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SIT Panamá Fall 2014

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II. Abstract

Mangroves provide critical habitat to endangered and commercial species, store carbon from the atmosphere, and support valuable industries around the world. At the site of an old army base in Isla Galeta, Colón, a mangrove reforestation project has struggled to take root. For 9 days, I laid 7 belt transects of between 175 and 220 m x 50m moving toward the shore. Two transects were taken in mangrove forest, while 5 transects were taken in the reforestation zone. Factors such as canopy density, water depth, and salinity were measured in an attempt to determine if there were noticeable differences in conditions between the two mangrove forest transects (Transect 1 and 7) and the reforestation zone. These conditions were also compared to seedling and tree conditions. Species basal area density increased with distance inland, and canopy density increased correspondingly. White mangroves dominated in basal area density for mangrove forest transects. White mangrove seedlings also produced the tallest seedlings with the most leaves. Water depth and salinity appeared to be largely unaffected by tidal inundation. The majority of water samples in both mangrove forest and reforestation channels were freshwater. New methods of combatting *Saccharum spontaneum* are recommended to improve reforestation efforts.

III. Introduction

Just off the Atlantic coast of Panama, a dynamic and self-renewing ecosystem takes advantage of the tropical climate and swampy conditions. Guarding Punta Galeta's shores since before it was a U.S. navy base in the 1930's, mangroves that have persisted here for centuries now draw scientists and tourists alike from all over the world to the Smithsonian Tropical Research Center.

Once viewed as unproductive, distasteful environments, mangroves are increasingly recognized worldwide as critical habitat for endangered and commercially significant species, as well as for their ecological and aesthetic value. Uniquely adapted to survive in saline environments, mangroves combine methods of excreting, excluding, and accumulating salt to survive in otherwise hostile saline environments. The beautifully haunting roots of R. mangle, the most iconic mangrove species, anchor trees to coastal fringes, providing extra surface area and stability in the stressful environment of the intertidal zone.

Mangroves have evolved to do more than endure the coastline's constant state of flux; their method of reproduction depends on it. With viviparous, buoyant seedlings, or propagules, young, immature mangroves can travel long distances in the ocean's currents before rooting on sandy coastlines or the sediments of an estuary. The ability to thrive in salt water gives them a competitive edge; though able to survive in freshwater, saline environments weed out competition from other tropical flora.

These incredible ecosystems hold countless benefits for humans; they serve as carbon sinks, emitting oxygen into the atmosphere. Their wood can be used for charcoal and tannin. They protect coastlines from erosion and mitigate natural disasters like hurricanes. And they provide habitats for endangered species like the pygmy three-toed sloth, and for commercially significant species like lobster and shrimp.

Without the ample benefits provided by mangrove ecosystems, benefits from scientific study, carbon accumulation, and fishing and ecotourism industries would decline. Already, about one third of mangrove populations around the world have been lost to anthropogenic causes over the past 50 years.

Despite their immense financial and aesthetic value, mangrove populations in Panama are declining at an alarming rate. While government authorities like ANAM are working with scientific institutions like STRI to conserve and protect these incredible ecosystems, a better understanding of mangrove communities local to Panama would aid in better protection and reforestation efforts for Panama's mangroves. In 2004, a 1,250 hectare reforestation project was begun for mangrove reforestation on degraded lands. With good assessment and progressive methods, these reforestation projects could provide substantial carbon offsets and important ecological and economic benefits to Panama's local communities.

Isla Galeta itself contains its own reforestation zone. By comparing conditions of healthy mangroves on Isla Galeta to those of the reforestation zone, I provide an assessment of the progress of mangrove reforestation on Isla Galeta.

IV. Literature Review

1. What is a mangrove?

The term "mangrove" is a non-taxonomic term referring to a group of trees and shrubs that grow in intertidal zones in tropical climates all over the globe. There are 17 families and 70 known species of mangrove worldwide (Duke et al., 1998). While most mangroves are angiosperms, also known as Magnoliophyta or "flowering plants," non-angiosperm mangroves also exist. These are the Polypodiophyta, belonging to the fern family (Mangrovewatch, 2013). The common theme between all mangroves, whether they are trees, palms, ground ferns, or shrubs, is their unique adaptation to a wet, saline habitat (Feller & Sitnik, 2002). Because of this, they are usually found growing above mean sea level in areas with regular tidal inundation, such as coastal intertidal zones or estuarine margins. Mangroves tend to share these common characteristics: buttresses for structural support and/or exposed roots for breathing in anaerobic sediments, the presence of viviparous and buoyant propagules as reproduction, foliage salt-excretion or exclusion and zerophytic or water-conserving leaves for high salinity stress (Duke, et al., 1998).

Mangroves are typically characterized by a detrital food web in which detritus-feeding organisms eat dead organic matter and predators eat them in turn (Lewis & Reever, 2000). However, a grazing food web also exists. An ecosystem once viewed as unproductive and transitional, mangrove communities are now generally viewed as both highly productive and important to ecological systems worldwide (Feller & Sitnik, 2002).

2. Mangrove Reproduction

Mangroves reproduce using two strategies; they have viviparous propagules, or mangrove embryos that germinate while still attached to the parent tree, and then use hydrochory, or dispersal by water, to widen the distribution range of seeds, fruit, and propagules (Feller & Sitnik, 2002). Because of their unique reproduction strategy, mangroves share attributes from both pioneer and mature-phase forest communities. Their copious seed rain and adaptation to natural disturbances qualify them as pioneer species, while their large propagules, longevity, and long dispersal period are qualities of mature-phase species (Smith III, 1992). Species ranges in any given area depend on environmental factors, but also on the number of days the propagules remain buoyant and the rate of surface currents (Duke et al., 1998).

Adult mangrove species are sometimes distributed from low to high intertidal zones in a manner inversely related to the size of their propagules, though propagules of all sizes tend to be distributed to all areas of the intertidal zone (Smith III, 1992). Different mangrove species also vary in other propagule properties, like floating and rooting time; *Avicennia* and *Laguncularia* take about 5-7 days to root, while *Rhizophera* and *Pelliceria* take 11-15 days. Flotation times for different mangrove species can vary between a few days and many months (Duke et al., 1998).

Rhizophera, one of the focus species of the current reforestation project on Galeta Island and sometimes known as the "true mangrove" species, keeps its propagules about 4-6 months before they fall (Feller & Sitnik, 2002).

3. Mangrove Distribution and Zonation

Because mangroves are adapted to live in stressful intertidal environments, they have relatively low genetic diversity. As a group, they are generally restricted to areas with mean air temperatures that do not drop below 20° C, and where the seasonal range does not exceed 10°C (Duke et al., 1998). They are distributed in intertidal zones around the globe, mostly between 30° N latitude and 30°S (Feller & Sitnik, 2002), and have broader distributional ranges on eastern continental margins than on western coastlines due to warmer oceanic currents (Duke et al., 1998). At one point, 75% of the world's tropical coastlines were dominated by mangroves, but they have since been significantly reduced by human activities (Feller & Sitnik, 2002).

Mangroves have two main centers of worldwide diversity. In the Eastern or "Old World," (Australia, Southeast Asia, East Africa, the Western Pacific, and India), mangroves are much more diverse, with about 40-50 known species. In the Western or "New World," (West Africa, the Caribbean, Florida, Pacific North and South America, and Atlantic South America), only 8 known species of mangroves grow. Explanations for this phenomena can be speculated regarding limiting factors for mangrove distribution that include climate, salinity, and tidal fluctuation. Corresponding conditions include tropical air and water temperatures and rainfall levels. Though mangroves can grow in freshwater, they outcompete other vascular plants by staying in mostly saline habitats. Tidal fluctuations bring in saltwater, sediment, and necessary nutrients (Feller & Sitnik, 2002).

Because of these influencing factors, mangroves tend to reach their greatest development in low-lying regions with large tidal ranges (Feller & Sitnik, 2002). In Panama, for example, mangroves are more populous on the Pacific coast because of wider intertidal zones and excess sediment deposited from rivers (Mate, 2014). Because they tend to benefit from tidal fluctuation, mangroves growing closer to the edges of land masses tend to be larger and more productive than trees in the interior of land masses (Feller & Sitnik, 2002).

4. Mangrove Zonation

In estuaries and intertidal areas like Punta Galeta, mangroves tend to form monospecific bands of vegetation as they move inland from the shoreline. These patterns change with geography and environmental characteristics. For example, in Florida and in the Caribbean red mangroves (*Rhizophera mangle*), usually occupy seaward zones, followed by black mangroves (*Avicennia germinans*) and white mangroves (*Laguncularia racemosa*) in the most landward position. In Australia, however, this pattern is reversed, with red mangroves trending towards inland areas and white mangroves dominating the outskirts (Feller & Sitnik, 2002). Many different explanations for zonation patterns have been made by various scientists in mangrove ecosystems all over the globe in an attempt to understand the environmental factors causing zonation trends and the exceptions to those trends.

