Why do some live while others die?

A study of the effect of salinity and soil composition on the survival rate of Conocarpus erectus planted on Bonaire.

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1. Introduction

This research was conducted as part of my bachelor internship for the Tropical Forestry specialization of the forest and nature management studies at Van Hall Larenstein, University of Applied Sciences. The internship was conducted at Mangrove Maniacs, an Bonaire based NGO that mainly works to restore the mangrove forests on the island. Field work was conducted between May and July 2022.

2. Background

2.1. Area

Bonaire is an island in the Caribbean Sea, approximately 87 Km North of the coast of Venezuela. It has a land area of 288 km², plus Klein Bonaire, an uninhabited islet with a land area of 6 km² (De Freitas et al., 2005).

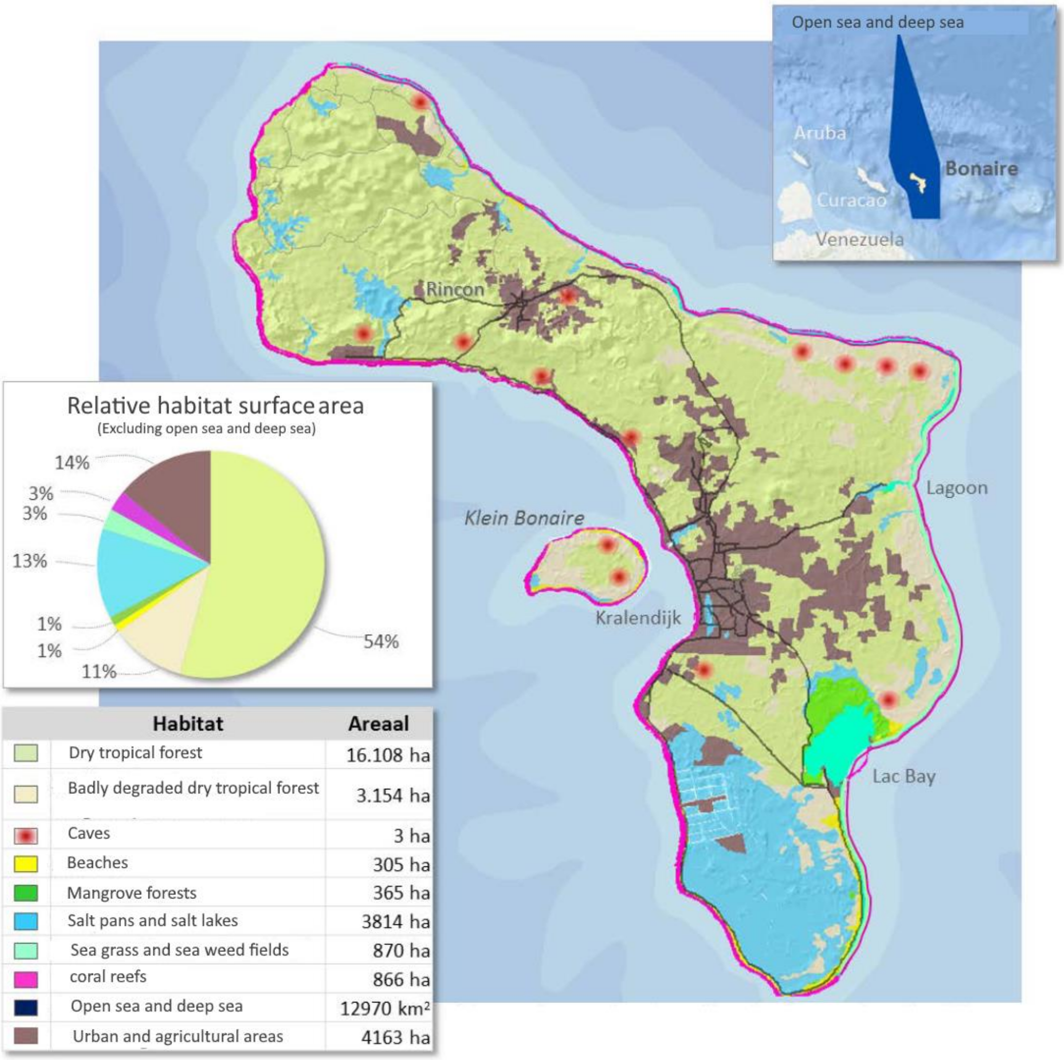
The island has a population of 22 573 as of 2022 (Centraal Bureau Statistiek, 2022), with the vast majority, 90.9% in 2020, living in the capital of Bonaire called Kralendijk (Centraal Bureau Statistiek, 2021).

