujete	21	49
137	Malpighia emarginata	115	115	187	Guaiacum officinale	22	49
138	Bourreria succulenta	78	088	188	Cordia dentata	92	216
139	Cordia dentata	72	104	189	Crescentia cujete	51	109
140	Cordia dentata	103	180	190	Quadrella odoratissima	33	90
141	Crescentia cujete	14	98	191	Haematoxylum brasiletto	91	135
142	Crescentia cujete	22	74	192	Bursera tomentosa	87	126
143	Haematoxylum brasiletto	138	176	193	Crescentia cujete	18	85
144	Cynophalla hastata	97	210	194	Crescentia cujete	15	59
145	Cynophalla hastata	63	147	195	Geoffroea spinosa *	102	91
146	Bourreria succulenta	82	153	196	Crescentia cujete	34	291

* gebroken

Conditions and risk analysis

Conditions

The following conditions have to be met if this research is to succeed:

- Time, there should be enough time at the thesis providing organisation to conduct the field research before turning back to the Netherlands.
- Accommodation, there should be a place to stay between work hours to spend the non-working hours for sleep, eating and free time.
- Expertise, there should be a supervisor at the study location to provide help with the research whenever necessary.
- Transport, there should be someone who can drive to bring me to the study location.

Risk analysis

The following risks are a part of this thesis:

- The soil is very hard in Bonaire. For my soil research I have to dig holes to get the data. There might be a possibility that this will not be possible, or that it will cost a lot of time to dig the holes. If I get in trouble with the remaining time, I can choose to collect a bit less soil data to make sure all the other data is collected on time. I can do this by choosing to do 2 rooi's outside the exclosures instead of four, for example.
- Cactus is very common in Bonaire and grows everywhere. Sometimes the cactus growth is so dense that it might not be possible to do a plot there. If this is the case I will try to do a plot in the near vicinity.
- Sources for most of the species chosen are scarce. Most information about health is obtained via information from colleagues from Echo. There are people working with Echo who have been working there for years and know a lot about these species.

Organisation and planning

I will do this thesis research by myself. This means that all thesis related responsibilities are my own. My supervisor from Van-Hall Larenstein is Anko Stilma. My supervisor in Bonaire is Quirijn Coolen. I have contact with my supervisor from Van-Hall Larenstein by email and skype whilst in Bonaire. The other way around whilst I am back in the Netherlands I will have contact by email with Quirijn Coolen.

The thesis period starts at January 12 2018 and lasts until the end of June of that same year. I have the following global planning for the milestones of this thesis research:

- Submit research proposal	12-03-2018 (new in May 2018)
- Fieldwork in Bonaire	12-01-2018 - 04-04-2018
- Orientation	4 weeks
- Fieldwork question 1	4 weeks
- Fieldwork question 2	4 weeks
- Fieldwork question 3	1 week
- Fieldwork question 4	1 week
- Report writing	05-04-2018 - 07-06-2018
- Hand in final report	07-06-2018
- Colloquium	End of June 2018

I use the following materials for the fieldwork part of this research:

- Measuring stick
- GPS (Garmin GPSMap 64s)
- Measuring tape
- Field forms
- Pencil
- Rope (for setting out plots)
- Compass (on the GPS)
- Camera (on a phone)
- Shovel
- Sandruler
- pH strips
- Water

ANOVA Tables

Distance to rooi – Health

Anova: Two-Factor Without Replication						
SUMMARY	*Count*	*Sum*	*Average*	*Variance*		
Bourreria succulenta	2	7.587044534	3.793522267	0.02048878		
Caesalpinia coriaria	2	6.331764706	3.165882353	0.120916263		
Cordia dentata	2	6.478221416	3.239110708	1.02931E-05		
Crescentia cujete	2	5.968569065	2.984284533	0.025307848		
Cynophalla flexuosa	2	6.425696594	3.212848297	0.013209414		
Guaiacum officinale	2	6.816652994	3.408326497	0.013526684		
Haematoxylum brasiletto	2	7.392857143	3.696428571	0.03125		
Malpighia emarginata	2	5.923076923	2.961538462	0.00295858		
Melicoccus bijugatus	2	6.897058824	3.448529412	0.078827855		
Pithecellobium unguis-cati	2	6.806722689	3.403361345	0.056493186		
Quadrella odoratissima	2	6.678947368	3.339473684	0.135747922		
Close to rooi	11	36.85851169	3.35077379	0.122165154		
Far Away	11	36.44810056	3.313463688	0.062729381		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	1.357864773	10	0.135786477	2.765054893	0.062105	2.978237
Columns	0.007656241	1	0.007656241	0.155905995	0.701245	4.964603
Error	0.491080584	10	0.049108058			
Total	1.856601598	21				

