An Assessment of Mangrove Cover and Forest Structure in Las Perlas, Panama

by

TANIA BETTS
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ABSTRACT

This study aimed to assess mangrove forest cover and structure at three locations within the Las Perlas archipelago of Panama. Five permanent plots were established at three different sites. Two of the sites were on the island of El Rey and one on the island of San Jose. It is believed that a continuing monitoring program can be carried out at these plots to ensure the area is kept in the pristine condition that it is presently in.

Forest cover and structure was determined by measuring adult tree heights and diameters at breast height (DBH). Seedling height data was also collected. It was found that San Jose had the most mature forest communities, whereas the more northerly site (El Rey 1) was the least mature. In sites El Rey 1 and San Jose it was found that *Rhizophora mangle* was the more important species, whereas at El Rey 2 *Pelliciera rhizophoreae* was the more important species. *Laguncularia racemosa* was found to be the most dominant species present at both El Rey 1 and 2. The muddy conditions and the ability to out compete other species meant that *Rhizophora mangle* was the most dominant species at San Jose.

A 1m PVC pole hammered into the ground permanently marked out the plots. This would allow scientists in the future to recreate the plot in the exact same location. In addition, The GPS coordinates of each plot (at point 0,0) were recorded so that the plots could easily be relocated.

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CHAPTER 1: An Introduction to the Biology and Ecology of the Mangrove Ecosystem

1.1 Aims of the study

To set up a monitoring program of mangrove ecosystems within Las Perlas, Panama. By measuring out 5 10m by 10m plots at three different sites.

To assess the state of mangrove forests within the selected sites by measuring parameters such as adult tree heights and diameters, as well as seedling heights. Forest composition will be determined by identifying what species are present within the plots.

1.2 Introduction to Mangroves

Mangroves are a forest community within the intertidal region of tropical areas, although some species can be found with the subtropics (Tomlinson, 1999). They are found with in tropical areas, as they are limited to warmer sea temperatures. World wide there are some 54 species of mangroves within 20 genera, belonging to 16 families. These 54 species can be biogeographically split into two sections, the Eastern Hemisphere and Western Hemisphere. The mangrove species within these two areas are extremely dissimilar both in size and composition (Tomlinson, 1999).

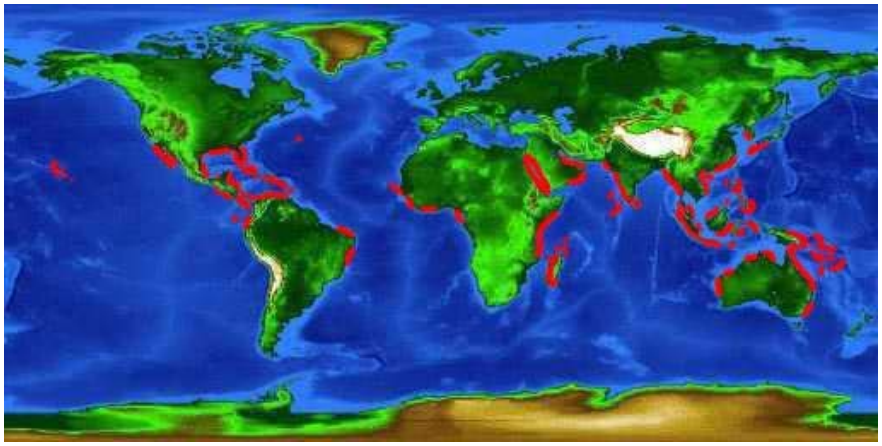

Fig 1.1 – World distribution of mangroves (www.flmnh.ufl.edu)

This distribution is mostly due to the species physiological adaptations, restricting them to a range of conditions that will allow them to prosper. Numerous authors have concentrated on these adaptations by measuring a variety of parameters, the most common being water salinity (Tomlinson, 1999). It has been found that red mangroves (*Rhizophora mangle*) are dominant within brackish waters along the Pacific Coast. Black mangroves (*Avicennia germinans*) were found to grow relatively far inland along the coasts of America and Africa. White mangroves (*Laguncularia racemosa*) are mostly found in North America and The Caribbean. The most commonly occurring species worldwide are those of Avicenniaceae and Rhizophoraceae families (Hogarth, 1999).

Mangroves play an important role within these areas as they guard the low-lying coastal land by forming a protective barrier. This biological barrier reduces damaged caused by storms by limiting wave energy and preventing the land from being flooded. This has become even more apparent after the 2004 Asian tsunami (Radhika, 2006). Their intricate root systems provide protection and a food source for estuarine and coastal fishery food chains. Many fish, shellfish, birds and other wildlife species adopt the mangrove areas as breeding, feeding and nursery areas. It has been estimated that nearly 90% of all marine animals spend some part of their life cycle within a mangrove ecosystem (Benfield, 2002). It is for this reason that mangroves should be protected and conserved (Farnsworth and Ellison, 1997). However, many mangrove ecosystems are being threatened with degradation, usually in the form of sewage. In recent years global warming is believed to becoming a threat to mangroves for the rising temperatures may ultimately lead to a rise in sea levels. This in turn could cause mangroves to become flooded. However, it has been suggested (Ellison and Farnsworth, 1996), that the increase in $C0^2$ will in fact serve to increase mangrove growth rate and will therefore offset any effect from flooding (Ellison and Farnsworth, 1997).

Mangroves are also being deforested, usually to make way for shrimp farms. The productive nature of the mangrove waters is due to the high concentration of leaf litter entering the water. Mangroves can produce up to 3.6 tones per acre of leaf litter per year, providing valuable nutrients to the farms and other wildlife communities (Davidson and Gauthier, 1993). Mangrove forests are being harvested for wood and

wood products such as firewood, charcoal, poles and timber. The method most commonly used to acquire the wood is clear-cutting. This leads to soil erosion and acidification, which will prevent the forest recovering as re-growth becomes limited (Ellison and Farnsworth, 1996).

1.3 Zonation Patterns and Forest Structure

Zonation patterns have been described in a variety of literature and have been greatly investigated by the botany community around the world. There are several hypotheses to explain how zonation within mangroves occurs, ranging from physico-chemical gradients to competition between individuals. Each of these factors do play a key role when establishing where a species is located along the intertidal zone, but ultimately it is the combination of these factors which derives the ultimate outcome. For this reason alone, interpreting zonation patterns can be extremely difficult. For example, Walter and Steiner (1936) found that *Avicennia* tends to be in the highest intertidal, where as Macnae (1969) found that 'double distributions' might occur through the intertidal area. They found that *Avicennia marina* was often dominant in both the lowest and highest intertidal area. Furthermore, the species was rare, or absent within the middle intertidal zone. Unfortunately, it would therefore appear that much of the literature on zonation pattern focuses more on specific examples rather than experimental testing.

1.3.1 Land Building and Plant Succession

By far the most popularly invoked mechanism of mangrove zonation is that of land building, where pioneer colonies growing in the lowest intertidal zone trap sediments making the soil more stable. This in turn causes sediment to build up. New mangroves are then able to invade and out compete the colonisers. One of the earliest claims to be made that land building occurs was made by Curtiss in 1888. He found evidence to suggest that *Rhizophora mangle* in Florida does indeed trap and hold sediment, in effect build land (Robertson and Alongi, 1992). There is, however, some debate as to the actual nature of zonation. For example, Watson (1928) claimed that mangroves respond to depositional processes rather than causing them. He believed that it were

factors such as tidal inundation, salinity and soil type that were determining mangrove zonations.

1.3.2 Physico-chemical Gradients and Zonation

Reviewing literature on mangroves zonation there appears to be two hypotheses when regarding physic-chemical gradients. One hypothesis by Pimm, 1978 states that each species of mangrove has an optimal position along the gradient. This controls where the species will be present within the intertidal zone. An alternative view by Vince and Snow (1984) states that many species have the same optimums and it therefore that other factors such as competition, seed dispersal and predation are the true causes of zonation (Robertson and Alongi, 1992). Indeed it is only via data collection that a true picture of mangrove forest structure can be determined.