The climate of Bonaire is classified as a hot semi-arid climate (BSh) according to the Köppen Geigar climate index (Beck et al., 2018). The temperature is quite constant, ranging from an average 29,1 C° in September to 26,7 C° in February. The precipitation of the island is characterized by short bursts of intense rainfall, particularly in the rainy season which runs from October to December, with the peak in November. The mean annual precipitation is 463 mm (De Freitas et al., 2005).

The island is a popular holiday destination, this is reflected in the economy of the island which is largely based on the tourism sector. In a 2019 study it was found that 38.4% of the economy is represented by tourism. In a 2020 survey, 42% of companies indicated that they are working in the tourism sector (Kamer van Koophandel Bonaire).

The largest habitat on Bonaire is dry tropical forest, parts of which are badly degraded (see map 1). Bonaire hosts two national parks: Washington Slagbaai National Park in the north which covers 17% of the land mass of the island, and Bonaire National Marine Park which consists of all waters surrounding Bonaire and Klein Bonaire.

Bonaire also hosts 4 sites protected by the RAMSAR convention, which in total consist of 87 km² (The Ramsar Convention Secretariat, 2021). These are Klein Bonaire and Washinton Slagbaai mentioned above, Pekelmeer, which are the salt pans in the south, and LAC bay, a shallow bay which is an important seagrass habitat and hosts mangrove forests (see map 2).



	Habitat	Areaal
	Dry tropical forest	16.108 ha
	Badly degraded dry tropical forest	3.154 ha
	Caves	3 ha
	Beaches	305 ha
	Mangrove forests	365 ha
	Salt pans and salt lakes	3814 ha
	Sea grass and sea weed fields	870 ha
	coral reefs	866 ha
	Open sea and deep sea	12970 km²
	Urban and agricultural areas	4163 ha

Map 1, Map of the habitat types of Bonaire, adapted from Debrot et al., 2017.

2.2. Problems

Although large areas of Bonaire are designated protected areas, the state of its ecosystem is in decline. Causes include invasive species outcompeting native species (Smith et al., 2014), an increase in human expansion (particularly coastal development), overfishing, erosion, pollution, and climate change.

In a report published in 2017 in context of the EU Habitats Directive, the conservation status of the Caribbean Netherlands (the islands Bonaire, Saba, and St. Eustatius) was determined to be ‘very unfavorable’ for 80% of the habitats found on these islands. The report gave a 100% ‘’moderate to very unfavorable’’ rating for the future perspective of the conservation status of these islands, mainly because not enough is being done to stop or slow the decline. Because of this, the habitats doing poorly are not resilient enough to withstand the growing effects of climate change, now and in the future (Debrot et al., 2017).

For the terrestrial ecosystems of Bonaire, the largest threat has been identified to be the (semi) wild livestock that roam the island, namely donkeys and goats (Dutch Caribbean Nature Alliance, 2019).

Particularly goats (*Capra hircus*) form a problem. These invasive animals were introduced on Bonaire by Spanish colonizers in 1527. Goats are generalists, able to eat many different types of plant materials and survive in different environments and habitats. Since Bonaire knows no big predators, the population has been able to grow uncontrolled. Since their introduction they have changed the vegetation from dry evergreen bushlands and forests to a community of thorny shrubs and cacti (Coolen, 2015). Their preferred diet consists of young palatable plants, but when this is unavailable, they will move on to poorer quality food. On Bonaire they are now also a threat to the native columnar cacti, which are important for native wildlife, such as birds, iguanas, and bats. An experiment showed that 60% of cacti planted in the field showed damage caused by goats within 48 hours of being planted (Van Grinsven, 2015).

