AN ASSESSMENT OF MANGROVE FOREST STRUCTURE IN THE LAS PERLAS ISLANDS, PANAMA

by

THOMAS McGOWAN

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ABSTRACT

Mangrove forest is an important ecosystem that provides surrounding habitats with many ecological services and can be exploited to the benefit of many communities, they are however under threat from a variety of human activities and large areas of this forest is being lost. It is therefore necessary to assess the state of mangrove forest where it is known to exist and in areas in which it may be susceptible to exploitation by man, such a location is the Las Perlas archipelago, Panama. The aim of this study was to first make initial observations and surveys of the mangrove cover in the northern islands of the archipelago and then to focus in greater detail on the forest structure of the two largest islands, Rey and San Jose. Permanent plots were established at two sites on the island of Rey and one on San Jose, this meant that the same areas of forest could be visited again in the future and re-assessed for any change. The methodology followed standardised protocol and recorded species, height and diameter at breast height (DBH) of adult trees in order to assess forest structure. The locations of trees within the plot were recorded and the trees tagged and numbered for future assessment. Seedlings species and height were also assessed. It was found that the forest structure differed at all three sites, the importance of species and stage of development making the sites distinct. The first site at Rey, "Rey 1" had *Laguncularia racemosa* as its most important species and was found to be either in an early stage of development or having its growth limited. The second site on Rey "Rey 2" was found to be dominated by the species *Pelliceria rhizophorae* which was in a mature stage of development although this was not the case in all plots within the site. The site at San Jose was dominated by *Rhizophora mangle* and was found to be in a very mature stage of development. The setting up of permanent plots would allow re-assessment of the sites and it is concluded that this would be a valuable exercise as the Las Perlas islands show a variety of mangrove forest structure including less common species and some very mature areas of forest.

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CHAPTER 1. INTRODUCTION TO THE STUDY AND CRITICAL REVIEW OF LITERATURE REGARDING MANGROVE FOREST STRUCTURE AND DYNAMICS.

1.1 Rationale, aims and objectives of the study.

The Las Perlas islands, Panama were selected as a site for a survey of mangrove forest structure for a number of reasons. Little scientific research has been carried out on the mangroves in this area and they remain largely un-explored (Guzman, *personal communication*). This is largely due to the isolated nature of the islands which lie some distance from the Pacific coast of Panama and the major population centre for the country, Panama City. Another consequence of their isolated nature is the lack of development on the islands leading to what can be regarded as a largely pristine environment (Guzman, *personal communication*). The Las Perlas islands were also selected because of the increasing interest in the area shown by developers, there are plans for tourist developments on the island of Rey, sand extraction operations have been licensed for areas in the archipelago and on some islands (for example Contadora) there is already tourist development. For this reason it was enviable to collect data on the areas mangroves before they became substantially impacted and to set up permanent plots so any future impacts could be monitored. The opportunity to survey these previously under-researched areas arose when the Smithsonian Tropical Research Institute visited the islands from the 10th to the 20th of May 2006.

The aims of the study was to do an initial survey of mangrove forest structure on a number of the archipelagos islands, concentrating on extensive forest areas on the two largest islands, Rey and San Jose. It was also an aim to establish permanent plots at a number of sites where forest structure could be re-surveyed in the future and thus the health of the habitat be monitored.

1.2 Mangroves, their importance and threats to survival.

Mangrove vegetation includes trees, shrubs, palms and ground ferns that grow within the intertidal areas of coastal and estuarine margins (Benfield, 2002). There are some 20 families of plants that have members in mangrove forests and they share a number of specialised features that allow them to cope with the stressors associated with regular inundation by the tide (Duke *et al*, 1998). These adaptations include pneumatophores (exposed breathing roots) to allow gas exchange in what are frequently

anaerobic sediments, supporting prop roots for support in what may be shallow and unstable sediment, buoyant and viviparous propagules that allows dispersion of the seed in an aquatic environment and salt excretion glands to manage salt balance within the plant in what is frequently a saline environment. Mangrove forests cover approximately 20 million hectares worldwide and are the main vegetation type in protected intertidal areas along tropical and subtropical coastlines (English *et al*, 1997) being limited in distribution by the temperature of the sea water and the winter position of the 20°C isotherm (Hogarth, 1999). They grow in highly humid to extremely arid conditions, and in several substrate types including clay, peat, sand, coral rubble and bare rock (Cardona and Botero 1998 and English *et al*, 1997).

Mangroves provide humans with many useful products and ecological services. Due to their coastal location mangroves maintain coastal water quality (English *et al*, 1997) form a barrier for coastal protection from wave storm and flood damage (Yoshiro *et al*, 1997). Mangroves are also important breeding grounds for juvenile fish that stock many offshore adult populations including fishery species (Nagelkerken *et al*, 2000), and can also sustain fisheries through their nutrient export (Robertson *et al*, 1991). There may also be fisheries that involve taking directly from the mangrove (e.g. Wolfe *et al*, 2000) and they can be used as filters for aquaculture effluent, namely from shrimp ponds (Robertson and Phillips, 1995). Mangroves are also used by many indigenous peoples for traditional uses including as a source of medicine (see Bandaranayake, 1998 for a review) as well as for building materials (Walters, 2005).

Although mangroves cover vast areas of tropical and sub-tropical coasts in many of these areas they are found to be under threat from a variety of anthropogenic activities, Alongi (2002) reports that approximately one-third of the worlds mangrove forests have been lost. Large areas of mangrove forests may often be cleared to make way for shrimp aquaculture in developing countries (Primavera, 1993, Adeel and Pomeroy, 2002). Other impacts include population pressure, wood extraction (Walters, 2005), conversion to agriculture, salt production, tin mining, coastal industrialisation and urbanization (Ong, 1995; Macintosh, 1996). Oil spills may also cause large-scale damage to mangrove ecosystems (Duke *et al*, 1997). As well as direct impacts from human activity mangroves may also be under threat from global warming (Field, 1995) this is especially significant for mangroves, their intertidal location means they are likely to be one of the first habitats to be affected by a rise in sea level. Alongi (2002) describes the greatest hope for the future of mangrove forests as a reduction in the human population.

1.3 Factors influencing mangrove forest structure

The structure of a mangrove forest at any one point in time will be a function of its stage in succession, the species present, zonation, growth and primary productivity, mortatality and survival, propagule dispersal, establishment and survival as well as seedling and sapling growth and survival. These are all in turn under the influence of a number of factors, these could be biotic;

- Propagule size, weight and viability.
- The predation on and availability of propagules.
- Herbivory.
- Human interference.
- Interspecific competition.

Or abiotic factors:

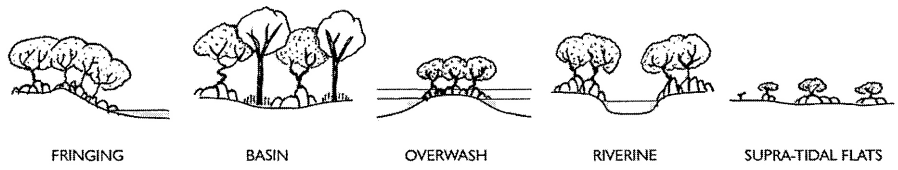
- Stressors e.g. hurricane, storm, drought or frost.
- Tidal influence (inundation and amplitude).
- Change in sea level.
- Freshwater input/Rainfall.
- Temperature/Evapotranspiration.
- Soil dessication, pore water salinity, type redox potential and texture.
- Sedimentation rate (erosion/accretion).
- Nutrients.
- pH.
- Light

(Benfield, 2002). There are obviously many factors to consider and to analyse each one of the above components and relate them to mangrove forest structure (and each other) would turn into a complicated exercise in ecological modelling (such attempts have been made (e.g. Schaeffer-Novelli *et al*, 2005; Twilley and Rivera-Monroy 2005 and Twilley *et al*, 1998)). This review instead of investigating all possible influences on mangrove forest structure will look at more broad topics e.g. factors affecting propagules or succession in mangrove forests and attempt to bring together the relevant literature to see what controls these and how these effect mangrove forest structure.

1.3.1 Mangrove community types.

Mangrove communities can vary in their location as long as the environment in that location meets a number of broad criteria, i.e., mangrove communities can grow in a variety of locations as long as the conditions are correct. These conditions are described by Lacerda *et al*, (2001) as locations in a tropical climate, where the temperature does not drop below 20°C during the year and there is little (<5°C) variation in the water temperature during the year. If the communities are to develop to maturity then a low energy, sheltered coast line with abundant freshwater (rain or riverine) and with a salinity range between 5 and 30ppt is required (Lacerda *et al*, 2001). Thus mangrove communities were first classified in relation to the environment they are found in by Lugo and Snedaker (1974) who recognised 6 different types: fringe, riverine, basin, overwash, dwarf and hammock some of which are represented in figure 1.1. Cintrón-Molero *et al*, (1985) however supposed that the last three types are specific cases of the first three types which are described as follows:

1. Fringe forests are found on the borders of shorelines or protected bays and are exposed to the tide daily. Detritus from the forest does not remain within the system but is removed by the tide, this fact as well as increased erosion due to tidal influence and no riverine input means that sediments accumulate less and trees are often shorter in these systems than basin or riverine forests. Overwash forests that exist as small islands frequently over washed by the tides were thought by Cintrón-Molero *et al*, (1985) to fall into this class.
2. Riverine forests are found along rivers, creeks and estuaries that are flooded daily by the tides. Low water flow velocity in these forests prevents re-distribution of leaf litter and nutrients available in terrestrial run-off support high productivity in these forests.
3. Basin forests occur inland in areas of depressed drainage were freshwater run-off collects and the tide may only reach on spring tides, these areas may be extensive. Water velocity is low in these areas allowing nutrients to accumulate, any export of carbon is in the dissolved form (Twilley, 1985). Both hammock and scrub categories of forests were formerly part of the basin category.



Source: After Lugo and Snedaker (1974). Their scrub category has been dropped as it is just a variant of the basin one. Similarly, the hammock category has been dropped as it is considered only to be a minor variant within basin environments.

Figure 1.1 Some of the community types proposed by Lugo and Snedaker (1974). Taken from Murray *et al* (2003)

1.3.2 Mangrove species richness

It is common for mangrove forests to be made up of very few species, monospecific stands are not uncommon and larger forests may frequently be made up of 3 or 4 species found within distinct zones, with few species of associate flora. This may in part due to the relatively small number of mangrove species but authors have identified other controlling factors believed to control species richness. Shaeffer-Novelli *et al* (1990) found that the dominance of a mangrove species in an environment was predominantly determined by the characteristics of the landforms that can be colonised by a particular species, the landforms being a function of the particular mix of fluvial, tidal and wave energies found in a region. Some authors have found freshwater run-off and rainfall to be an influential factor with species richness being greater in larger estuaries having moderate to high rainfall and moderated salinity regimes (Duke *et al*, 1998 in Benfield, 2002). Smith (1992) found that species richness in an estuary is not a result of propagule dispersal properties, concluding that these factors may not influence species richness at a local scale but that it may play an important role at the biogeographic scale.

1.3.3 Zonation

Zonation within mangrove forests is one of the most apparent aspects of mangrove forest structure, monospecific bands parallel to the shore are often clearly visible even to the casual observer. Accounts of zonation are numerous in the literature and describe zonation throughout those areas in which mangrove is found. Zonation has been described in Panamanian mangrove (Chapman, 1976, Rabinowitz, 1978a and 1978b) as *Rhizophora (R. mangle, R. harrisonii)* as the pioneer species with *Avicennia germinans* and *A. bicolour* or mixed *Avicennia*/*Laguncularia* behind with *Conocarpus* and the

palm *Bactris subglobosa* at levels only reached by the highest tides (after Lötschert, 1959) (see figure 1.2).

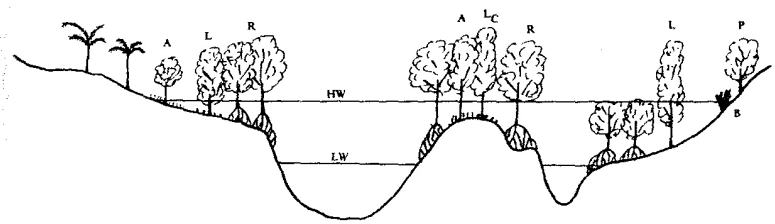


Fig. 45: Vegetation profile in mangal, El Salvador (A = *Avicennia*; R = *Rhizophora*; L = *Laguncularia*; C = *Conocarpus*; B = *Bactris*; P = *Pithecolobium*). (Modified from Lötschert).

Figure 1.2 Typical mangrove zonation in Panama (taken from Chapman, 1976). Note; although the table states "vegetation profile in mangal, El Salvador" this is the same zonation typical in Panama (Chapman, 1976).

In the past zonation schemes would often describe their proposed scheme using the factor they believe to be responsible, for example; Watson (1928) classified the location of species in relation to frequency of inundation, assigning each species an "optimum requirement" of tidal inundation. Macnae (1968) described the zones not by an environmental factor but according to the dominant species. These two examples reflect two different schools of thought within the literature, the first being that zonation is controlled either by abiotic factors such as land building processes or responses to environmental gradients meaning that a mangrove species is limited physiologically to specific locations in which it can grow, referred to by Ellison and Farnsworth (1993) as the "distinct preference hypothesis". The second hypothesis is the "same preference hypothesis" which dictates that mangrove species can establish in a range of habitats and that their location is dictated by biotic factors (Ellison and Farnsworth 1993). The literature concerning the abiotic and biotic factors that are thought to have greatest influence is covered below.

Abiotic factors influencing zonation

i**) Zonation represents land building and plant succession**

This mechanism dictates that the zoning of different mangrove species in bands parallel to the coast represents successional development from pioneer species on the

waters edge or offshore (characterised by *R. mangle* in the biogeographical area most relevant to this study) to a climax ecosystem at the point at which the mangrove reaches furthest inland. This is an accepted process terrestrially and so was an early argument held by those that believed mangrove communities to be a precursor to the development of terrestrial forests on the coast. In 1940 Davis argued that mangroves induce the accumulation of sediment so that the level of the soil rises. This rise makes the habitat suitable for the invasion of the next higher mangrove. Chapman (1976) has been a chief advocate of the zonation-equals-succession debate (Tomlinson, 1999) but Tomlinson (1999) believes this to be untrue and merely a result of the idea being strongly embedded in the literature. Smith (1992) believes that mangroves are responding to deposition of sediment rather than actually causing it. Vann (1959), a geologist, does not believe that mangroves accumulate sediment and states that mangrove "does not precede the appearance of new land and colonises flats only after they have risen above low tidal level" but does remind us of the increment of material through death and decay. The literature does not discount succession (this is a common theme within current research and will be covered in a later section) but is in general agreement that mangrove does not play a role in sediment accumulation as a means to succession.

ii) Abiotic gradients in the intertidal zone causing zonation.

There are a number of abiotic gradients that influence the intertidal zone, these include tidal inundation, soil salinity (soil pore water salinity), soil waterlogging (Ellinson and Farnsworth, 1993) and nutrient availability from terrestrial run-off. The study mentioned previously by Watson (1928) described mangrove zonation in terms of inundation and his scheme has been applied in more recent studies (e.g. Chai, 1982). The formation of distinct zones that match the topographic contours of the intertidal area is possibly an indicator of the importance of tidal inundation in zonation (Duke *et al*, 1998 in Benfield, 2002).

Chen and Twilley (1998) found that *A. germinans* and *L. racemosa* showed a reduced basal area downstream in a riverine mangrove community in areas that showed lower nutrient levels. It is apparent to the author however that these sites must by definition also show higher salinity and so this gradient must also be taken into account. However, *A. germinans* and *L. racemosa* outcompeted *R. mangle* at higher nutrient level downstream sites. I believe this study to be inconclusive in determining the effect of the nutrient gradient on mangrove zonation. The case is similar for sulphide concentrations and redox potential within the soil. In their study Chen and Twilley

(1998) state that “these (sulphide) soil values indicate that abiotic stress cannot explain the decrease in forest structure along this estuarine gradient”. It has been found that *A. germinans* and *R. mangle* share an adaptation of their roots which posses arenchyma which allow effective transport of gasses. This allows them to exploit reduced soils equally well (Benfield, 2002). Smith (1992) believes that soil redox potential might not determine zonation between these species.

The most apparent gradient in the intertidal zone (biologically) is salinity and there are many studies in the literature relating to this physico-chemical gradient. Normally the lowest salinity would be expected at the high intertidal zone and the highest salinity found in the lowest intertidal zone. Species would be expected to show interspecific differences in tolerances along this gradient (Benfield, 2002). The studies relating to salinity are however complicated by the salinity of the flooding water, rainfall, evaporation and freshwater run-off altering the gradient on a constant basis. As well as altering gradient Tomlinson (1999) states that it is often only the extremes in environmental gradients that become limiting and that in the case of a salt flat, for instance, the salinity gradient will determine zonation only at the margin. From this we can infer that in locations that are frequently inundated by the tide and terrestrial sources such as the intertidal that these “margins” will be plastic and that salinity will be of little significance to zonation. Studies on the tolerance to salinity shown by mangroves have found that the majority of species prefer lower salinities but can be found in a broad range of salinities. For example, seedlings of some species can tolerate salinities over 65‰ and mangroves and mangroves of the eastern Pacific and Caribbean have been found over a broad range of salinities up to 90‰ (Smith, 1992). Smith (1992) also identifies a group of species that are restricted to salinities <40‰ which are normally found in upstream areas of river dominated estuaries. In conclusion therefore mangrove species generally have too wide a tolerance to salinity and salinity varies too greatly to affect zonation greatly except perhaps in more extreme gradients found in riverine communities.