Distance to rooi – Growth

Anova: Two-Factor Without Replication						
SUMMARY	*Count*	*Sum*	*Average*	*Variance*		
Bourreria succulenta	2	182.3803419	91.19017094	1050.738997		
Caesalpinia coriaria	2	89.18588235	44.59294118	47.76668789		
Cordia dentata	2	90.82404951	45.41202476	32.0282998		
Crescentia cujete	2	59.80465116	29.90232558	21.74931314		
Cynophalla flexuosa	2	141.2755418	70.6377709	12.70204833		
Guaiacum officinale	2	52.84700574	26.42350287	2.04205637		
Haematoxylum brasiletto	2	101.0714286	50.53571429	43.77806122		
Malpighia emarginata	2	97.47435897	48.73717949	539.856098		
Melicoccus bijugatus	2	29.625	14.8125	3.4453125		
Pithecellobium unguis-cati	2	106.7436975	53.37184874	1.419400113		
Quadrella odoratissima	2	101.3736842	50.68684211	92.12245152		
Close to rooi	11	524.6019966	47.6910906	725.1170315		
Far Away	11	528.0036451	48.00033137	326.2819868		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	8666.867421	10	866.6867421	4.692090641	0.011253	2.978237
Columns	0.525964222	1	0.525964222	0.002847478	0.958495	4.964603
Error	1847.122761	10	184.7122761			
Total	10514.51615	21				

Texture – Health

Anova: Two-Factor Without Replication						
SUMMARY	*Count*	*Sum*	*Average*	*Variance*		
Bourreria succulenta	3	11.33333	3.777778	0.064815		
Caesalpinia coriaria	3	8.857143	2.952381	0.863946		
Cordia dentata	3	9.584967	3.194989	0.08465		
Crescentia cujete	3	8.96707	2.989023	0.020907		
Cynophalla flexuosa	3	10.3141	3.438034	0.075622		
Guaiacum officinale	3	10.62963	3.54321	0.159579		
Haematoxylum brasiletto	3	11.08929	3.696429	0.004145		
Malpighia emarginata	3	8.916667	2.972222	0.043981		
Melicoccus bijugatus	3	11.25	3.75	0.0625		
Pithecellobium unguis-cati	3	10.25714	3.419048	0.005374		
Quadrella odoratissima	3	9.397436	3.132479	0.180857		
Extreme Fine	11	38.83694	3.530631	0.188489		
Medium Fine	11	36.0602	3.2782	0.100568		
Very Fine	11	35.69964	3.245421	0.275223		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	3.045891	10	0.304589	2.345784	0.050174	2.347878
Columns	0.535848	2	0.267924	2.063408	0.153215	3.492828
Error	2.596907	20	0.129845			
Total	6.178646	32				

Texture - Growth

Anova: Two-Factor Without Replication						
SUMMARY	*Count*	*Sum*	*Average*	*Variance*		
Bourreria succulenta	3	233.9167	77.97222222	1434.599537		
Caesalpinia coriaria	3	136.7929	45.59761905	387.3285884		
Cordia dentata	3	127.5294	42.50980392	232.4957495		
Crescentia cujete	3	81.265	27.08833432	117.5652983		
Cynophalla flexuosa	3	225.2596	75.08653846	121.1955436		
Guaiacum officinale	3	80.16931	26.72310406	2.511025261		
Haematoxylum brasiletto	3	162.2976	54.09920635	548.19024		
Malpighia emarginata	3	88.75	29.58333333	44.02083333		
Melicoccus bijugatus	3	49.52381	16.50793651	43.86923658		
Pithecellobium unguis-cati	3	134.7	44.9	469.63		
Quadrella odoratissima	3	157.7949	52.5982906	813.7918036		
Extreme Fine	11	323.4704	29.40640168	335.4023341		
Medium Fine	11	618.4653	56.22412196	725.3659506		
Very Fine	11	536.0634	48.73303695	514.0295272		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	11529.94	10	1152.994186	5.466971438	0.000626	2.347878
Columns	4212.359	2	2106.179728	9.986541609	0.000983	3.492828
Error	4218.036	20	210.9018127			
Total	19960.34	32				