1.3.3 Seed Predation

Predation on mangrove seeds has been widely recognised to contribute how a mangrove community will grow, in fact it is an important process in a variety of ecosystems. Dahdouh-Guebas *et. al*. (2002) found that there was a direct correlation between crab distribution and mangrove distribution with mangroves in Kenya. Crabs are a major predator on mangroves as they consume mangrove propagules. The consumption of the propagules greatly affects the natural regeneration of mangroves, affecting their distribution across the intertidal zone (Robertson and Alongi, 1992 and Dahdouh-Guebas *et. al*., 2002).

1.3.4 Competition

There is a great deal of literature focusing on competition for a variety of wetland plant communities (e.g. Morris, 2006). There have, however, been few studies on competitive interactions with a mangrove forest. Ball (1980) examined mangrove competition in South Florida. Using aerial photographs and measurements of living and dead individuals she was able to determine that *Laguncularia* was being replaced by *Rhizophora* (Ball, 1980). This may suggest that *Rhizophora* is better at competition than other mangrove species. Other research carried out on mangrove competition

suggests that field observations on forest structure may not correspond to laboratory experiments. An example of this is a laboratory experiment carried out by Smith in 1988 showed that at higher salinities *C. australis* was the stronger competitor to *C. tagal*. In the field, however, both species were found in areas that had a higher salinity than their growth optima. Smith (1988) hypothesised that both species were outcompeted at lower salinities by other species such as *Heritiera littoralis, Xylocarpus granatum* or *Brugiuera gymnorrhiza* (Robertson and Alongi, 1992). It is therefore important to note that long-term field monitoring programs would be needed in order to understand the role of competition in mangrove forests.

1.3.5 Gap Dynamics

A number of authors have stated that gap dynamics are important when concerning forest structure (Rabinowitz 1978a; Robertson and Alongi, 1992; Tomlinson, 1999). However, no detail analysis has been made to date. Rabinowitz's experiments in Panama showed that seedling mortality is related to propagule size. She found that species such as *Avicennia* and *Laguncularia*, which annually establish cohorts on the forest floor, die relatively quickly. Other species such as *Rhizophora* and *Pelliciera*, which have larger propagules, with cohorts that overlap, tended to survive. Gaps within the canopy tend to be created by lightning strikes. Any seedlings, which are present under the canopy where the lightning bolt strikes will often be killed as well as the trees directly hit.

1.4 Introduction to the Study Area

This study took place on the islands of Las Perlas, Panama in Central America (Fig 1.2). The Isthmus of Panama joins South and Central America together. Costa Rica borders Panama to the West where as Colombia borders it to the East.

Fig 1.2 – Map of Panama (www.worldpress.org)

1.4.1 Las Perlas

Las Perlas (or the Pearl islands) make up an archipelago of over 100 islands (Fig 1.3). It is situated within the Gulf of Panama on the Pacific side of Panama. Many of these islands are uninhabited due to their isolated nature. It is for this reason that many of the islands are undisturbed by human activities and thus the mangrove ecosystems present on the islands are pristine. However, like all habitats, the mangroves and other ecosystem present throughout the archipelago are increasingly becoming threatened by human development, particularly regarding the tourist industry. It is for this reason that the Smithsonian Tropical Research Institute (STRI) wishes to designate the islands as a protected management zone (www.darwin.gov.uk).

Fig 1.3 – Map of Las Perlas archipelago (www.darwin.gov.uk)

Mangroves are of a great importance as discussed earlier. The mangroves of Las Perlas are therefore of no exception. Many fishing communities, which are scattered around the Las Perlas islands, regularly fish within the mangrove areas. Even fishermen who do not fish within the mangrove waters themselves indirectly utilise them for many commercial fish species begin their life cycles with the protected waters. Indeed, many people within the Las Perlas region rely on the mangroves for their livelihood and they should therefore be protected from development.

1.4.2 Mangrove Species Present at Study Sites

There are four genera of mangrove trees found within Panama. These are *Laguncularia, Avicenia, Rhizophora* and *Pelliciera* (Rabinowitz, 1978c). Although these four sepecies are extremely different form each other, they do share two common traits: dispersal by seawater and vivipary (Rabinowitz, 1978b and Rabinowitz 1978c). Apart from a tree seedlings, prop roots and pneumatophores,

Panamanian mangrove stands have no understory (Rabinowitz, 1978c). At the study sites themselves, only three species of mangroves were found: *Laguncularia racemosa, Pelliciera rhizophoreae* and *Rhizophora mangle*. This dissertation will therefore focus on these three species.

Laguncularia racemosa

Laguncularia is widely distributed throughout the Americans and western Africa. Within a mangrove community, they tend to be located landward but they do have pioneering abilities, which allows them to occupy disturbed sites where pure stands can be formed (Tomlinson, 1999).

L. racemosa is shade intolerant and it also has a high salinity tolerance. Perhaps the reason as to why *Laguncularia* is a pioneer species is because there are many self-fertilising individuals. Fertilisation usually occurs via insect pollination and fruiting (Tomlinson, 1999). The propagules of *L. racemosa* are small and they commonly bare roots while germinating. Dispersion within Panama occurs during mid-August till late November (Rabinowitz, 1978b).

Pelliciera rhizophoreae

Pelliciera has a limited distribution along the Pacific coast of central and northern South America. It is believed that its limited distribution is due to competition from *Rhizophora* (Tomlinson, 1999). *P. rhizophoreae* tend to be small trees (usually 5 to 10m high) but they can reach heights of around 18m. Flowering occurs over an extended season in winter and early spring (November to February), however, during October there can be a period of heavy fruiting (Tomlinson, 1999).

Rhizophora mangle

R. mangle was the most commonly occurring species within the plot areas. They are most commonly found from western Africa to the Pacific coast of tropical America. They do not extend far into the sub tropics for they are limited by cold. *Rhizophora* is killed by frost and they will perish when exposed to extended periods of near-freezing

temperatures (Tomlinson, 1999). Like *L. racemosa*, *R. mangle* is shade intolerant, but has a wide tolerance range for salinity (Benfield, 2002).

Perhaps the most noticeable characteristic of *Rhizophora* are their aerial stilt roots. The trees themselves can grow to around 30m tall, their root system will then be extremely large and complex. The propagules are shaped like rods that have elongated hypocotyls that float. *R. mangle* is a hardy species, so they tend to be long lived, which allows them to grow to such heights. Dispersion within Panama occurs during September and October, off-season production may also occur (Rabinowitz, 1978b).

1.5 Rationale Behind the Study

In view of the pristine nature of the Las Perlas site, it was seen as an ideal location to perform the study objectives. As mentioned in section 1.4.1, STRI wishes to designate the archipelago as a protected management zone. Before this can happen, it is essential to have a general understanding of what the present mangrove forest structure is like and to monitor the area to see how the forests develop. The data collected for this project will therefore help to protect the natural environment of the Las Perlas area.

The data gathering and analysis methodology is described in the following section. Although there is a large amount of published data on mangrove sites worldwide, there is little, or no data on mangrove forest communities within the Las Perlas area. Indeed the sites used to set up the monitoring program seemed to be totally undisturbed by anthropogenic activities.

CHAPTER 2: Materials and Methods

2.1 Field Methods to Determine Forest Structure

In order for a monitoring program to work successfully, a uniform measuring system must be employed so that future filed observations can be related to data collected in previous field visits. It is important to use a uniform measuring system as in the past comparison of data collected on forest structure was impossible. This was due to the fact that different research goals led to non-uniformed measurements, producing results that were so different between projects that it was difficult to compare one experiment with another (Benfield, 2002). It is for this reason that the method chosen for this study was the one created by Benfield (2002).