Biotic factors influencing zonation

i) Predation on propagules

There is much in the literature concerning the predation of propagules by the fauna associated with the mangal community. The most important group to predate on mangrove propagules is the graspid crabs, Lee (1998) in their review summarises that

predation on propagules by graspid crabs played an important role in diminishing the relative abundance of certain species whose propagules were preferred, thus maintaining species dominance. There are a number of different ways in which graspids and other predators affect the zonation of mangrove species within a forest. Differential predation on propagules across the intertidal zone was proposed by Smith (1987a) as a determinant of mangrove zonation. Smith (1987a) showed that an inverse relationship existed between predation rate and dominance in the canopy in four out of the five species studied. In other studies Smith and colleagues have reported that crabs often consume 100% of post-dispersal propagules in Australian forests, especially the genus *Avicennia* (Smith, 1987a, 1987b, 1988, Smith *et al*, 1989 and Osbourne and Smith, 1990). It is reported by McKee (1995a) that *Avicennia* propagules are preferred by graspids due to their small size (facilitating burial in crab burrows), a higher nutritive content, and lower amounts of defensive chemicals such as tannins. McKee (1995a) found that in forests in Belize predation on propagules of *A. germinans* and *R. mangle* were highest in areas were these species dominated the canopy and that predation on *R. mangle* was lowest in areas of forest dominated by *A. germinans.* Bosire *et al* (2005) found that the planting of propagules (to mimic establishment) strongly influenced the reduction of predation intensity. These findings concur with the findings of Dahdouh-Guebas *et al* (1997) and Clark and Kerrigan, (2002) who found propagules dispersed in the prone position to have higher mortality. It has also been observed that predation varies with position on the shore, predation being low in the lower intertidal and highest in the high intertidal were greater populations of crabs are normally found. Predation also varies biogeographically, with highest predation in the Indo-Pacific and a decrease across the Pacific (towards Panama) (Smith, 1992). In their 2005 study Bosire *et al* find that zonation in their forest follows the canopy-gap model whereby crabs are only found in areas under the canopy and not in gaps which contain less plant material on which to feed. This results in predation only in areas that are forested and it is suggested that a mutual relationship may exist between the crabs and the mangrove; the mangrove providing a suitable habitat for the crabs and the crabs predating the propagules of the mangroves competitors.

With a variety of factors influencing predators choice of propagule various models have been proposed in support of propagule predation, as summarised in Bosire *et al* (2005):

1. The dominance-predation model, which postulates that an inverse relationship exists between the rate of predation of a particular species and the conspecific dominance in the canopy (Smith 1987).
2. The canopy-gap mediated model (Osbourne and Smith, 1990, Clark and Kerrigan, 2002).
3. The flooding regime model (Osbourne and Smith, 1990, Clark and Myerscough, 1993).

Predation of propagules is certainly an important factor in determining mangrove zonation but as has been made clear already no one factor can be held exclusively responsible.

ii) Tidal sorting of propagules

This is perhaps the simplest hypothesis used to explain mangrove zonation. It states that mangrove with heavier propagules (early stage seedlings that are released from the parent tree and float to disperse and establish new areas) will colonise the part of the intertidal nearest the shore and those species with lighter, more buoyant propagules will establish further up the shore. The main advocate of this hypothesis is Rabinowitz (1975, 1978a, 1978b and 1978c) who found that seedlings that were (artificially) transported from their habitat to another species' or "wrong" habitat could still grow there. Concluding that as the species cannot be physiologically identical (a truism) Rabinowitz (1975 and 1978a) cites the propagule size, weight and rooting times as reasons for their different distributions in Panamanian mangrove. For example, *A. germinans* is found in the higher intertidal (Rabinowitz 1978b and 1978c) it requires freedom from tidal inundation and so constantly floats, meaning it can only settle in the high intertidal, it is able to do this by having a very small, buoyant propagule. *R. mangle* has a larger, heavier propagule meaning it has a shorter sinking time and is found in the lower intertidal. This theory would seem to be logical, but perhaps too simplistic to account for a complex process like zonation. Smith (1992) pointed out that the rooting times cited by Rabinowitz (1975, 1978a) were contradictory to the zonation observed. Species such as *A. germinans* and *L. racemosa* that were found at the highest intertidal locations (and thus under the least tidal influence) showed the shortest rooting times and *R. mangle*, which was found in the low intertidal had the longest rooting times. Smith (1992) points out that these rooting times should give the reverse zonation than is exhibited. There are also multiple examples within the literature of species with small propagules such as *Sonneratia* and *Avicennia* being found in the low intertidal (Chai,

1982, Smith, 1992 and Tomlinson, 1999). Tomlinson (1999) also points out that this theory assumes that establishment of a seedling will result in the development of a mature tree.

Abiotic versus biotic.

It is commonly understood that in ecology, no one factor will be responsible for the community exhibited in a habitat, this is the case when considering mangrove zonation. On different parts of the shore for example different factors may show the strongest influence. The zonation of common species such as *R. mangle* can be accounted for by both abiotic and biotic factors. *R. mangle* is found in the low intertidal because of biotic factors: it can apply more biomass to its root system, lower herbivory and heavier propagules and abiotic factors: it can tolerate anoxia and high waterlogging better than other species (Ellinson and Farnsworth, 1993). When it is found in the mid intertidal range its abundance is controlled by interspecific competition and herbivory (Ellinson and Farnsworth, 1993). Abiotic or biotic factors will influence mangrove species at different stages in their life cycle, while adult trees may be tolerant to a broad of conditions seedlings may be less tolerant (Benfield, 2002). Tomlinson (1999) gives an account of work by Lugo (1980) who when summarizing the interrelationships between biotic and abiotic factors by means of a diagram represents the system with 35 interconnected factors and what seem to be a “limitless” number of relationships between them.

1.3.4 A successional or steady state ecosystem?

It is a common assumption that mangrove communities represent a system in succession, and are a stage to the climax terrestrial community. It is argued however that this is not the case and an alternative steady-state hypothesis is put forward inferring that the mangrove community (and every zone within it) is at climax. Thom (1967) first presented the steady state hypothesis. Lugo (1980) agrees with the steady state model, and argues that succession in mangrove ecosystems needs to be examined separately for different types of mangroves and the question must be related to the cyclic nature of the mangrove environment. Lugo (1980) argues that succession in mangroves is cyclic and leads to a series of cyclic stages. As long as one mangrove zone, treated as a community, is replaced by mangrove species then the mangrove status is maintained and is therefore in a steady state. Johnstone (1983) proposes an alternative

model of steady state, maintaining that the mangrove community should be regarded as separate from the terrestrial and its own climax community identified. It is reasoned that if all species can grow anywhere in the intertidal then zonation must be at least in part due to interspecific competition, competition being a sign of succession. It is then argued that the zone with the highest biomass and greatest development is the climax (Johnstone, 1983). The difference between the hypothesis of Lugo (1980) and Johnstone (1983) being that Lugo believes that zones should be regarded as separate communities not in competition. Johnstone assumes however zonation in mangroves represents succession, this has been demonstrated not always to be the case (Lugo, 1980 and Tomlinson, 1999). In order to solve this problem Tomlinson (1999) attempted to compare the characteristics of individual mangrove species and communities (mangal) with pioneer and mature phase species (table 1.1).

Table 1.1 Comparison of pioneer and mature phase species and communities with mangroves and with mangal (from Tomlinson, 1999)

Species	Pioneer	Mature	Mangrove
Seed size	Small	Large	Usually large
Seed number	Numerous	Few	Often numerous
Dispersal agent	Often abiotic (e.g., wind)	Usually biotic	Always abiotic (water)
Dispersibility	Wide	Limited	Wide
Geographic range	Broad	Narrow	Broad
Seed production	Continuous	Discontinuous	Sometimes continuous
Seed dormancy and viability	Long	Short	Short (?)
Seedlings	Light-demanding, not dependent on seed reserves	Not light-demanding, dependent on seed reserves	Light-demanding(?), dependent on reserves
Reproductive maturity	Early	Late	Early
Life span	Short	Long	Probably long
Leaf size	Often large	Medium or small	Medium
Leaf palatability	High	Low	Low
Wood	Soft, light	Hard, heavy	Hard, heavy
Architecture	Model-conforming	Not model-conforming	Model-conforming
Crown shape	Uniform	Varied	Uniform
Competitiveness	For light	For many resources	For light and other resources
Pollinators	Not specific	Highly specific	Not specific
Flowering period	Prolonged or continuous	Short	Prolonged or continuous
Breeding mechanism	Inbreeding favored	Outbreeding favored	Inbreeding favored

Community	Pioneer	Mature	Mangal
Floristic composition	Poor	Rich	Poor
Stratification	Absent	Well developed	Absent
Age composition	Even-aged	Uneven-aged	Even-aged(?)
Large stems	Absent	Present	Usually absent
Undergrowth	Dense	Sparse	Absent
Climbers	Few	Many	Few
Epiphytes	Few	Many	Few

Source: Budowski (1965), Gomez-Pompa and Vazquez-Yanes (1974), UNESCO (1978); see also Ewel (1980), Primack and Tomlinson (1980), Whitmore (1983).

Tomlinson also concludes that mangrove communities should be considered independently from terrestrial forest communities and successional marine communities. Tomlinson (1999) states that mangrove communities posses clearly pronounced characteristics of pioneer species in their reproductive biology but of mature-phase species in aspects of their community structure and vegetative growth. An alternative designation would be to say that they have the properties of r-selected selected species in finding their habitat, but of K-selected species in maintaining it.

We can categorise mangroves as pioneer species (and therefore part of a succession) but they form a community without succession, this would lead us to believe that they are a climax community, this relationship could be a focus of future research (Tomlinson, 1999).

1.3.5 Forest Dynamics

Once the community type, species richness and pattern of zonation have been established factors that effect mangrove forest structure through time should also been considered i.e. the forest dynamics. Jimenez *et al* (1985) defined four stages in stand development, colonisation, early development, maturity and senescence. The colonisation stage involves the arrival of propagules at a new site and their establishment. The early development stage involves the development of seedlings into saplings and mature trees. The mature stage concerns adult growth and factors concerning primary productivity. The final stage, senescence, involves the death of mature trees and the system of regeneration that follows; gap-dynamics. Below I will summarise some of the literature concerning these topics.

The colonisation phase, factors affecting propagules.

In order to replenish existing stands and establish new stands mangroves release large numbers of propagules. The direction of these propagules depends on the ocean currents carrying them but the distance they travel depends on the time that the propagules remain buoyant and viable (Duke *et al*, 1998) this viability varies between species but can also be affected by frugivory of the propagules (Minchinton, 2006). As mentioned in section 1.3.2 Rabinowitz (1978c) believes propagule establishment not to be dependent on the physiochemical gradients in the intertidal, this is supported by the work of Clark and Kerrigan (2000). Propagules of different species also respond in different ways to the level of water in the sediment. When propagules of *R. mangle*, *L. racemosa* and *A. germinans* are compared it is found that the propagules of *R, mangle* respond best to water logged soils, can survive the greatest level of desiccation and have the fastest growth rate. *A. germinans* shows the highest propagule mortality and can only establish in shaded, wet soils and can not settle in open sites or sites that may become flooded due to the small size of their propagules, this is also true of *L. racemosa*. *A. germinans* has the lowest propagule growth rate, while *L. racemosa* can potentially have a faster growth rate than *R. mangle* if the conditions are favourable (Elster, 2000 in Benfield, 2002).

The early development phase, factors affecting seedlings.

The seedling stage in a trees life-cycle is the most vulnerable, seedlings do not show as great a tolerance to a range of environmental conditions as adult trees and are not as robust. McKee (1995b) outlines a number of factors influencing the density and survivorship of seedlings of *R. mangle, L. racemosa* and *A. germinans*. Distance from reproductive adults is the most important factor when explaining the density of *R. mangle seedlings*, this would infer that the conditions they are found in are not as important as the ability to reach them i.e. that they can grow in most places they can reach. The availability of resources (NH_4 and light) was the most important factor in establishing the density of seedlings of *A. germinans*. It has been shown that as a rule, growth in seedlings decreases with a decrease in light (Ball, 2002). The factors controlling the density of *L. racemosa* changed throughout the year, for the first 7 months of the year it was accounted for by the distance from reproductive adults, from then on it was explained intensity of flooding and salinity related stresses (McKee, 1995b). Regarding survivorship McKee (1995b) established that mortality was highest during the establishment phase and that this was due to failure to strand before viability was lost, predation and desiccation. Once established factors affecting survivorship varied, for *R. mangle* the orientation of the seedling was important while for *A. germinans* physiochemical stresses were more important. Physiochemical stresses such as salinity have been shown by Ball (2002) to influence the ability of seedlings to exploit resources. When maximum irradiance is available it was found, differences in salinity will affect growth. Availability of light was shown to be more important than position on shore (and thus salinity) in *A. germinans*. in the study by Osunkoya and Creese (1997). The interaction between salinity and irradiance was shown to be different for the seven species in the study by Ball (2002).

Once established seedlings are established they can be prone to attack by insects, often because they are not as robust as adult trees. Insects can cause the death of seedlings through leaf removal (Robertson, 1991) or from boring of the stem (Sousa *et al* 2003). If propagules have been attacked at an earlier stage this may effect survival, growth and biomass allocation between leaves, stems and roots of the seedlings (Robertson, 1991).

The mature phase, factors affecting growth and primary productivity.

An important factor in determining biomass in mature forests is salinity; basal area, biomass volume, biomass increment, mean standing biomass, annual litterfall rates, leaf

area index, above ground primary productivity and growth efficiency all being inversely correlated with salinity and high salinities associated with dead or dwarfed vegetation (Cardona and Botero, 1998 and Sherman *et al*, 2003). As a result of this relationship it has been found that estuarine communities show higher rate of (above-ground) primary productivity relative to fringing communities (Amarasinghe and Balasubramaniam, 1992). Increasing salinity will result in stress to any plant as it is vital that plants maintain the osmotic pressure within their cells. In saline environments mangroves will have to expend energy to stop the loss of water to the hyper-saline environment around them and maintain their hydrostatic pressure. Many species of mangrove manage their water balance by using salt glands to excrete excess salt from their system. As well as salinity nutrients available in the sediment are an important factor determining primary productivity, this is a complex topic that involves many physiochemical and biochemical pathways and interactions. A detailed analysis of the nutrient-primary productivity relationship is given by Clough (1992) and summarised here. A complex relationship exists between the redox potential of the soil, the availability of nutrients and the formation of H_2S, which may become toxic in high concentrations. All plants need nitrogen to survive and this is available to mangroves in the form of ammonium ions, different species exploit ammonium with differing success and ammonium will become toxic at high levels.

Mature mangrove forests are often subjected to events that can lead to mass leaf loss, these can be abiotic such as freeze or hurricane damage or can be biotic such as attacks from large numbers of herbivorous insects. The results of these events are to damage the photosynthetic ability of the trees but also to remove nutrients from the mangrove ecosystem. The flow of nutrients within any forest ecosystem is regulated, in part, by the resorption of nutrients from fallen trees (Hörtensteiner and Feller, 2002). Freeze damage is a danger to mangroves found at latitudinal extremes as they are highly sensitive to cold, Norby *et al* (2000) state "(resorption) cannot be performed in leaves that have been killed due to the physical damage of freezing" and so nutrients cannot be recycled back into the system. If leaves remain on the forest floor the nutrient rich litter will provide a boom to fauna that may result in stress to the system (Ellis *et al*, 2006) and if not this, in intertidal areas the large volume of litter may be removed by the tide. Hurricanes are common in tropical and sub-tropical regions were mangrove species are found and may also cause mass leaf removal removing the leaves directly from the system without opportunity for resorption. Insects may also cause mass leaf removal,

for example; accounts of plagues of moths whose caterpillars consume almost 100% of leaf biomass within a few weeks in Brazilian mangrove (Wolfe *et al*, 2000). Normal herbivory by insects can remove as much as 35% of the total leaves in a stand (Robertson, 1991). Canopy removal affects different species of mangrove to differing extents, Snedaker *et al* (1992) report that up to 74% of individuals of *R. mangle* may suffer mortality were as individuals of *L. racemosa* and *A. germinans* can recover entirely through releafing, coppicing and initiating trunk sprouts.

The senescence phase, mortality and gap-dynamics.

Net primary productivity and biomass decrease through time in mature mangrove stands, this may be due to physiological and ecophysiological effects as outlined above but may also be due to competition among neighbouring trees resulting in self-thinning (Berger *et al*, 2004 and Liao *et al*, 2004). Through time, the density of trees decreases in a mature stand, this is coupled with an increase in individual diameter and height and as a result an increase in the average individual biomass, but a fall in total biomass (Liao *et al*, 2004). This pattern can be explained through neighbourhood competition in the first phase but is a result of death and wood loss in the second phase (Berger *et al*, 2004). Trees can die through the natural processes of senescence, abiotic events such as lightening strikes or can be removed by humans. Once a mature tree has died it will leave a large gap in the forest canopy, the secondary succession by seedlings that follows these events is termed gap-dynamics in the literature.