Organic Matter – Health

Anova: Two-Factor Without Replication						
SUMMARY	*Count*	*Sum*	*Average*	*Variance*		
Bourreria succulenta	3	11.60714286	3.869047619	0.015731293		
Caesalpinia coriaria	3	9.579545455	3.193181818	0.600594008		
Cordia dentata	3	9.315384615	3.105128205	0.317771203		
Crescentia cujete	3	8.968195891	2.98939863	0.206360246		
Cynophalla flexuosa	3	10.63888889	3.546296296	0.163837449		
Guaiacum officinale	3	9.88451087	3.294836957	0.066493015		
Haematoxylum brasiletto	3	11.28571429	3.761904762	0.06292517		
Malpighia emarginata	3	9	3	0		
Melicoccus bijugatus	3	10.96666667	3.655555556	0.022592593		
Pithecellobium unguis-cati	3	10.25	3.416666667	0.048611111		
Quadrella odoratissima	3	9.575757576	3.191919192	0.171104989		
>5	11	35.78672789	3.253338899	0.323359992		
0 - 2.5	11	36.97775835	3.361614396	0.1177238		
2.5 - 5	11	38.30732086	3.482483714	0.146548256		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	2.81336	10	0.28133595	1.83701949	0.118578	2.347878
Columns	0.289081	2	0.14454059	0.943796483	0.405807	3.492828
Error	3.062961	20	0.153148049			
Total	6.165402	32				

Organic Matter – Growth

Anova: Two-Factor Without Replication						
SUMMARY	*Count*	*Sum*	*Average*	*Variance*		
Bourreria succulenta	3	243.3928571	81.13095238	1237.531604		
Caesalpinia coriaria	3	146.5795455	48.85984848	722.8316546		
Cordia dentata	3	138.0620513	46.02068376	531.4782065		
Crescentia cujete	3	80.52317291	26.84105764	40.83692885		
Cynophalla flexuosa	3	217	72.33333333	114.1111111		
Guaiacum officinale	3	71.77717391	23.92572464	61.27742005		
Haematoxylum brasiletto	3	179.7571429	59.91904762	1012.848231		
Malpighia emarginata	3	87.41666667	29.13888889	83.72453704		
Melicoccus bijugatus	3	50.75	16.91666667	76.89583333		
Pithecellobium unguis-cati	3	151.1944444	50.39814815	326.0588992		
Quadrella odoratissima	3	167.7575758	55.91919192	685.7165595		
>5	11	684.5086802	62.22806183	778.0756815		
0 - 2.5	11	383.0949301	34.82681182	667.694314		
2.5 - 5	11	466.6070202	42.41882002	361.3029595		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	12687.30913	10	1268.730913	4.713475134	0.001569	2.347878
Columns	4403.201556	2	2201.600778	8.179189467	0.002537	3.492828
Error	5383.420416	20	269.1710208			
Total	22473.93111	32				