5. Distribution Trends and Correlative Conditions

Mangrove distribution and zonation patterns are the result of many variables working together in complex patterns. Some geomorphological and hydrological factors that can affect these patterns are rainfall levels, average temperatures, nutrient inputs, water depth, frequency of tidal inundation, wave energy, predation levels from local fauna, substrate conditions, tidal position, water salinity, and the presence of light gaps (Feller & Sitnik, 2002). Indicators of changes in these factors include species richness, canopy height, basal area, tree density, age/size class distribution, and understory development. Factors that limit mangrove presence and growth will also limit benefits like primary productivity, habitats for dependent organisms, and shoreline stabilization (Duke et al., 1998). Studies on interactions between environmental conditions and these indicators offer insights for reforestation and conservation parameters.

Tidal inundation is commonly cited as the greatest cause of mangrove zonation; however, inundation introduces two other variables; soil pore water salinity and soil water logging, which do not necessarily vary correlatively to inundation. While lower intertidal zones tend to have lower salinity concentrations than higher tidal zones where evaporation leaves excess salt behind, abundant rainfall or freshwater runoff could leave a high intertidal zone with lower salinity than the flooding water in the low intertidal zone (Smith III, 1992). High rainfall levels in general tend to produce mangroves with tall canopies, high basal areas, and low tree densities (Lewis & Streever, 2000).

Other intercorrelated variables are nutrients, oxidation-reduction potential, pH, pore water sulfide concentrations and soil texture (Smith III, 1992). In general, clay sediments with finer grains tend to be more highly reduced, while coarser sands tend to be more oxidized. Crab burrowing can factor into topography and texture, by decreasing redox potentials and increasing forest productivity. They can improve soil aeration and reduce levels of harmful sulphides (Duke et al., 1998). These redox potentials do not generally limit mangrove growth for *R. mangle* (red mangrove) and *Avicennia* (white mangrove); both are equally capable of growing in highly reduced sediments, as long as functional root aeration pathways remain unobstructed (Smith III, 1992). Crab burrowing has, in some cases in Panama, been found to facilitate *R. mangle* propagule establishment (Duke et al., 1998).

Though crab presence can be beneficial in terms of soil aeration, *R. mangle* propagules can also experience significantly more herbivory when crabs are present. Even propagule predation varies depending on location. However, no predation from the same predator crab species was observed in *R. mangle* in Florida (Smith III, 1992). Predation can sometimes account for some distribution patterns; predation on *A. germinans* and *L. racemosa* can make way for dominant establishment of *R. mangle* and *P. rhisophorae*, but the inverse has now been found (Smith III, 1992). Grapsid crabs are known to consume *Avicennia* propagules, especially in high intertidal zones. While mangroves like *Heritiera* and *Xylocarpus* have hard seed capsules that protect them from crabs, they are often subject to attack from insects. Among established *R. mangle* propagules, weevils have been found burrowing into the propagules themselves (Duke et al., 1998).

Adaptions to disturbance sometimes correlate to the presence of light gaps; mangroves that are less shade intolerant might do better in areas with light gaps. While this area has not been extensively studied, results from Australia indicate that significantly different species tend to grow in light gaps compared to nearby canopy (Smith III, 1992). Because light gaps tend to have lower pore water salinity, more pronounced photosynthetically active radiation, and warmer soil temperatures, some scientists have speculated that *R. mangle* and *Pelliciera* would hold an advantage in these areas. However, studies showing that predation on *Avicennia marina* propagules tended to decrease as light gaps increased, which could offer this species a competitive advantage over *R. mangle* or *Pelliciera* (Smith III, 1992). Further study on light gaps could be very significant in aiding reforestation projects in disturbed areas.

6. Hypothesized Explanations

Various studies on mangrove zonation and distribution patterns have resulted in 6 distinct hypotheses about the causes behind these patterns (Feller & Sitnik, 2002). These hypotheses are: 1) Mangrove zonation is a result of land building and plant succession on the coasts, 2) Zonation is a result of geomorphological processes, 3) Tidal action “sorts out” species by differentially dispersing propagules across a gradient according to size, 4) Differentially selective predation eliminates species from certain zones, 5) Species are uniquely adapted to physiochemical conditions that vary along a gradient, and 6) Interspecific competition causes zonation (Feller & Sitnik, 2002). These hypotheses can be grouped into two basic subcategories: “distinct preference,” in which each species has its own optimum along a gradient, thus controlling where the species occurs, and the alternate view, in which many species share the same optimum, but confounding factors cause zonation (Smith III, 1992). Hypotheses 1, 2, and 5 might be classified as “distinct preference,” while factors like seed dispersal, predation, and competition, (Hypotheses 3,4, and 6), would fit into the second category. The first hypothesis has been largely discredited, on the basis that mangroves respond to coastal propagation, rather than causing it (Feller & Sitnik, 2002). This, as well the other two “distinct preference” hypotheses, is a hypotheses largely based on observational, and not controlled data. These studies can show only correlations, and without causational indications to from which to substantiate the hypothesis (Smith III, 1992). In Rabinowitz’s study of propagule properties and adult distribution, for example, she tested success for mangrove seedlings in habitats where other species dominated compared to habitats with their own species. After finding that mangroves in deeper swamps had larger and heavier propagules than mangroves in shallow waters, she concluded that differential sorting of propagules by the tides caused zonation (Rabinowitz, 1978). This hypothesis is partially confounded with the later discovery that tidal action delivers all propagules of all species to all portions of the intertidal zone. While Rabinowitz found an important correlation, it is likely that factors regulating establishment, survival, and growth after dispersal were greater influences on species zonation (Smith III, 1992).

However, lab experiments on mangroves can offer only one piece to a very complex puzzle; for example, one can measure optimum salinity requirements for mangrove species in the lab, but salinity across the intertidal zone is influenced by a combination of factors like the amount of rainfall, freshwater runoff, and seepage (Smith III, 1992). In one study, both *Ceriops tagal* and *C. australis* grew best at 15% salinity in the lab, but differentiated “optimal” salinity in the field, with *C. tagal* growing best at 20-35% and *C. australis* growing best at 50-60% salinity. In general, most mangrove species seem to maintain either a narrower salinity tolerance, (less than 40%), or a broader salinity tolerance (0-80%). In this way, salinity can sometimes, but not always play a role in mangrove zonation (Smith III, 1992).

To complicate matters more, it seems like most mangroves have a very high tolerance for a wide range of factors such as salinity, pH, nutrients, redox potential and soil texture, so determining a single optimum for each species is almost impossible. Additionally, studies must be conducted on both seedlings and adult mangroves, as conditions where adult mangroves thrive may no longer be conducive for less tolerant seedlings (Smith III, 1992). This requires infrequently conducted longer-term studies to properly address this concern.

Long term, in-field experiments measuring a dynamic range of variables are required to understand the interactions causing zonation in each unique mangrove environment.

7. Significance of Mangrove Habitat

Mangroves are recognized worldwide as both ecologically and anthropologically significant. They contribute to soil formations, combat erosion, and stabilize coastlines. They filter upland runoff, and provide important habitat for marine organisms, invertebrates, and other wildlife, and they provide detritus that continues a cycle of productivity in offshore waters.

With 44% of the world's populations living within 150 km of coastline, humans reap huge benefits from mangrove communities (Polidoro et al., 2010). Mangroves protect coastal communities from hurricanes, serve as refuge for endangered species and commercially valuable marine organisms, and support tourism-based industries like sport fishing, boating, bird watching, and snorkeling (Feller & Sitnik, 2002). In a 2004 report on biodiversity in Panama, mangroves are mentioned as one of five major biomes in the country. While the Caribbean coast is more dominated by coral species, the Pacific coast has more extensive mangrove ecosystems (Parker et al., 2004). According to the report, mangrove health is dependent on conservation of the mangrove areas and protection of inland terrestrial ecosystems. In turn, 70% of 25,000 metric tons of fish caught annually off Panama's coasts depends on the health of mangrove systems (Parker et al., 2004). The most important of these are in the Golf of Chiriqui, the Gold of Montijo, the Bay of Panama, the Gold of San Miguel, and Bocas del Toro (Parker et al., 2004). These critical areas support not only a large portion of Panama's fishing and tourism industries, but have an aesthetic and sentimental value for Panama that is unquantifiable.

8. Mangroves and Environmental Degradation

Mangroves around the globe are disappearing at an alarming rate. From 1958-2008, about a third of mangrove forests were lost to coastal development and other anthropogenic sources (Schmidt, 2008). As of 2010, 11 of 70 mangrove species (16%) were at elevated threats of extinction, with 40% of mangrove species along Atlantic and Pacific coasts in Central America threatened (Polidoro et al., 2010). Along Panama's Caribbean coast, development is the leading cause of mangrove deforestation (Schmidt, 2008), especially those prevalent in high intertidal and upstream estuarine zones, where land is cleared for aquaculture and agricultural development (Polidoro et al., 2010).

Biodiversity in general in Panama is most threatened by road construction and improvement along the Caribbean coast and in the Darien and Bocas del Toro regions, where agricultural expansion infringes on important tropical rain forest habitat. Mangrove forests suffer from conversion into shrimp ponds and other development. Secondary factors include industrial pollution, petroleum spills, and use of mangroves for charcoal production and materials for construction. As global temperatures rise, unusual weather patterns and sea level rise will greatly effect Panama's intertidal mangrove ecosystems (Parker et al., 2004). Within the next decade, several mangrove species could be extinct if serious and effective protective measures are not properly enforced (Duke et al., 1998). This would have serious effects on endangered animals' biodiversity, with 40% of animal species restricted to mangrove habitats at elevated extinction risks due to extensive habitat loss (Polidoro et al., 2010).

