Implications for white mangrove *(Laguncularia racemosa*) restoration

by

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B.Sc. (Biology) University of the West Indies, St. Augustine Campus, 2019

Project Submitted in Partial Fulfilment of the
Requirements for the Degree of
Master of Science

in the
Ecological Restoration Program

Faculty of Environment (SFU)
and
School of Construction and the Environment (BCIT)

SIMON FRASER UNIVERSITY
BRITISH COLUMBIA INSTITUTE OF TECHNOLOGY
Spring 2023

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Title:	**Implications for white mangrove (*Laguncularia racemosa*) restoration**
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Abstract

My applied research project consists of three goals: (1) to inform site selection for white mangrove restoration in St. Vincent and the Grenadines, and the greater Caribbean region, based on a zone of salinity tolerance; (2) to identify the invasive potential of Indian almond in St. Vincent and the Grenadines and the greater Caribbean region; (3) to inform management decisions for white mangrove restoration, in St. Vincent and the Grenadines and the greater Caribbean region. The growth response of white mangrove and Indian almond seedlings under different concentrations of salinity, 0, 5, 15, 35, and 55 practical salinity units (PSU) was investigated. The structural arrangement of white mangroves in Brighton Mangrove Forest was also investigated to further understand the invasive potential of Indian almonds. A two-way Anova was done to examine the effects of various saline levels on the two species of interest. The two-way Anova revealed no overall significant difference in growth response between the two species, however, revealed a notable interaction between species and saline levels. This is supported by trends in the figures, where white mangrove seedlings generally outgrew Indian almond seedlings, with increasing saline levels. The trends from the figures also highlight that white mangrove seedlings generally grew best at 15 PSU, while Indian almond seedlings grew best at 0 PSU. The results from the field analysis also revealed that white mangrove's density dropped from 23 individual trees to 0, immediately as they approached a landscape dominated by Indian almonds. Therefore, based on experimental design, field sampling, and literature analysis, non-native Indian almonds, could potentially be a stressor impeding white mangroves persistence and restoration, in the Atlantic, Caribbean, and eastern Pacific.

Dedication

To my parents, who facilitated this dream, thank you.

Acknowledgements

Firstly, to my supervisor, thank you! I came into this program fearful of the idea of 'research' and now it's my chosen career path! Thank you for your support, guidance, and for assisting in my development as a future researcher in aquatic, marine, and littoral ecology.

I would also like to take the time and thank Dr. Ruth Joy, Forrest Bjornson, Dr. Brendan Murphy, and Joseph Cormier for their assistance and guidance in my Data, and statistical analysis. As well as other faculty members such as Dr. Anayansi Cohen-Fernandez and Dr. Eric Anderson, who offered beneficial feedback during several of BCIT and SFU applied research project updates. I would also like to thank Jessica Meier, Daniel Cretu, and Sarah Kent for inspiring conversations that give rise to components in my methodological design.

Additionally, I would like to thank Zonique Dublin, for her technical support, without which, would have greatly reduced the accuracy of my results. As well as China Primus and Cruz Halbich for their assistance in collecting mangrove soil. I would also like to acknowledge Central Water and Sewage Authority (CWSA) and National Parks, Rivers and Beach Authority (NPA) for providing baseline data on rainfall regime, and data on Brighton Mangrove Forest.

Lastly, I would like to express my gratitude to my parents, who were excellent project assistants. I would like to thank Elvis Gooding, for the collection and transportation of organic salt from Mayreau salt pond, for the construction of the greenhouse, as well as assistance in removing Indian almond seeds. As well as Cashena Gooding, for her technical guidance and assistance in the mobilization of bottles, that housed Indian almond and white mangroves throughout the duration of my experiment.

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1.0 Introduction

Ecosystems across the globe are at risk of extinction. In small developing countries of the Caribbean, one ecosystem stands out more than the others, mangroves. Mangroves are a taxonomic group of halophytic woody shrubs and trees that inhabit the upper intertidal zone of the tropics and subtropics (Gupta - Joshi & Ghose 2014; Ricklefs & Latham 1993). Globally, mangrove ecosystems are one of the most productive and provide many ecosystem services; they function as a nursery habitat for a variety of fish and bird species, build & protect coastlines from natural disasters, and are an important sink for carbon (Brander et al 2012). However, even with such importance, there has been a decline of 35% in global mangrove forests over the past 25 years (Carugati et al. 2018).

In the eastern Pacific region, the significant loss of mangrove ecosystems has led to ecological, and socio-economic impacts for their associated host countries (Islam & Hague 2004; Carugati et al. 2018; Ellison et al. 2020). As a result, several restoration activities were undertaken to restore mangrove ecosystems, and their associated services (Carugati et al. 2018). However, results from the scientific literature have shown that most mangrove restoration efforts have a high failure rate. One study in Sri Lanka that monitored mangrove restoration success found that 54% of planting attempts were unsuccessful and approximately 40% of the sites chosen for restoration had no success (Kodikara et al. 2017). The study found the highest rates of failure for mangrove restoration occurred in dry and arid zones. They further attributed that lack of understanding of the ecological requirements for various mangrove species as another contributing factor to the failure of restoration efforts. In these cases, the health requirements of mangroves such as hydrology, salinity, and appropriate assemblage of species were ignored (Kodikara et al. 2017). Other studies suggest to increase the likelihood of mangrove restoration success in a given area, an in-depth analysis of the hydrology of tidal action, of a given reference site in a nearby region with a similar landform and tidal action should be undertaken (Ellison et al. 2020).

In the Caribbean, present-day, mangrove loss is not as significant as compared to other regions (Ferreria-Quadros & Zimmer 2017). However, due to the actions of colonization, many mangrove forests have been cleared, for timber production, charcoal, and tannins (Lopez-Angarita et al 2016). The underdeveloped bare coastline was subsequently colonized by native and non-native coastal flora like Indian almond (*Terminalia catappa*)(Based on observation and local knowledge). Indian almond is a tropical plant endemic to the eastern Pacific. It grows along raised coastlines, on rocky and sandy beaches, and within its endemic range, it can be found on the outskirts of mangrove forests (Thomson & Evans 2006). There is no documented date for the arrival of Indian almond to St. Vincent and the Grenadines, however, studies show that Indian almond arrived in Jamaica in the 1790s (Morton 1984). Thus, it can only be assumed, it arrived around the same time in St. Vincent and the Grenadines.

In the eastern Caribbean region, specifically, that of St. Vincent and the Grenadines four main species of mangroves are found, red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*), white mangrove (*Laguncularia racemosa*), and buttonwood (*Conocarpus erectus*) (OECS 2009). Together, these mangroves form a complex structural arrangement depending on their salinity tolerance (Florida Museum 2019) and occupy a total area of 50 hectares - a reduction of 8 hectares from the earliest identifiable research in 1980 (FAO 2005). Compared to red and black mangroves, white mangroves are significantly understudied, therefore creating gaps in the literature necessary to inform white mangrove restoration strategies. Current literature on mangrove restoration suggests that returning hydrologic function (full historical extent of tidal range) increases the chance of success. Yet, even when factored in, mangrove restoration success in best conditions is below 78% (Kodikara et al. 2017). Presently, in St. Vincent and the Grenadines, two mangrove restoration projects have occurred, one In Ashton Union Island (Sus Grenadines 2021), the other at Richmond Beach (Richmond Vale Academy n.d), and it is expected that more mangrove restoration projects are to come. Compared to the two mangrove restoration projects in St. Vincent and the Grenadines, the Richmond Beach mangrove restoration project had several white mangroves fail under the canopy of Indian almond. In a coastal environment dominated by Indian almond, within the niche space of white and black mangroves, it poses a question of whether, non-native Indian almond, is a potential invasive species impeding white mangrove's persistence and colonization. Additionally, with no available data on salinity ranges that Indian almond can exist, a question emerges: What salinity range facilitates the fastest growth response and persistence for white mangroves while reducing persistence of Indian Almonds? Knowledge of that information would inform site selection suitable for white mangrove restoration in St. Vincent and the Grenadines and on a global scale. It would also inform whether landscape-scale restoration is needed, to facilitate inundation by tidal action, which would provide the salinity needs for various growing mangrove seedlings. Additionally, it would increase the understanding of Indian almond, identifying the maximum salinity range that Indian almond can colonize and persist, as well as highlighting the invasive potential of Indian almond.