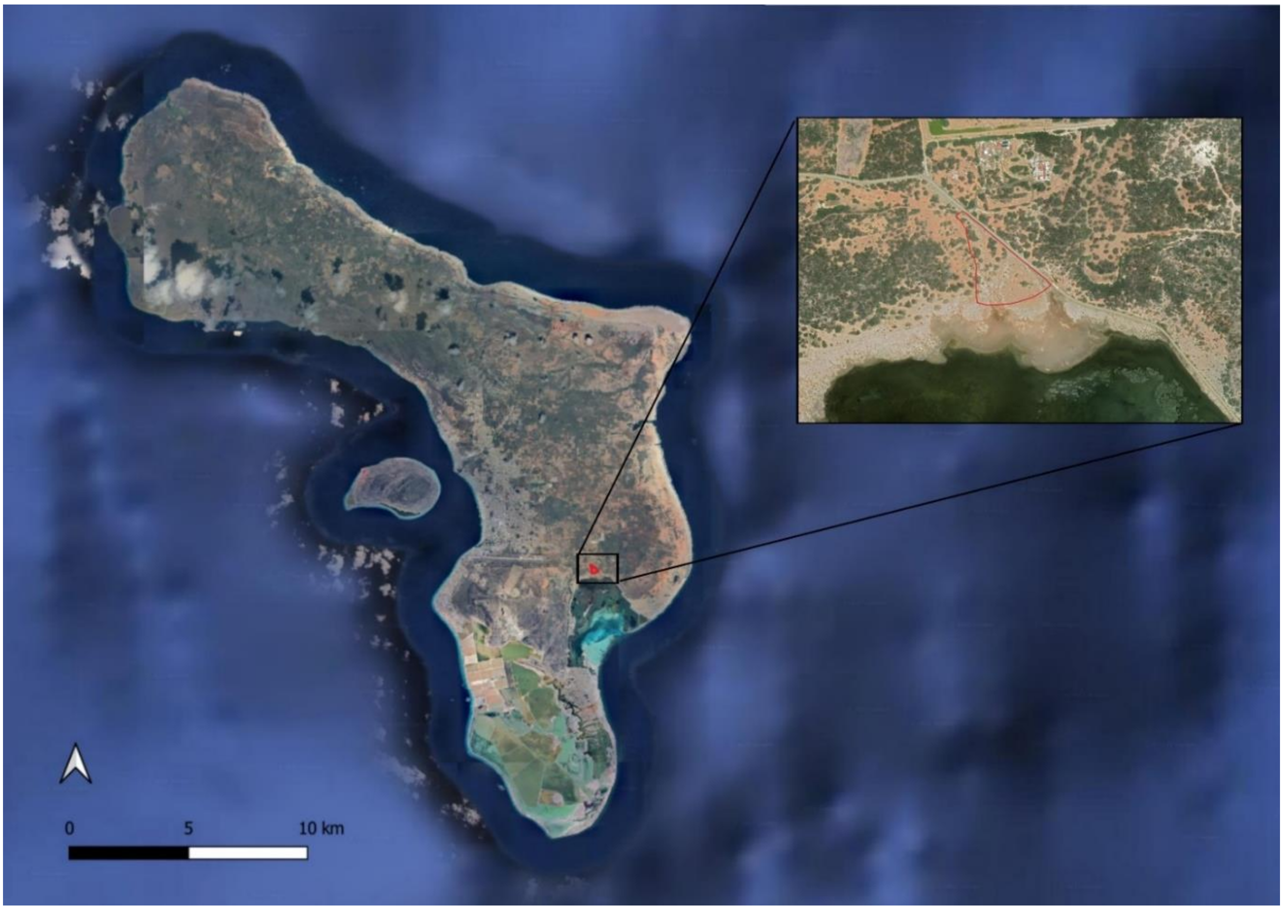
These changes in dominating vegetation also result in increased erosion (Coolen, 2015). This is possibly made worse by the topsoil layer being compacted due to trampling (Vergeer, 2017). If no intervention measures are taken, vulnerable parts of Bonaire could turn into secondary deserts due to the goats overgrazing (Coolen, 2015).

Goats are not the only cause of erosion. In the LAC bay area, activities like windsurfing and wading destabilize the soft sediment on the bottom of the bay and harm seagrass that would normally prevent erosion (Debrot et al., 2012). Around Kralendijk, urbanization combined with poor urban drainage system causes a large surface runoff, leading to high erosion rates. The erosion reduces the already thin topsoil layer, and eroded sediments end up smothering the mangrove forests and coral reefs that Bonaire is famous for (Koster, 2013).

Another large threat is climate change. In a report commissioned by Greenpeace (P. van Beukering et al., 2022), models were used to look at the consequences for Bonaire with different global warming scenarios. Even with the most optimistic scenario, with a temperature rise of 1,4° C, the sea level rise will cause permanent flooding on parts of Bonaire, with the entire south side disappearing. In the more extreme scenarios Kralendijk will flood by the year 2150, and the airport and fire station would become inaccessible due to the flooding. Global warming is also estimated to have a dire effect on the coral reefs surrounding Bonaire, which in turn will have big consequences for the economy of the island, which is largely based on diving/snorkeling tourism.

2.3 Research site

In 2019, Mangrove Maniacs have placed fencing around 4,4 ha of land in the south of Bonaire (see map 2) to cur donkeys and goats from grazing. This area is part of the greater LAC bay area, which means it part of a protected Ramsar convention site.



Map 2, map showing the location of the enclosure.

Like many areas of Bonaire, the area is degraded. Damage by grazing has already happened and only columnar cacti and thorny bushes are sparsely found in the area. The soil is loose and extremely dry. Patterns can be seen on the ground that show how water runs off towards the water of the bay when it rains (see appendix 6), little to no water is retained.

2.4. Reforestation project

Within this enclosure buttonwood (*Conocarpus erectus*) has been planted as a small-scale reforestation project.