Punta Galeta is an important point of reference for changes in biodiversity because its mangroves have been continuously studied by a number of scientists for over 30 years. It experienced two major oil spills, in 1968 and 1986 just off Galeta's coast, which provide insight into mangrove forest responses to disturbance. After more than 8 million liters of crude oil spilled into the region east of the Caribbean entrance to the Panama Canal, *R. mangle* populations along the Galeta coast experienced significant dead zones (Jackson et al., 1989). Abundance of foliose algae, sponges, hydroids, ascidians, oysters, barnacles and mussels were greatly reduced after the spill (Jackson et al., 1989). Although Punta Galeta itself is a reserve protected by ANAM (Panama's National Authority for the Environment) and administered by the Smithsonian Tropical Research Institute, development projects like the airport and storage lots in nearby Colon are leveling mangrove forests adjacent to Galeta (Parker et al., 2004). Official government reports recommend facilitation laws and regulations to transfer forest land rights to local communities, but at the same time macro-level groups like ITTO (International Tropical Timber Organization) try to find balance with ANAM by reviewing forest situations in Panama in the hope of providing sustainable management training for mangrove-dependent communities (Parker et al., 2004). As early as 1996, studies off the Caribbean coast found petroleum to be the primary pollutant leading to tree defoliation, stand death, and loss of associated sessile and mobile animal species in mangrove habitats. Hydrocarbons stayed in mangrove sediments for decades, correlated with increased seedling mutation rates, and chemical wastes were associated with increased heavy metal content in seedlings (Ellision, 1996). As of 2004, there were 1,250 hectares of reforestation projects on degraded lands in Panama (Parker et al., 2004).

9. Mangrove Reforestation Tactics

Restoration can be defined as any activity that aims to return a system to a preexisting condition. Rehabilitation is an activity that aims to convert a degraded system to a stable alternative (Brown, 2006). Though both views are necessary in mangrove habitats, many attempts to restore habitats have failed because they lacked the extensive research of the local area required to restore the environment to its stable, preexisting condition. In a swamp area in Indonesia, for example, the government replanted the same swamp five times, without analyzing why the plants continued to die each year (Brown, 2006).

When attempting to rehabilitate mangrove ecosystems, a comprehensive understanding is necessary, of both the ideal environment for nearby healthy mangroves and of the reforestation area itself. Because mangroves are generally self-renewing communities and native plants provide the best overall habitat, only native vegetation is recommended for use in mangrove restoration (Stratman, 2002). In general, planting of mangrove seedlings is unnecessary, because mangroves are excellent colonizers under proper hydrologic conditions (Brown, 2006).

In many cases, certain environmental factors are rendering the area inhospitable to mangrove propagule establishment or growth, and some basic changes to these factors are necessary in lieu of tree planting. The most commonly referenced strategy for mangrove reforestation is restoring the area's hydrology, which is defined as the frequency and duration of tidal flooding. The basic conditions needed for self-repair of a mangrove ecosystem are simple: 1) The normal tidal hydrology must be intact, and 2) There must be propagule availability. In many cases, searching for sources of blocked tidal flow and removing these environmental stressors is much more successful that simply planting mangroves that cannot thrive (Lewis & Streever, 2000).

Mangrove planting should only be used as a last resort, after the hydrologic patterns that control the targeted mangrove species have been restored and mangroves still fail to establish themselves. Because red mangroves tend to be a good “colonizing” mangrove species, they are most often planted in restoration projects. When planted, they should be placed directly into the substrate, with 1 m radius between individuals. A 50% mortality rate is expected, but within five years dense thickets should be forming, and close canopies are expected to form within fifteen years (Lewis & Streever, 2000).

Costs of mangrove reforestation vary, but many require construction to remove hydrological barriers, thus inflating costs. In general, these costs are estimated at about $62,000 per hectare, excluding the cost of the land. In some areas, “nurse species” like smooth cordgrass in Florida facilitate primary and secondary succession for mangroves by establishing themselves on bare soil (Lewis & Streever, 2000).

10. Conditions in Galeta

Isla Galeta has had its own reforestation zone for several years now. Though published, current information about mangrove reforestation in Galeta is not easily accessible, extensive research on mangrove history on Isla Galeta can offer a valuable basis for predictions and proceedings in Galeta’s mangrove reforestation zone.

The coordinates at Punta Galeta are (9°24’ 18’’N and 79°51’ 48.5”W). Located adjacent to the Atlantic entrance of the Panama canal, about 6.05 km² of Punta Galeta has been a protected area since 1997, jointly managed by ANAM and the Smithsonian Tropical Research Institute (Gallego et al., 2010). Extensive reef formations border the northern edge of the peninsula, and the area itself is made up of calcium carbonate reef deposits and lagoon sediment. Over thousands of years, *R. mangle* has colonized the reef flat, resulting in peat layers throughout the forest substrate reaching up to two meters in depth (Schmidt, 2008).

The mean annual temperature in Punta Galeta is 26.4°C, with a daily range that only extends about 5°C above or below this average. Like the rest of Panama, Punta Galeta experiences dry season from January to mid-April and rainy season from mid-April to December (Schmidt, 2008). Average rainfall in Galeta is about 320.0 cm/year (Gallego et al., 2010). The tidal gauge station at Cristobal, some 20 km west of Punta Galeta, records a tidal range of 23 cm and a spring tidal range of 34 cm (Schmidt, 2008).

Mangroves on Isla Galeta are represented by three main species; *Rhizophora mangle*, *Laguncularia racemosa*, and *Avicennia germinans*. While two other mangrove species, *C. erectus* and a mangrove fern, *A. aureum* are found on the island, they represent very minor portions of the mangrove population. The distribution of these three mangrove species tends to vary with the elevation gradient, and varies on Punta Galeta according to general zonation patterns for Caribbean mangrove species, with *R. mangle* at lowest elevations, *L. racemosa* at increasing elevations, and *A. germinans* greatly represented at the highest elevations, further inland. Some exceptions to the elevation gradient zonation involved recently disturbed areas with light abundance, where pure stands of *L. racemosa* are often found. In 2008, these three dominant mangrove species constituted more than 95% of all the vegetation surveyed. However, *R. mangle* pollen was overrepresented relative to *R. mangle* trees, while *L. racemosa* and *A. germinans* pollen was underrepresented, which seems to indicate that local wind and tidal conditions favor *R. mangle* (Schmidt, 2008).

11. *Saccharum spontaneum*

Wild sugarcane, also known as *Saccharum spontaneum*, is an invasive species of grass found all over the Panama Canal Watershed. Commonly referred to as "monte," this grass was originally introduced to Panama when the canal was built to mitigate erosion in the watershed. Unfortunately, the grass proved to be invasive, taking over disturbed areas like railroad tracks and abandoned agricultural lands. Growing 3-4 meters high on average, this invasive weed now constitutes over 3% of the Panama Canal Watershed (Bonnett et al, 2014). There is not much known about its salinity tolerance, but studies on similar invasive reeds indicate that low salinity windows improve chances for survival (Bart et al, 2003).

It is known to stunt reforestation efforts by inhibiting the germination, establishment, and growth of native tree species due to its rapid above and below ground dominance (Bonnett et al, 2014). The species covers the mangrove reforestation zone at Isla Galeta, and channels of it have cut away to accommodate the planted mangrove seedlings.

12. Mangrove Reforestation in Panama

In Panama the International Tropical Timber Organization supports ANAM (National Environment Authority of Panama) by reviewing and mitigating problems with unsustainable management for mangroves. They provide training to mangrove-dependent communities on sustainable harvesting techniques, and, in 2004, had established 1,240 hectares of mangrove reforestation projects on degraded lands (Parker et al., 2004). The mangrove reforestation project on Punta Galeta is run by a private company using the project for carbon offsets. Although the company's motives may come from government regulation rather than actual environmental considerations, the project must be successful in establishing a healthy mangrove canopy to work in the company's favor (Tomas, 11/14/14).

Remote sensing has been used in some cases to develop management plans for mangrove reforestation and restoration. For instance, remote sensing on Isla Galeta could demonstrate changes in mangrove cover before and after a disturbance, by looking at the role of stressors, plant-plant and plant-soil interactions, and impacts of disturbance at different temporal and spatial skills. This method is limited by its inability to really describe the ecological processes causing these changes (Berger et al., 2008).

The reforestation project on Isla Galeta has struggled since mangrove seedlings were first planted in a swampy inland area four years ago (Tomas, 11/14/14). In order to determine constraints on a mangrove system, 3 factors must be considered; regulators, resources, and hydroperiod. The term "regulators" refers to non-resource variables like salinity, sulfide, pH, and redox potential. "Resources" refers to nutrients, light, and space needed for growth, and "hydroperiod" is the duration, frequency, and depth of inundation. According to Twilly and River-Monroy's model, these three factors form a "constraint envelope" that defines the primary productivity of the system (Berger et al., 2008).