During a 10-day period in the months of May and June of 2006, three sites were chosen to be studied within the Las Perlas archipelago. Two sites were located on the largest island of El Rey and one site on the second largest island of San Jose (Fig 2.1). Within each site 5 plots were created to record data on the mangrove communities present. The main advantage of using a plot method is that no specialised equipment is required. Each plot was randomly chosen and mapped out into a 10m by 10m grid. This was determined as a standard size by research carried out by organisations such as the Australian Institute of Marine Science (AIMS) (Benfield, 2002; Defew, 2003).

A forty meter measuring tape was used to measure out the plot. At each corner of the plot a 1m PVC pole was hammered into the ground to permanently mark out the four corners. This was done so that future monitoring programs could re-establish the same plots used in this survey, allowing change in forest structure to be analysed. At the 0,0 corner, a plastic tie was used to mark which pole was determined the 0,0 pole. Once the plot had been measured out a rope with was used to outline the plot. Tape was placed along the rope at 1m intervals to allow coordinates to be taken as accurately as possible. At the 0,0 coordinate, a GPS reading was taken so that the plot could easily be relocated.

Fig 2.1 - The islands surveyed during the study. The three study sites are circled in red, the more northerly site on El Rey being "El Rey 1" and the more southerly site being "El Rey 2" (Benfield, 2006).

Photographs of the three sites and the five plots within each site can be seen in figures 2.2 to 2.4.

Fig 2.2 Location photos for El Rey 1

Fig 2.2.1 - Plot 1

Top: The location of "0,0"

Bottom: The location of the plot from a distance.

Fig 2.2.2 – Plot 2

Top: The location of "0,0"

Bottom: The location of the plot from a distance.

Fig 2.2.3 – Plot 3

Top: The location of "0,0"

Bottom: The location of the plot from a distance.

Fig 2.2.4 – Plot 4

Top: The location of "0,0"

Bottom: The location of the plot from a distance.

Fig 2.2.5 – Plot 5

Top: The location of "0,0"

Bottom: The location of the plot from a distance.

Fig 2.3 Location photos for El Rey 2

Fig 2.3.1 – Plot 1

Top: The location of "0,0"

Bottom: The location of the plot from a distance.

Fig 2.3.2 – Plot 2

Top: The location of "0,0"

Bottom: The location of the plot from a distance.

Fig 2.3.3 – Plot 3

The location of "0,0"

Bottom: The location of the plot from a distance.

Fig 2.3.4 – Plot 4

Top: The location of "0,0"

Bottom: The location of the plot from a distance.

Fig 2.3.5 – Plot 5

Top: The location of "0,0"

Bottom: The location of the plot from a distance.

Fig 2.3 Location photos for San Jose

Fig 2.4.1 – Plot 1

Top: The location of "0,0"

Bottom: The location of the plot from a distance.

Fig 2.4.2 – Plot 2

Top: The location of "0,0"

Bottom: The location of the plot from a distance.

Fig 2.4.3 – Plot 3

Top: The location of "0,0"

Bottom: The location of the plot from a distance.

Fig 2.4.4 – Plot 4

Top: The location of "0,0"

Bottom: The location of the plot from a distance.

Fig 2.4.5 – Plot 5

Top: The location of "0,0"

Bottom: The location of the plot from a distance.

2.2 Data Collection for Adults

Once the plots had been established all mangrove trees above 1m in height with a DBH (diameter at breast height) greater than or equal to 2.5cm were marked using colourful tape. This height restriction was used to ensure that the trees were mature (as stated by AIMS). Once all the measurements had been recorded, the tape was removed (to ease identification of which individuals still needed recording) and a metal tag with an embossed number was attached to the tree using garden wire. Garden wire was used, as it was believed to be environmentally friendly and easy to apply. The coordinates of the individual tree were also recorded to ensure that it could be relocated and re-measured at a future data. The coordinates were taken from the centre of the main root system of the tree. The species of the tree was also noted.

2.2.1 Measuring Height

The height of each mangrove tree was measured using a graduated telescoping measuring rod. When it was difficult to clearly see when the pole reached the canopy of the tree, another field worker would help judge when the pole was extended enough by standing at a distance.

2.2.2 Measuring Diameter

As pre-described in Benfield, 2002 and Defew, 2003 the diameter of a tree at breast height (DBH) was measured using a pre-calibrated DBH tape measure. The specially graduated tape converts the girth of the tree into its diameter. This meant that no post calculations were needed to determine DBH from girth, and a direct reading of diameter could be taken. Breast height was determined as being approximately at 1.3m. To ensure accuracy, the DBH tape had to be level and stretched firmly against the trunk. When abnormalities such as swelling, forks or prop roots prohibited a measurement being taken at 1.3m an appropriate height was chosen by following rules dictated in English *et al*, 1997 (Fig 2.5).

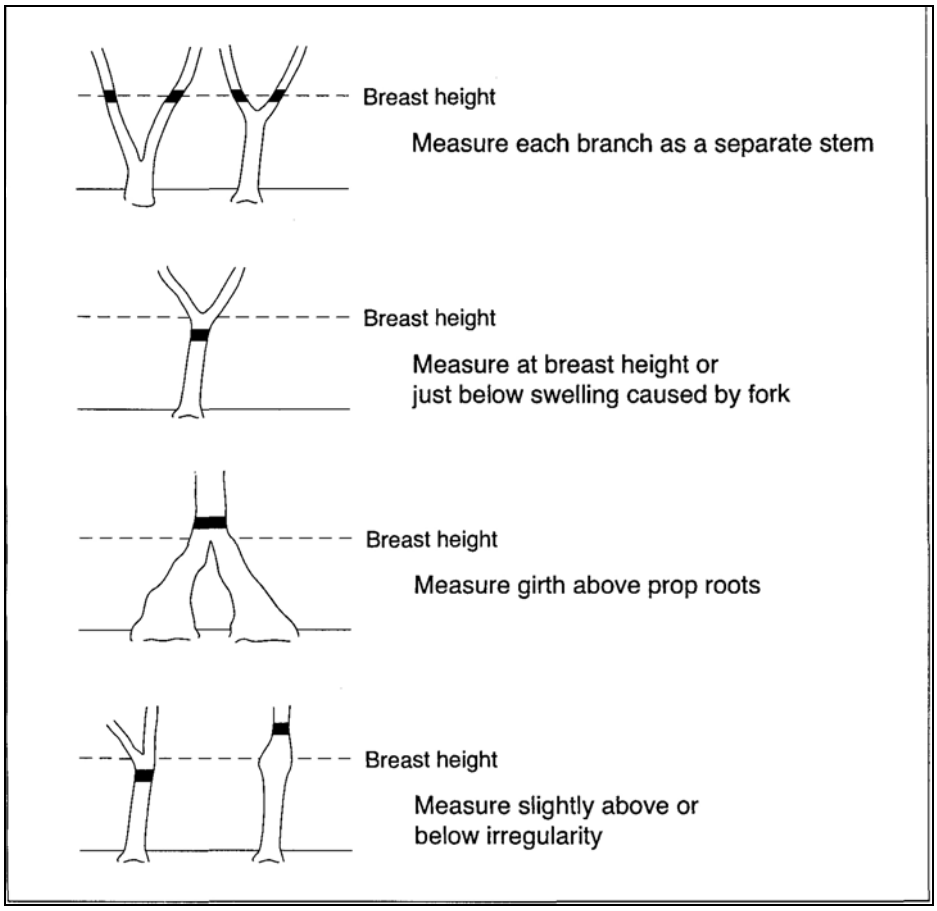

Fig 2.5 – Procedure for measuring DBH on trees with unusual or different growth forms (Eglish *et. al.,* 1997)

Once the DBH had been measured, a permanent blue marker pen was used to mark out where the measurement had been taken. This was to ensure that future monitoring programs could re-measure the DBH at the same location.