In this study, Indian almond and white mangrove seedlings were grown in different containers and treated with their respective salinity treatments of, 15 PSU, 35 PSU and 55 PSU, and 0 PSU. From accounts of literature and field observations, it is hypothesized that (1) white mangrove seedlings would experience their fastest growth response in salinity of 15 PSU, followed by 35 and 55 PSU, (2) Indian almond seedlings would have their lowest growth response in salinity of 35 PSU, (3) Indian almond seedlings would fail to persist in salinity of 55 PSU, (4) Indian almond seedlings would have a faster growth response than white mangrove seedlings, and (5) Indian almond trees would influence the structural arrangement of white mangroves, in Brighton Mangrove Forest.

2.0 Goals & Objectives

Goal 1: To inform site selection for white mangrove restoration in St. Vincent and the Grenadines, and the greater Caribbean region, based on a zone of salinity tolerance.

Objective 1.1: Identify the different growth responses of white mangrove seedlings under different levels of salinity.

Objective 1.2: Identify the salinity range that supports the fastest growth response for white mangrove seedlings, while reducing the growth and persistence of Indian almond seedlings.

Goal 2: Identify the invasive potential of Indian almonds in St. Vincent and the Grenadines and the greater Caribbean region.

Objective 2.1: Identify the different growth responses of Indian almond seedlings under different ranges of salinity.

Objective 2.2: Identify if Indian almond seedlings have a faster growth response than white mangrove seedlings.

Objective 2.3 Determine the influence of Indian almonds on the structural arrangement of white mangroves in Brighton Mangrove Forest.

Objective 2.4 Identify data from current literature, that can aid in identifying the invasive potential of Indian almonds on white mangroves.

Goal 3: Inform management decisions for white mangrove restoration, in St. Vincent and the Grenadines and the greater Caribbean region.

Objective 3.1 Create a framework to inform mangrove restoration.

Objective 3.2 Suggest management plans to assist in reducing the invasive potential of Indian almonds, while increasing the persistence and sustainability of white mangroves.

3.0 Method

3.1 Study site

Brighton mangrove forest is situated on the southern end of the main island of St. Vincent and the Grenadines. It borders the community Prospect and currently is privately owned land. The average width of the mangrove forest is 15 m, and 229 m in length. A small channel flows through the mangrove forest and widens near the mouth of the river. A sand berm built up by wave activity from the Caribbean Sea impedes the flow of the river, forming a small wetland that is drained to the left of the berm. The Brighton mangrove forest consists predominantly of white mangroves, however mangrove associates such as coin vine *(Dalbergia ecastophyllum*), seaside mahoe (*Thespesia populunea*), 'bread and cheese' (*Pithecellobium unguis-cati*), as well as Indian almond, are found within the canopy of Brighton Mangrove Forest. To the north of Brighton mangrove forest is a mixed forest dominated by Indian almonds.

Figure 1: Map of Brighton Mangrove Forest. The white line represents the boundary of the Brighton Mangrove Forest while the blue line represents a channel that runs through the Brighton mangrove forest. The light green line represents the boundary mark of a small wetland situated at the end of the white mangrove forest.

3.2 Sample design

The width of the white mangrove forest was determined with a keson-long tape measurer and using the same measuring tape a transect was laid randomly on the left side of the left (the right side was dissected with a road, and regularly pruned by landowners in the area). Every 20 meters a 10 by 10-meter quadrat was made and plants at least 2 meters in height and diameter at breast height (DBH) of 15 cm were recorded, as seen in Figure 2.

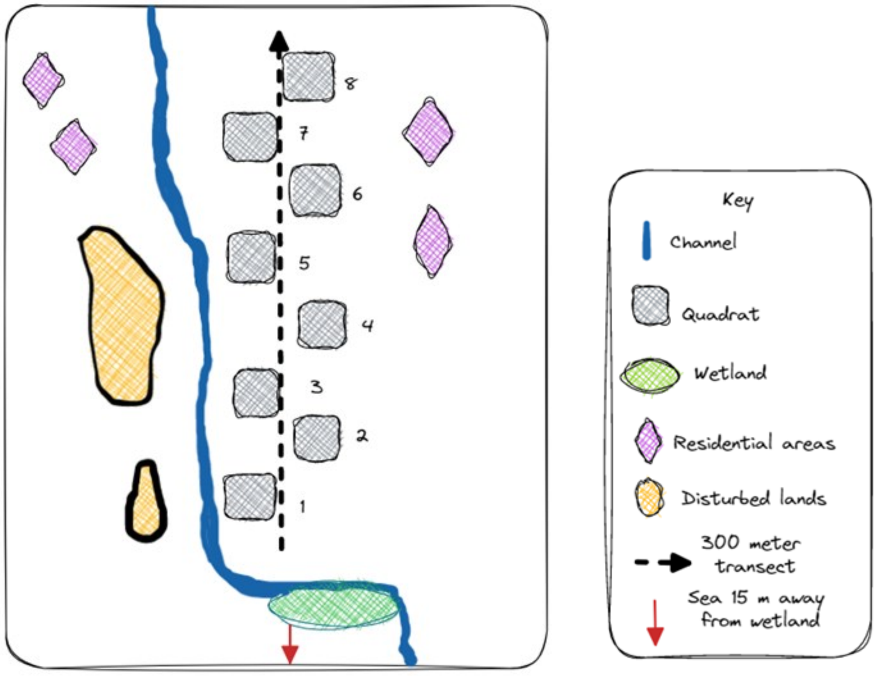

Figure 2: Illustrates field sampling design at Brighton Mangrove Forest. Brighton Channel is represented by a blue shape and the permanently inundated wetland is represented by a green oval. Disturbed lands are represented by yellow polygons and residential areas by purple diamonds. The 300-meter transect is represented by a black arrow, the 10 by 10-meter quadrat by grey squares, and the red arrow represents the distance between the wetland and the sea.

3.3 Experimental Design

Structure and design

Greenhouse materials were collected and built by January 20th, and 24-liter recyclable bottles were collected to grow individual seedlings. The top ¼ of the bottles were removed and two holes were made under the bottles using a pick. Two centimeters of the container were filled with gravel and the next 11 cm were filled with mangrove soil gathered from a mangrove forest situated in Brighton St. Vincent.

Seed collection and germination

White mangrove seedlings were collected at the start of the year from Brighton Mangrove Forest and set to germinate on the 12th of January. Seedlings were germinated and left to grow in waterlogged conditions at 0 PSU (freshwater) for approximately 5 months.

On May 29th, Indian almond seeds were collected from Brighton salt pond, and checked for viability, and 38 Indian almond seeds were planted and watered once daily. Of this group, only six seeds germinated. As such, an additional six seedlings with seed cases attached were harvested, from Sion hill bay. All seedlings were weighed due to differences in heights and germination dates.

Maintenance

Seedlings were transplanted into their respective sampling units (growing pots) on June 28th and left to acclimatize for 25 days. During this period each seedling received 500 ml of freshwater (0 PSU) every other day, between the hours of 6:00-9:00 am. On the 22nd of July (Friday) each treatment received 500 ml of their respective concentration of a saline solution, 15 PSU (brackish water), 35 PSU (average salinity of the ocean), and 55 PSU (hypersaline environments), while the controls received 500 ml of 0 PSU. This was repeated weekly. The saltwater solution was mixed using salt harvested from Mayreau salt pond and was renewed weekly (Chen & Yen 2014). Both white mangroves and Indian almond seedlings received 500 ml of water twice weekly on Mondays and Wednesdays, between the hours of 6:00-9:00 am.

Data Collection

Root length (recorded in centimeters using string and measuring tape) and live weight (recorded in grams using a digital kitchen scale) were recorded at the beginning and end of the experiment. Plant height (recorded in centimeters using a 30 cm ruler or measuring tape) and stem diameter (recorded in millimeters using a digital caliper) were recorded weekly. Leaf area (recorded in centimeters square) was recorded at the end of the experiment, three samples of mature leaves were collected from each plant, and using leafbyte an average leaf area was derived (Getman-Pickering et al. 2020). All areas of measurement had an area of uncertainty of +- 0.1, for each measurable unit, (g, cm, mm, cm^2).

Statistical analysis

All values were expressed as mean ± standard deviation (S.D.) values for white mangrove and Indian almond replicates. The growth response of the two species to different salinity levels was analyzed with a two-way ANOVA. To determine the difference in growth response between the two species and the different salinity levels of (0,15,35 & 55).