Mangroves can be nitrogen and phosphorus limited, like many forest systems. Determining nitrogen and phosphorus levels in a reforestation area could establish a better understanding of what nutrients are required to stimulate productivity in the system (Berger et al., 2008).

While adult mangroves may thrive well in certain areas, seedlings may not be able to do the same. For example, adult *A. germinans* and *R. mangle* are capable of oxidizing sulfide around the rhizosphere by transporting oxygen through their roots, but this ability to grow in soils with high concentrations of sulfide may be limited for *A. germinans* and *R. mangle* seedlings. Understanding the pre-disturbance conditions in the previous forest structure can provide valuable insight into the ideal conditions for a mangrove reforestation site (Berger et al., 2008).

V. Research Question

Do mangrove habitat conditions such as tidal inundation, water salinity, pH, and sunlight differ in correlation to abundance factors like basal area and species distribution for native adult mangroves factors like plant height and leaf count for planted mangrove seedlings on Isla Galeta?

VI. Research Objectives

- Determine the relation of factors like water depth, water salinity, pH, and sunlight to basal area and species distribution in healthy mangroves and height, leaf count, and species distribution of human-planted mangrove seedlings on Isla Galeta, and generate recommendations for the reforestation site based on results
- Determine the relative abundance of mangrove species in mangrove forests and in the mangrove reforestation zone

VII. Justification

Mangrove communities worldwide provide critical habitat for several threatened and endangered species, protect tropical coasts from erosion and storm-induced disasters, and protect important coastal industries like fishing and tourism. Understanding the zonation distribution and the conditions that promote the health and abundance of native mangroves on Isla Galeta will aid in maintenance and preservation efforts, as well as provide a reference point for the mangrove seedlings planted for reforestation in the northwest corner. By testing the parameters that might influence mangrove health and testing the same parameters in the reforestation zone, I can provide recommendations for current and future mangrove reforestation projects on Isla Galeta.

Mangrove reforestation projects like the one on Isla Galeta are sometimes used in Panama as carbon offsets for development projects through ANAM, Panama's National Environmental Authority. However, mortality among planted mangroves can seriously inhibit the benefits for which these sites are intended, especially in regard to carbon offsets. In this study, I hoped to provide a comprehensive study of the conditions influencing the mortality and growth rates of the mangroves in the reforestation zone, thus providing a useful point of reference for current and future mangrove reforestation projects used by ANAM in Panama.

VIII. Methods and Materials

1. Overview

I stayed in Isla Galeta for a total of 11 nights, from Sept. 14 to Sept. 25th, 2014. Data collection spanned a total of 9 days, from Sept. 16th- Sept. 24th. I identified species density, basal area, water depth, pH, and water salinity using transects. I used 7 transects in total: 5 in the reforestation zone, and 2 in healthy mangrove forest on either side of the reforestation zone. The following table describes the length of each transect. All transects were taken in a line perpendicular to the nearest coastline.

Transect	1	2	3	4	5	6	7
Total Length (m)	200	175	175	210	175	220	200

Each transect was divided into 50 meter segments. I used a 10 meter string stretched across the transect measuring tape at a 90° angle to delineate the catchment area. Methods varied between the mangrove forest (Transects 1 and 7), and the reforestation zone.

2. Mangrove Forest Transects

Transects 1 and 7 were each 200 meters in total length. In each 50x10 meter segment, I measured Diameter at Breast Height for all mangroves over 5 cm DBH. I identified species at each mangrove measured: Red, White, or Black. I took 2 measurements of water depth in each segment, with each measurement taken 25 meters into the segment, 5 meters directly out at a 90° angle from the transect (James-Pirri et al., 2002). At each point where I measured water depth, I also measured canopy light using a densiometer (Zotero, 2009). Finally, I collected a water sample, which I later tested for pH with pH paper and for water salinity using a refractometer (James-Pirri et al., 2002). In some cases, extra water samples were taken to test for pH and salinity. These cases are noted in the results. I also took note of general changes in the transect environment. The following picture depicts an estimation of the Transects. Transect numbering starts at the left and rotates right, from Transect 1 to Transect 7.

3. Reforestation Zone Transects

In transects within the reforestation zone, I used the same 10 m string stretched across the transect tape to determine the catchment area. Segments were thus divided into 50m x 10 m belt quadrats. In each quadrat I measured plant height and counted number of leaves for each mangrove seedling found. Because reforestation area was located in an open field without canopy presence, I took densitometer measurements at approximate height of a mangrove sapling, approx. 20 cm from the ground. Thus densiometer measurements within the reforestation zone measured grass encroachment and cover, rather than tree cover.

4. Bamboo Casings

"Seedling" was defined as any mangrove plant with an approximate DBH of less than 4 cm. Seedling height was measured in cm above water/soil height for each seedling. For seedlings found in bamboo casings, height was taken from the base of the casing. Seedling leaf count was counted from the bottom of the plant moving toward the top. Plants with too many leaves to be feasibly counted were estimated. All other methods of taking water depth and water samples for pH and salinity measurements remained the same.

5. Salinity Gradients

Salinity measurements from every transect were compared to their distance from the ocean and compiled into a bar graph for a visual aid to see where salinity appeared along a gradient from the beach. Measurements recorded with a distance of "0" were taken directly from the ocean water at the shoreline. "The ocean" is defined by the shoreline perpendicular to the transect line.

6. Graphs and Statistical Tests

I compared seedling height and leaf count between red and white mangrove seedlings by creating histograms of their distributions and running t-tests to compare the distributions.

Using data from the mangrove forests (Transects 1 and 7), I compared the basal area averages/m^2 between black, white, and red mangroves using pie charts to visualize average percentages. I also graphed scatter plots of conditions such as average basal area per species per m^2, canopy density, water depth, and salinity in Transects 1 and 7 in relation to their distance from the shoreline. For each scatterplot I found the R^2 value to determine how well the line of best fit described the data. Finally, I compiled the salinity measurements from every transect into a bar graph that showed the different salinity measurements taken along increasing distances from the shoreline

7. Materials

Transect line, water sample containers, refractometer, densiometer, pH paper, GPS, meter stick, DBH tape, marking tape, compass, string.

8. Ethics

For the duration of the project, I took precautions to have the least negative impact possible on the study site. Machetes were used to clear grass, but not used in mangrove habitats. In the reforestation zone, I walked in the grass where *Saccharum spontaneum* grows to avoid trampling mangrove seedlings. I measured mangrove seedlings and counted leaves without touching the leaves or the stalks. No plant matter was taken from the site; only small water samples were taken for salinity and pH measurements. All sample sites were approved by the Isla Galeta administration.

IX. Difficulties and Limitations

Time was a limitation for the project; ideally, a long-term study incorporating tidal fluctuation would have better quantified changes in salinity and water depth throughout the year. My data collection time was further limited by complications in finding accommodation at Isla Galeta; this delayed my data collection time by 5 days.

Another significant limitation was the lack of available data on the reforestation project in Punta Galeta. Because I was unable to meet with a representative from either ANAM or the company managing the project, all information about the reforestation project was either gathered from the staff at Punta Galeta or inferred from observation.

The biggest limitation, however, was the physical barrier presented by *Saccharum spontaneum*, the wild sugarcane plant that dominated the mangrove reforestation zone. Ideally, my transects would have extended from the mangrove planting zone to the shoreline. Unfortunately, *Saccharum spontaneum* grows in thick, 1-3 meter high stands between the planting area and the mangroves bordering the coast. This prevented me from accessing these areas to collect water samples. This also prevented me from accessing border mangroves along the shoreline, which could only otherwise be accessed from the waterline itself, where water depths were unpredictable in the tidal zone and too deep for access by foot.

These limitations could also have impacted sources of error. With more time, I could have collected data through variable weather patterns over the course of a year. As is, with 9 days of data collection, varied weather patterns like rain, humidity, and temperature could have affected water salinity, pH, or depth in different samples. These variations would have less of an effect on the data if more data were taken over a longer period of time. More time would also have allowed for more data collection. For instance, I refrained from documenting any seedling growth in Transects 1 and 7, where I only recorded mangrove trees above an estimated 5 cm DBH. Recording height and leaf count of mangrove seedlings in the mangrove forest would have aided in the comparison with mangrove seedlings in the reforestation zone.

X. Site Description

1. Transect 1: Mangrove Forest Fringe

Mostly dominated by thin, white mangroves, the transect moved north-west towards the western shoreline, following approximately the line of the border between mangrove forest cover and the cleared marshland of the reforestation zone. The cleared area was easily visible to the right of the transect at all times.

2. Transects 2-4: Mixed-Species Mangrove Reforestation

A road runs through the middle of the mangrove reforestation site, where cleared land is now dominated by wild sugarcane grass. Channels have been cut through the grass perpendicular to the road to facilitate mangrove seedling growth. Transects 2, 3, and 4 were taken in the reforestation area on the left side of the road, where 28 channels have been cleared for mangrove planting. The channels are planted with mangrove seedlings, approximately 2 meters apart, with approximately 5 meters of wild sugarcane between each channel. Starting with transect 2, about 40 meters perpendicular from the road, each of these transects travelled from the end of the trees and moved directly perpendicular to the lines of the cleared channels, parallel to the road. Seedlings are estimated to be about 50% white and 50% red, planted in no clear pattern according to species. A small group of seedlings were planted in bamboo casings.