C. erectus is a tree species associated with mangroves, although not considered a 'true mangrove'. It is related to the white mangrove (*Laguncularia racemosa*), both belong to the Combretaceae family.
C. erectus is known as an excellent reforestation tree due to its rapid grown and the fact that it is able to survive in harsh conditions, including high temperatures, poor air quality, poor drainage, compacted soil, and high salinity levels (Rehman et al., 2019).

Like true mangroves, it is able to survive high salinity environments by secreting excess salt through glands in the leaves. It is native to (sub)tropical coastal regions throughout the world including Bonaire (Naturalis Biodiversity Center, n.d.). In Papiamento it is called fofoti (Ketner, 2001).

If the reforestation project is successful, the trees would provide shade, cooling the area down. Erosion would be curbed as the roots of the trees keep the soil together and water would be retained better. The shade and better water retention would allow more plant species to thrive, and the trees would provide habitats and refuges for fauna, such as the endangered yellow-shouldered parrot (*Amazona Barbadensis*) (Echo Bonaire, 2015). The whole project is also a test to see what the effects of reforestation on Bonaire really are. If successful, this can be replicated in other areas.

The planting took place between September and October 2021. The buttonwood was planted in plots of various sizes scattered throughout the enclosure, ranging from the smallest plot of 5 plants to the largest of 232 plants. The saplings are watered by rain and in dry periods by hand.

2.5. State of the saplings

Despite every sapling getting the same treatment, the state of the saplings differs drastically (see image 1). Some plots are thriving while others are dying. In many plots, even within the plot there are big differences. A few trees can be thriving while trees right next to them are showing stress.

Image 1, photo showing the difference between two saplings

Generally, it is assumed that the salinity of the soil is the cause of the decline of some saplings. Buttonwood is usually found in habitats that do not exceed 10 ppt (parts per thousand) salinity, and growth has been observed to stop at soils exceeding 40 ppt salinity (Lonard et al., 2021). Alternatively, differences in soil composition may be a cause.

Discovering the true cause of the disparity in survival rate in this enclosure would help with a new management plan for this area that ensures that more saplings survive, and would also provide valuable information for other future reforestation projects on Bonaire.

3. Research questions

The main goal of this research is to discover why some *C. erectus* saplings in the study area are thriving while others are dying. Based on this, the following questions need to be answered:

What is the current state of the buttonwood saplings?

To be able to answer the main question, it is important to have knowledge on the current state of the saplings. This includes knowing how many are currently thriving and how many are dying, and what the survival rate per plot is.

What is the effect of salinity levels on the survival rate of C erectus?

One of the suspected reasons for the disparity in survival rate is high salinity levels in the soil. The effect of salinity on the survival rate of C. erectus needs to be investigated to see if there is a relation.

What is the effect of soil composition on the survival rate of C erectus?

Another possible reason is differences in soil composition. Thus, the possible relation between soil composition and survival rate also needs to be researched.

What is the effect of gravel present in the soil on the survival rate of C erectus?

The soil is known to contain gravel, this might also have an impact on the survival rate. Thus, this also needs to be investigated.

These questions together should answer the main question:

What is the reason for the disparity in survival rate of *Conocarpus erectus* within the study area?

4. Methodology

4.1. Field work

Data was gathered following a 5-step procedure:

1. A new inventory of the buttonwood saplings within the study area was conducted by field observation The amount of saplings within each plot were counted, noting the number of green, brown, and snapped plants. Snapped meaning the stem had been broken or the plant was entirely gone, likely due to accidental human interference or wildlife. If the plant had any green leaves, it was counted as green.

2. Soil samples were taken in each plot, with multiple samples for the larger plots. For each plot, two samples were taken, one near a dying and one near a living plant. For plots that exceeded 50 plants, four samples were taken (two living and two dying) and for the largest plot six samples were taken (three living and three dying). Samples were taken by digging near a sapling until the hard limestone layer, made out of fossilized coral, underneath the topsoil was hit. Soil was collected and placed in a marked bag.

3. Any organic material (leaves, cactus needles, twigs) was removed from the samples, and they were laid out in the sun to dry. Particularly wet samples were placed in an oven to dry. When completely dry, 8 grams of each sample were set apart for salinity testing. The rest of the sample was weighed and then sieved, using a sieve with holes 1 mm wide. A mortar was used to break up clumps of soil material and differentiate it from gravel. Any gravel left in the sieve was collected and weighed separately.