4.0 Results

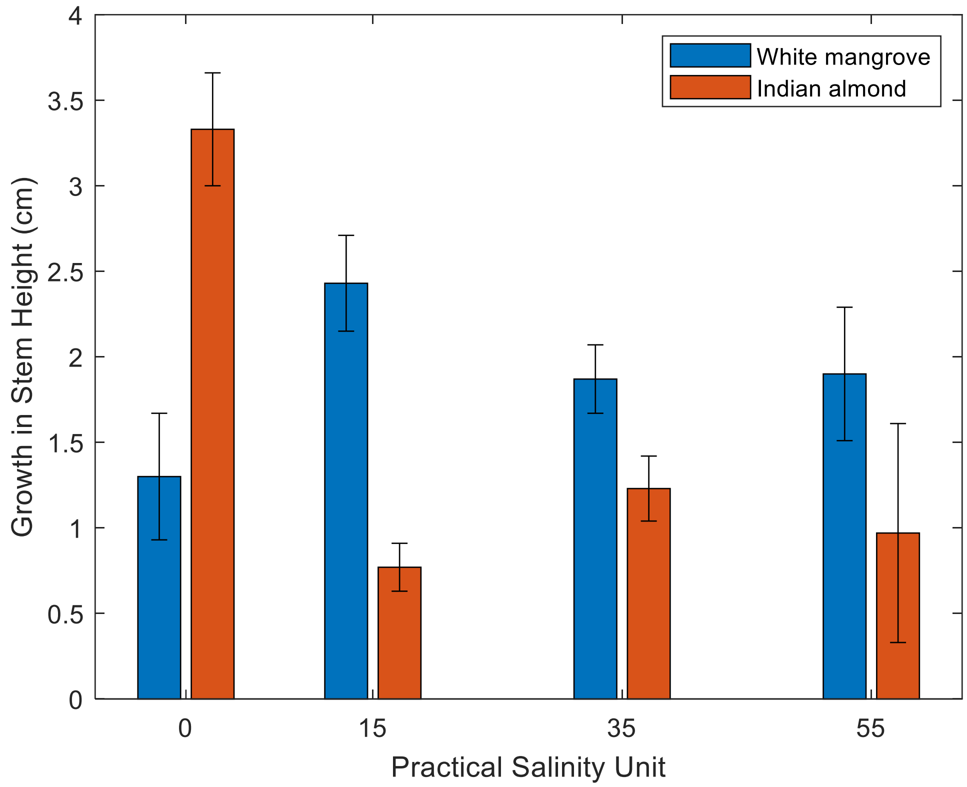

Figure 3: Growth response of white mangrove (n= 12; $p<0.05$) and Indian almond (n=12; $p<0.05$) seedlings in stem height, under different concentrations of salinity, within a 95% confidence interval. Blue bars represent white mangroves, while orange bars represent Indian almonds. The X-axis represents the different saline levels, measured in practical salinity units, while the Y-axis represents the total growth in stem height of white mangrove and Indian almond seedlings in centimeters (cm) over a period of 5 weeks. One Indian almond died in the 55 PSU levels.

Indian almond seedlings had their highest growth response in stem height within the 0 PSU level followed by the 35 PSU, 55 PSU, and 15 PSU. On the other hand, white mangrove seedlings had their highest growth response within the 15 PSU level, followed by 55 PSU, 35 PSU, and 15 PSU (Figure 2). Based on the two-way anova, there was no significant difference in stem height growth response between species (F 0.991, Pr>F 0.33436), and saline levels (F 1.767, Pr>F 0.19400). However, an interaction between species and saline levels was observed (F 7.178, Pr>F 0.00287). One Indian almond in the 55 PSU level expired by week 4.

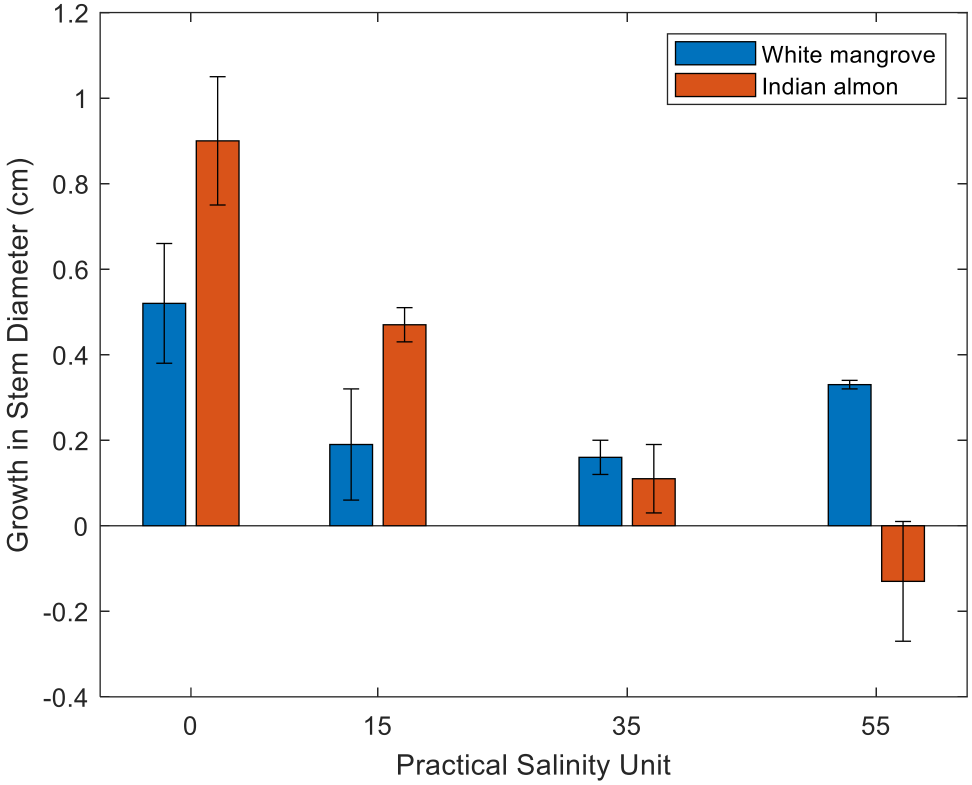

Figure 4: Growth response of white mangrove (n=12; $p<0.05$) and Indian almond (n=12; $p<0.05$) seedlings in stem diameter, under different concentrations of salinity, within a 95% confidence interval. Blue bars represent white mangroves, while orange bars represent Indian almonds. The X-axis represents the different saline levels, measured in practical salinity units, while the Y-axis represents the total growth in stem diameter of white mangrove and Indian almond seedlings in centimeters (cm) over a period of 5 weeks. One Indian almond died in the 55 PSU levels. The negative growth experienced by Indian almond seedlings, would be elaborated on in the discussion.

Indian almond seedlings had their highest growth response in stem diameter within the 0 PSU level followed by the 15 PSU, 35 PSU, and 55 PSU. On the other hand, white mangrove seedlings had their highest growth response in stem diameter within the 0 PSU level, followed by 55 PSU, 15 PSU, and 35 PSU (Figure 3). Based on the two-way anova, there was no significant difference in stem diameter growth response between species (F 0.126, Pr>F0.727517). However, there was a significant difference in growth response between the saline levels (F 9.295, Pr>F 0.000856), the two-way anova also revealed an interaction between species and saline levels (F 4.268, Pr>F 0.021495). One Indian almond in the 55 PSU level expired by week 4.

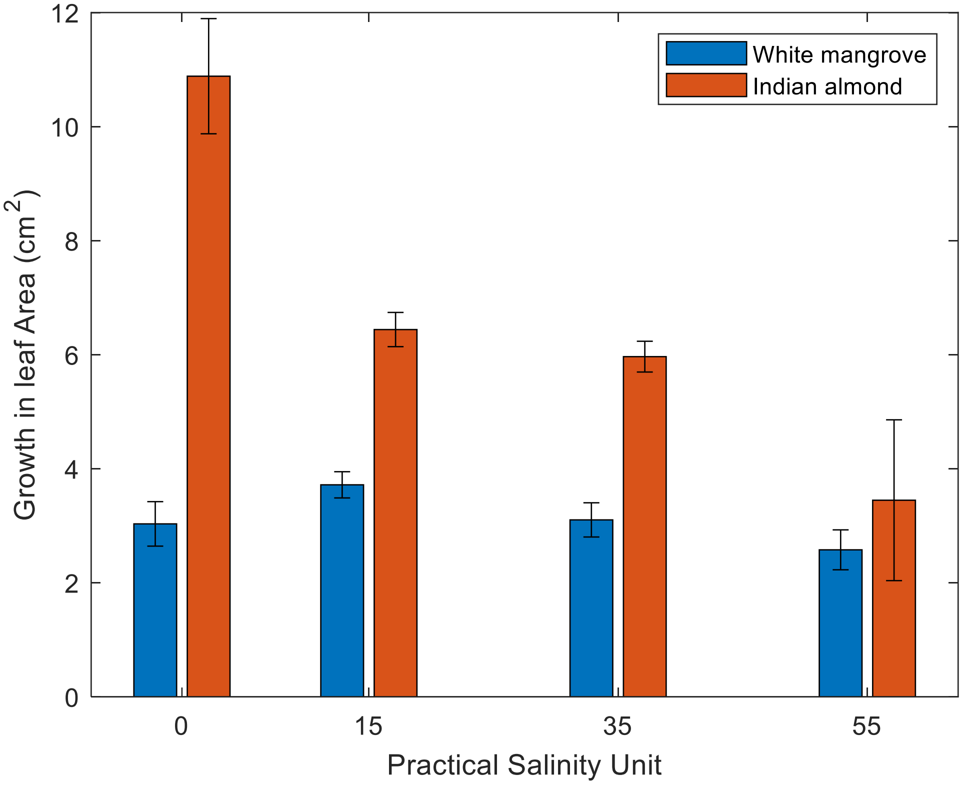

Figure 5: Growth response of white mangrove (n=12; $p<0.05$) and Indian almond (n=12; $p<0.05$) seedlings in leaf area, under different concentrations of salinity, within a 95% confidence interval. Blue bars represent white mangroves, while orange bars represent Indian almonds. The X-axis represents the different saline levels, measured in practical salinity units, while the Y- axis represents the total growth in leaf area of white mangrove and Indian almond seedlings in centimeter square (cm^2)over a period of 5 weeks. One Indian almond died in the 55 PSU levels.