3. Transects 5-6: Red Species Mangrove Reforestation

Transects 5 and 6 were taken from the right side of the road, where 9 channels have been cleared for mangrove seedlings, also cut perpendicular to the road. These channels have about 2-3 meters of wild sugarcane between them, with seedlings planted periodically every 5 meters away from the road, towards the nearest shore. These two transects were taken parallel to the channels, perpendicular to the road. All mangrove seedlings within these transects were red seedlings, and were all planted in bamboo casings.

4. Transect 7: Old Growth Mangrove Forest

Approximately 100 meters east of the reforestation zone, Transect 7 was taken perpendicular to the road, parallel to Transects 5 and 6. This was in mangrove forest, in what appeared to be “old growth,” forest in a higher state of succession compared to Transect 1. The transect moved directly north from the trail, towards the sea. Though dominated by white mangroves, black and red mangroves were also found. Many dead, rotting, or fallen trees were observed.

XI. Results

1. Seedling Height and Leaf Count According to Species: Red or White

Seedling heights were compared between red and white using a t-test with unequal variances. The seedling heights range from 9 cm to 250 cm for white mangroves, and range from 20 cm to 164 cm for red mangroves. The mean height for white seedlings is 57.38 with a standard deviation of 28.51, while mean height for red seedlings is 47.2 with an 18.56 standard deviation. Distribution for white sapling heights appears normal, while red sapling height distribution appears somewhat skewed right:

Figure 1 N=151

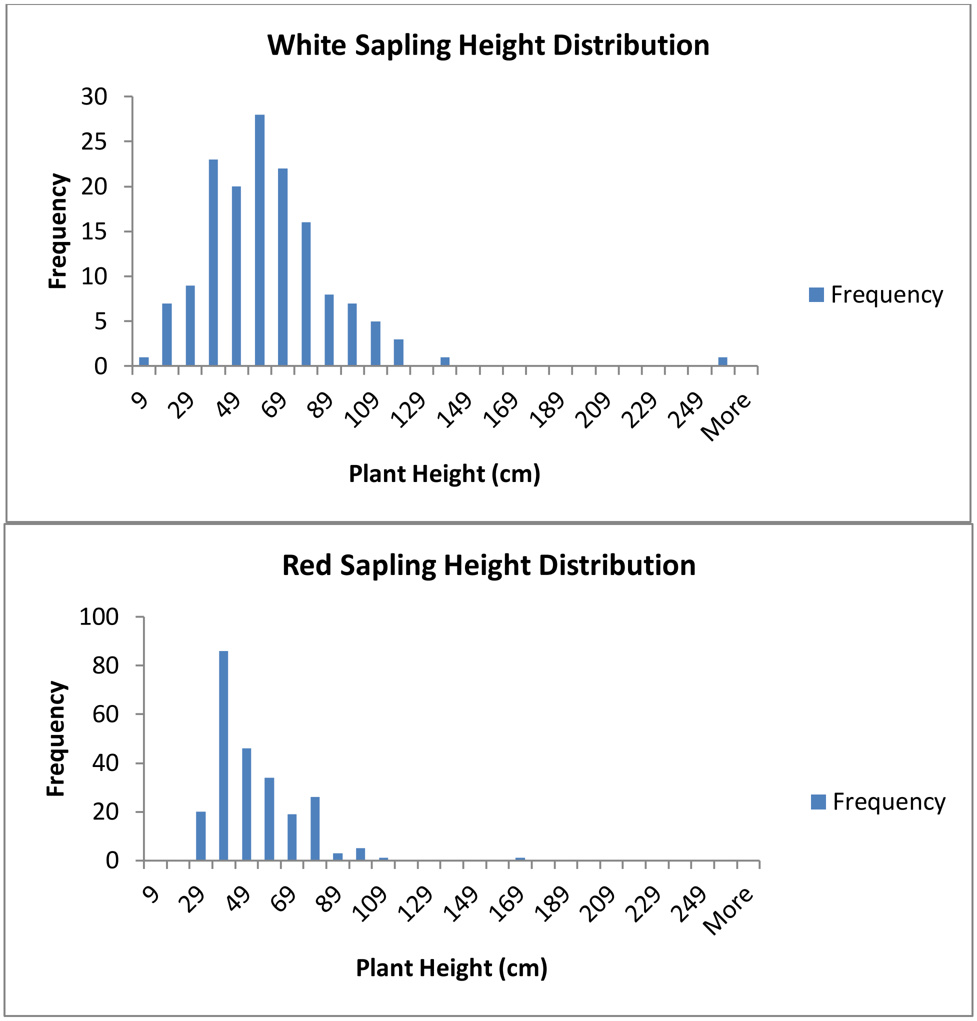


Figure 2 N=241

The t-test between the two distributions produced a significant two-tailed p value of 0.000127247:

t-Test: Two-Sample Assuming Unequal Variances

	White Height	*Red Height*
Mean	57.37748344	47.20332
Variance	812.7565563	344.621
Observations	151	241
Hypothesized Mean Difference	0	
df	230	
t Stat	3.898045147	
P(T<=t) one-tail	6.36237E-05	
t Critical one-tail	1.651505638	

P(T<=t) two-tail	**0.000127247**

Seedling leaf counts were also compared between red and white seedlings. The leaf count ranges from 4 to 700 for white mangroves and ranges from 2 to 200 for red mangroves. The mean leaf count for white mangroves is 28.25 with a standard deviation of 67.7, while mean leaf count for red seedlings is 11 with a standard deviation of 14.5. Distribution for both white and red leaf counts appear skewed right.

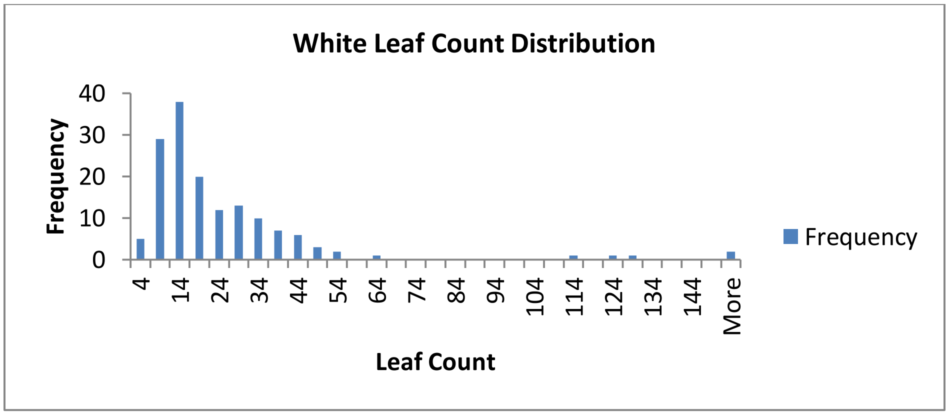


Figure 3 N=151

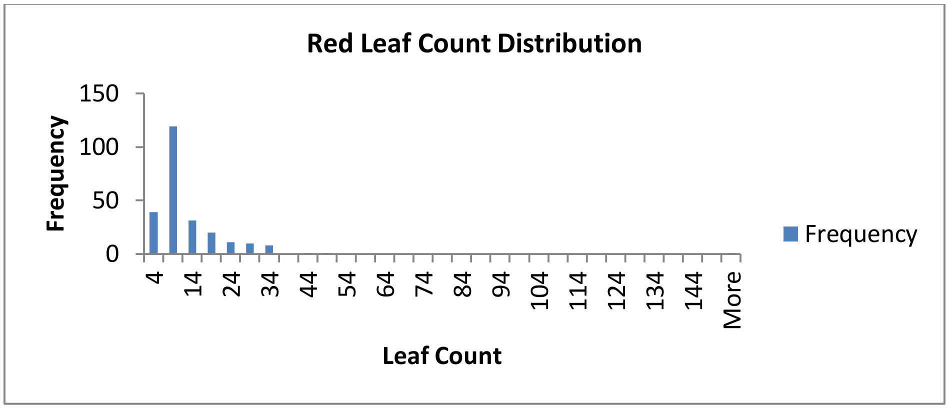


Figure 4 N=241

The t-test between the two distributions produced a significant two-tailed p value of 0.002391443:

t-Test: Two-Sample Assuming Unequal Variances

	White Leaf #	*Red Leaf #*
Mean	28.25165563	11.00414938
Variance	4583.696247	210.8791494
Observations	151	241

Hypothesized Mean Difference	0
df	159
t Stat	3.086284783
P(T<=t) one-tail	0.001195721
t Critical one-tail	1.654493503
P(T<=t) two-tail	**0.002391443**