When large trees are removed it is commonly found that the proportion of trees in smaller size classes (seedlings and saplings) increases (e.g. Smith and Berkes, 1993 and Walters, 2005). However, contrary to these reports Sherman *et al* (2000) found that only saplings and not seedlings were found in higher densities in gaps and Clark and Kerrigan (2000) report a greater recruitment of seedlings to saplings in canopy gaps only and not an increase in seedlings. A commonly suggested reason for this is the increase in irradiation available that is present within the gap (Smith, 1987c and Ewel *et al*, 1998) it is suggested that since all mangrove species are relatively shade-intolerant they depend on the availability of openings in the canopy to grow (Snedaker and Lahmann, 1998, Roth, 1992 and Smith, 1992). Seedlings of different species do not exhibit uniform requirements for irradiance however, Walters (2005) suggests that *Sonneratia* is especially light demanding and that *A. marina* has more of an affinity for understorey conditions and can persist longer here. Sherman *et al* (2000) believe that a species that can better utilise the light in gaps will be in a position to increase its

dominance in the forest over time. However, Clark and Kerrigan (2000) report (in terms of species composition) a “direct replacement” model in their study. When compared to seedlings in the understorey it has been found that seedlings in gaps suffer less predation and herbivory (Osbourne and Smith, 1990 and Ellinson and Farnsworth, 1993) due to the preferred habitat of many herbivores being in shade, detritus rich habitats. These factors allow coupled with the all year round seed production in many mangrove species allow secondary succession to occur very quickly within gaps.

1.4 The study area.

The study area will now be introduced in terms of the climate, mangrove forests and the mangrove species. There is little data available for the Las Perlas islands specifically but data will instead be presented for Pacific Panama as an alternative so that this information can be put into the context of the previous sections and allow a better appreciation of the results and discussion in the preceding chapters.

1.4.1 The Las Perlas islands.

The Las Perlas islands lie within the Gulf of Panama on the Pacific coast of the country. The archipelago lies approximately in the centre of the Gulf and covers a wide area, it is found at coordinates 08°14’N and 79°07’W (see figure 1.3). The major islands of Rey and San Jose lie in the east and south west of the archipelago respectively (see figure 1.3).

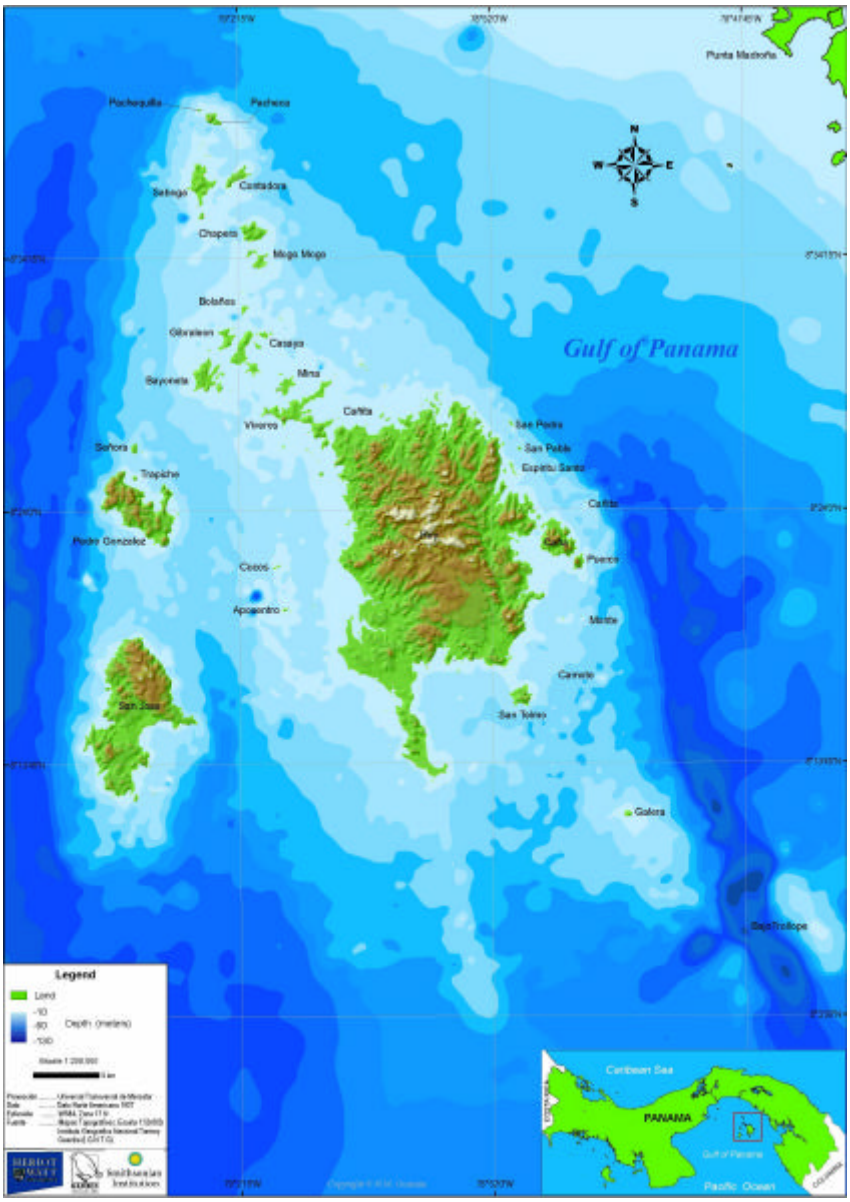


Figure 1.3 The archipelago of Las Perlas and its location in relation to Panama (inset). Figure courtesy of the Darwin Initiative (© H.M. Guzman)

1.4.2 Mangrove cover in the study area.

Mangrove forests along the Pacific coast of Central America cover around 4,000km^2 (Jimenez, 1990), mangrove is found along much of Panamas Pacific coast (Chapman, 1976). New world species of mangrove include only 11 species and 1 variety. The 11

species are made up of the *Rhizophora, Avicennia, Laguncularia, Conocarpus* and *Pelliceria* groups (Lacerda *et al*, 2002). On the Pacific coast of Central America *R. mangle* and *A. germinans* are the most widely distributed species, on the Pacific coast of Panama the species *Rhizophora (R. mangle, R. harrisonii), Avicennia germinans, A. bicolour, Laguncularia racemosa, Conocarpus erectus, Pelliciera rhizophorae* and the palm *Bactris subglobosa* are all recorded (Chapman, 1976 and Lacerda *et al*, 2002). The typical zonation of these species in the area is discussed in section 1.3.3. and is displayed in figure 3.2. *R. mangle* forms the principle forest type in most regions in this area with *Aviccenia* and *Laguncularia* in less favoured localities while *R. harrisonii* and *Pelliciera rhizophorae* are characteristic species of the region (Chapman, 1976 and Lovelock *et al* 2005).

There have been numerous studies conducted on the mangroves of Panama (e.g. Benfield, 2002, Benfield *et al* 2005, Duke *et al*, 1997, Lovelock *et al*, 2005, Rabinowitz 1975, 1978a, 1978b and 1978c and Smith, 1989) but as far as the author is aware non in the islands of Las Perlas.

1.4.3 The mangrove species in the Las Perlas islands.

Rhizophora mangle

R. mangle is found from western Africa to the Pacific coast of tropical America see figure 3.3a (Tomlinson, 1999). *R. mangle* can be found in diverse forms, it can form short scrubs, or woody trees that may grow up to around 30m tall (Tomlinson, 1999). *R. mangle* has a high tolerance to salt but is shade intolerant and can be found in off-shore stands, fringing, riverine or inshore basin forests. It possesses the characteristic prop roots and evergreen characteristics of the genus to which it belongs. It possesses seedlings (propagules) are 15 to 20cm long which are shaped like rods and are elongated propagules that float (Benfield, 2002). The propagules are hardy and long-lived an exhibit a peak in production in September and October although are produced all year round (Rabinowitz, 1978a).

Laguncularia racemosa

L. racemosa is found throughout the tropical latitudes of the Americas see figure 3.3b. This species is typically restricted to the landward fringe of the mangrove community but also pioneers readily into disturbed sites where it can form pure stands (Tomlinson, 1999). However in Pacific Central America it generally found behind *R. mangle*. Like *R. mangle L. racemosa* has a wide salt tolerance and is shade intolerant. The propagules

of *L. racemosa* are small numerous, germinate while they disperse and can reach very high densities on the forest floor (Tomlinson, 1999), all characteristics that can be associated with a pioneer species.

Avicennia germinans

A. germinans is distributed throughout the Central America region. Like *R. mangle* and *L. racemosa A. germinans* has a wide tolerance to salt and is also a shade intolerant species. The propagules of *A. germinans* are small and light (Rabinowitz, 1978a).

Pelliciera rhizophorae

P. rhizophorae is a characteristic species of the Central American region and is restricted only to this area (see figure 3.3c). Significant stands of this species are now only found on the Pacific side of Costa Rica in areas of high rainfall (Jimenez, 1984). In the past *P. rhizophorae* enjoyed a much wider distribution and Jimenez (1984) believes the low salinity tolerance of the species to be responsible for its reduced distribution at present, restricted only to areas with high run-off or rainfall. Trees of *P. rhizophorae* are relatively small, growing up to a maximum of 18m and have a distinct swollen trunk which is fluted at the base (Tomlinson, 1999).

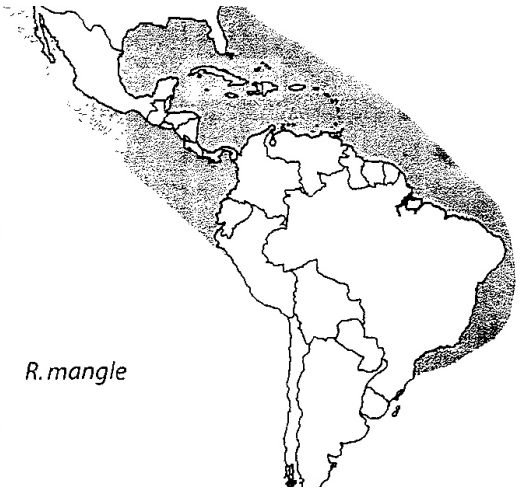


Figure 3.3a Distribution of *R. mangle* in the Americas (taken from Lacerda *et al*, 2002)

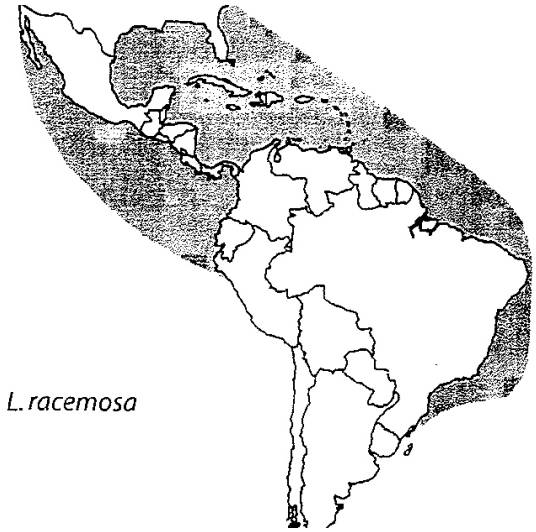


Figure 3.3b Distribution of *L. racemosa* in the Americas (taken from Lacerda *et al*, 2002)

Figure 3.3d Distribution of *P. rhizophorae* in the Americas (taken from Lacerda *et al*, 2002)

CHAPTER 2. METHODOLOGY

2.1 Initial surveys and establishment of permanent plots in the northern islands.

The first stage of the study involved initial surveys of mangrove cover in a number of the smaller, northern islands of the archipelago namely, Chapera, Mogo mogo and Bayoneta (see figure 2.1). These surveys were carried out by inflatable boat in the case of Chapera and by foot for Mogo mogo, a GPS device was used to record the location of areas of mangrove on the islands. The species present, the number of trees and the development of the stand were all estimated and recorded for each GPS "waypoint" taken. In this way all the mangrove on the island of Mogo mogo was recorded and the substantial areas of mangrove on Chapera. A second boat survey was carried out on the island of Rey, this was carried out by inflatable boat and again using a GPS device to record areas of mangrove and the species composition, depth of fringing forest and estimates of numbers of trees and maturity of the mangrove where appropriate. In this way the entire coastline of Rey was surveyed over a number of days.

Surveys of forest structure were also carried out on two of the islands, Mogo mogo and Bayoneta. Two 10m by 10m plots were carried out on Bayoneta and one plot on Mogo mogo, the methodology used is outlined in detail in sections 2.3 and 2.4 below. Sediment samples were also taken at these locations following the methodology outlined in section 2.5. These plots were marked permanently to allow re-location as is discussed below in sections 2.3 and 2.4. The opportunity to carry out surveys at these plots not only allowed the collection of valuable data but also allowed the team to practice the methodology and techniques required. These initial surveys also allowed the team to understand the logistics required travelling between locations and setting up equipment efficiently, before data collection at the three main sites commenced.

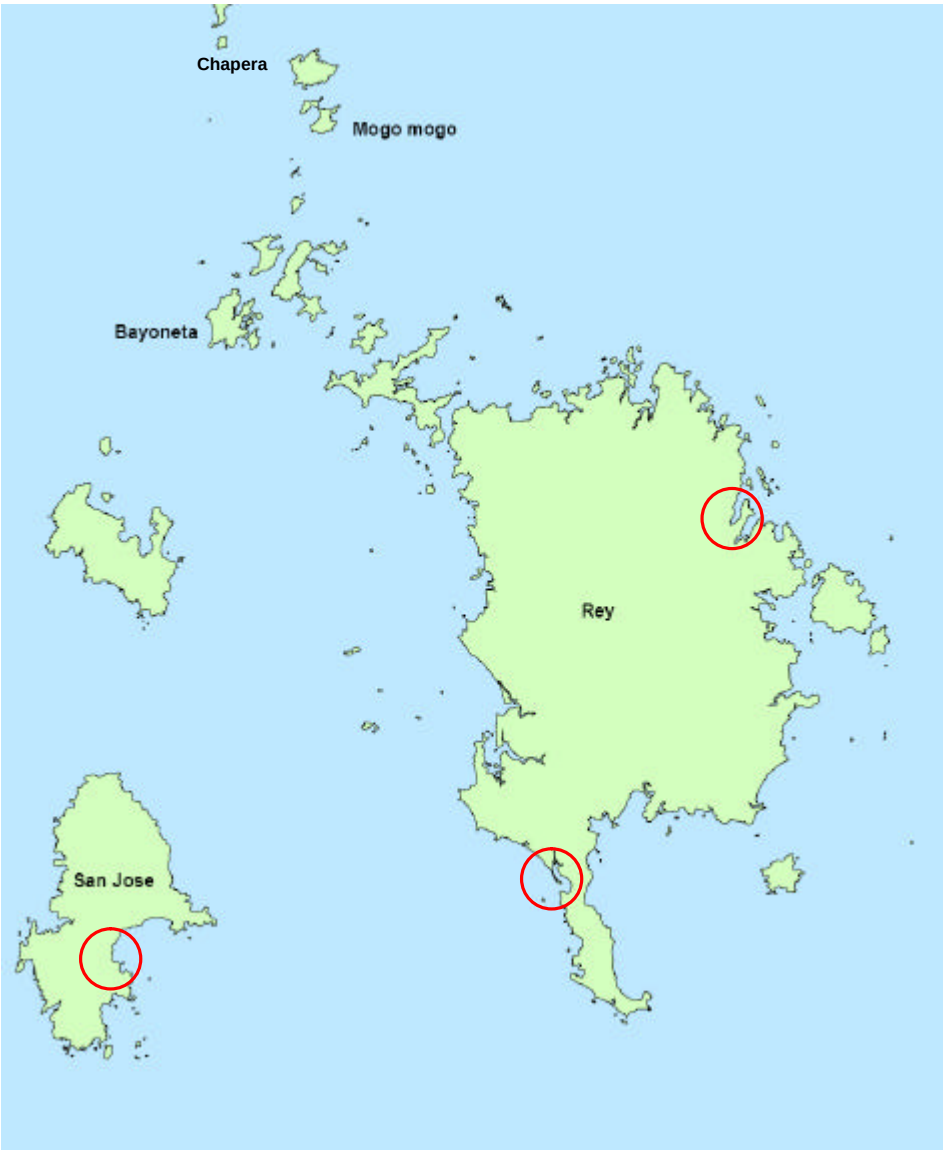


Figure 2.1 The islands surveyed during the study. The main study sites are circled in red, the more northerly site on Rey being "Rey 1" and the more southerly site being "Rey 2" (original GIS map courtesy of Benfield, 2006).

2.2 The main study sites

The three study sites were located in the Las Perlas islands, Panama (see figure 2.1). The study sites were chosen from previous visual surveys of the area by boat. Two sites on the island of Rey referred to as "Rey 1" and "Rey 2" in the text and one site on the island of San Jose were chosen. Rey 1 and Rey 2 were found at 08°24'N, 07°51'W and 08°16'N, 078°55'W and San Jose at 08°14'N, 079°06'W.

Each of the five plots within a site was chosen to be representative of the site as a whole and to be accessible by boat to allow access in the future. The locations of these plots are shown in figures 2.2a,b and c and their locations recorded using GPS as well as photographically to allow re-location (see Appendices).

Figure 2.2a The location of plots at the site Rey 1 (original GIS map courtesy of Benfield, 2006).