Indian almond seedlings had their highest growth response in leaf area within the 0 PSU level followed by the 15 PSU, 35 PSU and 55 PSU. On the other hand, white mangrove seedlimgs had their highest growth response in leaf area within the 15 PSU level, followed by 35 PSU, 0 PSU, and 55 PSU (Figure 4). Based on the two-way anova, there was a significant difference in leaf area growth response between the species (F 57.518, Pr>F 1.1e-06), and saline levels (F10.492, Pr>F0.000465). An interaction between species and saline levels was also observed (F 6.926, Pr>F 0.003354). One Indian almond in the 55 PSU level expired by week 4.

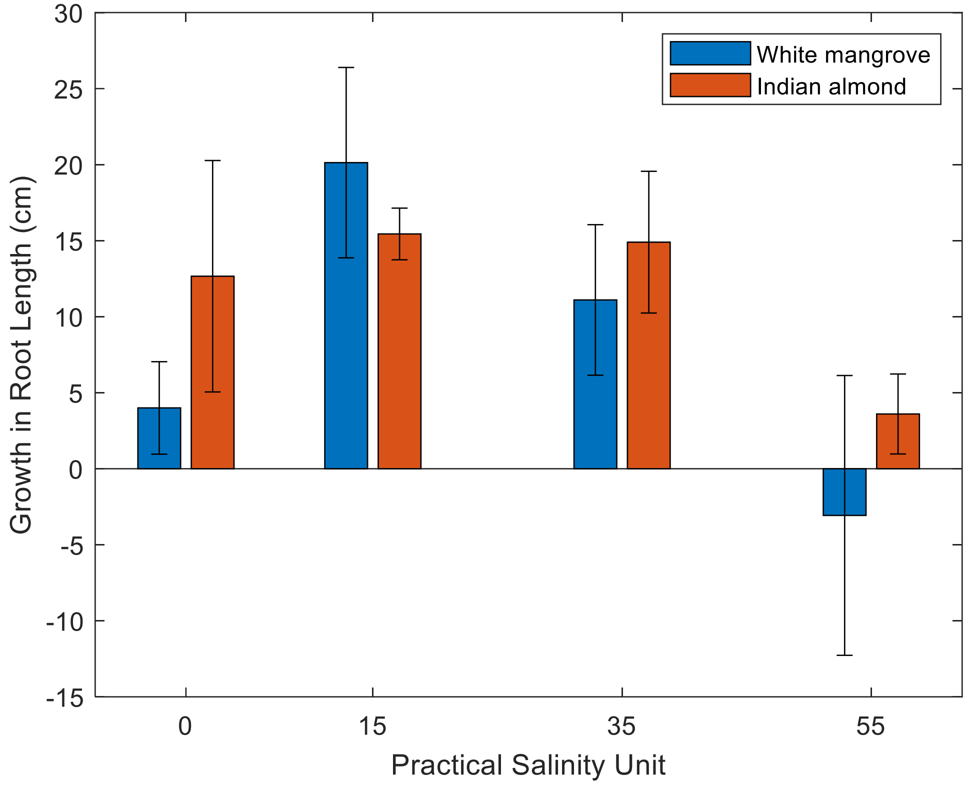

Figure 6: Growth response of white mangrove (n=12; $p<0.05$) and Indian almond (n=12; $p<0.05$) seedlings in root length, under different concentrations of salinity, within a 95% confidence interval. Blue bars represent white mangroves, while orange bars represent Indian almonds. The X-axis represents the different saline levels, measured in practical salinity units, while the Y-axis represents the total growth in root length of white mangrove and Indian almond seedlings in centimeters (cm) over a period of 5 weeks. However, one Indian almond died in the 55 PSU levels. The negative growth experienced by white mangrove seedlings would be elaborated on in the discussion.

Indian almond seedlings had their highest growth response in root length within the 15 PSU level followed by the 35 PSU, 0 PSU, and 55 PSU. On the other hand, white mangrove seedlings had their highest growth response in root length within the 15 PSU level, followed by 35 PSU, 0 PSU, and 55 PSU (Figure 5). Based on the two-way anova there was no significant difference in live weight growth response between species (F 0.559, Pr>F 0.465), and saline levels, (F 2.400, Pr>F 0.106). The two-way anova also revealed no interaction between species and saline levels (F 0.376, Pr>F 0.771). One Indian almond in the 55 PSU level expired by week 4.

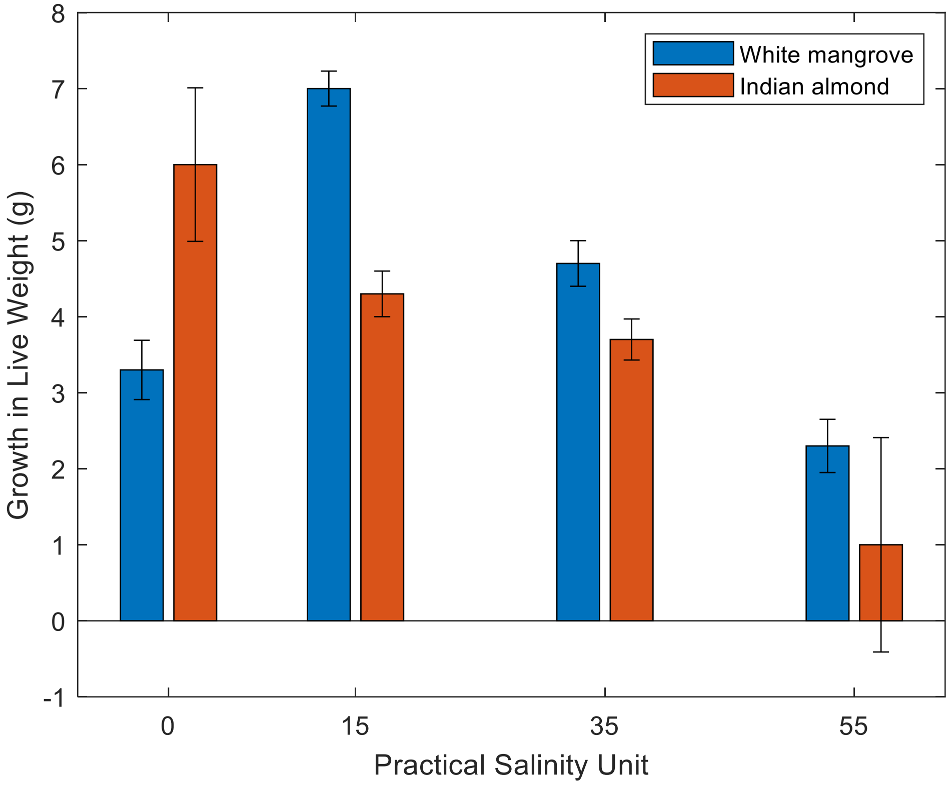

Figure 7: Growth response of white mangrove (n=12 $p<0.05$) and Indian almond (n=12; $p<0.05$) seedlings in live weight, under different concentrations of salinity, within a 95% confidence interval. Blue bars represent white mangroves, while orange bars represent Indian almonds. The X-axis represents the different saline levels, measured in practical salinity units, while the Y- axis represents the total growth in live weight of white mangrove and Indian almond seedlings in grams (g) over a period of 5 weeks. One Indian almond died in the 55 PSU levels.