2. Mangrove Forests: Comparing Average Basal Area: Red, White, Black

Units for basal are in m^2 of each species per m^2 within the quadrat. The total basal area was found for each species in each 50m x 10 m quadrat. Basal areas were totaled, then divided by the area of the quadrat, 500 m. Each number is average basal area per m^2. The average basal area for each transect was calculated as the average of the 4 sections. White mangroves have the highest basal area represented in these transects, while red mangroves have the second highest basal area, and black mangroves are least represented. Black mangroves are present in Transect 1 only in the section furthest from the shore, while they are present in Transect 7, the older growth forest, in the first 3 sections, though they disappear by the time they reach the quadrat closest to the shoreline. Pie charts can be used to show percentages of species distribution relative to each other:

Averages/Area:

Transect 1			Transect 7		
Section 1			**Section 1**		
White	Red	Black	White	Red	Black
0.005672	0.000498619	0.001867	0.003975	0.000235816	0.000213731
Section 2			**Section 2**		
White	Red	Black	White	Red	Black
0.003759	0	0	0.005413	.0000390642	0.00015034
Section 3			**Section 3**		
White	Red	Black	White	Red	Black
0.004121	0	0	0.003201	.0000226195	0.000280231
Section 4			**Section 4**		
White	Red	Black	White	Red	Black
0.00050232	0	0	0.007121134	0	0

Table 1

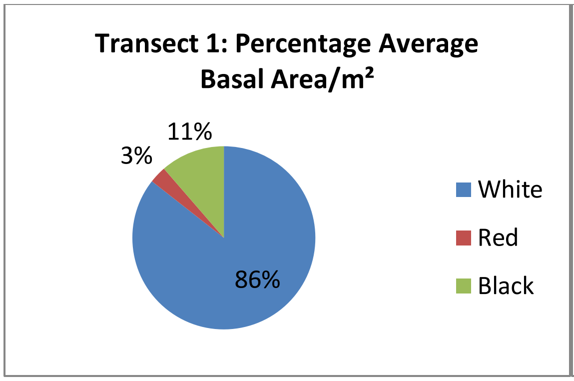


Figure 9, N=477

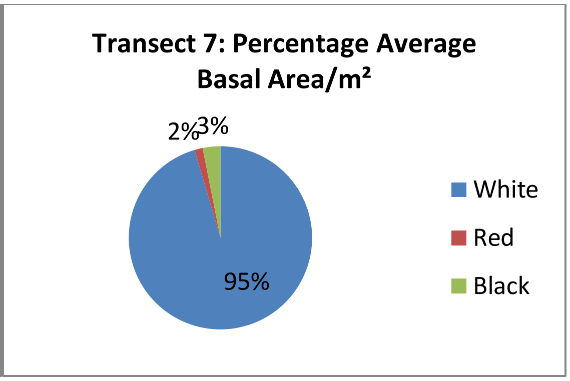


Figure 10, N=477

3. Mangrove Forests: Comparing Species Distribution in Reference to the Shoreline: Canopy Density, Water Depth, Salinity

I created a scatter plot of species distribution with red, black, and white basal area averages represented for both Transect 1 and Transect 7. Each number is corresponded to sections 1, 2, 3, and 4, which move away from the sea. The data for each section was converted to its equivalent distance from the shoreline:

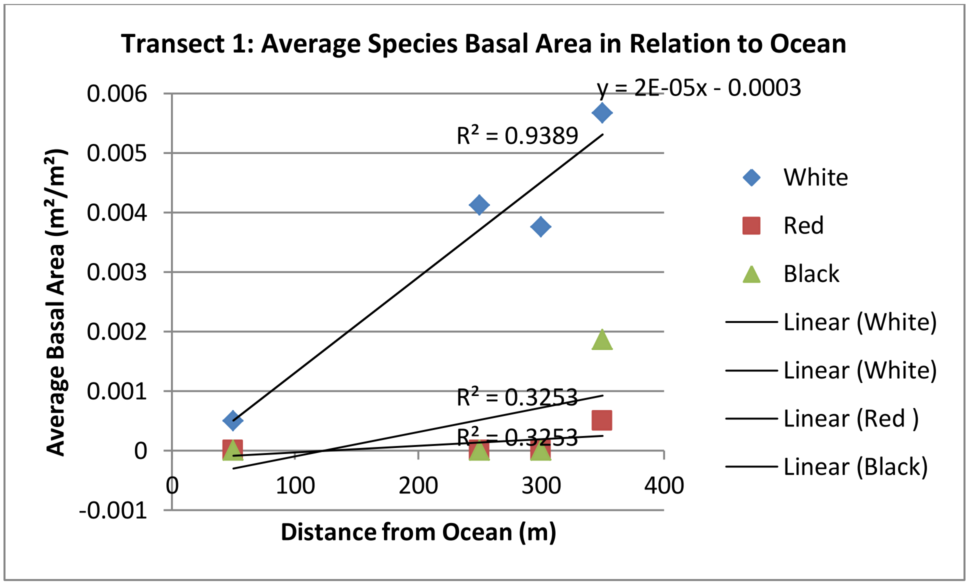


Figure 11

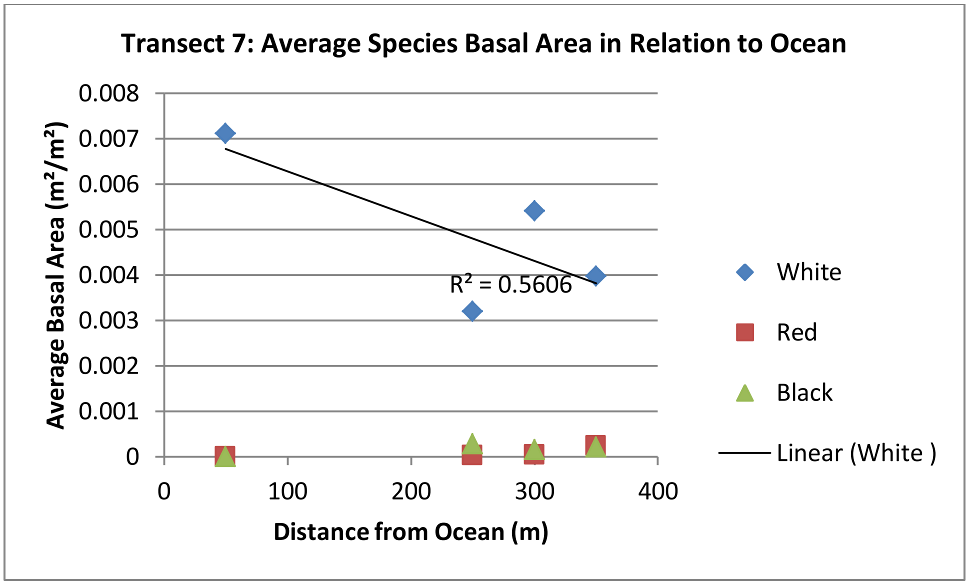
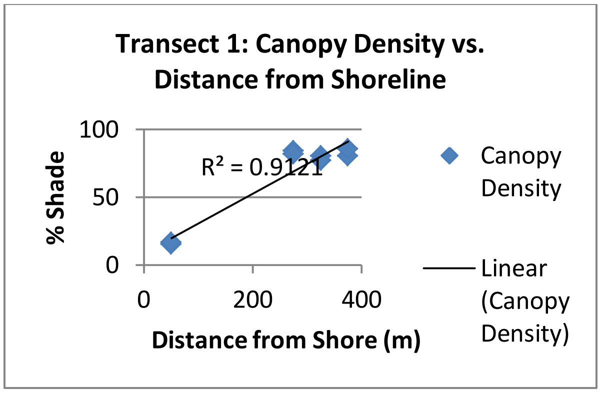


Figure 12

In Transect 1, species basal area seems to increase for each species as distance from ocean increases. For white mangroves in particular, this correlation is the strongest, with an R^2 value of .9398. Red and black mangroves also have positive correlations to distance from ocean, with R^2 values of .3253 for both species. It appears that species abundance generally increases with distance from the ocean for all three mangroves species studied in Transect 1.

In Transect 7, however, basal area for white mangroves showed a negative correlation to distance from the ocean, with an R^2 value of .5606. Both black and red mangroves showed positive correlations, with R^2 values of .6114 and .4644, respectively.

Measurements for canopy density were compared to distance from shoreline and graphed on scatterplots:



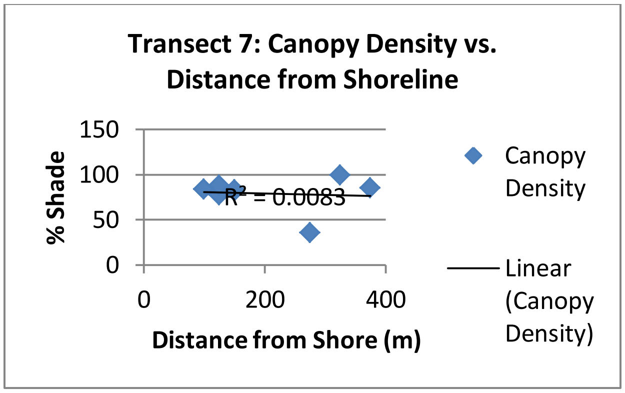


Figure 13, N= 8

Figure 14, N= 9

In Transect 1, canopy density seems to be strongly positively correlated to distance from shore, with an R^2 value of .9121. However, in Transect 7, canopy density shows no correlation to distance from shoreline, with an R^2 value of only 0.0083.