Figure 2.2b The location of plots at the site Rey 2 (original GIS map courtesy of Benfield, 2006).

Figure 2.2c The location of plots at the site San Jose (original GIS map courtesy of Benfield, 2006).

2.3 Collecting the data on saplings and adult trees

The 10m by 10m plots were marked out by first inserting a 1m PVC pole into the sediment that would represent 0,0 for the grid system of the plot. A 30m measuring tape was then used to measure a 10m axis from the mark. The second axis was measured from the point using a second 30m tape and a square to ensure the angle was a right angle. These were the x and y axis in the grid system, the way the plot was orientated in relation to 0,0 was common to all plots and is described in figure 2.3.

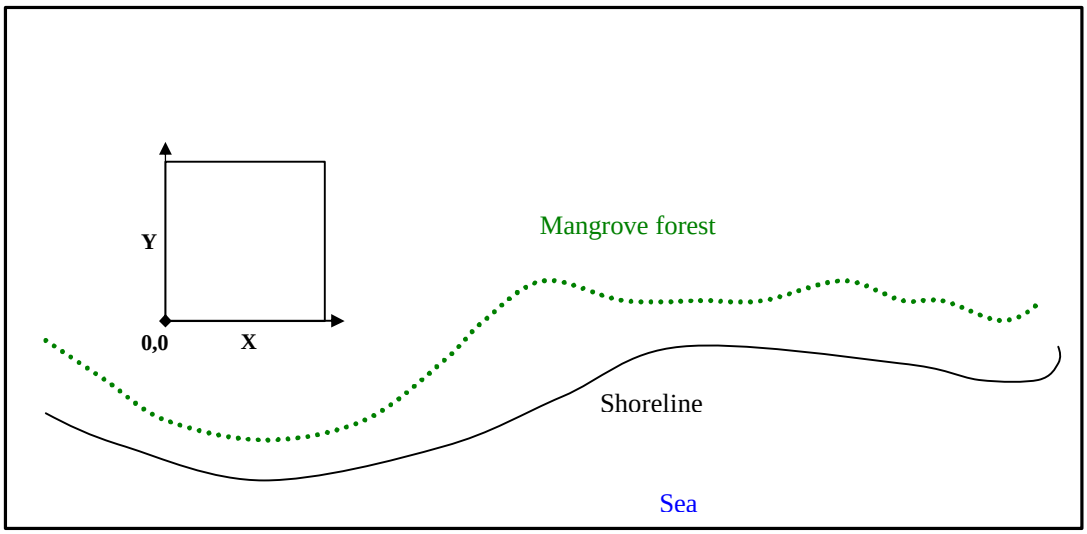


Figure 2.3 0,0 of 10m by 10m plot was always in the same position in relation to the shore i.e. on the shore side of the plot and to the left when back is to shore.

The remaining two sides of the plot were measured out using the same technique and the corners marked again by inserting PVC poles into the sediment. The sides of the plot were then re-checked with a tape measure to ensure they were 10m long. The sides of the plot were then marked out using two 30m ropes tied between the four corners, these ropes were then marked using tape at intervals of 1m to provide a grid from which to take the co-ordinates of the trees (see figure 2.4).

Figure 2.4 "0,0" of Reyes 1 plot 1 marked with PVC pole and the axis made up of two ropes with 1m markers.

After the plot had been marked out all trees within the plot greater than 1m in height from the sediment surface were marked using coloured tape. This height limit is used by organisations such as the Smithsonian Tropical Research Institute, CARICOMP (www1) and the Australian Institute of Marine Science (English et. al. 1997) to define the height above which trees should be regarded as saplings and more mature trees i.e. not seedlings. The Diameter at Breast Height (DBH) was then measured, the DBH is the diameter of the trunk of the tree at a height of approximately 1.3m. The DBH was measured using a calibrated measuring tape meaning no post-calculations were necessary. In many occasions the tree branched below 1.3m or in the case of *Rhizophera mangle* would branch above 1.3m to form prop roots. On these occasions the DBH was measured following the procedures described in figure 2.5. If the DBH was greater than 2.5cm then it was recorded. The cut off point of 2.5cm for DBH is another parameter used by organisations such as the Smithsonian Tropical Research Institute, CARICOMP (www 1) and the Australian Institute of Marine Science (English et. al. 1997) to distinguish between seedlings and more mature trees.

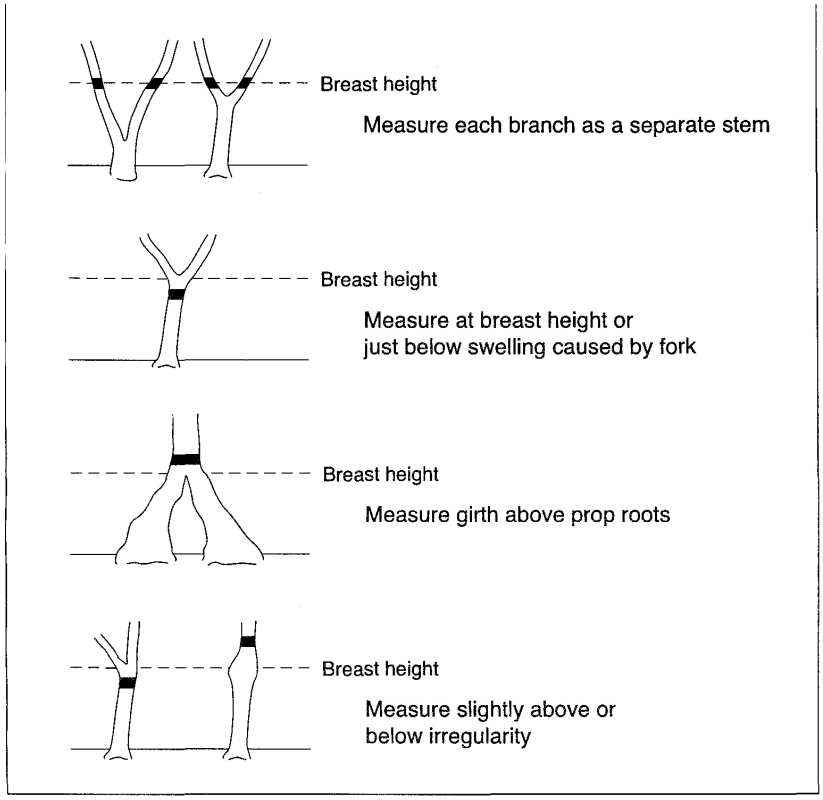


Figure 2.5 Procedure for measuring DBH of trees with different growth forms (taken from English *et al*, 1997)

The point at which the DBH had been taken was then marked with a band painted with a blue forestry pen to allow future recordings to be made accurately (see figure 2.6). The co-ordinates of the tree were then taken using the pre-marked grid and the species of the tree recorded. The height of the tree was taken using a graduated telescopic measuring pole to measure the highest point of the trees foliage. If this point was hard to identify due to dense foliage then a second person was required to stand at a distance to distinguish when the pole had reached the correct height. The tree was then marked with a metal tag embossed with a number that was attached by garden wire; it was ensured enough slack was left in the wire to allow the tree to grow in the future (see figure 2.6). The tag numbers were recorded to allow future relocation and identification.

Figure 2.6 Mangrove with metal tag attached with garden wire and tree marked with blue ink, note that tag is not embossed with number (photo taken from alternative survey site).

After all the relevant data had been recorded from the tree the coloured tape was removed, this way trees that were still to be recorded could be identified. After all the trees in the plot had been measured the ropes were removed from the sides and the PVC corner poles inserted into the ground further so that only 20cm (approx) was showing above the sediment surface. This was done to ensure the poles would stay in place despite sediment accretion or erosion. The point that was 0,0 in the grid was then marked with a black tie-wrap on the pole, the number (1-5) of the plot was written on the pole with a marker pen and the GPS location recorded, this was done to allow for ease of re-location, identification between plots and of the 0,0 point to aide future monitoring.

2.4 Collecting seedling data

Within each plot data on seedlings was also taken. Methodology adopted in previous studies (e.g. Benfield, 2002 and Defew, 2003) involved the recording of seedling data in five sub plots within each plot, this is also the standard methodology employed by organisations such as the Smithsonian Tropical Research Institute, CARICOMP (www 1) and the Australian Institute of Marine Science (English et. al.

1997). In this study however many of the 10m by 10m plots had a very low number of seedlings within them and it was possible to measure every seedling. Some plots did however contain a higher number of seedlings and so the standard methodology was adopted in these cases. The distinction between those plots at which the standard methodology was adopted and plots that would have all their seedlings measured was made by eye, approximately 50 seedlings per 10m by 10m plot was the cut-off point.

Figure 2.7 *Rhizophera* seedlings marked with orange tape at Reyes 1, plot 5.

The standard methodology dictates that five sub plots should be set up within the 10m by 10m plots. The location of the sub plots were chosen at random within the larger plot and the point that would represent 0,0 in the grid marked with a PVC pole. A 1m by 1m quadrat was then placed at this point as described in figure 2.8 1m rules placed along the x and y axis in order to get more accurate co-ordinates. The co-ordinates of each seedling within the sub plot were then recorded as well as the species and the height. If the tree was over 1m in height it was regarded as a sapling and not included in the survey. The seedlings were then tagged with a metal tag embossed with an identification number and these tags attached with garden wire. It was especially important in the case of tagging seedlings to ensure the wire was loose enough to ensure future growth. In those plots in which it was deemed the number of seedlings was low enough to measure them all the co-ordinates of the seedling were taken within the larger

10m by 10m plot see (figure 2.8). These co-ordinates, the species, height and tag number were all recorded in the same way as in the standard methodology.

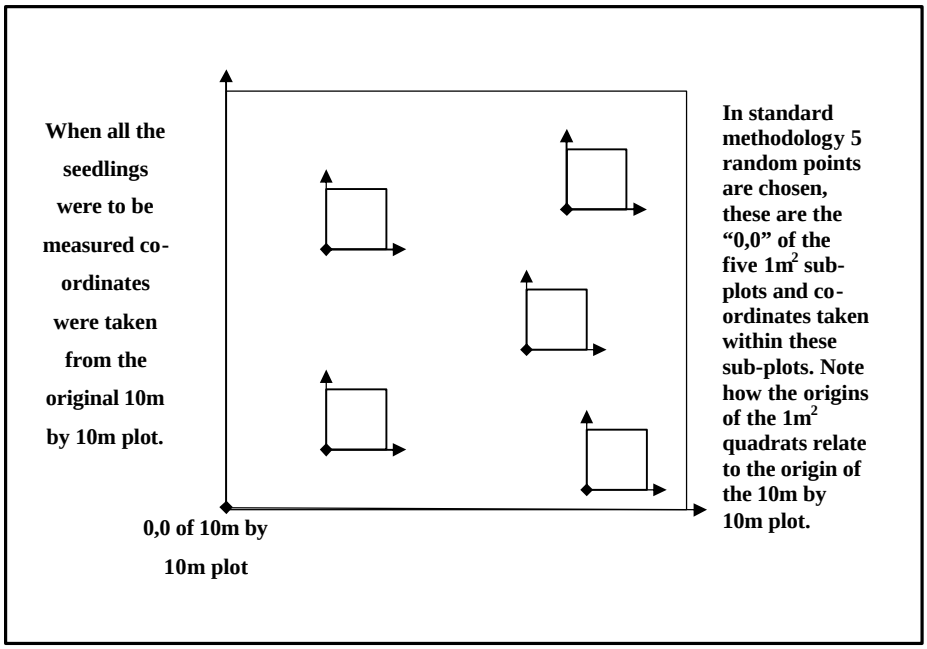


Figure 2.8 Showing the different quadrats used in standard methodology and the methodology used to record all the seedlings in a 10m by 10m plot.

2.5 Collecting sediment samples for character analysis

Within each 10m by 10m plot one sample was taken for analysis of sediment characteristics. A sample of approximately 1kg (wet weight) was taken by hand from the sediment surface, placed in a sealed plastic bag, excess water drained off and labelled. The samples were then frozen as soon as possible in order to minimise any biological or chemical processes that might occur within the sample.

2.6 Collecting sediment samples for metal analysis

Within each 10m by 10m plot three samples was taken for metal analysis. Each sample of approximately 1kg (wet weight) was taken by hand from the sediment surface, placed in a sealed plastic bag, excess water drained off and labelled. The samples were then frozen as soon as possible in order to minimise any biological or chemical processes that might occur within the sample. Once returned to the lab the samples were thawed, washed with distilled water and the sediment isolated and placed in an oven for 48 hours to remove all water making them ready for analysis.

2.7 Collecting Benthic samples

Two benthic samples were taken from each 10m by 10m plot. Each sample was made up of 4 grab samples using a Van r Veen grab with a capacity of $0.025m^2$. The sample was filtered through a 1mm mesh sieve to remove fine sediment. The sample was then transferred to 1 litre plastic bottles, labelled and formalin solution added in order to preserve the sample. Each sample was drained at the earliest opportunity and ethanol added to the sample. Once back at the lab the samples were sorted through and any benthic fauna found removed and identified to phylum level, they were then stored in 75% alcohol for further identification.

2.8 Data processing and analysis

The data from the initial surveys by boat including the waypoints that had been recorded were transferred to computer on returning from the survey. No analysis on the data was carried out as it was purely observational and was carried out to give a qualitative account of mangrove cover and is not part of the main study. The data from the initial survey is available in the Appendices.

Once the data from the main sites had been collected they were entered into standardised Microsoft Excel CARICOMP spreadsheets (available at www1). Adult and seedling data were entered into independent spreadsheets as well as being divided on the basis of species. Data on the plots including their GPS location were also entered for future reference. These spreadsheets are available in the appendices. The CARICOMP spreadsheets calculate a number of parameters relating to forest structure, the parameters used in this study include the basal area of each adult tree as well as the total, mean, standard deviation and standard error for the plot according the calculations outlined in Cintrón and Schaeffer Novelli (1984). These were calculated for each species in each sub plot. The importance value of each species was then calculated for each plot to analyse the contribution of each of the three species to the forest and to determine the most important species in each plot. The importance value was calculated by summing the relative density, frequency and dominance of a species within the plot using the equations described in English *et al* (1997) and Cintrón and Schaeffer Novelli (1984).

Adult and seedling data on height were then exported to Minitab version 14 where histograms were produced for all plots (see Appendices) and for the three sites.

Box and whisker plots were also produced for the three sites. Data on adult DBH were also exported to Minitab and histograms and box and whisker plots produced for the three sites and for all plots (see Appendices). Data on adult and seedling species composition were exported to new Microsoft Excel spreadsheets and pie charts produced for the three sites and for all plots (see Appendices).

No further statistical analysis was carried out on the adult or seedling data. This was because the sites and plots within sites were chosen to be representative of mangrove cover i.e. they were not chosen at random but purposefully chosen to cover a range of forest structure and give a qualitative rather than quantitative analysis. In addition, for seedling data two different methodologies were adopted meaning further statistical comparison between plots or sites would give results not directly comparable (due to differing sample sizes).

The sediment samples were left in the Smithsonian Tropical Research Institute were they were analysed for organic carbon content, carbonate content and particle size. The results of these analyses were then sent by e-mail to the author. The analyses were carried out in Panama due to the large size and weight of the samples and monetary restraints that would be involved in sending them back to Scotland.

The sediment samples for metal analysis as well as benthic samples were not processed any further than outlined above: monetary restraints meant that the benthic samples could not be sent back to Scotland. The author was advised that at this stage it was not cost-effective to go to the expense of analysing sediment samples taken for metal contamination as the experience of the staff at the Smithsonian Tropical Research Institute predicted that metal concentrations in the area were very low and that results were likely to be inconclusive. All samples were however preserved, labelled and stored within the Smithsonian Tropical Research Institute providing a potential set of baseline data for the area should it be required in the future.

CHAPTER 3. RESULTS

3.1 Adult data

A summary of adult parameters derived from the field data is given in table 3.1.

Table 3.1 Parameters derived from all field data collected from all 15 plots including the means, standard deviation (SD) and standard error (SE) for the 3 sites.

Plot	Total Number of Trees (>1m in height and DBH >2.5cm)	Density of trees >1m and DBH >2.5cm per m2	Total basal area of stand in 10m plot (m2/ha)
Rey 1,1	56	0.56	12.27
Rey 1,2	32	0.32	16.17
Rey 1,3	23	0.23	5.40
Rey 1,4	24	0.24	3.57
Rey 1,5	5	0.05	7.00
Rey 1 means	**28**	**0.28**	**8.88**
Rey 1 SD	**19**	**0.19**	**5.20**
Rey 1 SE	**8**	**0.08**	**2.33**
Rey 2,1	76	0.76	6.72
Rey 2,2	20	0.20	24.75
Rey 2,3	13	0.13	22.95
Rey 2,4	15	0.15	9.40
Rey 2,5	23	0.23	21.49
Rey 2 means	**29**	**0.29**	**17.06**
Rey 2 SD	**26**	**0.26**	**8.35**
Rey 2 SE	**12**	**0.12**	**3.74**
San Jose 1	6	0.06	42.47
San Jose 2	8	0.08	25.37
San Jose 3	1	0.01	0.20
San Jose 4	3	0.03	11.45
San Jose 5	6	0.06	0.57
San Jose means	**5**	**0.05**	**16.01**
San Jose SD	**3**	**0.03**	**18.01**
San Jose SE	**1**	**0.01**	**8.05**

The mean number of trees was almost equal in Rey 1 and Rey 2 (28 and 29 trees respectively) both being much higher than in San Jose that had a mean value of 5 trees. However, when standard deviation is compared it can be seen that Rey 2 had a very large standard deviation (26) relative to its mean value showing a wide variation in the number of trees within its plots (13-76). The San Jose site had a very low standard deviation of 3, this was due to the narrow range in the number of trees within its plots (1-8 trees). Because the plots are all of the same size the density of trees in the plots

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follows the pattern described by the number of trees, namely Rey 2 being the most dense and San Jose being the least dense. Table 3.1 also shows that the mean total basal area is highest in Rey 2 (17.06 $m^2 ha^{-1}$), this is part in due to the large number of trees in the plots of Rey 2. San Jose has the second highest mean total basal area with a value of 16.01 $m^2 ha^{-1}$ despite its very low number of trees . San Jose shows a standard deviation higher than its mean value (18.01 $m^2 ha^{-1}$) this is due to plot San Jose 3 having a very low value (0.2) and San Jose plots 1 having a very high value (42.47).