4. The sieved soil was used to conduct jar tests to identify the soil composition. The cleaned and dried samples that had the gravel removed were put in transparent, clean jars until the jars were filled about two thirds, and water was added to fill the jars, leaving some space so the jars could be shaken. The jars were then shaken thoroughly and left to settle. After two hours the sand layers were marked by placing a piece of masking tape on the jar and drawing a line on the tape (see image 2). The jars were then left to settle for another 48 hours. After this the silt layer, if present, of the sample had formed on top of the sand layer. The silt layer was also marked on the tape and bother layers were measured in mm. The percentage of the layers was calculated.

Image 2, a photo showing a jar with soil, the sand layer marked

5. Salinity tests were conducted using an RHS-10ATC Handheld 0-10% ATC Salinity Refractometer. The 8 grams of dried soil sample that were set apart earlier were added to individual test tubes. 40 ml water that was tested as not being saline was added to each sample, making the ratio 1 part sample to 5 parts water. Each tube was shaken thoroughly and left to settle for 3 hours. After three hours the water close to the surface of the settled soil was extracted and tested using the refractometer to determine the salinity of the sample in PPT (Parts per thousand, or ‰).

4.2. Data Analysis Method

Results were recorded in Excel, with separate sheets for the salinity data and the soil/gravel data. The analysis consisted of three different components that were tested separately: Gravel, Salinity and Soil.

Some data preparation was required because the jar test uses differently sized jars and different soil/water amounts per sample. Therefore, percentages of salt and silt had to be calculated of each sample so the results can be compared to each other. No clay was found, so there was no need to calculate clay percentages. For gravel, the percentages of every sample also had to be calculated as different soil samples used had different weights. In the salinity tests the samples used were all the same weight diluted in the same amount of water, so calculating percentages was not needed.

To test the difference between the living and dying plants with respect to salinity, soil, and gravel of the samples, T-tests were applied. To select the appropriate T-Test (assuming equal or unequal variances), F-Tests (Two-Sample for Variances) were applied first.

Note that for the soil, the calculated percentages of sand were used. The results would have been the same would silt have been used, as together they would form 100%.

5. Results

The results of the buttonwood inventory are presented in the graphs below. For the background data, see appendix 1.

Figure 1 shows the sapling status per plot for plot A to M. I becomes apparent that plots C, D, E, and F have the highest relative amount of green plants, and that plot H and I have the least. It should also be noted that plot I has a high amount of snapped plants.

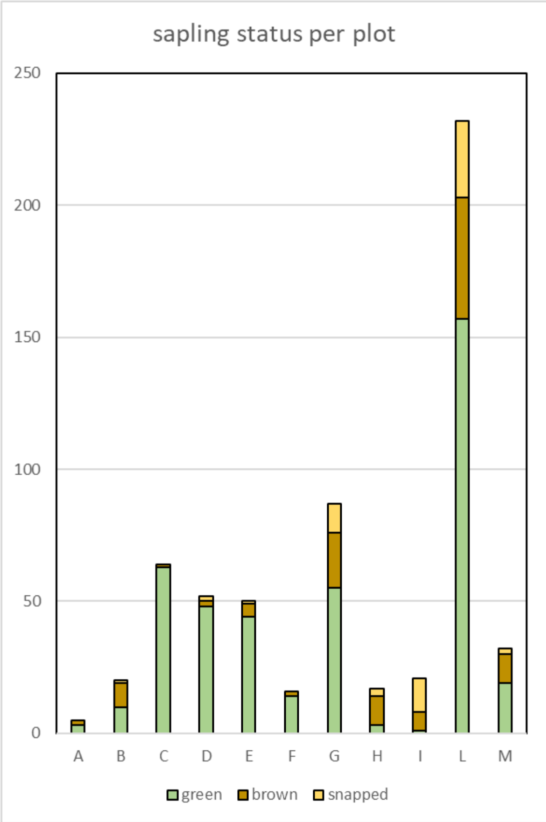


Figure 1, sapling status per plot.

Figure 2 shows the survival rate per plot, with brown and snapped grouped together as 'dying'. For a map of the survival rate per plot, see appendix 5. Overall, the survival rate of all saplings in all plots is an average of 70%.