Indian almond seedlings had their highest growth response in live weight within the 0 PSU level followed by the 15 PSU, 35 PSU, and 55 PSU. On the other hand, white mangrove seedlings had their highest growth response within the 15 PSU level, followed by 35 PSU, 0 PSU, and 55 PSU (Figure 6). Based on the two-way anova there was no significant difference in live weight growth response between the species, (F 0.459, Pr>F 0.508), and saline levels, (F 1.817, Pr>F 0.185). The two-way anova also revealed no interaction between species and saline levels (F 0.544, Pr>F 0.659). One Indian almond in the 55 PSU level expired by week 4.

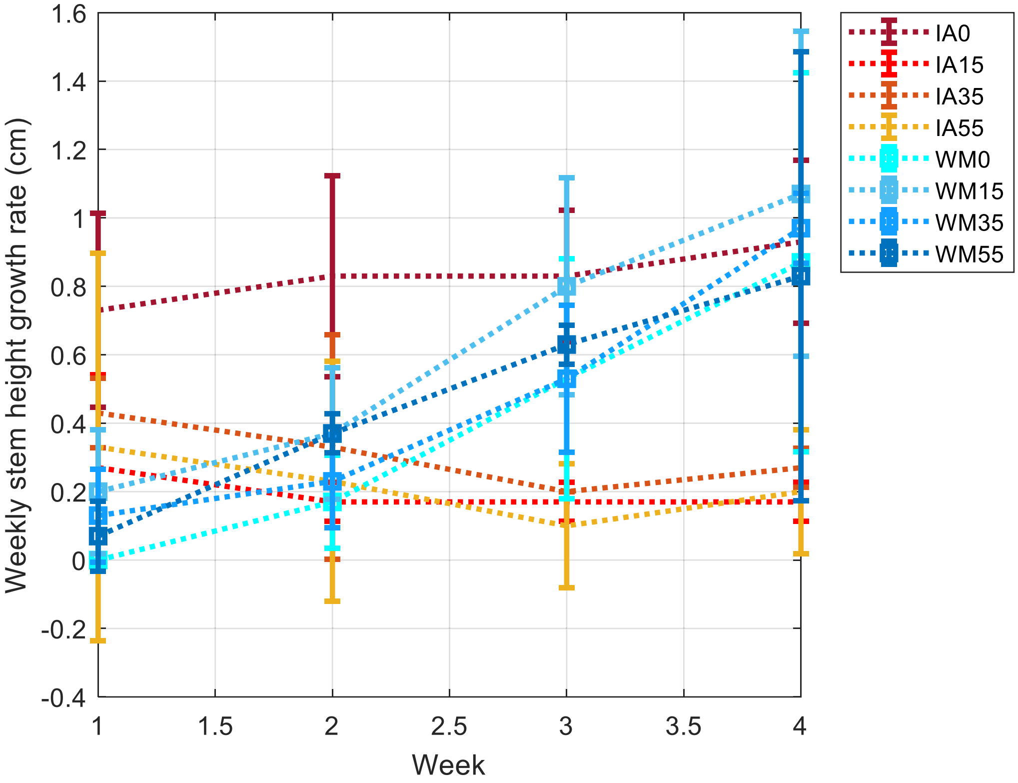

Figure 8: Growth rate of white mangrove and Indian almond seedlings in stem height, under different concentrations of salinity over time, within a 95% confidence interval. Shades of blue represent white mangroves, while shades of orange and red represent Indian almonds, under different concentrations of salinity. Lines are present for ease in the interpretation of data trends. The X-axis represents the length of time plants were tested with their respective saline levels, while the Y-axis represents the growth rate in stem height of white mangrove and Indian almond seedlings in centimeters (cm) over a period of 4 weeks (the growth rate of white mangrove and Indian almond seedlings were determined from the difference of previous weeks from consecutive weeks, hence why this figure is represented by 4 weeks of growth, instead of 5 weeks). One Indian almond died in the 55 PSU level.

Indian almond seedlings had their highest growth rate in stem height over a period of four weeks at 0 PSU, while white mangrove seedlings had their fastest growth rate at 15 PSU level (Figure 7). All saline levels of white mangrove seedlings had a rate of increase that was greater than the previous week. The 55 PSU white mangrove seedlings had the second fastest growth response in stem height, followed by white mangrove seedlings at the 35 PSU level, which overtook the 55 PSU saline level in the final week of the experiment (Figure 7). White mangrove seedlings slowest growth rate was recorded in the 0 PSU saline level (Figure 7). Indian almond seedlings in the 15 PSU, 35 PSU, and 55 PSU saline levels all grew at a slower rate than white mangrove seedlings for the duration of the experiment (figure 7). Following 0 PSU Indian almond seedlings had their second-highest growth rate in 35 PSU, followed by 55 PSU and 15 PSU. All three saline levels had a decrease in stem height growth in week 3, however, increased in growth response by week 4(Figure 7). The three saline levels of Indian almond seedlings had a slower growth rate when compared to white mangrove seedlings, and by week 4 white mangrove seedlings in the 15 PSU and 35 PSU saline levels, had a faster growth rate than Indian almond seedlings in the 0 PSU level (Figure 7).

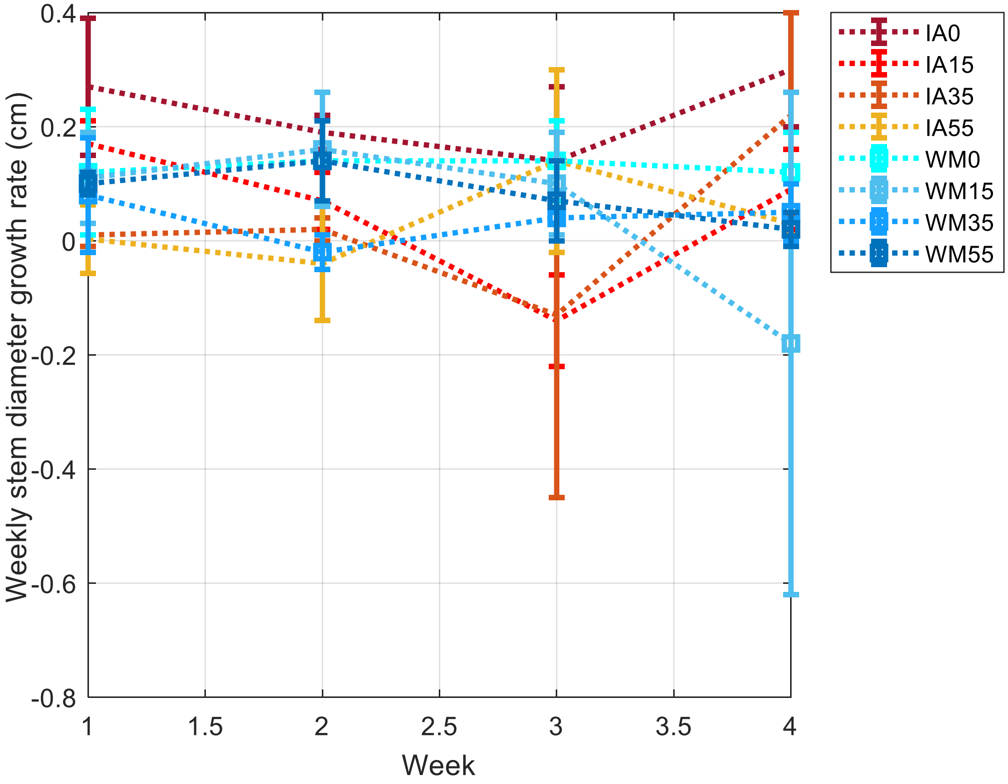

Figure 9: Growth rate of white mangrove and Indian almond seedlings in ¼ stem diameter, under different concentrations of salinity over time, within a 95% confidence interval. Shades of blue represent white mangroves, while shades of orange and red represent Indian almond, under different concentrations of salinity. Lines are present for the ease in interpretation of data trend. The X-axis represents the length of time plants were tested with their respective saline levels, while Y-axis represents the growth rate in stem diameter of white mangrove and Indian almond seedlings in centimeters (cm) over a period of 5 weeks(the growth rate of white mangrove and Indian almond seedlings,

were determined from the difference of previous weeks from consecutive weeks, hence why this figure is represented by 4 weeks of growth instead of 5 weeks). One Indian died in the 55 PSU level.