Table 3.2 shows that for the three sites a different species is ranked as the most important. At Rey 1 *L.racemosa* is calculated to be the most important, it is ranked as the most important in plots 2,3 and 5 having higher density and dominance in plots 3 and 5 than the *R. mangal* and *P. rhizophorae* although *R. mangle* has a higher density in plot 2. *R. manglel* is the most important species in the remaining 2 plots (1 and 4) and the second most important in plots 2 and 3. *P. rhizophorae* is the least important species in plots 1-4 but is the second most important species in plot 5 ahead of *R. mangle*. At Reyes 2 *P.rhizophorae* is calculated as the most important species being the most important species in three out of the five plots (2,3 and 5) however, the only plot were it is clearly dominant is plot 5. *P. rhizophorae* is the least important species in plot 3. *R. mangle* is the most important species in plot 1 and is the second most important species in plots 2,3 and 5 it is the least important species in plot 5. In plot 4 *L.racemosa* is the most important species, but the least important species in plots 2,3 and 5 making it the least important species in the site as a whole behind *R. mangle*. Reyes 2 is the most balanced of the three sites in terms of the share of importance ranks between the three species. In contrast to Rey 2, San Jose is dominated by *R. mangle* in all of its plots. In plots, 1-4 *R. mangle* is the only species to be found and so receives a score of 300 (100%) in these plots, in these instances *L.racemosa* and *P. rhizophorae* are both given a rank of 2 as opposed to 2 and 3. In San Jose plot 5 there is *L. racemosa* present although this was only one individual and so *R. mangle* remains the dominant species.

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Table 3.2 The relative density, frequency and dominance values of the three species in the 15 plots and sums for the 3 sites. (L=*L.racemosa*, R=*R,mangle*, P=*P.rhizophore*). The importance value is obtained by summing these values to give a score out of 300. Here they are summed to give a score out of 1500 for each site and ranked where 1=most important and 3=least important.

Plot	Relative Density			Relative Frequency			Relative Dominance			Importance Value			Importance Rank 1-3		
	L	R	P	L	R	P	L	R	P	L	R	P	L	R	P
Rey 1,1	10.71	89.29	0	50	50	0	53.8	46.2	0	114.52	185.47	0	2	1	3
R 1,2	31.25	56.25	12.5	33.33	33.33	33.33	71.42	15.16	13.42	136	104.74	59.25	1	2	3
R 1,3	65.22	34.78	0	50	50	0	82.6	17.4	0	197.81	102.19	0	1	2	3
R 1,4	4.17	95.83	0	50	50	0	8.45	91.56	0	62.62	237.38	0	2	1	3
R 1,5	80	0	20	50	0	50	85.16	0	14.84	215.16	0	84.84	1	3	2
Sum of Rey 1	**191.35**	**276.15**	**32.5**	**233.3**	**183.3**	**83.33**	**301.43**	**170.32**	**28.26**	**726.11**	**629.78**	**144.09**	**7 (1)**	**9 (2)**	**14 (3)**
Rey 2,1	51.32	48.68	0	50	50	0	61.25	38.76	0	162.56	137.44	0	2	1	3
R 2,2	15	35	50	33.33	33.33	33.33	54.91	7.79	37.3	103.24	76.12	120.64	3	2	1
R 2,3	0	69.23	30.77	0	50	50	0	26.64	73.36	0	145.87	154.13	3	2	1
R 2,4	33.33	6.66	53.33	33.33	33.33	33.33	80.37	0.75	15.28	147	40.75	101.94	1	3	2
R 2,5	0	4.35	95.62	0	50	50	0	1.9	98.1	0	56.24	243.76	3	2	1
Sum of Rey 2	**291**	**440.07**	**262.2**	**350**	**400**	**249.99**	**497.96**	**246.16**	**252.3**	**412.8**	**456.42**	**620.47**	**12 (3)**	**10 (2)**	**8 (1)**
San Jose 1,1	0	100	0	0	100	0	0	100	0	0	300	0	2	1	2
SJ 1,2	0	100	0	0	100	0	0	100	0	0	300	0	2	1	2
SJ 1,3	0	100	0	0	100	0	0	100	0	0	300	0	2	1	2
SJ 1,4	0	100	0	0	100	0	0	100	0	0	300	0	2	1	2
SJ 1,5	16.66	83.33	0	50	50	0	16.97	83.05	0	83.61	216.39	0	2	1	3
Sum of San Jose	**16.66**	**483.33**	**0**	**50**	**450**	**0**	**16.97**	**483.05**	**0**	**83.61**	**1416.4**	**0**	**10 (2)**	**5 (1)**	**11 (3)**

The dominance of each of the three species is further demonstrated in figure 3.1 that shows the number of individuals of each species at each site as a percentage of the total number of individuals. Pie charts showing the number of individuals of each species in each plot as a percentage of the total number of individuals were also produced (see Appendices). Figure 3.1 shows *R. mangle* to be the dominant species in at Rey 1 as opposed to *L. racemosa* as described in table 3.2, this is because figure 1 does not to take into account the basal area or frequency of the species as the calculations for relative importance do but merely the number of individuals. When compared together figure 3.1 and table 3.2 show that although *L. racemosa* makes up only 26% of individuals it is the dominant species at Rey 1 when other factors are taken into account. Table 3.2 and figure 3.1 both describe *P. rhizophorae* as the least important species at Rey 1. Figure 3.1 shows a much more even spread of species importance at Rey 2 but again showing *R. mangle* to be dominant with a value of 38% and *L. racemosa* and *P. rhizophorae* having values of 32% and 30% respectively. Both table 3.2 and figure 3.1 demonstrate the evenness of species importance at Rey 2. In the case of Rey 2 *P. rhizophorae* is identified as the most important by table 3.2 but the least important in terms of numbers of individuals by figure 3.1. Figure 3.1 identifies *R. mangle* to be by far the most abundant species at San Jose, this is unsurprising as all but 1 tree recorded at San Jose was *R.mangle* the individual tree being *L. racemosa*.

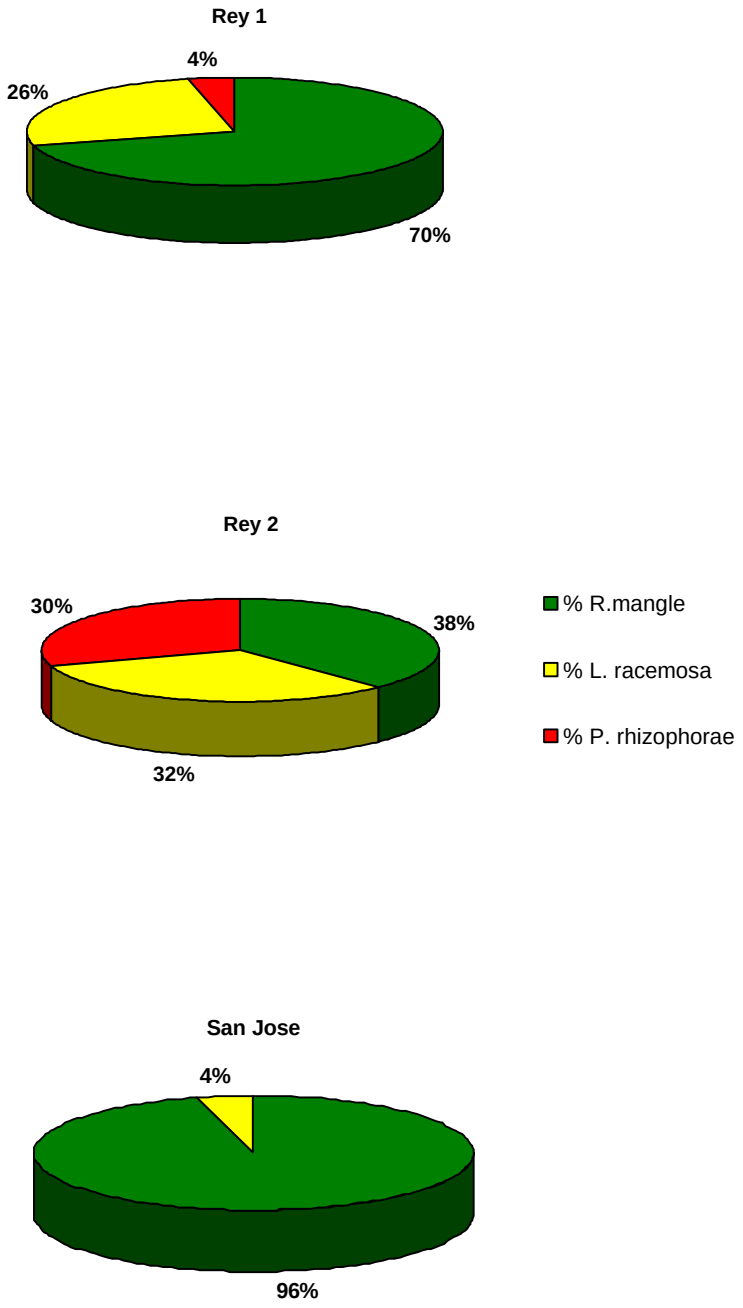

Figure 3.1 A comparison was made of the species composition of adult trees in each of the three sites. Results are expressed as the number of species in each plot as a percentage of the total number of trees in the plot.

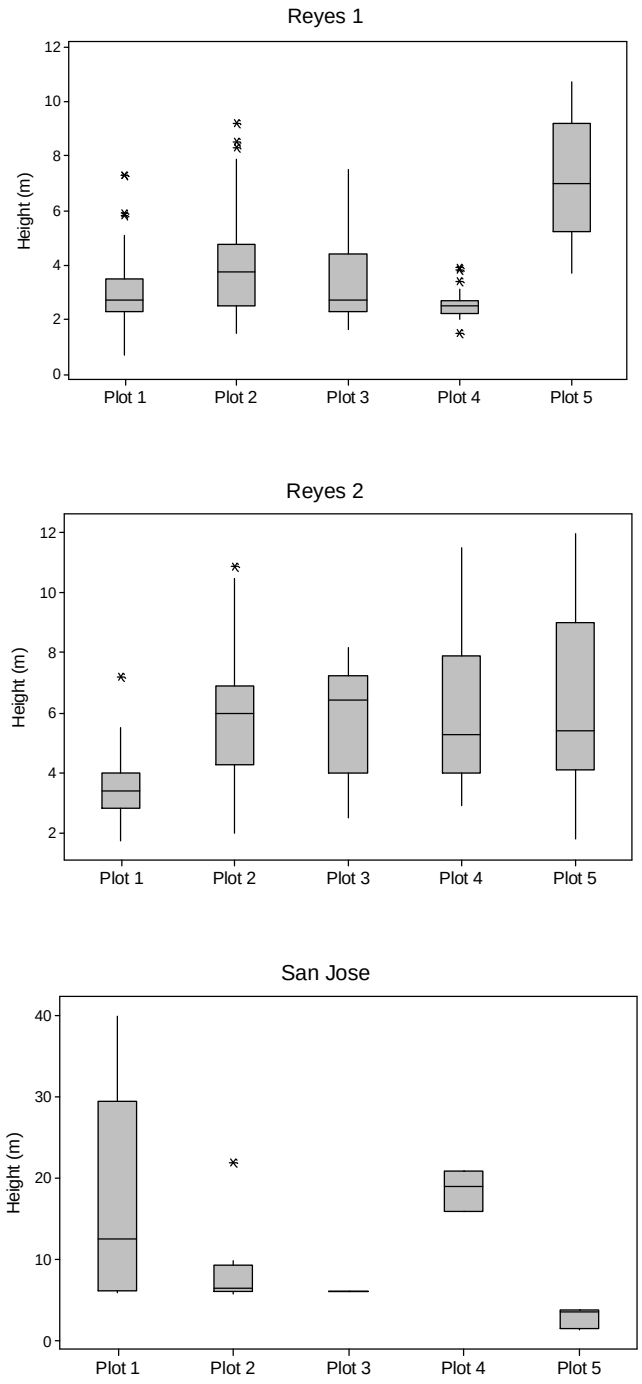

Figure 3.2 A comparison of adult height means and ranges amongst the 5 plots surveyed in the 3 sites. The asterisks show those trees which were out of the interquantile range for each site. Note; difference in scale in height axis between box plots.

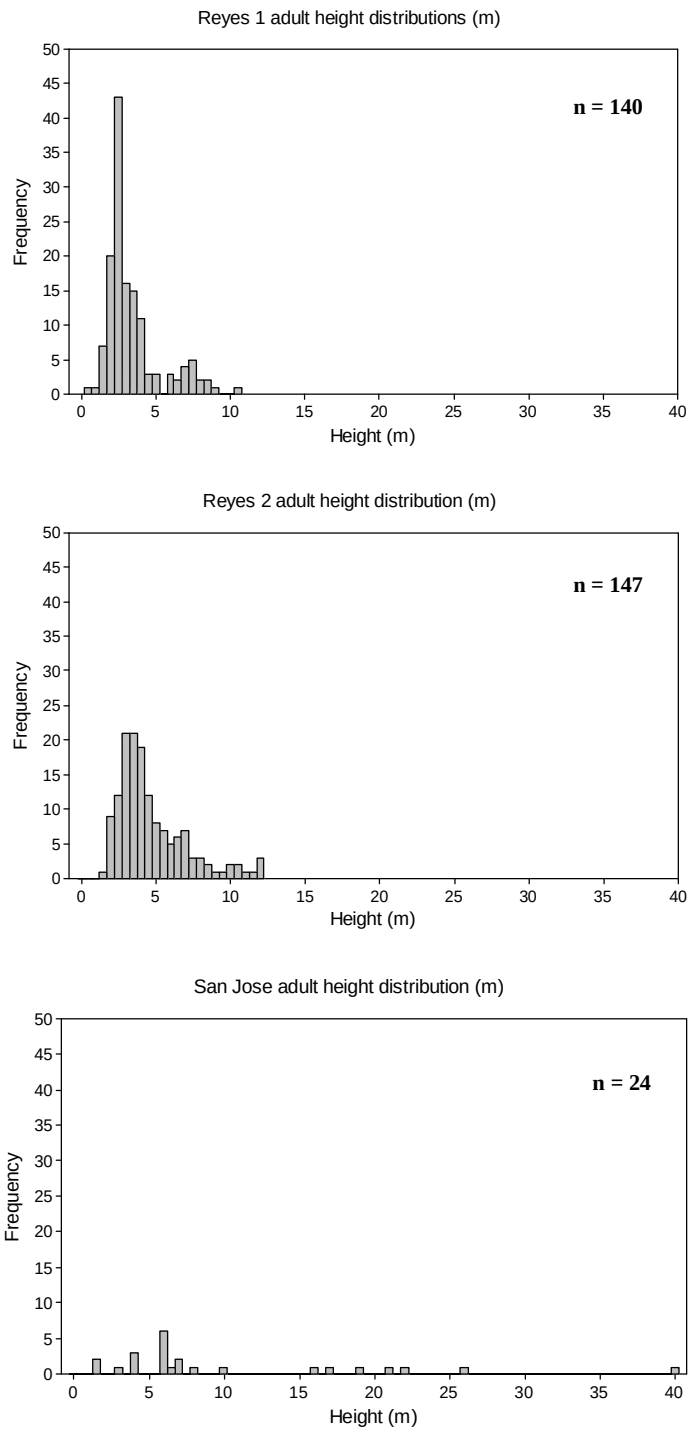

Figure 3.3 Histograms showing the distribution of adult height classes between the three sites.

Figure 3.2 shows the differences in mean height and range between the 3 sites and also within the plots for each site. Figure 3.2 shows that Rey 1 has a generally more narrow range in height than Rey 2 but that these ranges fall within those of Rey 2 and that there is no substantial difference in heights. San Jose shows less regularity between its plots than the other two sites. San Jose plot 1 shows the largest range in height of any of all the 15 plots and also has the narrowest range in plot 4 although this is due to the presence of just 1 tree in this plot. The other 3 San Jose plots all fall out of each other's height ranges this can be explained by the fact that San Jose plots had very few trees (no plot had greater than 8 trees within it). The differences in heights between the 3 sites can be analysed further in figure 3.3 which shows the distribution of adult height classes between the 3 sites. Histograms showing the distribution of adult height classes between the individual plots were also produced (see Appendices). Figure 3.3 shows that Rey 1 and Rey 2 show a very similar distribution in heights, both being skewed to the left showing that these sites are dominated by (relatively) shorter trees. Rey 1 does however have a substantially larger frequency of its most dominant size class, 2.5m than Rey 2 that has equal dominant size classes of 3m and 3.5m. Rey 2 also has a slightly wider range of heights that are generally taller than those in Rey 1, Rey 2 also reaches a higher maximum height class of 12m as opposed to the maximum of 10.5m found in Rey 1. San Jose shows a markedly different range of height classes when compared to the sites on Rey. San Jose exhibits a much wider range in height classes than the Rey sites showing a maximum value of 40m. The height classes on San Jose are also skewed to the left similarly to the Rey sites but its most frequent size class is much larger at 6m and its range is not continuous like those of the Rey sites with many intermediate height classes unrepresented.