2.3 Data Collection for Seedlings

When sampling seedlings within a plot, 5 sub-plots were used. The sub-plots were 1m by 1m. A quadrat had been created out of PVC poles. Every 10cm was marked out along the quadrat using a blue permanent marker pen. The sub-plots were randomly distributed throughout the plot. The 0,0 corner of the sub-plot was permanently marked using by hammering a 1m PVC pole in. The sub-plot number was also written on the pole and the coordinates of the 0,0 corner within the main plot was recorded to ease relocation within the future. Each individual sapling under 1m in length was

measured. The height of the saplings were recorded using a ruler. The coordinates were read using either a ruler or the 10cm markers on the quadrat. The sapling species was also noted.

If there were not many saplings present with in a plot, sub-plots were not used and instead all the saplings were measured and recorded. If this was the case, a metal tag was placed onto seedling, making sure that the garden wire was not attached too strongly to allow plenty of room for growth.

2.4 Sediment and Benthic Collection

Within each plot sediment was collected for future analysis. Three samples of sediment were taken to be analysed for metal contamination. These samples were obtained by scraping the topsoil off using a corer. The sediment samples were placed in zip lock bags. One sediment sample was taken using a grab. This was to be analysed for sediment composition. Furthermore, a benthic sample was taken so that macrofauna could be identified at a future data to get a better understanding of macrobenthic communities with the mangrove ecosystem.

2.5 Processing Sediments and Benthic Samples

Once back at base, the samples were preserved so that they could be transported back to Panama City. The sediments were frozen, whereas the benthic samples were fixed in formaldehyde. Once back in Panama City the sediment samples destined for metal analysis were sieved and dried in an oven for until they were dry. The benthic samples were sorted into phyla. All samples were then labelled and stored for future analysis.

2.6 Health and safety

Before any data collection was carried out risk assessment forms were completed and emergency contact details were given to both the research team leader and to STRI. When out in the field, radios were carried inside a waterproof box. This was so that if need be the research vessel could come and pick up the researchers.

2.7 Structural Parameters

Once the data had been collected, it was entered into CARICOMP, a program designed to help analyse mangrove data (Appendix 1). It allows the following parameters to be easily calculated: Basal area, relative density, relative dominance, relative frequency and importance value.

Basal area is the area covered by the stem at the cross-section of the stem where DBH is measured. It is normally expressed in m^2 per hectare. The CARICOMP spreadsheet used for entering the data automatically calculated basal area so there was no need for extra calculations.

The importance value of each species in all 15 plots was calculated to determine the composition of mangrove trees within each location. The importance value was calculated by summing the relative density, frequency and dominance of a species. The equations used to calculate each of these parameters can be seen below (Snedakar and Snedarker, 1984).

Relative density = (number of individuals of a species / total number of individuals) x 100

Relative dominance = (total basal area of a species / basal area of all species) x 100

Relative frequency = (frequency of a species / sum frequency of all species) x 100

Importance value = relative density + relative dominance + relative frequency

2.8 Statistical Analysis

Mature and seedling data for height and DBH for adults only were entered into Minitab version 14.2. All data was subjected to Anderson-Darling Normality Tests to determine whether or not the distribution of the data was normal. Barlett's and Levene's tests were used to test for homogeneity of variances in order to rule out any assumptions of the variances being heterogeous.

If the data did not follow a normal distribution, or there was no equality of variances, non-parametric tests were used. Kruskal-Wallis was used in these instances to test if there were any significant differences in height and DBH between the plots for the three species of mangroves. If the data did follow a normal distribution, or there was an equality of variances, One-way ANOVAs were used to test if there were any significant differences in height and DHB between the plots for the three species of mangroves.

Mann-Whitney tests were used to compare adult height and DBH readings between El Rey 1 and El Rey 2 to see if there was any difference in forest structure between the two sites for both sites are located on the same island.

The various statistical tests were carried out using a 95% confidence level. Tables were composed to illustrate the findings of these tests.

CHAPTER 3: Results and Analysis

3.1 Adult Data

Tables 3.1 to 3.3 show a summary of the mangrove data collected from the three sites (El Rey 1 and 2 and San Jose). Tables on the mangrove diameters can be seen in tables 3.4 to 3.6 for the three different locations. Pie charts showing mangrove composition within each location can be seen in Figures 3.1 to 3.3. Table 3.7 shows the results of statistical tests carried out on heights of the three mangrove species. Table 3.8 shows the results of statistical tests carried out on DBH data for the different species.

3.1.1 El Rey 1

It is possible to see that for El Rey 1, *R. mangle* and *L. racemosa* were the two species, which were most abundant. *L. racemosa* tended to have higher values in the structural parameters but overall *R. mangle* was the more important species within El Rey 1. Only in plots 3 and 5 was *L. racemosa* the more important species. *R. mangle* had the highest relative density in El Rey 1, but *L. racemosa* was the more dominant species. The prop roots of *R. mangle* means that each individual tree needs a lot of space to grow. As can be seen in figure 2.2, a lot of ground is covered by *R. mangle* root systems. *P. rhizophoreae* was only present in plots 2 and 5, and in both plots it was not a particularly dominant species. However, due to the lack of *R. mangle* within plot 5, *P. rhizophoreae* was ranked as the second most important species within plot 5.

From table 3.7 it is possible to see that there is no significant difference in heights for *L. racemosa, P. rhizophoreae* and *R. mangle*. This means that all the mangrove trees of the same species were of similar heights throughout the plots. Plot 5 had the highest mean height, whereas plot 4 had the lowest mean height (Table 3.1). Although by looking at table 3.1, it is possible to see that when taking all species into account, plots 1 through to 4 the mean heights of trees seemed to be similar. This could be an indication that all plots were of similar maturity.

From table 3.8 it is possible to see that there is no significant difference in DBH for *P. rhizophoreae* and *R. mangle* but there is sufficient evidence to suggest that there is significant difference in DBH for *L. racemosa* between the five plots. Plot 5 had the highest average DBH (Table 3.2), which would coincide with the results of plot 5 also having the highest mean height (Table 3.1). Furthermore, plot 4 also has the lowest average DBH (Table 3.2) as well as the lowest mean height (Table 3.1). This would suggest that plot 4 was the least mature plot at El Rey 1, although plots 1 to 4 do have similar DBHs.

3.1.2 El Rey 2

Unlike El Rey 1, it was found that *R. mangle* was never the most important species at El Rey 2. In fact, *P. rhizophoreae* was found to be the most important species, with *L. racemosa* coming a close second, due to its high dominance. Table 3.5 clearly shows that *P. rhizophoreae* was the most important species. *R. mangle* had the highest relative density in plot three but due to its low dominance, it was not the most important species. However, as can be seen from table 3.5, it almost was. In plots 3 and 5, where *P. rhizophoreae* was found to be the most important species, *L. racemosa* was not even found to be present within the plots. This could mean that *L. racemosa* out competes *P. rhizophoreae* and so *P. rhizophoreae* only thrives when competition from *L. racemosa* is low.

From table 3.7 it is possible to see that there is sufficient evidence to suggest that the heights of *L. racemosa* and *R. mangle* did significantly differ between plots. There is, however, no evidence to suggest a significant height difference between plots for *P. rhizophoreae*. Plot 5 had the highest mean height for all species, whereas plot 1 had the lowest mean height (Table 3.1). This could therefore indicate that plot 1 was the least mature forest. Plots 2 to 5 were of similar heights and therefore it is not clear which plot was the most mature plot.

Table 3.8 shows that there is a significant difference in DBH between the plots for all three species. This means that the trees present were not of uniform size. The extensive range of mean DBHs found within the five plots further supports this. Plot 3 has the highest average DBH, whereas plot 1 had the smallest. The low DBH result of

plot 1 coincides with that of the height for plot 1 also had the lowest height measurements. This therefore further suggests that plot 1 was indeed the least mature plot studied at El Rey 2.

3.1.3 San Jose

As can be seen from table 3.3, *R. mangle* has the highest relative density, dominance and importance value in all five plots, making it the most important species throughout the location. This is due to the fact that it was the only species present within the site except for plot 5 where one individual of *L. racemosa* was found. San Jose was a location with a very mature mangrove community and therefore only a few individual mangrove trees were found to be present (Table 3.3).