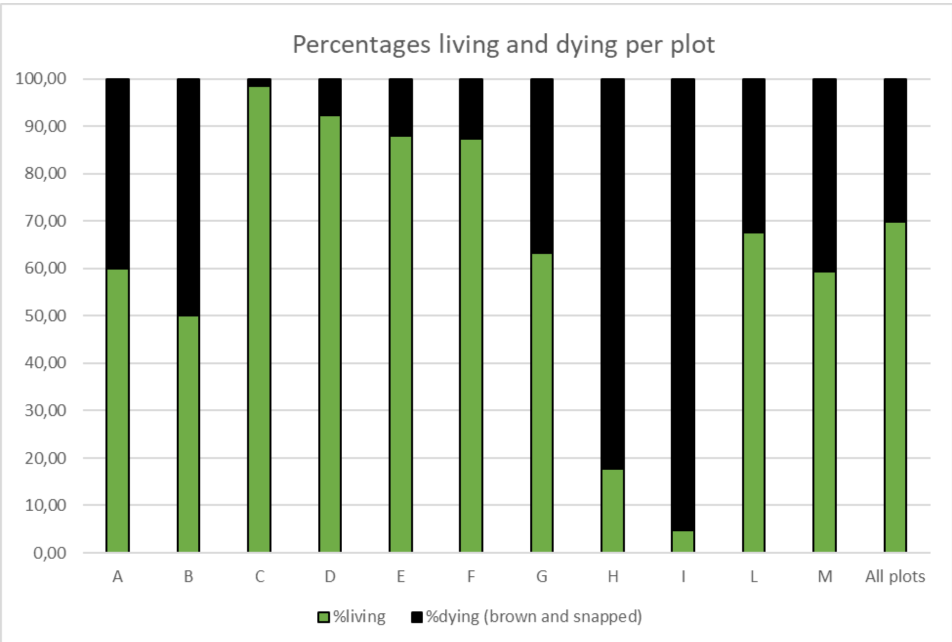


Figure 2, percentages living and dying per plot.

The differences between living and dying plants with respect to sand, gravel, and salinity is presented in three boxplots (figures 3, 4, and 5 respectively). See appendices 2, 3, and 4 for the background data.

It immediately becomes clear that the results are rather similar between living and dying. Although there are outliers, the mean is nearly the same for both gravel and sand. The biggest difference is in the salinity, with the mean being different by 1 ppt between living and dying.

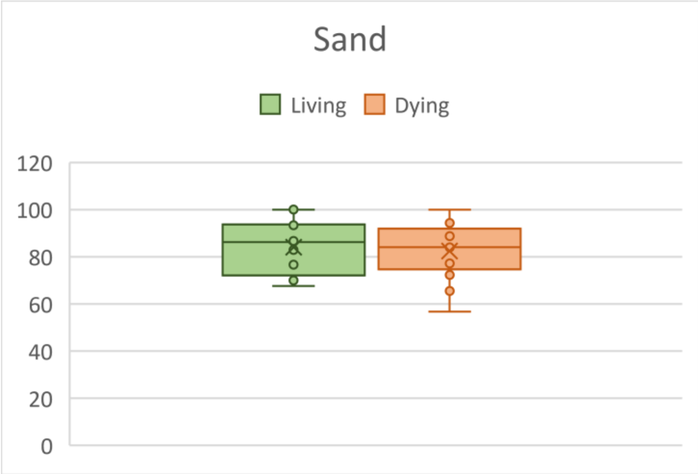


Figure 3, sand boxplot.

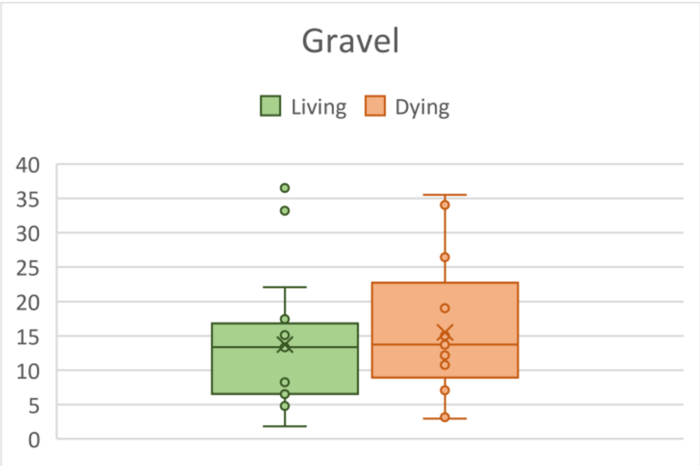


Figure 5, gravel boxplot.

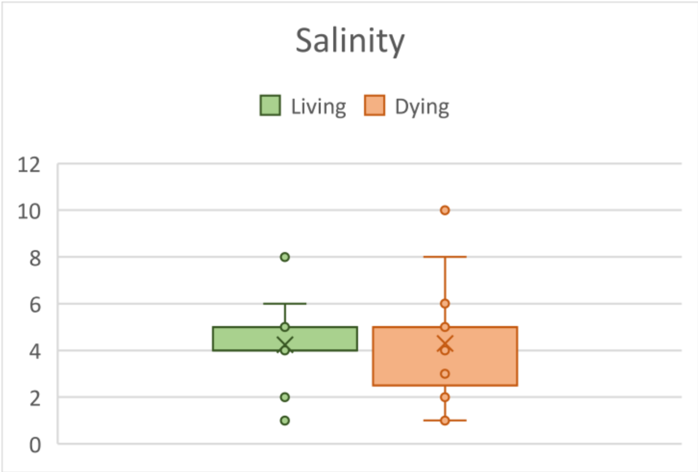


Figure 4, salinity boxplot.