Figure 3.4 shows the differences in mean DBH and range between the 3 sites and also within the plots for each site. Figure 3.4 shows Rey 1 to have narrower range of DBH values when compared to Rey 2 but that both sites have largely similar mean values for their plots with the exception of Rey 1, plot 5 which has a substantially higher mean value. Much like the height data represented in figure 3.2 San Jose has a markedly different set of means and ranges for its 5 plots with a large range for plot 1

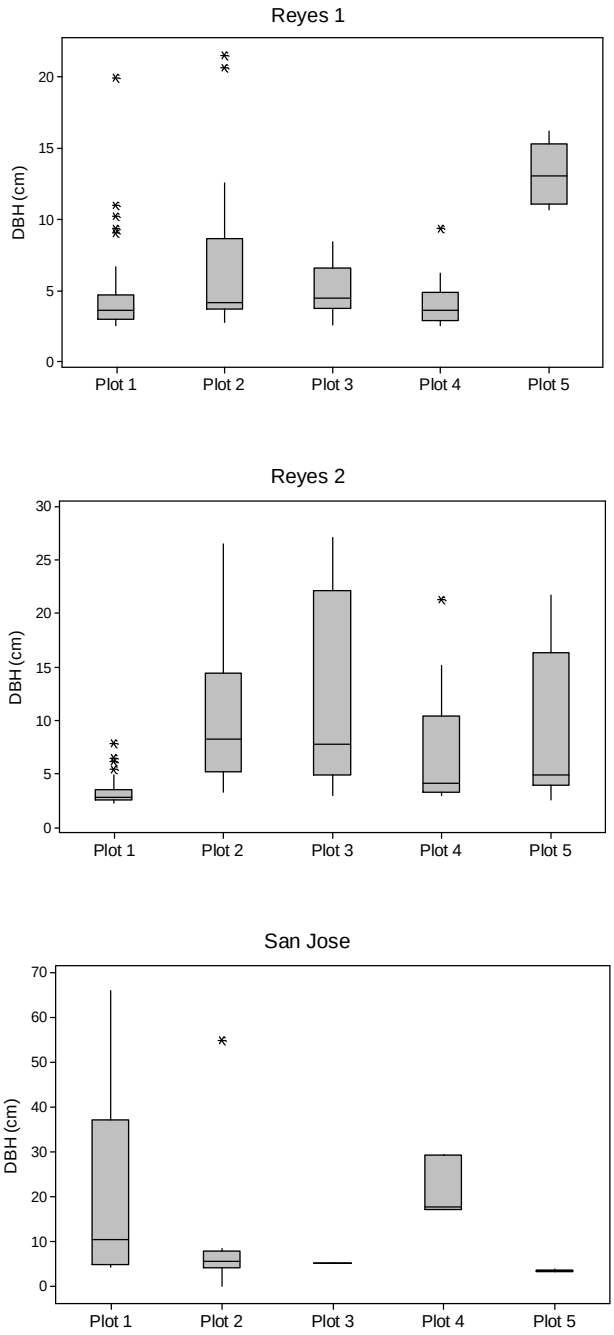

Figure 3. 4 A comparison of DBH means and ranges amongst the 5 plots surveyed in the 3 sites. The asterisks show those trees which were out of the interquantile range for each site. Note; difference in scale on DBH axis between box plots.

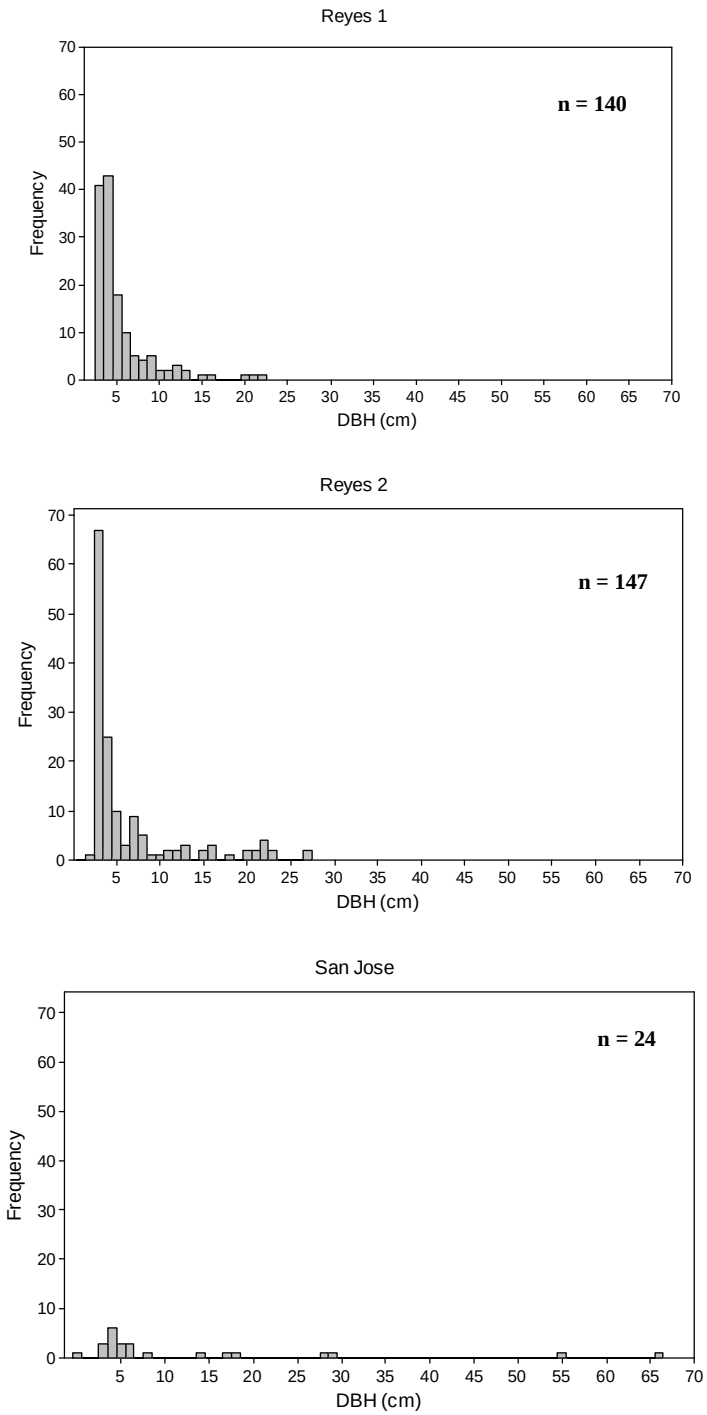

Figure 3.5 Histograms showing the distribution of DBH >2.5cm between the three sites.

and very narrow ranges in the rest of its plots owing to the low number of trees. The mean values in plots 1,2,3 and 5 are comparable to some of the plots in Rey 2 being around 10m, plot 4 does however have the highest mean value for any of the 15 plots. Figure 3.5 also represents DBH data from the three sites in the form of histograms showing the distribution of DBH value classes. Histograms showing the distribution of adult DBH within the individual plots were also produced (see Appendices). All of the 3 sites show a skewed distribution to the left showing a tendency for trees with a lesser girth. Rey 1 and Rey 2 both show a roughly similar distribution with the classes found in highest frequency being the smallest classes with a drop in frequency with an increasing DBH, there are however some differences. Rey 1 and 2 both show very similar median DBH classes (2cm and 3cm respectively) although Rey 2 shows a much higher frequency in its median class. Rey 2 also shows a slightly higher maximum value (27cm) when compared to Rey 1 (22cm). San Jose shows a similar distribution in that it is skewed to the left and also shows a similar median class value (4cm). San Jose does however have a much larger range with a maximum class of 66cm and shows far lower frequencies than the Rey sites as well as an incomplete range of classes.

3.2 Seedling data

Figure 3.6 shows the number of individual seedlings of each species at each site as a percentage of the total number of seedlings. Pie charts showing the number of individual seedlings of each species in each plot as a percentage of the total number of individuals were also produced (see Appendices). Figure 3.6 shows that at all three sites *R. mangle* is the dominant species among seedlings, *L. racemosa* is the second most abundant at the 2 Rey sites with 34 % and 3% respectively but is not represented at San Jose. No seedlings of *P. rhizophorae* were recorded at any of the sites.

Figures 3.7 and 3.8 were produced to describe the height distribution among seedlings at the three sites. Figure 3.7 shows the differences in mean height and range between seedlings at the 3 sites and also within the plots for each site. Figure 3.7 shows that all sites show a wide variety of distributions between their plots. While having a wide range of overall values the mean value for each plot in Rey 1 are very similar

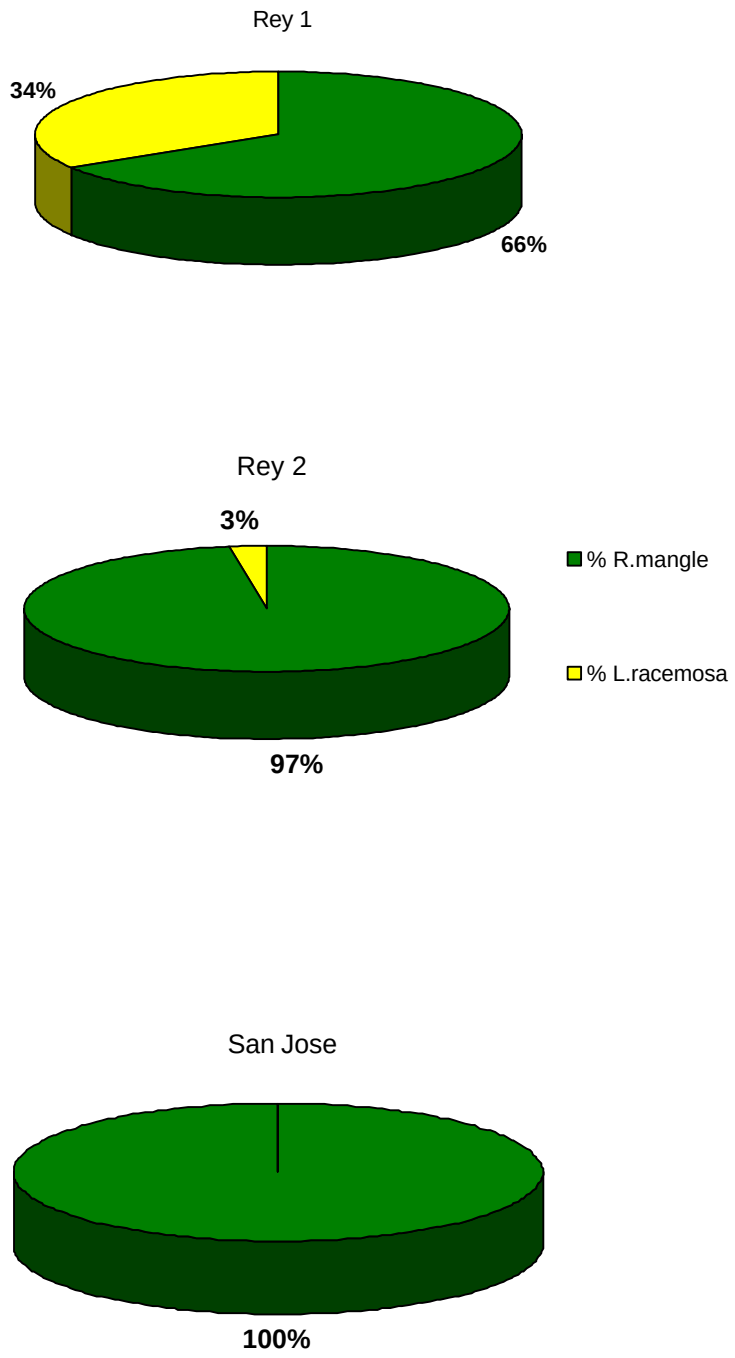

Figure 3.6 A comparison was made of the species composition of seedlings in each of the three sites. Results are expressed as the number of species in each plot as a percentage of the total number of seedlings in the plot.

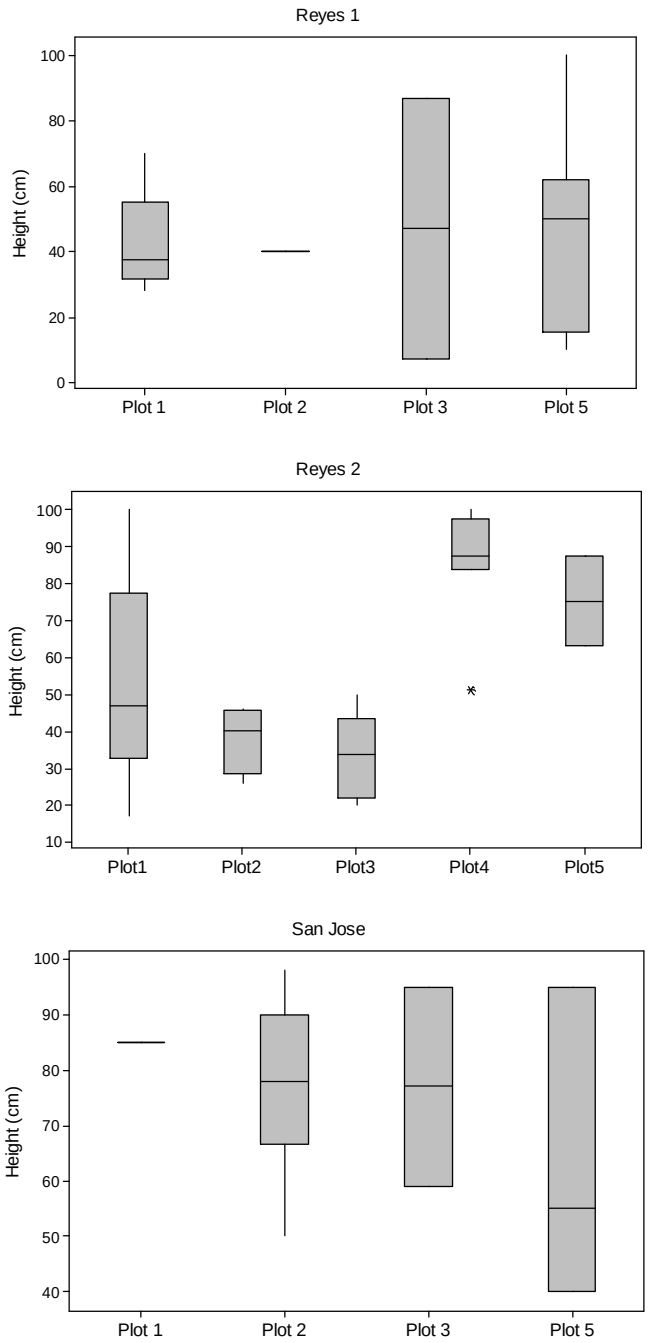

Figure 3.7 A comparison of seedling height means and ranges amongst the 5 plots surveyed in the 3 sites. The asterisks show those seedlings which were out of the interquantile range for each site. Note; no seedlings were present in Rey 1, plot 4 or San Jose, plot 4. Note differences in scales of height axis.

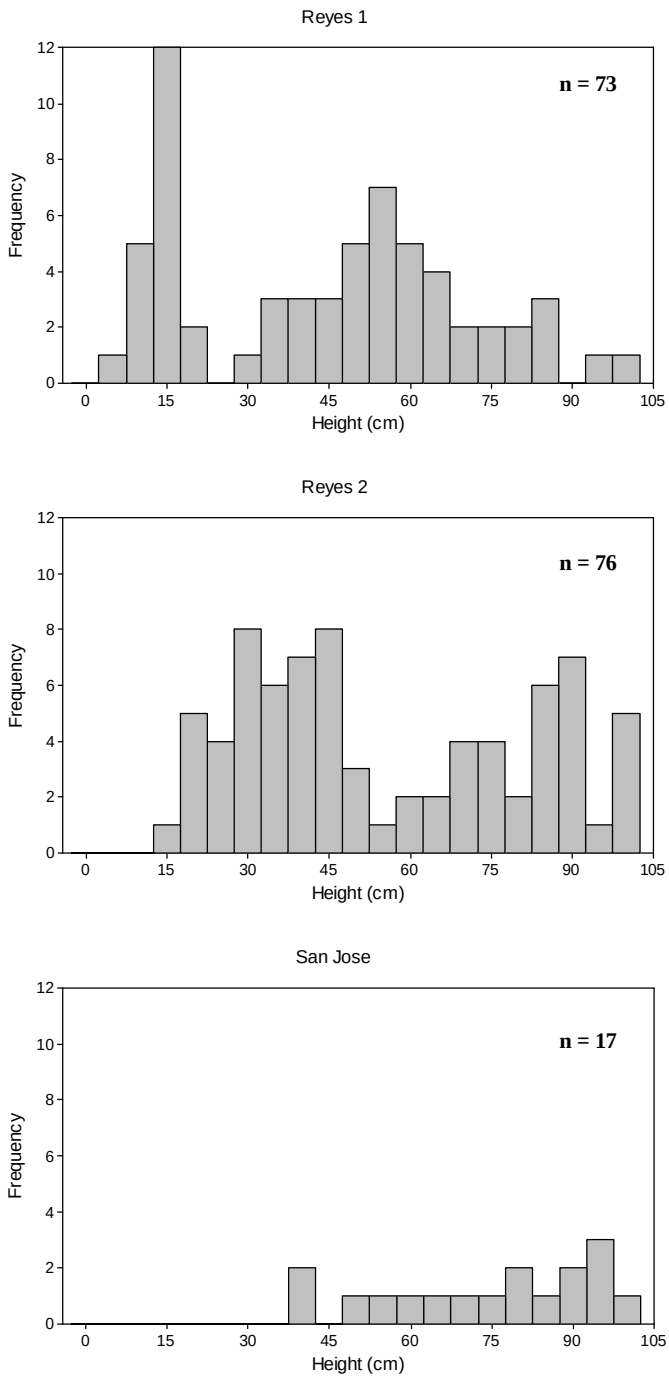

Figure 3.8 Histograms showing the distribution of seedling height classes between the three sites.