Next, I compared water depth to distance from shoreline on two side-by-side scatterplots:

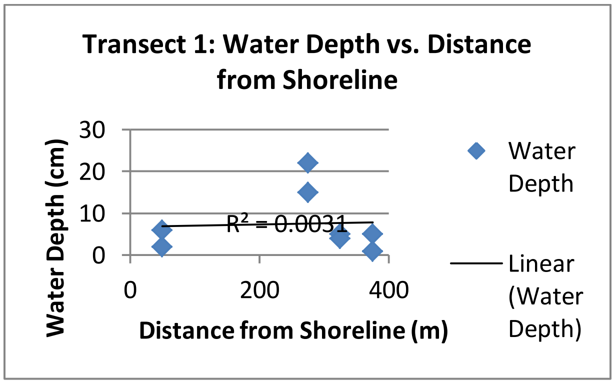


Figure 15, N=8

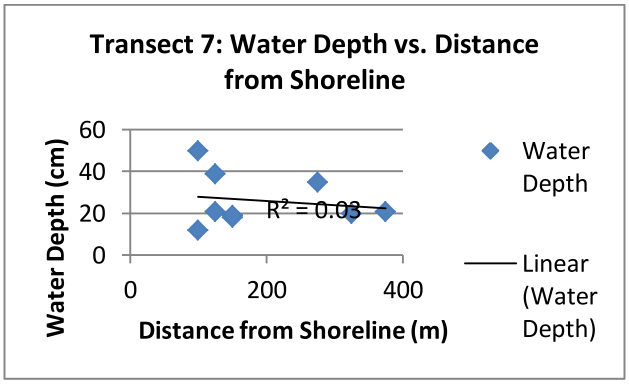


Figure 16, N=9

There appears to be very little correlation between water depth and distance from the shoreline in both mangrove forest transects, with an R² value of 0.0031 in Transect 1 and an R² value of 0.03 for Transect 7.

Finally, salinity measurements were compared and graphed in reference to distance from the shoreline:

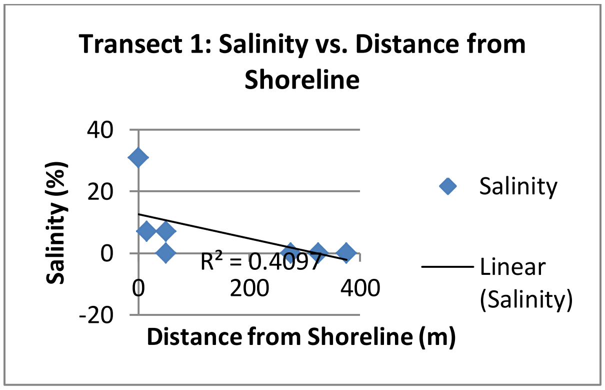


Figure 17, N=8

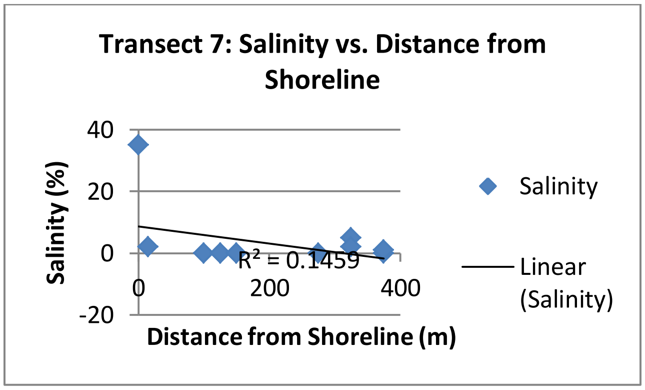


Figure 18, N=9

Both Transects appear to show negative correlations between salinity and distance from the shoreline, with salinity measurements falling as distance from shoreline increases. The data fits the line of best fit better in Transect 1, where the R² value is 0.4097, while Transect 7 has an R² value of 0.1459 and a shallower slope.

4. All Transects: Comparing Salinity Measurements to Distance from Shoreline

The bar graph shows salinity measurements in percentage compared to the distance from the shoreline. Measurements of "0" meters distance represent water samples taken directly from the shore water. Salinity measures fall at a steep incline within 15 meters of the shore, then appear mostly nonexistent with a few exceptions.

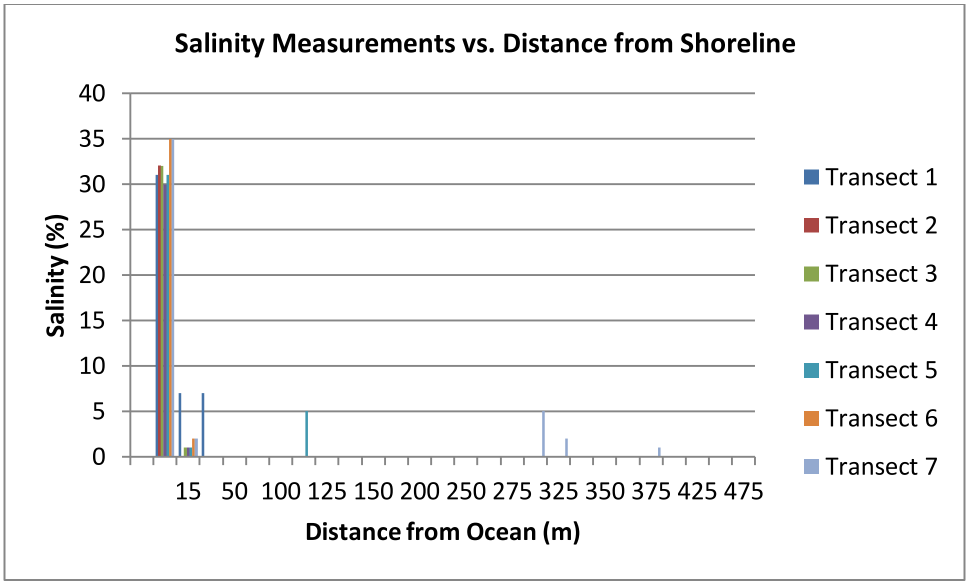


Figure 19, N=71

XII. Discussion

1. Seedling Height and Leaf Count According to Species: Red or White

Histograms show basically normal height distributions for both red and white seedling populations. Both have a few outliers, which I speculate to be unplanted mangrove trees that have either grown on their own or are left over from development. These were generally found either on the outskirts of the reforestation zone, or were clearly incompatible with the planting pattern. The red sapling height distribution appears to be skewed right. This could be the result of a number of factors. In both samples, most of the data fell between the 30 and 70 cm height range. This is likely due to the method of seedling planting- most seedlings were probably originally planted within this range. With the white mangrove seedlings, this planting has resulted in a more or less normal distribution, with some seedlings doing better than others.

In the case of the red seedlings, the bottom “half” of the histogram in missing. This could be because most of the red seedlings have grown, rather than withering and losing leaves. However, this result does not seem likely because Transects 5 and 6 were planted entirely with red mangroves, and many mangroves here were missing. This could point to the conclusion that mangroves otherwise on the bottom of the histogram have already died. The third possible explanation for the skewed histogram is the different planting method in Transects 5 and 6, where only red mangroves were planted, and all were planted in bamboo casings. This possibility will be explored further later.

While these possible explanations may affect the data, overall the significant p-value of 0.000127247 is evidence that the red and white distributions differ significantly from each other. Though white mangrove seedlings were less populous than red mangrove seedlings, both the mean height and the mean leaf counts were significantly higher than mean heights and leaf counts for red mangroves.

Because these seedlings were planted, it can be reasonably assumed that relative species abundance in the reforestation zone is the result of deliberate placement of red mangrove seedlings over white mangrove seedlings. The white seedlings, however, tend to be taller plants with more leaves, indicating that they might carry some advantages over the red seedlings in the reforestation zone.

2. Mangrove Forests: Comparing Average Basal Area: Red, White, Black

Comparing the average basal areas of red, white, and black mangroves in Transects 1 and 7 could offer an idea of mangrove zonation as it occurred naturally in the area, and could offer insight into which species of mangrove seedlings might grow well in the reforestation zone. Results demonstrated that areas in the same relative position to the ocean as the reforestation transects (Sections 1-3) were dominated in both Transects by primarily white mangroves (86% of total basal area in Transect 1, 95% in Transect 7), with black mangroves taking the middle position (11% in Transect 1, 3% in Transect 7), and red mangroves covering the least amount of basal area (3% in Transect 1, 2% in Transect 7). These results can be explained by a number of possible factors.

The first point worth noting about the data is that black mangroves take up more basal area than red mangroves. This could be due to a tendency for black mangroves measured to be bigger than red mangroves, but overall this was still enough to compensate for any differences in individual number. This raises the question of the possibility for some black mangrove seedling planting, at least in the reforestation areas furthest inland where black mangroves in mature mangrove forest are also found. The conditions along the gradient from the ocean in the mature mangrove forest may be conducive to white mangrove tree growth primarily, and black mangroves secondarily. Similarly, these conditions may continue in the reforestation area, which might benefit from integration of some black mangrove seedlings, perhaps over some red mangrove seedlings.