Only *R. mangle* data was analysed for height and DBH as there was not enough data available for analysis on the other species. Table 3.7 shows that there was a significant difference in heights between the five plots for *R. mangle*. Plots 1 and 4 had similar average heights but plot 4 had the highest average height (Table 3.3). Plot 5 had, by far the lowest mean height.

Table 3.8 shows that there was sufficient evidence to suggest that there was a difference in DBH readings between the five plots. Plots 1 and 4 have similar mean DBH readings, with plot 4 having the highest (Table 3.3). This coincides with plot 4 also having the highest mean height. It was found that plot 2 has the lowest mean DBH, which does not coincide with the finding of plot 5 having the lowest heights.

Plot No.	No. of trees	Total basal area (m^2/hectare)	Mean height (m)	Mean DBH (cm)
1	56	12.27	3	4.5
2	32	16.17	4.1	6.5
3	23	5.4	3.6	5.2
4	24	3.57	2.6	4.1
5	5	7	7.1	13.2

Table 3.1 – Summary of El Rey 1 data

Plot No.	No. of trees	Total basal area (m^2/hectare)	Mean height (m)	Mean DBH (cm)
1	76	6.72	3.4	3.2
2	20	24.75	6	10.6
3	13	22.95	5.7	12.3
4	15	9.4	6	7.2
5	23	21.49	6.4	8.8

Table 3.2 – Summary of El Rey 2 data

Plot No.	No. of trees	Total basal area (m^2/hectare)	Mean height (m)	Mean DBH (cm)
1	6	42.47	17.2	20.6
2	8	25.37	8.7	1.8
3	1	0.2	6	5
4	3	11.45	18.7	21.3
5	6	0.57	2.9	3.5

Table 3.3 – Summary of San Jose data

El Rey 1

Plot	Relative Density			Relative Dominance			Relative Frequency			Importance Value			Importance rank		
	L	P	R	L	P	R	L	P	R	L	P	R	L	P	R
1	10.71	0	89.29	53.79	0	46.21	50	0	50	114.5	0	235.5	2	3	1
2	31.25	12.5	56.25	71.43	17.69	15.15	33.33	33.33	33.33	136.01	63.52	171.4	2	3	1
3	65.22	0	34.78	82.59	0	17.41	50	0	50	197.81	0	152.19	1	3	2
4	4.17	0	95.83	8.4	0	91.6	50	0	50	62.57	0	287.43	2	3	1
5	80	20	0	85.14	14.86	0	50	50	0	215.14	84.86	0.00	1	2	3

Table 3.4 – Summary of mangrove parameters for El Rey 1

El Rey 2

Plot	Relative Density			Relative Dominance			Relative Frequency			Importance Value			Importance rank		
	L	P	R	L	P	R	L	P	R	L	P	R	L	P	R
1	51.32	0	48.68	61.31	0	38.69	50	0	50	162.63	0	137.37	1	3	2
2	15	50	35	54.91	37.29	7.8	33.33	33.33	33.33	103.24	120.63	76.13	2	1	3
3	0	30.77	69.23	0	73.38	26.62	0	50	50	0	154.15	145.85	3	1	2
4	35.71	57.14	7.14	80.43	15.32	0.74	33.33	33.33	33.33	149.47	105.8	41.22	1	2	3
5	0	95.65	4.35	0	98.09	1.91	0	50	50	0	243.74	56.26	3	1	2

Table 3.5 – Summary of mangrove parameters for El Rey 2

San Jose

Plot	Relative Density			Relative Dominance			Relative Frequency			Importance Value			Importance rank		
	L	P	R	L	P	R	L	P	R	L	P	R	L	P	R
1	0	0	100	0	0	100	0	0	100	0	0	300	2	2	1
2	0	0	100	0	0	100	0	0	100	0	0	300	2	2	1
3	0	0	100	0	0	100	0	0	100	0	0	300	2	2	1
4	0	0	100	0	0	100	0	0	100	0	0	300	2	2	1
5	16.67	0.00	83.33	17.54	0.00	82.46	50	0	50	84.21	0.00	215.79	2	3	1