Indian almond and white mangrove seedlings had their fastest growth rate at the 0 PSU saline level. Both plant species fluctuated in growth rates for the duration of the experiment. White mangrove seedlings in the 0, 15 & 55 PSU levels had a higher growth rate compared to the Indian almond seedlings saline levels for the first 2 weeks of the experiment, however, started to decrease in growth rate by week 3, with the exception of white mangrove seedlings in the 0 PSU level. By week 4, Indian almond seedlings in the 0 and 35 PSU surpassed the growth rate of all saline levels of white mangroves. Indian almond seedlings compared to white mangrove seedlings had a greater degree of fluctuation. In the first week, three of the Indian almond seedlings saline levels with the exception of the 35 PSU had a decrease in stem diameter growth rate. This decrease in growth rate continued, with the exception of the 55 PSU. However, by week 4 Indian almond seedlings growing in the 0,15 and 35 PSU had a significant increase in growth rate, while Indian almond seedlings in the 55 PSU level experienced a reduction in the rate of stem diameter growth.

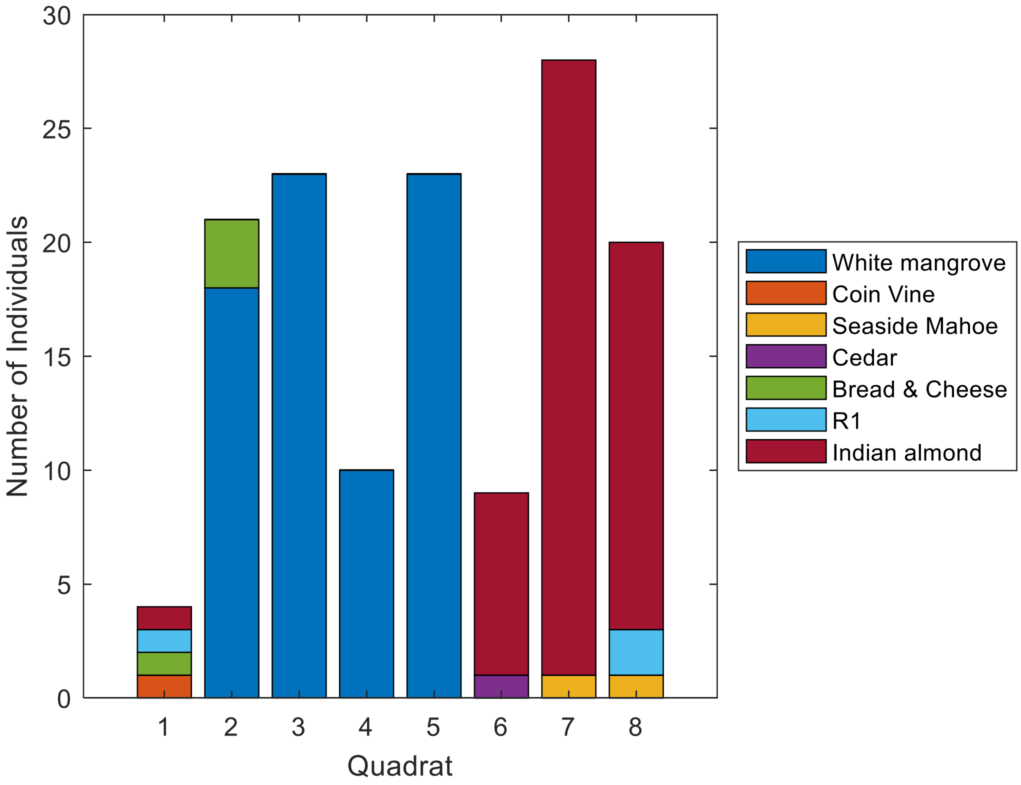

Figure 10: Illustrates the density change of white mangroves along a 300-meter transect, in Brighton Mangrove Forest. The bar graph is separated by species type: white mangroves (blue), coin vine (orange), seaside mahoe (yellow), cedar (purple), bread and cheese (green), R1 (cyan), and Indian almond (maroon). The X-axis represents the quadrat a number and the Y-axis represents the number of individuals.

Seven species of plants were sampled within 8, 10*10-meter quadrats along a 300-meter transect within Brighton Mangrove Forest. Quadrat 1 had the highest species richness, consisting of four species, coin vine, bread & cheese, R1, and Indian almond, while quadrats 3,4 & 5 have the lowest species richness, consisting of one species, white mangrove (Figure 9). Quadrat 8 had the second highest species richness consisting of three species, R1, seaside mahoe, and Indian almond. Quadrat 2, 6 & 7 all have a species richness of two, consisting of species, cedar, seaside mahoe, and Indian almond. Of all the species white mangrove had the highest density (74 individuals), followed by: Indian almond (53 individuals), bread and cheese (4 individuals), R1 (3 individuals) seaside mahoe (2 individuals), and coin vine and cedar (1 individual each). There is a notable change in the density of white mangroves from quadrat 5 to quadrat 6, where the density of white mangroves fell from 23 individuals to 0 (Figure 9).

5.0 Discussion

Ecological restoration is often limited by gaps within literature. In the case of coastal restoration, the ecological requirements of ‘true’ mangroves and mangrove associates are underwhelmingly studied, particularly concerning the salinity range that would facilitate a sustainable population. Therefore, in a period of time with significant movement in mangrove restoration it is crucial to understand the ideal salinity range that would facilitate sustainable populations, thereby informing appropriate site selection in restoring individual species. In this project, the growth response of native white mangrove and non-native Indian almond seedlings were analyzed to better understand their ecological requirements and the invasive potential of Indian almonds.

Based on the results generated from a two-way anova, there was no significant difference in growth response between white mangrove and Indian almond seedlings in terms of stem height, stem diameter, root length, and live weight but not for leaf area. However, there was a notable interaction between the two species with increasing salinity. This was evident in stem height, stem diameter, and leaf area. Indian almond seedlings had a smaller growth response than white mangrove seedlings with increasing salinity for stem height and stem diameter with the exception of leaf area. The latter of which was expected as Indian almonds have naturally larger leaves in comparison to white mangroves. However, as salinity increased there was an observed decrease in leaf area, for both species. This can be attributed to the decrease in water potential as salinity increases (due to a decrease in external osmotic potential, below that of the cell water potential), therefore more metabolic energy (from carbohydrate metabolism) is directed at maintaining osmotic balance, than leaf growth (Läuchli & Grattan 2011). Additionally, the inhibition of nutrient uptake particularly that of nitrates, potassium, and calcium ions, is an additional factor reducing leaf growth with increasing salinity (Läuchli & Grattan 2011; Parida & Jha 2010).

An increase in salinity also significantly reduced growth response in stem diameter for both species. For example, Indian almond seedlings saw a decrease in stem diameter growth response with increasing salinity, with an observed negative growth at 55 PSU. Thus, this would suggest that stem diameter growth for Indian almond seedlings is inhibited by increasing saline concentrations. This can be attributed to

Indian almond seedlings prioritizing metabolic energy to maintain internal osmotic balance as well as nutrient deficiency caused by increasing salinity which inhibits the uptake of essential ions (Läuchli & Grattan 2011). In comparison to Indian almond seedlings, white mangrove seedlings had two of their highest observed growth in stem diameter at 0 and 55 PSU. Thus, this would suggest that a salinity threshold was passed that enabled an increase in growth in white mangrove seedlings' stem diameter. The mechanism that facilitates this, to the best of my knowledge is not well understood as current literature on mangrove ecology suggests they prefer areas of low salinity (Ewers et al. 2004). However, some studies suggest that salt stress-associated genes could be expressed during extreme salinities (Parida &Jha 2010). Thus, potentially explaining the sudden increase in stem diameter growth for white mangrove seedlings at 55 PSU.

Salinity increase resulted in a positive growth response in stem height for white mangrove seedlings in 15 PSU, although this difference was not statistically significant. This can be attributed to an increase in photosynthetic activity at this saline level, due to increased succulence of white mangrove leaves from the accumulation of salt in their leaves. The increase in succulence, and consequently leaf surface area, facilitate greater uptake of carbon dioxide, thereby resulting in a higher level of photosynthetic activity (Parida &Jha 2010). This increase in energy production enabled the allocation of resources into biomass production for stem height growth for the white mangrove seedlings growing at the 15 PSU saline level. This is supported by Smith et al. (2009) who found that white mangroves had a net higher growth with lower salinities. Indian almond seedlings, in comparison to white mangrove seedlings, had a lower growth response in stem height, with variable growth responses to different saline levels, as seen in Figure 3. In the analysis of growth response trends of other growth parameters to different saline levels, Indian almond seedlings prioritizes different areas of growth with increasing saline concentration. Therefore, this potentially explains why Indian almond seedlings had their lowest growth in stem height at 15 PSU and second highest growth in stem diameter at 15 PSU. This would also explain why the Indian almond seedlings had their third-highest growth response in stem height at 55 PSU and negative growth at 55 PSU for stem diameter, as seen in Figures 3 and 4 respectively.