3. Mangrove Forests: Comparing Species Distribution in Reference to the Shoreline: Canopy Density, Water Depth, Salinity

I was interested by forest structure in the area; the cleared reforestation zone lies in the middle, full of wild, invasive sugarcane; the old mangrove forest is on either side of the developed area, and a strip of mangrove forest grows between the ocean and the development. Because this area was hard to reach, I was unable to gather much data from the outskirting mangroves; instead I organized data on conditions that might affect seedling growth, like canopy density, water depth, and salinity, according to their distance from the shoreline. These conditions remained almost exactly the same throughout the reforestation zone, with very little, if any, canopy density; very little, if any, water salinity; and highly variable water depths that showed no overall trends. To see if these conditions might show correlation to distance from the ocean in undeveloped mangrove forest, I graphed these conditions for Transects 1 and 7.

Transect 1 showed some slightly contradictory results when average species basal area was compared to distance from the shoreline. White mangrove basal area showed the strongest positive correlation to distance from the shore, while red and black mangrove basal area also increased with distance.

However, in Transect 7, black and red mangroves showed a similarly positive correlation to distance, while white mangroves demonstrated a negative correlation to distance.

Though salinity did decrease with distance from shore, a drop from a salinity measurement in the 30’s to a single digit salinity percentage (%) habitually occurred within the first 15 meters of the shoreline. For all salinity measurements taken within transects with tree cover, salinity measurements showed no significant change. Therefore, it is unlikely that salinity measurements are factors in the red, white, and black zonation along the gradient from the shoreline. While it is possible that the two weeks of data collection were skewed towards unusually freshwater samples, this is unlikely because winter tides in Galeta are significantly higher than the summer tides (Schmidt, 2008).

One possible explanation for these results is the difference in forest type between the two transects. Transect 1 was “fringe cover,” bordering the cleared, disturbed area. It was characterized by thin, younger trees. Transect 7 was old growth forest, characterized by fallen and rotting mangroves. It is possible that the younger, thin trees grew closer together in Transect 1, but the presence of fallen and rotting trees in Transect 7 barred space where new white mangroves might otherwise grow more densely, thus spacing out the mangroves furthest from the shore, where white mangroves dominate. Of course, this hypothesis would need much more data to be properly tested.

A more likely explanation for these findings is the difference between the data point for white mangroves in Transect 7 in the 4th segment, closest to the shore, and the remainder of Transect 7. Without this spike in white mangrove basal area density, the trend-line would be positive, as is the case with the other species. Perhaps something site-specific resulted in uncharacteristically high white mangrove basal density in this particular segment. Overall, mangrove basal area density increased with distance from the shore, regardless of species.

As basal area increases with distance, one might expect canopy density to increase with distance from the shore, as well. The results affirmed this hypothesis in Transect 1, with a strong positive correlation between canopy density and distance and an R^2 value of .9121. In Transect 7, however, canopy density remained largely constant, regardless of distance from the shore. Again, this might be explained by the difference in forest succession between the two transects, and requires further study.

Water depth measurements fluctuated throughout the transect measurements, but showed no significant correlation to distance from the shoreline. While this was initially surprising, it was consistent with the results from the salinity measurements. Though they appeared to show a negative trend between % salinity and distance, the graph data are skewed by the measurements taken in the ocean water itself. Without those points, the graphs show almost constant measurements of 0% salinity, regardless of distance from the shore. This data is consistent with the insignificant change in water depth; it appears that neither water depth nor water salinity within more than 15 meters inland from the shore was affected by tidal inundation. Salinity data from Transects 1 and 7 was consistent with data from all transects, as demonstrated in the final bar graph.

XIII. Conclusion

The results support evidence that white mangroves and non-bamboo planted seedlings seem to grow taller and with more leaves in the reforestation zone. Conditions seem to favor white seedlings over red seedlings. Comparisons between basal area density for red, black, and white mangroves in the mangrove forest demonstrated a clear dominance of white mangroves over black and red mangroves. In areas that corresponded to reforestation transects in terms of distance from shoreline, white and black mangroves had denser basal area averages than red mangroves. While distance from shoreline did not correlate to salinity or water depth measurements beyond the 15 meter width of the coast, it was correlated positively with overall basal area density and canopy cover in forest transects on either side of the reforestation area.

The most alerting condition found in the reforestation zone was the almost complete lack of salinity in all water samples found where seedlings were planted. While water samples from the mangrove forest were also almost entirely freshwater, adult mangroves have sometimes been found to thrive in conditions where mangrove seedlings have trouble establishing themselves (Smith, 1992). Mangroves are capable of growing in freshwater, as other studies have demonstrated and my data affirmed, but they adapted to grow in saltwater to combat competition from freshwater species (Feller & Sitnik, 2002). Mangrove seedlings in the old growth forest might be protected by canopy cover from long-established adult mangroves, but the seedlings growing in the open, cleared reforestation zone may be unable to compete, exposed as they are in freshwater to the wild sugarcane, the invasive "monte" known to inhibit native tree growth (Bonnett et al, 2014).

Methods of controlling *Saccharum spontaneum* have thus far proved largely ineffective, especially in Panama (Bonnett et al, 2014). Herbicide use to control the weed has been largely avoided in the Panama Canal Zone, especially in conjunction with reforestation efforts like the mangrove reforestation effort in Punta Galeta. However, the current method of control- the removal of above-ground biomass, is not effective for long, and is therefore not a sustainable means of controlling the weed. In many cases, I observed planted seedlings that appeared to be stifled by the 2 meter grass that encroached on them from all sides. Because the seedlings were planted in rows at regularly spaced intervals, missing seedlings were easily identifiable.

Research on *Saccharum spontaneum* suggest that dried up buds are still capable of sprouting for up to six weeks after being cut from the plant. Those attempting to control the weed's growth, especially in cases where reforestation is desirable, are encouraged to cut the grass into smaller pieces once cut, or to remove the cut matter from the area (Bonnett et al, 2014).

Saccharum spontaneum has been tested for drought tolerance, and can thrive in a wide range of diverse habitats, from poorly drained marshlands to rocky regions and deserts (Munawarti, 2013). Though its salinity tolerance has not been extensively studied, other studies on similarly invasive marsh grasses illuminate potential limitations on its growth. Once study showed that a similar species of salt marsh grass grew best in fresh water, with higher levels of proteins, potassium, and lipids when compared to its growth in its natural salt water habitat (Phleger, 1971). A study of the salinity tolerance of *Phragmites australis,* a similarly invasive reed with large rhizome dispersal like *Saccharum spontaneum,* showed that smaller rhizome fragments were unable to emerge in saline treatments, and large rhizome growth diminished in a natural salinity regime. The results implicated that for this grass, low salinity windows improved its changes for survival (Bart et al, 2003).

In this case, there were historical links between establishment and human activities like hydrological alterations, construction, and lowered salinity. Though I do not have data for condition measurements in the current mangrove reforestation zone, prior to development, there is a reasonable chance that common side effects of development in Panama like landfill, lowered salinity, and the invasion of *Saccharum spontaneum* affect current efforts to foster mangrove regrowth at Punta Galeta.

XIV. Recommendations

To improve conditions for mangrove seedlings in Punta Galeta's reforestation zone, I propose three basic disparities and three tentative solutions.

The first disparity, and perhaps the most easily addressed, is the type of mangrove planted and the method. Mangrove zonation nearby shows black mangroves are more represented than red mangroves. Perhaps conditions favoring the establishment of black seedlings near the reforestation zone would favor black mangrove seedlings in the reforestation zone as well. These seedlings should be planted only within the 50 meters closest to the old growth, and should be closely monitored and compared to the success of white and red seedlings nearby.

The third disparity is the apparent lack of tidal inundation in the reforestation zone. Although this seems to be present in the mangrove forest transects as well, optimal conditions for adult mangroves and mangrove propagules tend to vary (Smith, 1992). In many reforestation or wetland restoration projects, land excavation is necessary to allow tidal inundation into the reforestation area, especially in previously developed areas where landfill is common (Brown, 2006).

The final, and perhaps the gravest disparity is the invasive presence of *Saccharum spontaneum*. Notorious for inhibiting the growth of native trees and for springing up in developed areas, the densely abundant presence of this species throughout the reforestation zone is likely the biggest threat to the mangrove reforestation project at Isla Galeta. A long-term solution like the previous recommendation for excavation is desired and could potentially inhibit *Saccharum spontaneum* growth. However, this is a costly endeavor with many other ecological implications. Seedlings channels should be cleared regularly to prevent the wild sugarcane encroachment on mangrove seedlings, and cut pieces should be removed from the site location in an effort to impede the weed's regrowth within cleared channels.

The biggest problem in this case is one that cannot be undone. The army base at Galeta Point has been out of use for decades. The fence has been removed; the building is irrelevant to human use. However, the development of the area that allowed for the invasion of a seemingly unstoppable weed continues to plague reforestation efforts there. Mangrove cover nearby is thick with production in not dissimilar conditions; the biggest difference is the window of opportunity opened to invasion by the penetrative force of human influence. Until a truly comprehensive method is introduced to combat *Saccharum spontaneum* and other invasive species like it, that window will remain closed. The best advice for future reforestation projects is to prevent the need for reforestation itself.

XV. Bibliography

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