Table 3.6 – Summary of mangrove parameters for San Jose

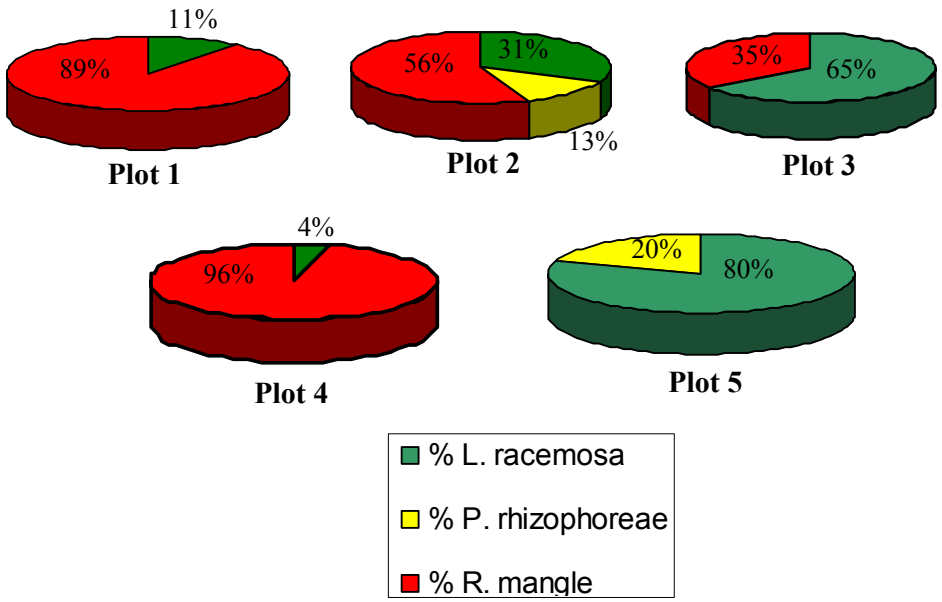

Fig 3.1 – Species composition in El Rey 1

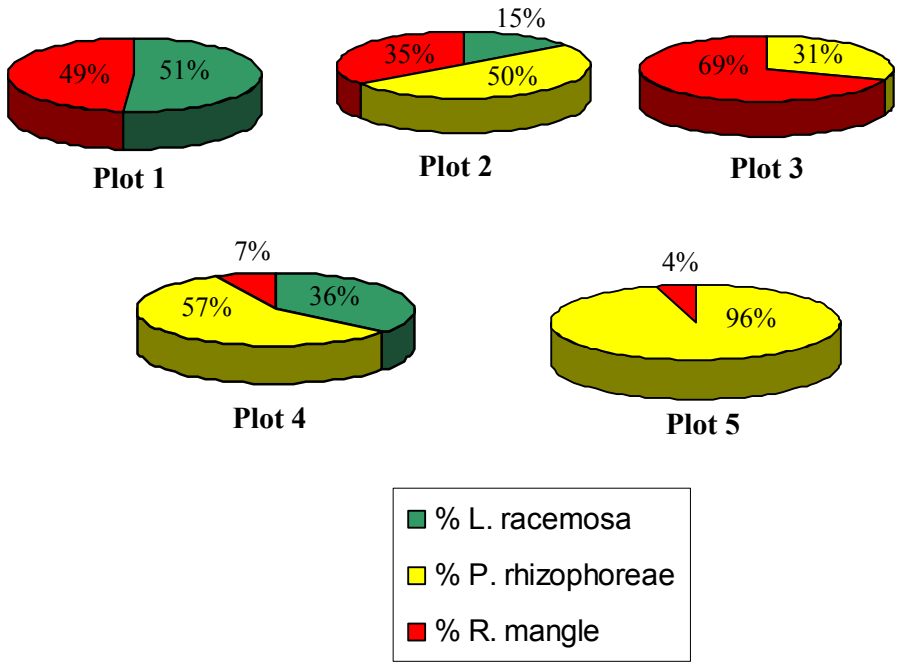

Fig 3.1 – Species composition in El Rey 2

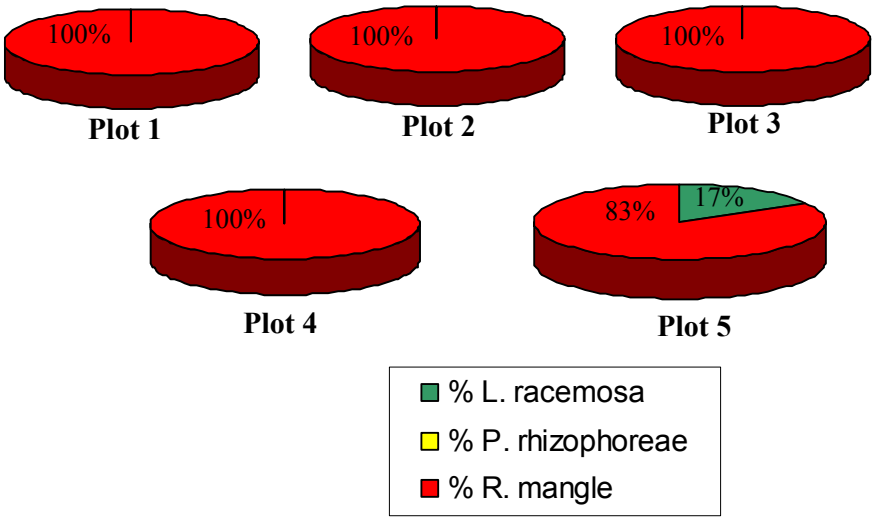

Fig 3.1 – Species composition in San Jose

Site	Species		
	L. racemosa	*P. rhizophoreae*	*R. mangle*
El Rey 1	0.148	0.169	0.42
El Rey 2	0	0.183	0.007
San Jose			0.006

Table 3.7 – Results of One-way ANOVAs and Kruskal-Wallis tests for height. Results highlighted in yellow were those of Kruskal-Wallis tests.

Site	Species		
	L. racemosa	*P. rhizophoreae*	*R. mangle*
El Rey 1	0.005	0.408	0.465
El Rey 2	0	0.001	0
San Jose			0.016

Table 3.7 – Results of One-way ANOVAs and Kruskal-Wallis tests for DBH. Results highlighted in yellow were those of Kruskal-Wallis tests.

3.2 Seedling Data

Tables 3.9 to 3.11 show a summary of the seedling data collected at the three sites. Table 3.12 shows the results of statistical tests to see if there was a significant difference in height for *R.mangle* between plots. Only data for *R.mangle* was analysed as there was not enough data available for *L. racemosa*. *P. rhizophoreae* was not analysed as no *P. rhizophoreae* seedlings were found in any of the plots studied. The pie charts of figures 3.4 to 3.6 show species composition for seedlings at the different plots.

3.2.1 El Rey 1

Most of the seedlings found at El Rey 1 were *R. mangle*. Only plot 3 and 5 had *L. racemosa* seedlings present (Fig 3.4). It was found that plot 5 had the highest abundance of seedlings present, whereas plot 4 had no seedlings present (Table 3.9). This could be evidence to suggest that plot 5 is a young mangrove forest where seedlings are able to thrive, whereas plot 4 is a mature forest where seedlings are unable to survive due to growth restrictions such as light. However, it was found that plot 4 had the lowest values for both height and DHB, which would suggest that it was the least mature forest.

Where seedlings were found, they seemed to all have similar heights between the plots as mean heights are similar between plots. This is further supported by looking at table 3.12, for it is possible to see that there is no significant difference in seedling height for *R. mangle* between the plots.

3.2.2 El Rey 2

As with El Rey 1, most of the seedlings found in the plots at El Rey 2, were *R. mangle* (Fig 3.5). Only plot 4 had any *L. racemosa* seedlings present. Plot 1 was found to have most seedlings present whereas plot 5 had the least. Plot 1 also had the lowest average heights and DBH (Table 3.2). This is the opposite as to what was found on El Rey 1, where the plot with the lowest mean height and DBH had the least amount of seedlings present, not the most.

Plot 4 had the highest mean seedling heights whereas plot 3 had on average the shortest seedlings (Table 3.10). Table 3.12 shows that there was a significant difference in *R. mangle* seedling heights.

3.2.3 San Jose

Only *R. mangle* seedlings were found in the plots of San Jose (Fig 3.6), and overall, not many seedlings were present in any of the plots. In fact, no seedlings were found in the subplots in plot 4. Plot 2 had the highest amount of seedlings found in the subplots (Table 3.11). As mentioned in section 3.1.3, plot 4 had the highest mean height and DBH for adult trees.

Apart from plot 4 (as it had no seedlings present), plot 5 was found to have the smallest seedlings present whereas plot 1 was found to have on average the largest seedlings present (Table 3.11). Table 3.12, however, shows that there was no significant difference in seedling heights between the sites.

El Rey 1

Plot No.	No. of seedlings	Mean height (cm)
1	6	42.7
2	1	40
3	2	47
4	0	0
5	53	44.7

Table 3.9 – Summary of El Rey 1 seedling data

El Rey 2

Plot No.	No. of seedlings	Mean height (cm)
1	54	55.3
2	4	38
3	8	33.6
4	8	85.5
5	2	75.25

Table 3.10 – Summary of El Rey 2 seedling data

San Jose

Plot No.	No. of seedlings	Mean height (cm)
1	1	85
2	9	77.1
3	2	77
4	0	0
5	5	65

Table 3.11 – Summary of San Jose seedling data

Site	P value
El Rey 1	0.064
El Rey 2	0.003
San Jose	0.694

Table 3.12 - Results of One-way ANOVAs and Kruskal-Wallis tests for seedling heights of *R. mangle*. The result highlighted in yellow was a Kruskal-Wallis test.