Sunlight - Health

Anova: Two-Factor Without Replication						
SUMMARY	*Count*	*Sum*	*Average*	*Variance*		
Bourreria succulenta	3	11.4893617	3.829787234	0.021729289		
Caesalpinia coriaria	3	8.27486631	2.75828877	0.431315737		
Cordia dentata	3	9.019946809	3.006648936	0.134736644		
Crescentia cujete	3	8.616213152	2.872071051	0.093801044		
Cynophalla flexuosa	3	8.921960073	2.973986691	0.188309569		
Guaiacum officinale	3	10.23327189	3.41109063	0.005972693		
Haematoxylum brasiletto	3	11.19375	3.73125	0.060603299		
Malpighia emarginata	3	9.117794486	3.039264829	0.096521588		
Melicoccus bijugatus	3	11.15204678	3.717348928	0.060337654		
Pithecellobium unguis-cati	3	9.847744361	3.282581454	0.070383901		
Quadrella odoratissima	3	8.957915273	2.985971758	0.034035191		
FS	11	35.5714386	3.233767145	0.173941938		
PS	11	35.98200367	3.271091243	0.074254592		
S	11	35.27142857	3.206493506	0.422686044		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	4.336468483	10	0.433646848	3.655830901	0.006563	2.347878
Columns	0.02313596	2	0.01156798	0.097523084	0.90751	3.492828
Error	2.372357257	20	0.118617863			
Total	6.731961699	32				

Sunlight – Growth

Anova: Two-Factor Without Replication						
SUMMARY	*Count*	*Sum*	*Average*	*Variance*		
Bourreria succulenta	3	290.7954701	96.93182338	254.6007664		
Caesalpinia coriaria	3	98.74102368	32.91367456	113.2977115		
Cordia dentata	3	151.3785461	50.45951537	2.465909924		
Crescentia cujete	3	89.71339376	29.90446459	14.19479792		
Cynophalla flexuosa	3	169.7439201	56.58130672	197.133934		
Guaiacum officinale	3	79.02239631	26.34079877	6.622237859		
Haematoxylum brasiletto	3	181.2541667	60.41805556	31.49826968		
Malpighia emarginata	3	96.62406015	32.20802005	333.0253893		
Melicoccus bijugatus	3	65.05952381	21.68650794	78.1757842		
Pithecellobium unguis-cati	3	105.422807	35.14093567	395.6052026		
Quadrella odoratissima	3	151.5476589	50.51588629	299.6495866		
FS	11	482.8954787	43.89958897	405.8076908		
PS	11	523.6360594	47.60327813	378.6352149		
S	11	472.7714286	42.97922078	944.1714752		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	13965.40772	10	1396.540772	8.411031376	3.18684E-05	2.347878
Columns	131.8030905	2	65.90154523	0.39690926	0.67757514	3.492828
Error	3320.736089	20	166.0368045			
Total	17417.9469	32				

pH – Health

Anova: Two-Factor Without Replication						
SUMMARY	*Count*	*Sum*	*Average*	*Variance*		
Bourreria succulenta	2	7.789473684	3.894736842	0.022160665		
Caesalpinia coriaria	2	6.169934641	3.08496732	0.001366996		
Cordia dentata	2	6.454545455	3.227272727	0		
Crescentia cujete	2	5.845959596	2.922979798	0.021965233		
Cynophalla flexuosa	2	6.844444444	3.422222222	0.000987654		
Guaiacum officinale	2	6.820366133	3.410183066	0.009269175		
Haematoxylum brasiletto	2	7.416666667	3.708333333	0.003472222		
Malpighia emarginata	2	6	3	0		
Melicoccus bijugatus	2	7.433333333	3.716666667	0.027222222		
Pithecellobium unguis-cati	2	7.016666667	3.508333333	0.050138889		
Quadrella odoratissima	2	5.676691729	2.838345865	0.142489683		
4.7 - 5.5	11	36.61182725	3.328347932	0.074580905		
5.8 - 7.0	11	36.8562551	3.350568645	0.201897012		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	2.488422	10	0.24884221	9.004373261	0.000889	2.978237
Columns	0.002716	1	0.002715681	0.098267096	0.76036	4.964603
Error	0.276357	10	0.027635706			
Total	2.767495	21				