(between 40cm and 50cm) while in Rey 2 the means show a range between 38cm and 91cm. San Jose has generally higher value ranges in height than the Rey sites but none of these go below 40cm. 3 out of the 4 plots at San Jose have their means between 75cm and 85cm while plot 5 has a much lower mean of 56cm. Figure 3.8 further describes the seedling height distributions between the 3 sites. Figure 3.8 shows that Rey 1 and Rey 2 show a similarly wide range in seedling height distribution. Rey 1 represents what could be regarded as a normal distribution were it not for its median value being 15cm and another high frequency at 10cm. The height distribution of Rey 2 is roughly bi-modal with one peak between 30cm and 45 cm and another peak at 90cm. Rey 2 seedlings are not represented below 15cm. The height distribution of seedlings at San Jose does not show any obvious pattern and has a much narrower range than the Rey sites with a lowest value class of 40cm. The median value class for San Jose is 95cm.

3.3 Sediment analysis

Table 3.3 shows sediment composition of all plots from the 3 sites in terms of percentage of organic carbon, carbonate and percent composition in terms of particle size. Table 3.3 shows that Rey 1 has generally lower organic carbon and carbonate content than the other two sites and that in terms of particle size is made up of medium to very fine sand. Rey 2 has the most carbonate content of any of the three sites and is made up mostly of medium and fine sands. San Jose shows the highest levels of organic carbon of any of the 3 sites and it has substantially more of its particle composition made up of the silt-clay fraction.

Table 3.3 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.

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

CHAPTER 4. DISSCUSSION

4.1 Assessment of the 3 sites

The forest structure of the 3 sites will be discussed in relation to their maturity. It is commonly accepted within the literature that increasing stand basal area (calculated using DBH) and lower densities are indicative of more mature plots (e.g. Cintrón and Schaeffer-Novelli, 1984). Height can also be used as it will increase through time and so this can be used as a measure of maturity in some cases although using such data in isolation may lead to false conclusions. The species composition and importance of each species at the 3 sites will also be discussed as well as species composition, height and density for seedling data.

4.2 Assessment of Rey 1

4.2.1 Assessment of Rey 1 species composition

The species present at Rey 1 can be regarded as typical of the area, *R. mangle, L. racemosa* and *P. rhizophorae* are all known in the area, *R. mangle, L. racemosa* being particularly common but *P. rhizophorae* less so. The fact that there are only 3 species is not uncommon, Central American mangroves are generally species poor (Murray *et al*, 2003). *R. mangle* was found to be the most numerous and densely distributed species at the site although *L. racemosa* was found to be the most important in relation to forest structure (table 3.2). *L. racemosa* is usually regarded as an excellent pioneer species that is out-competed as the forest develops and therefore moves back to higher elevations. The importance of *L. racemosa* at the site would infer that this is an early stage community. There is an alternative hypothesis however, the mangrove cover at Rey 1 is in a relatively narrow band between the shore and the terrestrial forest, therefore it could be possible that the stand is in a more mature phase and *L. racemosa* is dominant because it has larger trees in a very narrow band behind the more numerous *R. mangle*.

4.2.2 Assessment of Reyes 1 forest structure

The data gathered from Rey 1 indicates that it is either a reasonably young forest or that its growth and development is being stunted by unfavourable conditions. The basal area for the stand is calculated to be 8.8 m^2 ha^{-1} (table 3.1), this is low when compared to other values for the Pacific Central America area which range from 6 to 96.4 m^2 ha^{-1}, the highest

value of 96.4 m^2 ha^{-1} being for nearby Costa Rica (Jimenez, 1990 and Pool *et al*, 1977) it should be noted however that these high values were recorded for a species not recorded at Rey 1 (*Pterocarpus officinalis*). The density of adult trees at Rey 1 is very low when compared to some figures in the literature (e.g. Cox and Allen, 1999 and Ong *et al*, 1995) low densities are indicative of either a young or a very mature forest. From the data relating to basal area it is logical to conclude that the low tree density at Rey 1 is due to the under-development of the site. The height distribution between the plots support these conclusions, the median value group for height is 2.5m (figure 3.3), this is in the dwarf range outlined by Murray *et al* (2003) albeit at the "top end", 3m being the cut-off point. This height distribution is also small when compared to the value for Panamanian mangroves quoted by Mayo (1965) of 22m. The height range of Rey 1 does however fall into the middle of the range described for mangrove forests on Panamas Caribbean coast (Lovelock *et al*, 2005).

We can therefore conclude that the forest at Rey 1 is either young, or is having its growth restricted by abiotic or biotic factors. Rey 1 is a fringing forest (personal observation), which Lacerda *et al* (2002) tell us to be the least productive of the three community types owing to a lack of nutrients. It was noted that little or no leaf litter was found on the sediment surface at Rey 1, presumably having been removed by the tide (see photographs in Appendices) this would result in low nutrient availability. Analysis of the sediment (see table 3.3) tells us that the sediment at Rey 1 contained relatively little organic carbon, although this does not directly relate to nutrient availability it is possible to infer that the sediment had little nutritive quality if it did not contain much organic matter. It may be possible to conclude therefore that poor nutrient availability is one of the factors contributing to the forests structure.

4.2.3 Assessment of Rey 1 seedling data

The species composition of the seedling cohort at Rey 1 differs from the adult species composition in that there are no individuals of *P. rhizophorae* present (see figure 3.1 and 3.6). This was common with all sites visited during the study and seems unusual. The proportion of *L. racemosa* and *R. mangle* are however roughly representative of the adult species composition. The mean heights of the seedlings are close to uniform (see figure 3.7). The distribution of seedlings between plots was uneven, out of a total of 62 seedlings 53 were found in plot 5, none were found in plot 4 leaving 9 seedlings between the first 3 plots (see

appendices for raw data). The high number of seedlings in plot 5 was most likely due to the low number (5) of adult trees in the plot, meaning more light was available, an important factor for the development of *L. racemosa* seedlings (Smith, 1987c and Ewel *et al*, 1998). If plot 5 is ignored we can see that there are 9 seedlings between the remaining four plots and that the density of seedlings at the site is extremely low. This could be due to the fact that the community is in a very early stage of development, which is obviously not the case, or is in a more mature phase. However, neither of these explanations makes sense when the adult data is considered, it is therefore more likely that the seedlings are being prevented from establishing by some limiting factor.

4.3 Assessment of Rey 2

4.3.1 Assessment of Rey 2 species composition

The species present at Rey 2 are the same species found at Rey 1, *R. mangle, L. racemosa* and *P. rhizophorae*. They are found in near equal numbers throughout the site but *P. rhizophorae* is identified as the most important species (table 3.2). This is important, *P. rhizophorae* has a very limited distribution and Jimenez (1984) reports that significant stands of this species are found only in neighbouring Costa Rica. Although *P. rhizophorae* shares the smallest share in terms of number of individuals of the 3 species present it is deemed the most important due to its high basal area meaning that it must be relatively well developed in this area. The dominance of this species tells us that the area must experience the high rainfall or terrestrial run-off required to support this species (Jimenez, 1984) and when the numbers of *P. rhizophorae* are compared to the location of plots within the site we see that they increase following a creek in-land, this makes sense as more freshwater influence would be expected in land.

4.3.2 Assessment of Rey 2 forest structure

When compared to the values for basal area for Pacific Central America (6 to 96.4 m^2 ha^{-1} (Jimenez, 1990 and Pool *et al*, 1977)) it can be seen that Rey 2 (with a mean value of 17.06 m^2 ha^{-1} (table 3.1) is relatively immature. This is supported by the value of 290 stems (with DBH >2.5cm) per hectare for density, which is also relatively low. I do not believe this low density is indicative of immaturity in all the sites however, in plots 2,3,4 and 5 the vegetation was dominated by fewer numbers of larger individuals of *P. rhizophorae* than in

plot 1 that had no *P. rhizophorae* and only *R. mangle* and *L. racemosa*. Plot 1 has a density value substantially higher than the other four plots (see table 3.1) indicating it is less mature. The mean heights in the 5 plots range from 3.4m to 6.4m (see figure 3.4) and so fall within the range defined by Murray *et al* (2003) for medium trees the heights are also substantially less than the values of 16m reported in Costa Rica by (Pool *et al*, 1977). The heights recorded by Pool *et al*, (1977) and Murray *et al* (2003) do not refer to *P. rhizophorae* however, Tomlinson (1999) tells us that mature trees of *P. rhizophorae* can be expected to grow between 5 and 10m, the mean heights at plots dominated by *P. rhizophorae* at Rey 2 fall within this range and therefore it is likely that they are mature.

4.3.3 Assessment of Rey 2 seedling data

The seedling species composition at Rey 2 is odd in that there are no seedlings of *P. rhizophorae* present which was found to be the most important species in the adult phase (table 3.2). Tomlinson (1999) states that *P. rhizophorae* is found in competition with *R. mangle*, the proportion of seedlings that were *R. mangle* were almost completely dominant, make up 97% of the observed frequency of seedlings and this may explain the absence of *P. rhizophorae* seedlings. Another possible explanation for the absence of *P. rhizophorae* seedlings may be the salinity regime at the site. As stated previously *P. rhizophorae* is known to have a low tolerance to higher salinities and it would be reasonable to assume that this is a limiting factor for its seedlings that may show a greater intolerance to high salinities. It should be noted however that this is conjecture, the lack of literature available for this species makes drawing conclusions problematic. The heights of seedlings were much greater in plots 4 and 5 than the first 3 plots, this pattern relates to the dominance of *P. rhizophorae* in the adult phase, a possible explanation for this is that more incidental light reaches the seedlings under the canopy of these tall trees.

The methodology for collecting seedling data differed between plots at Rey 2, at plots 1, 4 and 5 the standard 5 quadrat methodology (English *et al*, 1997) was adopted while at plots 2 and 3 all seedlings in the plot were measured, in hindsight this was a mistake. The differing methodology between plots makes analysis of the number of seedlings at the site as a whole unreliable and analysis between plots at the site impossible. However, from the data presented and observations in the field it would seem that the number of seedlings at Rey 2 is a lot greater in plot 1 than the rest of the plots, this would support the theory that plot 1 is a lot

less mature than the other 4 plots. It is however misleading to accept this as evidence given the discontinuity in methodology.

4.4 Assessment of San Jose

4.4.1 Assessment of San Jose species composition

The species composition of San Jose is highly regular and the most monospecific of the three sites, figure 3.1 shows us that all but 4% of the adult trees found at San Jose are *R. mangle*, in real numbers the 4% *L. racemosa* is just one tree. This is not particularly unusual as it is common for mangroves to form monospecific stands. Examples of *R. mangle* out competing *L. racemosa* are common (e.g. Ball, 1980 and Sherman *et al*, 2000) and Lacerda *et al* (2002) tell us that is the most common species in the area. The importance ranks calculated for San Jose support the notion that it is the most important species as would be expected (table 3.2).

4.4.2 Assessment of San Jose forest structure

San Jose showed a low mean total basal area with a value of 16.01m^2 ha^{-1} (table 3.1) and had a very low density with a value equal to 50 stems (with DBH >2.5cm) per hectare. From this we may assume that the forest is either establishing or is mature, analysis of the data tells us that the trees found at this site have a wide range of mean heights between plots ranging from approximately 4 to 20m but that there are a number of individuals over 20m and 1 individual (plot 1) recorded at 40m. The values for DBH mirror the distribution of height. The site at San Jose was a basin forest community being found behind a large sand bank and out of the intertidal range (personal observation). Lacerda *et al* (2002) tell us that basin communities retain nutrients and therefore we would expect a higher productivity, this is corroborated by the sediment analysis (see table 3.3) that shows a much higher organic carbon content relative to the other two sites. From this evidence it is easy to conclude that San Jose represents a mature forest.

4.4.3 Assessment of San Jose seedling data

The seedling cohort at San Jose is made up entirely of *R. mangle* (figure 3.6) this is not surprising in regards to the adult species composition but is strange as San Jose was the only site not to have seedlings of *L. racemosa* when this is a common species throughout the

surrounding area. It would therefore seem unlikely that propagules of *L. racemosa* do not reach the site (there is 1 adult tree at the site) but that they can not establish at the site or are out competed by *R. mangle*. The height distribution of seedlings at San Jose (see table 3.8) shows us that are no seedlings under the 40cm height class, this suggests that the site is favourable for those seedlings that can establish. The frequency of seedlings shows us that there are few seedlings found at this site, a likely explanation would be the increased canopy cover provided by the mature trees reducing irradiance at this site. It does not seem likely that competition from other seedlings is the cause as the seedling community is 100% *R. mangle.*

4.5 Summary and comparison of the 3 sites

The species composition at all 3 sites studied was unremarkable and the 3 sites showed a variety of structures and stages of development and each site showing a different dominant species in terms of importance rank. Rey 1 is dominated by *L. racemosa*, has low values for total basal area, density and height. This evidence would lead us to believe that the mangrove here is in its early stages of establishment and growth or that growth is being limited in some way, a lack of nutrients could be a possible cause. Rey 2 is notable by the dominance of *P. rhizophorae* a less common species than either *L. racemosa* or *R. mangle*. Low values for basal areas and density are found throughout the site but the height distributions fall into the “medium” range as defined by Murray *et al* (2003). It is suggested that for 4 out of the 5 plots at this site these values represent a forest dominated by mature individuals of *P. rhizophorae* which are generally small when mature (Tomlinson, 1999) and that at plot 1 these values represent an early stage, establishing forest owing to the higher density found here. San Jose was almost entirely dominated by mature individuals of *R. mangle* and showed the most developed structure of the three sites.

CHAPTER 5. CONCLUSIONS AND FUTURE WORK

Previous observations by boat and the knowledge of those familiar with the Las Perlas archipelago reported extensive areas of mangrove on many of the islands. The research presented within confirms these observations and reports a variety of forest types and structures within the archipelago. From the initial surveys of the area carried out by boat it is apparent that many of the smaller islands in the north of Las Perlas have extensive fringing mangroves surrounding large portions of their coastline. A survey by boat of the island of Rey indicated a variety of stages of development and a mixture of species around the island. Permanent plots were also set up on the islands of Mogo mogo and Bayoneta.

The first site to be studied in detail, Rey 1 is an underdeveloped site but is not believed necessarily to be young owing to the low number of seedlings, it is proposed that low nutrient availability may be responsible for this under-development and this could be an area for future research as this level of development is representative of much of the mangrove found throughout the islands (personal observation). The site at Rey 2 was noteworthy in that it was dominated by a less common species, *P. rhizophorae*. Individuals of *P. rhizophorae* were in a relatively mature stage of development, Jimenez (1984) states that well developed stands of *P. rhizophorae* are only present in Costa Rica and although the forest found at Reyes 2 was not substantial enough to disprove this further surveying of the area would be desirable to measure the extent and development of this species in the area. A mature forest of *R. mangle* dominated the site at San Jose with the most mature trees being comparable with the most mature individuals recorded in the literature. This is of interest as such mature forests are the exception rather than the rule and forests with such a maturity were observed only once in the early surveys by boat.

The setting up of permanent plots will aide further research and monitoring of these sites. This would be highly desirable not only to collect data on these poorly studied mangroves but also in order to monitor any changes brought about by the future development in the islands that is predicted.

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CHAPTER 7. APPENDICES

7.1 Mogo mogo survey

LA=*L.racemosa* RN=*R. mangle* and AG=*A. germinans*

11/5/06

1. N 08 34 36.4
   W 079 01 29.5
2. N 08 34 32.1
   W 079 01 26.1

Stand of approximately 12 LA

3. N 08 34 37.9
   W 079 01 30.1
4. N 08 34 39.9
   W 079 01 28.5

Stand of approximately 12 LA

5. N 08 34 40.5
   W 079 01 29.2
6. N 08 34 40.5
   W 079 01 32.1

Fringing line of LA, 47 trees approx

7. N 08 34 12.8
   W 079 01 32.6
8. N 08 34 15.1
   W 079 01 30.8

Stand of approximately 27 LA

9. N 08 34 30.5
   W 079 01 42.4
10. N 08 34 27.9
    W 079 01 42.7
11. N 08 34 26.2
    W 079 01 43.2

Stand of approximately 250 RN

7.2 Chapera Survey

11/3/06

Describing one stand of RN and LA with very distinct zonation, a mid-point exists along the shore were species change.