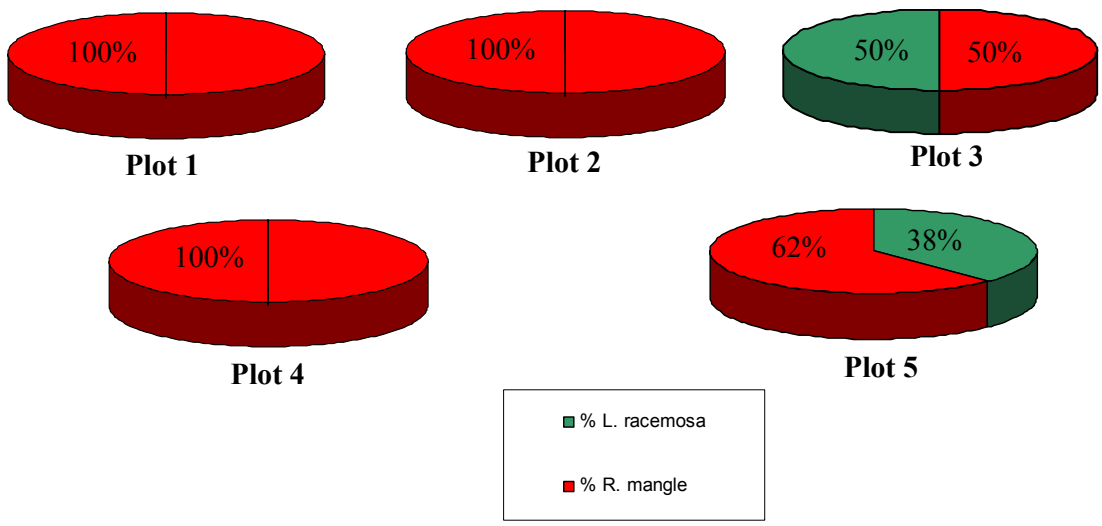

Fig 3.4 - Species composition of seedlings in El Rey 1

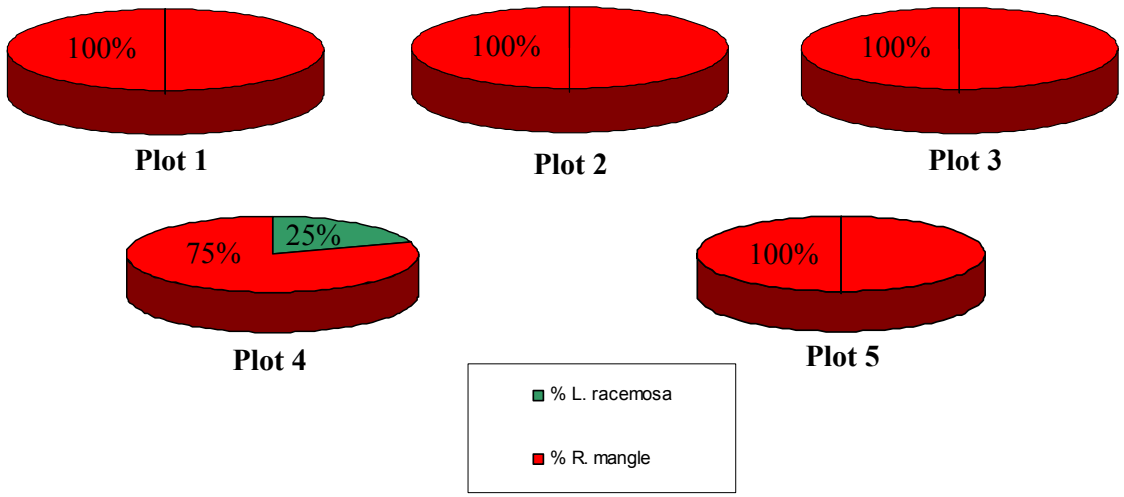

Fig 3.5 - Species composition of seedlings in El Rey 2

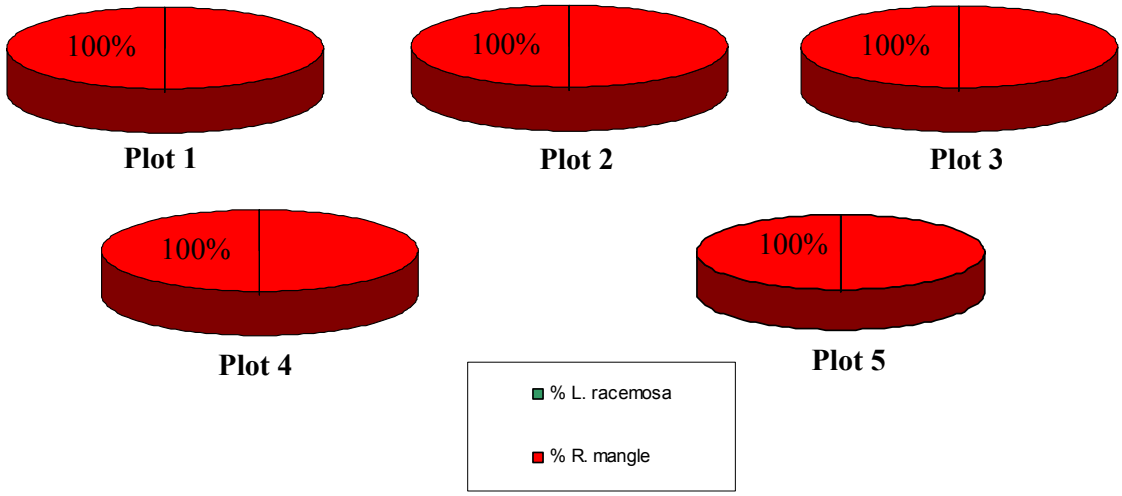

Fig 3.6 - Species composition of seedlings in San Jose

3.3 Comparison

3.3.1 El Rey 1 and El Rey 2

Both El Rey 1 and El Rey 2 are sites on the same island. It may be therefore possible that the mangrove communities present at both sites are similar. This, however, was found not to be the case. There was definitely a difference in forest composition between the sites. The most important species at El Rey 1 was *R. mangle* whereas *P. rhizoporeae* was the most important species at El Rey 2. Both sites did, however have *L. racemoda* as the most dominant species.

Table 3.13 shows that there was a significant difference in adult tree heights between El Rey 1 and El Rey 2, but there was no significant difference in DBH between the two sites.

	P values
Height	0.00
DBH	0.09

Table 3.13 - Results of Mann-Whitney test showing differences between El Rey 1 and El Rey 2.

3.3.2 Seedlings and adults

To assess how mature a mangrove forest is, parameters such as basal area and adult tree heights, as well as DBH can be used, together with abundance of seedlings. El Rey 1 was found to have the lowest average basal area, suggesting it was a young forest. It had the least amount of seedlings present, plus trees had the lowest heights and DBH (plot 4). It had the most seedlings present where there were the tallest trees and largest DBH measurements (plot 5).

El Rey 2 had the largest average basal area, suggesting that it was the most mature forest, but the basal area of San Jose was very similar so it is possible that in actual fact El Rey 2 was not the most mature site. El Rey 2 had the least amount of seedlings present where there were the tallest trees (plot 5). On El Rey 2 plot 1 had the highest abundance of seedlings, and it is this plot where the forest had the lowest average adult height and DBH.

San Jose had the least amount of seedlings out of all three sites, and no seedlings were present in plot 4 where adult tree heights were tallest. Most seedlings were present in plot 2 where the average DBH was the lowest.

These results therefore show that seedling communities are not dependent on height or diameter of adult trees. San Jose though was the site that had the most mature mangrove forest communities for there were few trees and seedlings present and also on average the adult trees were the tallest and had the largest diameters.

3.3.3 Soil composition

Table 3.14 shows the analysis of soil samples collected at the different plots. It is possible to see that the two sites on El Rey had mostly fine sand, whereas the soil at San Jose was muddy with a high organic compound concentration.

Station	organic C %	Carbonate %	Particle Size Analysis						
			Granule %	V C Sand %	C Sand %	M Sand %	F Sand %	V F Sand %	Silt-Clay %
Rey 1, plot 1	0.5	6.6	0.3	1.9	6.9	9.5	40.2	34.1	7.1
Rey 1, plot 2	0.6	4.8	0.4	4.4	5.0	21.5	29.3	37.1	2.4
Rey 1, plot 3	0.3	5.3	4.3	1.9	11.4	58.7	13.3	8.4	2.0
Rey 1, plot 4	0.9	8.2	1.4	1.2	1.4	4.6	76.9	14.2	0.3
Rey 1, plot 5	0.3	5.3	1.2	0.8	1.9	24.6	65.4	6.0	0.1
Rey 2, plot 1	0.3	31.2	0.4	5.7	5.5	39.0	43.3	1.8	4.3
Rey 2, plot 2	0.6	16.7	1.5	3.6	12.3	44.1	34.8	1.7	2.1
Rey 2, plot 3	0.9	38.1	0.0	0.0	2.7	21.5	62.0	6.7	7.1
Rey 2, plot 4	4.3	33.1	0.5	0.3	2.3	27.1	44.3	11.7	13.8
Rey 2, plot 5	3.7	26.3	1.6	0.3	1.5	14.8	65.9	7.5	8.4
San Jose, plot 1	8.2	14.2	15.4	6.9	1.5	8.9	7.3	6.8	53.2
San Jose, plot 2	23.4	10.9	3.2	3.9	6.0	9.1	12.5	13.4	51.9
San Jose, plot 3	12.8	16.4	8.5	2.7	5.4	7.4	13.0	1.2	61.8
San Jose, plot 4	4.1	2.3	1.7	3.4	3.9	5.9	12.7	47.1	25.2
San Jose, plot 5	11.7	22.9	10.6	3.5	9.4	9.6	12.2	9.7	45.1

Table 3.14 - Organic carbon (organic C%), carbonate (Carbonate %) and particle size analysis in terms of percentage total for all plots at the three sites surveyed. Note; the Wentworth grade Classification was used to analyse sediment particle size were by; granule= 4000-2000µm, very coarse sand (V C Sand)= 2000-1000µm, coarse sand (C Sand)= 1000-500µm, medium sand (M Sand)= 500-250µm, fine sand (F sand)= 250-125µm, very fine sand (V F Sand)= 125-62µm and silt-clay= <62µm.