pH – Growth

Anova: Two-Factor Without Replication						
SUMMARY	*Count*	*Sum*	*Average*	*Variance*		
Bourreria succulenta	2	147.7192982	73.85964912	661.9692213		
Caesalpinia coriaria	2	103.2875817	51.64379085	4.306057499		
Cordia dentata	2	78.95454545	39.47727273	33.84400826		
Crescentia cujete	2	47.84155844	23.92077922	103.4930713		
Cynophalla flexuosa	2	145.2222222	72.61111111	62.9691358		
Guaiacum officinale	2	54.35697941	27.1784897	34.04541051		
Haematoxylum brasiletto	2	100.2833333	50.14166667	42.47347222		
Malpighia emarginata	2	57.16666667	28.58333333	130.6805556		
Melicoccus bijugatus	2	39.1	19.55	21.125		
Pithecellobium unguis-cati	2	92.88333333	46.44166667	101.0568056		
Quadrella odoratissima	2	117.8571429	58.92857143	291.4387755		
4.7 - 5.5	11	541.2591508	49.20537734	546.8931819		
5.8 - 7.0	11	443.4135109	40.31031917	272.5133823		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	7141.835458	10	714.1835458	6.787331864	0.002805	2.978237
Columns	435.1713293	1	435.1713293	4.135704676	0.069381	4.964603
Error	1052.230184	10	105.2230184			
Total	8629.236971	21				

Vegetation Cover – Health

Anova: Two-Factor Without Replication						
SUMMARY	*Count*	*Sum*	*Average*	*Variance*		
Bourreria succulenta	5	18.68174598	3.736349196	0.020054488		
Caesalpinia coriaria	5	15.40570175	3.081140351	0.048838211		
Cordia dentata	5	15.22748538	3.045497076	0.027084216		
Crescentia cujete	5	14.9606537	2.99213074	0.018990792		
Cynophalla flexuosa	5	15.76393886	3.152787772	0.00227506		
Guaiacum officinale	5	16.90948829	3.381897658	0.006628815		
Haematoxylum brasiletto	5	18.19551188	3.639102375	0.004997757		
Malpighia emarginata	5	14.96414636	2.992829272	0.081101976		
Melicoccus bijugatus	5	17.94681818	3.589363636	0.003989215		
Pithecellobium unguis-cati	5	17.17990422	3.435980844	0.055685371		
Quadrella odoratissima	5	15.25	3.05	0.036947279		
>50%	11	36.27398909	3.297635372	0.108584628		
0 - 15%	11	36.58455492	3.325868629	0.086214956		
16 - 30%	11	36.03682239	3.276074763	0.107592754		
16- 30%	11	35.4625731	3.223870282	0.120386203		
31 - 50%	11	36.1274551	3.2843141	0.091991075		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	3.982785367	10	0.398278537	13.67584682	5E-10	2.077248
Columns	0.061461932	4	0.015365483	0.527610639	0.716046	2.605975
Error	1.164910786	40	0.02912277			
Total	5.209158086	54				

Vegetation Cover – Growth

Anova: Two-Factor Without Replication						
SUMMARY	*Count*	*Sum*	*Average*	*Variance*		
Bourreria succulenta	5	431.7959111	86.35918223	131.0821349		
Caesalpinia coriaria	5	190.7637684	38.15275368	39.64081534		
Cordia dentata	5	261.1551606	52.23103213	25.52326151		
Crescentia cujete	5	160.0867227	32.01734455	81.86802755		
Cynophalla flexuosa	5	341.6995494	68.33990988	146.6808229		
Guaiacum officinale	5	140.6168736	28.12337472	8.509055125		
Haematoxylum brasiletto	5	300.2562985	60.0512597	71.764237		
Malpighia emarginata	5	153.7809497	30.75618995	206.0265028		
Melicoccus bijugatus	5	146.0686364	29.21372727	144.6336653		
Pithecellobium unguis-cati	5	232.5123249	46.50246499	159.3956286		
Quadrella odoratissima	5	225.7738095	45.1547619	50.37108489		
>50%	11	577.981518	52.54377436	566.2421321		
0 - 15%	11	461.5765497	41.96150452	440.8565945		
16 - 30%	11	553.096369	50.28148809	354.4678829		
16- 30%	11	488.8338346	44.43943951	302.187355		
31 - 50%	11	503.0217337	45.72924852	402.4699228		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	17225.90602	10	1722.590602	20.05149881	1.4E-12	2.077248
Columns	825.6480928	4	206.4120232	2.40270116	0.065706	2.605975
Error	3436.332851	40	85.90832128			
Total	21487.88697	54				