The T-Tests (see appendix 5) show that the living plants did not differ from the dying plants with respect to sand ($t = 0.42$, $p > 0.05$, two tailed), gravel ($t= -0.53$, $p > 0.05$, two tailed) and salinity ($t = 0.08$, $p > 0.05$, two tailed).

6. Conclusion

The research results show that soil composition, gravel amount and salinity do not have an influence on the survival rate of *Conocarpus erectus*.

Which means that according to this research, none of them are the cause for the disparity in survival rate of C. erectus in the study area. This means that further research is needed to find out the true cause.

7. Discussion

The reliability of the results presented in this research rapport is highly limited by the chosen methods. Although the jar test provides a good estimation of soil composition, future research should aim to have the soil analyzed in a laboratory with more specialized equipment.

The salinity should also be tested with different, more specialized methods.

The AC tester used should give reliable information about the salinity level of a given sample relative to other salinity levels within this research, because the method used to gather salinity data was the same for every sample. However, the salinity levels cannot be compared to salinity levels in other studies. If the decision had been made to add more water or to use different settling times the results would have been different, thus the 'true' salinity cannot be certified.

Further research to discover the true cause of the disparity in survival rate should also focus on water. Although *C. conocarpus* is known as a highly drought tolerant tree species, research conducted by Moftah & Al Humaid (2004) suggests it may need more water than previously thought. A factor that would support this theory is that the plot that was thriving the most, plot C, was planted along a road that lays alongside the enclosure and is higher than the ground around it. Runoff water from this road may cause the plants in plot C to receive more water when it rains. See appendix 6 for a map of the survival rate per plot.

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Appendix

Appendix 1, buttonwood survey data

plot	total plants in plot	brown	green	snapped	brown/snapped	%dying (brown and snapped)	%living
A	5	2	3	0	2	40,00	60,00
B	20	9	10	1	10	50,00	50,00
C	64	1	63	0	1	1,56	98,44
D	52	2	48	2	4	7,69	92,31
E	50	5	44	1	6	12,00	88,00
F	16	2	14	0	2	12,50	87,50
G	87	21	55	11	32	36,78	63,22
H	17	11	3	3	14	82,35	17,65
I	21	7	1	13	20	95,24	4,76
L	232	46	157	29	75	32,33	67,67
M	32	11	19	2	13	40,63	59,38
All plots	596	117	417	62	179	30,03	69,97

Appendix 2, Salinity data

Sample	Li/Dy	salinity (ppt)
A	Li	8
B	Li	1
C1	Li	6
C2	Li	4
D1	Li	4
D2	Li	5
E1	Li	2
E2	Li	5
F	Li	2
G1	Li	5
G2	Li	4
H	Li	4
I	Li	4
L1	Li	4
L2	Li	4
L3	Li	5
M	Li	5
A	Dy	4
B	Dy	4
C1	Dy	5
C2	Dy	1
D1	Dy	5
D2	Dy	3
E1	Dy	1
E2	Dy	2
F	Dy	5
G1	Dy	1
G2	Dy	3
H	Dy	5
I	Dy	10
L1	Dy	8
L2	Dy	6
L3	Dy	5
M	Dy	5

Appendix 3, Gravel data

Sample	Li/Dy	Total weight (g)	Gravel weight (g)	% gravel
A	Li	196,42	12,95	6,59
B	Li	177,75	8,63	4,86
C1	Li	253,52	21,72	8,57
C2	Li	279,22	5,14	1,84
D1	Li	181,92	31,73	17,44
D2	Li	144,99	6,94	4,79
E1	Li	244,45	20,16	8,25
E2	Li	182,12	25,16	13,82
F	Li	203,46	67,50	33,18
G1	Li	245,85	38,58	15,69
G2	Li	274,37	60,60	22,09
H	Li	174,96	63,90	36,52
I	Li	151,65	13,30	8,77
L1	Li	158,64	23,98	15,12
L2	Li	134,80	17,99	13,35
L3	Li	203,25	13,23	6,51
M	Li	218,22	35,22	16,14
A	Dy	147,96	20,29	13,71
B	Dy	163,85	4,81	2,94
C1	Dy	126,25	13,61	10,78
C2	Dy	263,29	8,33	3,16
D1	Dy	174,58	59,38	34,01
D2	Dy	147,98	17,99	12,16
E1	Dy	298,56	44,80	15,01
E2	Dy	274,14	52,10	19,00
F	Dy	255,54	67,50	26,41
G1	Dy	245,17	65,56	26,74
G2	Dy	270,48	31,06	11,48
H	Dy	219,78	29,28	13,32
I	Dy	155,35	23,43	15,08
L1	Dy	177,19	5,77	3,26
L2	Dy	150,52	21,00	13,95
L3	Dy	262,26	93,17	35,53
M	Dy	217,32	15,44	7,10