CHAPTER 4: Discussion of Forest Structure and Dynamics

4.1 Forest Maturity

The data collected and analysed for the three sites was used to determine the forest structure and dynamics of the mangrove communities. Both basal area and tree height can be used to determine the maturity of a mangrove forest. Higher stand basal areas, diameters and lower densities are an indication of a more mature forest (Snedaker and Snedaker, 1984). Trees of higher heights are also an indication of a more mature forest as high heights can only be achieved over a long period of time.

4.1.1 Most Mature Location

Taking these factors into consideration, it can be concluded that San Jose was the site that has the most mature forest community, although it did not have the highest stand basal area. There were few seedlings present in the plots of San Jose as the tall trees deprive seedlings of light and nutrients (Putz and Chan, 1986). Furthermore, all the seedlings that were present within the plots were relatively tall. This could cause further shading and prevent younger seedlings from developing. Perhaps the muddy conditions of San Jose caused high seedling mortality, as seedlings prefer firm, sandy soils to colonise (Elster, 2000). As can be seen from figures 2.4, the prop roots were extremely extensive of *R. mangle*, which is a further indication that the mangrove forests were very mature. Indeed because of the extent of the prop roots of the area, it made data collection very challenging.

4.1.2 Least Mature Location

The least mature site was that of El Rey 1. El Rey 1 had the lowest stand basal area. Tree height was also relatively low, and tree diameters were small. The forest community has not had much time to develop, so the adult trees are still relatively short. Plot 5 had the most seedlings present in it, an indication that this plot was the least mature plot. When trees are less developed, there is more light and space available for seedlings to grow. Initial development and early development phases are characterised by dense stands of seedlings

(Jiménez *et al.,* 1985). Plot 4 on the other hand had no seedlings present. This is unexpected within an immature mangrove forest. One possible explanation as to why no seedlings were present is because the plot was located in an area of an estuary that may experience rough currents. Propagules and seedlings can easily be washed away by the currents (Elster, 2000).

El Rey 1 also had a high adult density, which is an indication that the forest is maturing. The adult density, however, was higher on average at El Rey 2. As table 3.13 showed, there was a significant difference in adult heights between El Rey 1 and El Rey 2. Rey 2 had on average taller trees. However, on average the diameters of trees were smaller at Rey 2, but as table 3.13 shows, there was no significant difference of DBH measurements between El Rey 1 and 2. Seedling density was also found to be similar within the two sites. For these reasons it is difficult to determine which site was the least mature. Perhaps they are of similar maturity. The larger stand basal area for EL Rey 2, however, establishes it as the more mature forest. Perhaps the reason as to why there were not more seedlings present within most of the plots of both El Rey 1 and 2 was because the soil was not firm enough and was too course. Water tends to quickly seep through course sandy areas, washing away any available nutrients with it.

4.2 Forest composition

At sites El Rey 1 and San Jose *R. mangle* was found to be the most important species, while at El Rey 2, *P. rhizophoreae* was found to be the most important. Indeed, only one individual of *L. racemosa* was found in plot 4 at San Jose, all the other individuals at the site were *R. mangle*. As discussed in section 4.1.1, it is believed that San Jose was the most mature forest investigated. Therefore because *R. mangle* was the foremost species present, it could be concluded that *R. mangle* is the most competitive species. It was able to out compete the other species and thrive in its environment. Further evidence to support this theory is that most seedlings found were *R. mangle*, indicating that they are a pioneering species. However, as stated by Tomlinson 1999, *L. racemosa* is an extremely pioneering species. It could therefore be argued that the majority of seedlings should have been *L. racemosa* rather than *R. mangle*.

At El Rey 2 it was found that *P. rhizophoreae* was the most important species but *L. racemosa* was the most dominant species. This is further evidence to support Tomlonson's claim that *L. racemosa* is indeed a pioneering species. What is apparent, however, is that where there was a high density of *P. rhizophoreae*, there tends to be a low density of *L. racemosa*. This could possibly be evidence to suggest that *L. racemosa* out competes *P. rhizophoreae* and *P. rhizophoreae* only tends to flourish when *L. racemosa* is absent or in low abundance. Further evidence to support this theory is that at El Rey 1, *P. rhizophoreae* had a low density in plots where *L. racemosa* had a high density.

Perhaps one possible explanation as to why average tree height was low at Rey 2 for a mature forest is because the density of *P. rhizophoreae* was so high. *P. rhizophoreae* tend to be small trees, usually reaching heights of 5 to 10m (Tomlinson 1999). This would cause the average height of the site to drop considerably.

The high dominance and density of *R. mangle* at San Jose might be due to the type of soil that was present there. Table 3.14 shows that San Jose was extremely muddy and had a very high organic content. Not many species can tolerate such unstable muddy conditions. Furthermore, there may have been a high hydrogen sulphide concentration within the substrate. It has been found that soils of more mature forests tend to have higher levels of hydrogen sulphide present, causing the soil to have a dark red tinge to it (Lee *et al.,* 1985). As can be seen from figure 2.4, the soil was dark with a red tinge to it. Most mangrove species, such as *L. racemosa* not adapted to oxidise substances such as hydrogen sulphide and so do not thrive in areas where it is present (Lee *et al.,* 1985).

Perhaps the reason as to why the forest communities are different between El Rey 1 and 2 is because there are different biotic and abiotic factors within the two locations. Rey 1 was situated further north of El Rey 2. The plots of El Rey 1 were situated within an estuary where the mangrove forest may have been more sheltered from wind. The benthic samples that were collected were not analysed and therefore it is not possible to say what benthic communities were present at each location. If identification and analysis had been carried out then perhaps predation could have been a possible explanation for the difference between the two sites.

CHAPTER 5: Conclusion and Future Work

As discussed in the above chapter, San Jose was the most mature mangrove forest community site studied. Each plot had a low abundance of adult trees but the individuals that were present were very tall and had large diameters. This resulted in a high stand basal area. Due to *R. mangle* being a competitive species and adapted to harsh environments, it was able to out compete the other species. El Rey 1 was found to be the least mature community site investigated. Low tree heights allowed seedlings to colonise the area as there was more light available for them to grow. El Rey 2 had a high density of *P. rhizophoreae* which atoned for the lower tree heights, and higher seedling abundances.

The three sites were set up so that future monitoring could be carried out. Due to El Rey 1 being a relative immature forest community, it would be interesting to see how it develops into a mature forest. Monitoring the other sites is also extremely necessary to make sure the areas stay in the pristine condition that they are presently in. As mentioned in chapter one, STRI want to make Las Perlas an area of protected management. The monitoring program will therefore allow researchers to make sure the area is not being misused in any way.

Although sediment samples were obtained at the different sites, intending for metal analysis, no analysis could be carried out in the time available carried out. It would be interesting if at some point these samples could be analysed to see if there is any contamination within the Las Perlas area. Contamination at the sites chosen is unlikely as there is little anthropogenic activity within the locations. This does not, however, mean that more anthropogenic activities will occur in the near future and it therefore important to continue to monitor the area to make sure the area does not become contaminated. Indeed there are already plans in motion to build an airstrip within the Las Perlas region.

Perhaps when the sites are revisited in the future other abiotic factors such as salinity readings could be taken. Mangrove ecology is dependent on salinity as they are subjected to marine waters. Perhaps salinity readings would give a clearer insight as to why the mangrove forests have established in the manor that they have.

The way that the plots were chosen means that proper analysis on mangrove zonation could not occur. Perhaps in the future it would be possible to include more plots in a way that zonation could be analysed.

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