Notably, there was no observed statistical difference in interaction between white mangrove and Indian almond seedlings with increasing salinity for growth parameters, live weight, and root length. However, based on the trend exhibited in Figure 7, white mangrove seedlings had their highest growth response in live weight at 15 PSU, with a decrease in growth as salinity increased. On the other hand, Indian almond seedlings had their highest live weight growth response at 0 PSU, followed by a decrease in growth as salinity increased. The trends for root length revealed that both white mangrove and Indian almond seedlings had their highest growth response in 15 PSU, and lowest growth response in 55 PSU, with a negative growth being exhibited by white mangrove seedlings. Both species' reduction in growth response in live weight and root length with increasing salinity could be a result of nutrient deficiency brought about by the inhibitory action of high salinities on nutrient uptake. In addition to the prioritization of metabolic energy for maintaining internal osmotic balance, over vegetative growth. For root length in particular, the reduction in the uptake of calcium ions (essential for root growth), could be the factor that reduced the growth response for both species (Läuchli & Grattan 2011). However, the negative growth exhibited for root length by white mangrove seedlings could be a combined effect of nutrient deficiency and plant roots being damaged during the transplant process. Furthermore, previous studies from Smith et al. (2009) found that white mangrove seedlings allocated more biomass to root growth, during high salinities. Therefore suggesting that increasing salinity may not be the limitation, however, this may also be dependent on the genotype of white mangroves.

There was a notable interaction in growth response between species to the different saline levels in three out of the five measured growth parameters. However, there was no overall statistical difference in growth response between white mangrove and Indian almond seedlings, except for leaf area. Based on the trends of the figures white mangrove seedlings generally grew best in 15 PSU and this is supported by Cardona-Olarte et al. (2006), who found white mangroves have their best growth response in low saline environments. Therefore suggesting lower salinities are the most energy-productive pathway for white mangrove seedlings. On the other hand, Indian almond seedlings grew best in 0 PSU. One Indian almond failed to persist in the 55 PSU saline level, and based on the general trends of the figure Indian almond seedlings may struggle to persist in salinities at or greater than 55 PSU. However, this may be dependent on the genotype of Indian almonds (Läuchli & Grattan 2011), as the other Indian almond seedlings in the 55 PSU level didn’t express any signs of ailments.

5.1

Invasive potential of Indian almond

Based on accounts of literature, Indian almonds are endemic to the eastern Pacific region, while white mangroves are native to Atlantic Caribbean and eastern Pacific, thus both species have not evolved alongside each other. In white mangroves native range, they are usually the first mangrove species to colonize a site, however, in time gradually become replaced by taller mangrove species such as black mangroves. Suggesting that white mangroves are shade intolerant and are inhibited by light deficiencies (Berger et al. 2006). Therefore, the presence of Indian almonds poses an additional issue for successful mangrove restoration in St. Vincent and the Grenadines, as Indian almond trees can grow to heights exceeding120 feet, while mature white mangroves have an average height of 50 feet (Florida Museum 2019; Thomson & Evans 2006). Results from this experiment also suggest that Indian almonds can persist in salinities as high as 35 PSU, thereby existing in the same salinity range as white mangroves. Indian almond trees have also been observed to have an allelopathic effect. A paper from de Gouveia Baratelli et. al (2012) investigated allelopathic impacts of Indian almond on vegetation *Lactuca sativa L.* (lettuce), *Euphorbia heterophylla L.* and *Commelina benghalensis L*, after field observations revealed a reduction or absence of vegetation around trees of *Terminalia catappa*. Their findings found dichloromethane and ethyl-acetate compounds within the leaves and seeds of Indian almond, with the highest concentrations in green leaves and accumulated fallen fruits. Moreover, they found that these allochemicals have the potential to be leached into the rhizosphere and potentially impact plant growth. Thus, leading to the assumption that Indian almond has an allelopathic effect on neighboring vegetation (Baratelli et al. 2012). The field analysis revealed that white mangroves' density dropped from 23 individual trees to 0, as they approached a landscape dominated by Indian almond (Figure 10). This abrupt drop in density of white mangroves may be a result of the allelopathic effect of Indian almond seeds and leaves on germinating white mangrove seedlings, coupled with shade intolerance of mature white mangrove trees. Indian almonds, like white mangroves also use water as a form of dispersal mechanism, and upon observation their reproductive cycles coincide. This poses a problem for germinating white mangrove seedlings. Although white mangrove seedlings have a faster growth rate, and growth response when compared to Indian almond seedlings (when soil salinity is greater than 0 PSU).

Indian almond seedlings will eventually outgrow white mangrove seedlings and consequently shade them out. All these combined factors suggest that non-native Indian almond, is in fact an invasive species impeding white mangrove colonization and persistence, as well a stressor that can impact white mangrove restoration.

5.2

Management implications

Mangrove restoration across the globe often results in low rates of success (Kodikara et al. 2017). On the accounts of literature, improper return of hydraulic function, poor species selection and inadequate understanding of their ecological requirements, as well as not addressing stressors that could potentially impact planted propagules have been ignored (Kodikara et al. 2017 & Rodríguez-Rodríguez et al. 2021). Additionally, poor planning, followed by an absence of monitoring and maintenance are other factors that contribute to poor success rates of mangrove restoration (Kodikara et al. 2017 & Rodríguez et al. 2021). Recognizing limitations observed from literature on mangrove restoration, I suggest a framework for pre-mangrove restoration, that I believe would aid in enhancing mangrove restoration.

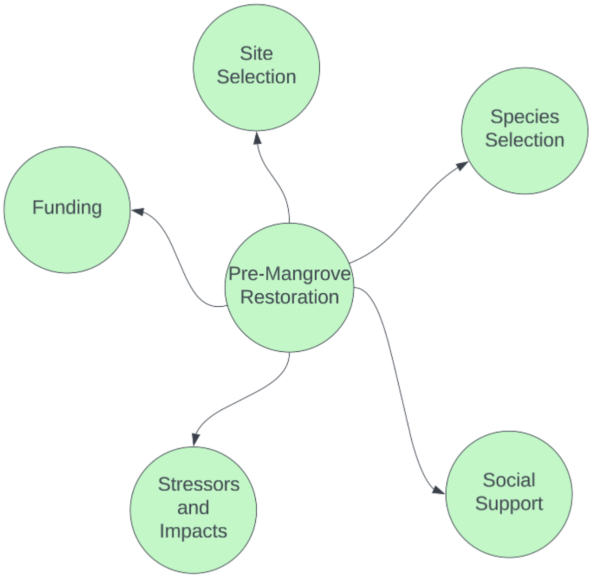

Figure 11: Pre-mangrove restoration framework: Walking-person-concept

In the walking-person-concept, all these factors inform the other and are important for achieving mangrove restoration. Social support from the community in the desired area for mangrove restoration is a crucial aspect that increases mangrove restoration success (Rodríguez-Rodríguez et al. 2021). A paper published by Rodríguez-Rodríguez et al. (2021) highlights that community-based approaches had a higher success rate in mangrove restoration, as compared to other mangrove restoration techniques. Involving the community in mangrove restoration could potentially inform potential stressors and/or impacts that could reduce mangrove restoration success. In an example from Sri Lanka, cattle grazing was identified as one of the reasons for failure in mangrove restoration (Kodikara et al. 2017). Therefore, by engaging with the community past and future stressors from anthropogenic sources may be identified and mitigated.

Apart from community support, funding is an additional factor that determines mangrove restoration success. Funding informs the scale of mangrove restoration. However, budgets often do not include monitoring and maintenance (post-restoration activities)(Kodikara et al. 2017). Therefore, future mangrove restoration projects need to ensure monitoring and maintenance are incorporated into budget development.

Moreover, site selection alongside stressors and impacts would aid in understanding restoration measures that may be necessary to increase the success of mangrove restoration, as well as inform species selection. Understanding hydraulic requirements, nutrient regime, salinity tolerance, species interaction, nearby mangrove communities, and mangrove associates are all crucial for determining species needed to recreate a mangrove forest. While crucial, the ecology of individual mangrove species is often limited, with most research being done on mangroves from *Rhizophora* and *Avecinna* genus (Rossaner's research 2019). Thus, it creates a gap in literature, in informing holistic mangrove restoration.

In the case of white mangrove restoration, it is essential to select a landscape that is regularly inundated by tidal action, and/or overbank flow from rivers. Regularly inundated landscapes would inhibit the encroachment of species that cannot persist in waterlogged conditions, and/or saline environments. (Biswas et al. 2007) Also, tidal action and overbank flows are an important source of nutrients, for nutrient-poor mangrove ecosystems (Reef et al. 2010). Additionally, it's important to select a site with an open canopy. While studies from Gu et al. (2019) have highlighted phenotypic plasticity in phenotypic traits (assimilation rate, transpiration rate, and water use efficiency) that allow white mangrove seedlings to grow in a wide variety of light intensity, mature plants appear to lose that adaptive ability as they age (Berger et al.2006; Flores-de-Santiago 2012; Berger et al. 2006). In the case of the ideal salinity range, most studies suggest white mangroves grow best in a salinity range from 5 to 35 PSU. (Cardona-Olarte et al.2006 &Gu et al.2019).