Appendix 4, Soil composition data

Sample	Li/Dy	Total soil (mm)	Clay (mm)	Silt (mm)	Sand (mm)	% sand	% silt
A	Li	51	0	7	44	86,27	13,73
B	Li	34	0	0	34	100,00	0,00
C1	Li	58	0	6	52	89,66	10,34
C2	Li	45	0	3	42	93,33	6,67
D1	Li	41	0	7	34	82,93	17,07
D2	Li	24	0	0	24	100,00	0,00
E1	Li	48	0	14	34	70,83	29,17
E2	Li	22	0	6	16	72,73	27,27
F	Li	34	0	2	32	94,12	5,88
G1	Li	28	0	8	20	71,43	28,57
G2	Li	50	0	6	44	88,00	12,00
H	Li	37	0	6	31	83,78	16,22
I	Li	40	0	12	28	70,00	30,00
L1	Li	72	0	3	69	95,83	4,17
L2	Li	30	0	4	26	86,67	13,33
L3	Li	68	0	22	46	67,65	32,35
M	Li	60	0	14	46	76,67	23,33
A	Dy	40	0	8	32	80,00	20,00
B	Dy	30	0	6	24	80,00	20,00
C1	Dy	35	0	8	27	77,14	22,86
C2	Dy	50	0	2	48	96,00	4,00
D1	Dy	22	0	0	22	100,00	0,00
D2	Dy	34	0	1	33	97,06	2,94
E1	Dy	71	0	8	63	88,73	11,27
E2	Dy	56	0	8	48	85,71	14,29
F	Dy	39	0	5	34	87,18	12,82
G1	Dy	38	0	4	34	89,47	10,53
G2	Dy	53	0	3	50	94,34	5,66
H	Dy	35	0	11	24	68,57	31,43
I	Dy	39	0	8	31	79,49	20,51
L1	Dy	37	0	16	21	56,76	43,24
L2	Dy	25	0	4	21	84,00	16,00
L3	Dy	47	0	13	34	72,34	27,66
M	Dy	55	0	19	36	65,45	34,55

Appendix 5, F- and T-Test results

Salinity		
F-Test Two-Sample for Variances		
	Variable 1	*Variable 2*
Mean	4,294117647	4,235294118
Variance	5,845588235	2,566176471
Observations	17	17
df	16	16
F	2,277936963	
P(F<=f) one-tail	0,054873972	
F Critical one-tail	2,333483627	

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	4,294117647	4,235294118
Variance	5,845588235	2,566176471
Observations	17	17
Pooled Variance	4,205882353	
Hypothesized Mean Difference	0	
df	32	
t Stat	0,083624201	
P(T<=t) one-tail	0,466938088	
t Critical one-tail	1,693888748	
P(T<=t) two-tail	0,933876175	
t Critical two-tail	2,036933343	

percentage sand		
F-Test Two-Sample for Variances		
	Variable 1	*Variable 2*
Mean	84,11142227	82,4853818
Variance	117,4019571	141,4591771
Observations	17	17
df	16	16
F	0,829935247	
P(F<=f) one-tail	0,3568923	
F Critical one-tail	0,428543825	

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	84,11142227	82,4853818
Variance	117,4019571	141,4591771
Observations	17	17
Pooled Variance	129,4305671	
Hypothesized Mean Difference	0	
df	32	
t Stat	0,416698932	
P(T<=t) one-tail	0,339840334	
t Critical one-tail	1,693888748	
P(T<=t) two-tail	0,679680668	
t Critical two-tail	2,036933343	

percentage gravel		
F-Test Two-Sample for Variances		
	Variable 1	*Variable 2*
Mean	13,73562994	15,50910401
Variance	92,34337446	99,51874674
Observations	17	17
df	16	16
F	0,92789929	
P(F<=f) one-tail	0,441436406	
F Critical one-tail	0,428543825	

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	13,73562994	15,50910401
Variance	92,34337446	99,51874674
Observations	17	17
Pooled Variance	95,9310606	
Hypothesized Mean Difference	0	
df	32	
t Stat	-0,527903672	
P(T<=t) one-tail	0,300604016	
t Critical one-tail	1,693888748	
P(T<=t) two-tail	0,601208032	
t Critical two-tail	2,036933343	

Appendix 6, Map showing the survival rate per plot