Biotic interactions are an additional factor that influences productivity and sustainability within mangrove ecosystems (Smith et al. 2009). Therefore, it is important to consider native species with which white mangroves would usually interact. For example, cord grass (*S. alterniflora)* was found to be instrumental in the stabilization of sediment and trapping mangrove propagules, and burrowing activities of fiddler crabs were found to increase white mangrove growth (Lewis 2006; Smith et al. 2009). It is assumed that fiddler crabs burrowing activity increases the nutrient uptake ability, due to increased redox potential of the sediment, which prevents the accumulation of sulfide to toxic levels in marsh ecosystems (Smith et al. 2009). Therefore, more energy was attributed to nutrient uptake, instead of oxidation of sulfides (Smith et al. 2009). Timing of species inclusion is an added factor to consider in the restoration of a landscape with white mangroves. White mangroves are pioneer species, and in their native range usually are the first to colonize a site (dependent on nearby populations). They are later followed and replaced by black and red mangroves (Cardona- Olarte et al. 2006 & Duke and Allen 2005).

An additional factor not discussed in literature is the restoration of white mangroves in a landscape dominated by non-native plants whose invasive potential is not well known. Based on data generated from the experimental design, field sampling, and literature analysis, non-native Indian almonds can compete with white mangroves. Indian almond seedlings effectively grew up to 35 PSU and depending on the genotype as high as 55 PSU (with the exception of one). Therefore, restoration activities that restore tidal action may not be an effective measure in reducing the persistence of Indian almond. Thus, to effectively restore white mangroves in a landscape dominated by Indian almond trees, Indian almond would have to be removed from proximate and local areas, to reduce recruitment via ocean currents. Currently, there are no best practice measures to remove Indian almond. However, University of Florida Institute of Food and Agricultural Science (IFAS) extension created a manual on how to control non-native plants in natural areas of Florida. One of the species highlighted in the manual is Indian almond, and they suggested basal bark treatment, with 10% Garlon 4 application, and /or cut stump with 50% Garlon 3 A applications (Enloe et al. 2018). However, these herbicide measures are dependent on the regulations and policies of the host state or country, therefore mechanical and manual removal by machete and saw are possible methods to remove Indian almond. It is important, regardless of the treatment, that all parts of Indian almond, including seeds and leaves, be removed and disposed of off-site, to reduce potential allelopathic effects. Conversely, if removal methods are not an option due to limited funding and or socio-cultural beliefs, I'd recommend identifying areas where soil salinity can reach as high as 55 PSU, as Indian almond seedlings struggled to persist in such saline conditions.

5.4

Limitations and future directions

As with every experimental design, there are usually some unforeseeable circumstances that can change the trajectory of an experiment. In the case of this project, the loss of viable white mangrove and Indian almond seeds was one such example. The original intent of this experiment was to germinate Indian almond and white mangrove seeds, before the start of the experiment, to ensure both species were in similar age ranges. However, that was not possible, as the stored white mangrove seeds were not viable, and a 5-month-old pre-planted white mangrove stock was used instead (there is no current literature on the correct process to preserve white mangrove propagules). Additionally, white mangroves across the country had only started flowering, and would have taken an additional 5 weeks for the seeds to mature (based on observation from flowering to seed browning). It was also found that Indian almond seeds have a low viability rate, six out of thirty-eight seeds planted germinated, and with a 3–6week germination time, it was not feasible to restart the process. Thus, wild stock of similar size was used for this experiment and later supplemented with planted seed stock after some plants did not recover from transplant shock.

The small sample size between the treatments was an additional limitation that could potentially reduce statistical power. However, the results observed in white mangrove growth matched descriptions from Cardona - Olarte et al. (2006) with the exception of increased growth in stem diameter for white mangroves in 55 PSU. However, this could be attributed to a maximum PSU of 55 being used in this experiment, as compared to 40 PSU used in Cardona - Olarte et al. (2006). Besides these factors, plant physiology could have been damaged during the transplant process which could affect the accuracy of results. While much care was given during the transplant process, roots could have been damaged which, could explain the negative growth observed for white mangroves growing in the 55 PSU saline level. However, this could also be due to the inhibitory action of increased salinity in calcium ion uptake, which is essential for root growth (Läuchli & Grattan 2011).

The results generated from this research suggest that Indian almond is an invasive species that could potentially impede white mangrove colonization, persistence, and restoration. However, due to time constraints and limited funding, the experiment was unable to go beyond five weeks. Therefore, it is suggested, that similar research be done with a larger sample size and a period of at least 12 months, to quantify the growth response of Indian almond to different concentrations of salinity. As well as to examine the potential allelopathic effects of Indian almond on germinating white mangrove seedlings. Indian almond also depicted traits found in mangroves, such as excreting salt on their leaves and adjusting their stem diameter to adapt to varying saline concentrations. Thus, future research should examine criteria that classify mangroves and distinguishes mangroves from mangrove associates.

6.0 Conclusion

Based on the result generated from a two-way Anova, there is no significant difference in growth response between white mangrove and Indian almond. However, there is a notable interaction between the two species with increasing saline concentrations for growth areas, stem height, stem diameter, and leaf area. Based on the trends from the figure, as salinity increases there is a general decrease in growth response for white mangrove and Indian almond seedlings, with Indian almond seedlings having a lower growth response than white mangrove seedlings with increasing salinity. The trends from the figure also suggest that white mangrove seedlings generally grow best in 15 PSU and Indian almond seedlings in 0 PSU. The results also indicate that Indian almond seedlings may struggle to persist in salinities over 55 PSU, this is attributed to one Indian almond expiring before the end date of the experiment in the 55 PSU saline level. Additionally, based on the outcomes from the growth response experiment, field sampling Brighton Mangrove Forest, and literature analysis, Indian almonds could potentially impede white mangroves' persistence and restoration and should be considered a potential stressor inhibiting the restoration of a landscape with white mangroves. Therefore, in a landscape dominated by Indian almonds, where removal methods are not an option, I would suggest identifying sites where soil salinities can reach as high as 55 PSU. As white mangrove seedlings, based on the results generated from this research can persist in salinities as high as 55 PSU, while Indian almond seedlings struggle to persist under such saline conditions. However, if Indian almond is not an immediate stressor on-site I would recommend identifying sites where soil salinity can reach as high as 15 PSU.

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Appendix A.

Figure 1A: Highlights, white mangrove growing away from Indian almond, as well as the height difference between white mangrove and Indian almond. Red circle shows the angle of growth, while red line separates the height difference between white mangroves and Indian almond.

Figure 2 A: Highlights, response of white mangroves to Indian almond. In the first picture, germinating white mangroves, grow in a ring around Indian almond seedling. In the second image are mature deceased white mangroves under the canopy of Indian almond. Blue circle helps illustrate the perimeter boundary of Indian almond seedling

effect on germinating white mangrove and red circles assist in identifying deceased mature white mangrove.

Appendix B

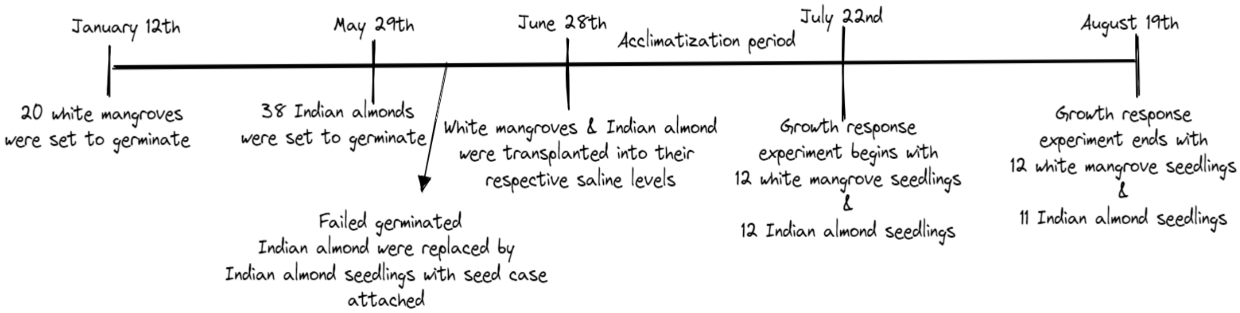

Figure 1B: Represents the timeline growth response of white mangroves and Indian almonds to different saline levels.