1. N 08 35 37.8
   W 079 01 53.5

RN end of forest, approximately 65 trees.

2. N 08 35 35.4
   W 079 01 54.5

Boundary of species, point of change

3. N 08 35 35.2
   W 079 01 54.5

LA end of forest, approximately 25 trees

7.3 Rey boat survey

13/5/06 Rey Survey

All fringing approx 10m unless otherwise stated

1. N 08 25 35.2
   W 078 51 29.3

RN, LA fringing approx 20m

2. N 08 25 36.8
   W 078 51 33.4

RN less dense

3. N 08 25 44.0
   W 078 51 33.0

LA sparse, scattered individuals from 2 to 3

4. N 08 25 53.6

W 078 51 39.8

RN, LA dense, young RN more mature behind including LA 30-40m deep approx

5. N 08 25 56.9

W 078 51 40.8

RN approx 5m deep

6. N 08 25 55.0

W 078 51 35.7

Similar mix as 4 but less dense

7. N 08 27 07.8

W 78 52 11.0

Very thin fringing, individual trees but large size

8. N 08 27 00.8

W 078 52 06.9

RN change in species, very mature individual trees

9. N 08 26 57.1

W 078 52 03.5

RN, LA mixture more dense 30-50m approx stands of RN approx 100m out

10. N 08 26 55.1

W 078 52 09.1

RN 10m from shore

11. N 08 26 53.9

W 078 52 12.0

Mixture, very deep

12. N 08 26 59.4

W 078 52 11.5

LA ended but recommences after 100m approx mostly RN 30m deep approx

13. N 08 27 04.3

W 078 52 15.4

End of RN

14. N 08 27 09.6

W 078 52 21.4

RN, LA start RN outer, more LA inner 20m deep approx

15. N 08 27 05.6

W 078 52 26.3

LA, RN, LA dominant

16. N 08 27 10.6

W 078 52 25.5

LA, RN

17. N 08 27 14.1

W 078 52 22.0

End

18. N 08 27 23.3

W 078 52 19.6

LA, RN small patch

19. N 08 27 28.1

W 078 52 26.5

LA start, thin fringing

20. N 08 27 22.9

W 078 52 27.7

LA, RN thicker

21. N 08 27 23.6

W 078 52 31.0

LA dominant over RN

22. N 08 27 22.5

W 078 52 36.8

LA, RN start becomes very thick 60m approx

23. N 08 27 22.9

W 078 52 41.2

RN, LA RN dominant start becomes very thick 60m approx

24. N 08 27 32.4

W 078 52 31.9

LA ends shortly after

25. N 08 27 53.2

W 078 52 40.8

RN dominant over LA

26. N 08 27 47.4

W 078 52 43.8

End

27. N 08 27 43.1

W078 52 47.3

RN

28. N 08 27 40.2

W 078 52 51.0

RN very deep in

29. N 08 27 34.1

W 078 52 51.0

RN furthest point “upstream” reached

30. N 08 27 43.0

W 078 52 49.3

RN, LA, AG

31. N 08 27 49.2

W 078 52 47.4

Ended

32. N 08 27 52.2

W 078 52 58.0

LA, RN outer fringe

33. N 08 27 55.0

W 078 53 00.2

LA, RN outer fringe

34. N 08 27 57.4

W 078 52 59.0

Ended

35. N 08 28 09.0

W 078 52 58.6

LA start

36. N 08 28 10.8

W 078 52 59.0

LA RN, LA dominant, patch of RN

37. N 08 28 10.7

W 078 52 56.4

RN, small patch

38. N 08 28 02.7

W 078 53 42.3

AG begins, not too thick

39. N 08 27 54.8

W 078 53 45.6

AG begins, not too thick

40. N 08 27 48.2

W 078 53 41.7

AG, RN

41. N 08 27 48.6

W 078 53 38.3

AG, RN

42. N 08 27 56.6

W 078 53 38.0

AG, RN very deep and extensive

43. N 08 27 49.5

W 078 53 36.2

RN dominant

44. N 08 27 40.3

W 078 53 38.0

RN dominant

45. N 08 27 30.8

W 078 53 39.2

RN dominant, LA behind, site of house, potential for development

46. N 08 27 24.0

W 078 53 41.9

RN, huge area covered, very deep

47. N 08 27 20.0

W 078 53 44.3

Same site, inner channel

48. N. 08 27 19.5

W 078 53 44.2

RN, same area

49. N 08 27 18.3

W 078 53 47.2

RN still same area, inner channel

50. N 08 27 11.3

W 078 53 49.1

RN less thick approx 10m

51. N 08 27 11.2

W 078 53 49.0

RN both sides of channel

52. N 08 27 23.2

W 078 53 48.2

RN both sides of channel

53. N 08 27 23.9

W 078 53 48.4

RN, both sides of channel

54. N 08 27 23.3

W 078 53 56.5

RN, AG both sides of channel

55. N 08 27 15.3

W 078 53 59.8

RN, very large individuals very thick trunks

56. N 08 27 08.1

W 078 54 08.1

Near end of estuary

46 to 56 narrow estuary, very thick forest on both sides

57. N 08 27 04.0

W 078 54 05.8

RN

58. N 08 26 59.1

W 078 54 10.6

RN, LA behind R 50m deep approx

59. N 08 26 56.7

W 078 54 10.4

End

14/5/06- Second day of survey

60. N 08 27 37.8
W 078 53 54.8
LA individuals, mature, thin fringe 19 trees approx

61. N 08 27 39.8
W 078 54 04.3
LA, RN mix thin fringing at this end, individuals 52 LA approx

62. N 08 27 38.4
W 078 54 06.2
LA, RN mix thin fringing at this end, individuals 52 LA approx, same as above

63. N 08 27 33.4
W 078 54 11.9
RN continuous begins, 40m deep approx, thinning out towards 64.

64. N 08 27 42.6
W 078 54 15.1
LA, RN individuals approx 43 LA to point 65.

65. N 08 27 45.6
W 078 54 18.2
Still fringing, 5-10m approx 42 LA approx to point 66

66. N 08 27 52.8
W 078 54 15.7
LA approx 24 to point 67

67. N 08 27 57.9

W 078 54 18.4

RN, LA thicker 10m approx RN at front

68. N 08 27 50.9

W 078 54 22.5

RN, LA thicker and more mature

69. N 08 27 41.1

W 078 54 26.8

RN into bay 2 pictures

70. N 08 27 58.2

W 078 54 23.1

LA, RN dominant much thicker 40m approx

71. N 08 28 07.8

W 078 54 20.4

Same mix, corner of bay

72. N 08 28 10.7

W 078 54 27.6

73. N 08 28 07.8

W 078 54 20.4

LA mature 50m approx from shore

74. N 08 28 11.7

W 078 54 36.0

Thin between 72-73 approx 4 individuals

75. N 08 28 10.1

W 078 54 39.2

LA, RN thicker between 74 and 75, RN dominant 30m approx

76. N 08 28 08.4
W 078 54 42.9
RN dominant start of new thick fringe

77. N 08 28 10.1
W 078 54 45.7
End

78. N 08 28 05.8
W 078 54 54.0
LA thin fringe 7 individuals approx

79. N 08 27 58.8
W 078 54 57.2
LA, thin 10m out approx
80. N 08 27 54.6
W 078 54 56.0
End

81. N 08 27 50.8
W 078 54 54.2
RN, AG, LA mix

82. N 08 27 43.8
W 078 55 05.5
Same mix, photo

83. N 08 27 42.7
W 078 55 08.1
LA, RN slightly thin but far offshore (mature ?) RN dominant

84. N 08 27 39.9

W 078 55 12.4

Same mix, thick (20-30m) from last point but thinner at this point

85. N 08 27 43.5

W 078 55 15.6

New fringe, LA at back, RN at front

86. N 08 27 55.1

W 078 55 10.3

Gap, new fringe starts, more LA than usual

87. N 08 27 58.5

W 078 55 10.9

End

88. N 08 27 52.6

W 078 55 28.5

3 small patches

89. N 08 27 50.2

W 078 55 27.1

2nd of 3 patches, sandy shoreline

90. N 08 27 47.6

W 078 55 30.5

3rd patch of three

91. N 08 27 49.8

W 078 55 40.7

LA small patch, 6 individuals after

92. N 08 27 44.3

W 078 55 48.1

RN dominant small patch, approx 2 individuals of LA

93. N 08 27 38.8

W 078 55 45.4

End

94. N 08 27 35.1

W 078 55 41.8

New fringing, thin at this point

95. N 08 27 26.3

W 078 55 25.2

RN dominant, extensive 2 photos

96. N 08 27 27.6

W 078 55 38.5

End of extensive area

97. N 08 27 17.7

W 078 55 40.5

RN, thick and mature

98. N 08 27 25.5

W 078 55 45.7

Exposed, fewer individuals

99. N 08 27 24.6

W 078 55 55 .7

RN dominant, dense, 60m approx

100. N 08 27 31.8

W 078 55 55.1

End

7.4 Location photos of initial 3 plots surveyed

Figure 7.1 Location of Mogo mogo plot.

Figure 7.2 Location of Bayoneta plots Top: First plot and Bottom: second plot

7.5 Location photos for all plots at Rey 1, Rey 2 and San Jose

Figure 7.3 Reyes 1, plot 1. Top: The location of "0,0"
Bottom: The location of the plot from a distance.

Figure 7.4 Reyes 1, plot 2. Top: The location of "0,0"
Bottom: The location of the plot from a distance.

Figure 7.5 Reyes 1, plot 3. Top: The location of "0,0"

Bottom: The location of the plot from a distance.

Figure 7.6 Reyes 1, plot 4. Top: The location of "0,0"
Bottom: The location of the plot from a distance.

Figure 7.7 Reyes 1, plot 5. Top: The location of "0,0"
Bottom: The location of the plot from a distance.

Figure 7.8 Reyes 2, plot 1. Top: The location of "0,0"
Bottom: The location of the plot from a distance.

Figure 7.9 Reyes 2, plot 2. Top: The location of "0,0"

Bottom: The location of the plot from a distance.

Figure 7.10 Reyes 2, plot 3. Top: The location of "0,0"

Bottom: The location of the plot from a distance.

Figure 7.11 Reyes 2, plot 4. Top: The location of "0,0"

Bottom: The location of the plot from a distance.

Figure 7.12 Reyes 2, plot 5. Top: The location of "0,0"

Bottom: The location of the plot from a distance.

Figure 7.13 San Jose, plot 1. Top: The location of "0,0"

Bottom: The location of the plot from a distance.

Figure 7.14 San Jose, plot 2. Top: The location of "0,0"

Bottom: The location of the plot from a distance.

Figure 7.15 San Jose, plot 3. Top: The location of "0,0"

Bottom: The location of the plot from a distance.

Figure 7.16 San Jose, plot 4. Top: The location of "0,0"

Bottom: The location of the plot from a distance.

Figure 7.17 San Jose, plot 5. Top: The location of "0,0"

Bottom: The location of the plot from a distance.

7.6 Raw data from plots conducted at Mogo mogo, Bayoneta, Rey 1, Rey 2 and San Jose.

Note that the data for the second plot at Bayoneta is not reproduced here as it was unavailable to the author at the time of writing. Also note that in order to remain as concise as possible; species are placed within the same spreadsheet (for data analysis each species is entered into its own spreadsheet) and that the spreadsheets below have been modified from the original CARICOMP spreadsheets (www1).

7.6.1 Mogo mogo

11/05/2006 N 08 34 37.5 W 079 01 29.0

POSITION		Tree No.	Species		Diameter	Basal
X	Y			Tree height	at Breast Height (cm)	Area (cm2)
3.5	1	1 (312)	LA	5.8	5.90	27.34
4.5	1	2 (313)	LA	3.5	3.90	11.95
5.5	1	3 (302)	LA	4.2	2.60	5.31
9.75	4	4 (303)	LA	5.2	3.40	9.08
9.3	3.6	5 (304)	LA	3.0	5.10	20.43
9.6	4.3	6 (305)	LA	4.4	4.50	15.90
9.15	5	7 (306)	LA	9.1	16.60	216.42
9.3	5	8 (307)	LA	3.8	5.60	24.63
8	7.3	9 (308)	LA	4.5	2.90	6.61
8	7.3	10(309)	LA	9.7	20.90	343.07
9.9	7	11 (310)	LA	6.6	5.60	24.63
6.25	6	12 (311)	LA	7.5	8.80	60.82
8	7.3	13 (314)	LA	9.2	6.15	29.71
8	7.3	14 (315)	LA	9.5	5.70	25.52
6.7	3	15 (316)	LA	6.2	7.55	44.77
7.7	2.8	16 (317)	LA	6.2	4.70	17.35
7.7	2.8	17 (318)	LA	6.2	5.50	23.76
7.7	2.8	18 (319)	LA	3.2	4.30	14.52
3.4	1.3	19 (320)	LA	6.4	4.80	18.10
4	1	20 (321)	LA	11.1	36.40	1040.62
3.4	1	21 (322)	LA	8.6	7.90	49.02
2.8	4.2	22 (323)	LA	5.3	3.05	7.31
2.8	4.2	23 (324)	LA	4.7	2.90	6.61
2.8	4.2	24 (325)	LA	5.1	6.85	36.85
2.8	4.2	25 (326)	LA	5.8	6.85	36.85
2.8	4.2	26 (327)	LA	3.8	3.50	9.62
2.8	4.2	27 (328)	LA	8.9	21.20	352.99
0.25	7.4	28 (329)	LA	3.7	2.80	6.16
0.25	7.4	29 (330)	LA	4.2	4.20	13.85
0.25	7.4	30 (331)	LA	6.3	10.60	88.25
6.25	6	31 (332)	LA	6.3	3.40	9.08

7.6.2 Bayoneta

12/05/2006 N 08 29 40.3 W 079 03 03.4

POSITION		Tree No.	Species		Diameter	Basal
X	Y			Tree height	at Breast Height (cm)	Area (cm2)
0.4	2.4	1 (333)	RN	3.2	3.60	10.18
3	2	2 (334)	RN	3.3	3.80	11.34
2.5	1.7	3 (335)	RN	2.7	2.80	6.16
3.25	1.7	4 (336)	RN	3.7	2.80	6.16
0.1	4.5	5 (337)	RN	3.1	2.80	6.16
5.2	3	6 (338)	RN	3.5	2.60	5.31
7	3.5	7 (339)	RN	3.8	2.90	6.61
9.5	5	8 (340)	RN	3.3	2.50	4.91
9.5	5	9 (341)	RN	3.8	3.40	9.08
8.2	9.6	10 (342)	AG	4.2	5.10	20.43
8.2	9.6	11 (343)	AG	6.2	10.70	89.92
8.2	2.2	12 (344)	RN	3.1	4.20	13.85
7.7	4.5	13 (345)	RN	2.3	2.50	4.91
6.9	3.2	14 (350)	RN	3.8	3.00	7.07
6.9	3.2	15 (351)	RN	3.8	3.10	7.55
2.5	6.5	16 (352)	RN	3.1	2.90	6.61
1.75	6.3	17 (353)	RN	2.7	2.70	5.73
1.2	9	18 (354)	AG	3.6	3.90	11.95
9.5	9	19 (355)	RN	2.1	3.40	9.08
5.05	8.5	20 (356)	RN	3.4	3.40	9.08
5.15	8.8	21 (357)	RN	3.3	3.20	8.04
8.5	9.5	22 (358)	RN	1.9	2.50	4.91
6.5	8.5	23 (359)	RN	2.0	2.50	4.91
8.5	9.5	24 (400)	RN	2.0	2.60	5.31

Bayoneta seedlings

12/5/06

Lat. North: 08 29 40.3
Long. West: 079 03 04.4

Plot	Sub.	POSITION		Sapling #	Dbh	Species	Height (cm). (from
(a,b,c)	Plot #	X	Y		If needed		sediment surface)
		9.1	3.57	1 (346)		RN	52
		8	2.57	2 (347)		RN	89
		8	4.48	3 (348)		RN	41
		8	4.48	4 (349)		RN	22

7.6.3 Rey 1

Rey 1, plot 1

13.5.06 N 08 25 19.0 W 078 51 32.6 9.30-12.00

POSITION		Tree No.	Species		Diameter	Basal

X	Y			Tree height	at Breast Height (cm)	Area (cm2)
0.4	1.1	1 (360)	RN	3.6	4.10	13.20
1.7	1.45	2 (361)	RN	3.2	5.00	19.63
2.5	3	3 (362)	RN	3.4	2.50	4.91
2	2	4 (363)	RN	3.6	2.80	6.16
3.5	3.25	5 (364)	RN	2.4	3.00	7.07
3.5	3.5	6 (365)	RN	3.5	3.15	7.79
2.25	4	7 (366)	RN	3.5	3.60	10.18
1	4	8 (367)	RN	2.7	2.60	5.31
1	5.5	9 (368)	RN	2.2	3.55	9.90
0.5	4.3	10 (369)	RN	2.1	3.27	8.40
0.5	4.2	11 (370)	RN	0.7	3.00	7.07
0.5	6.5	12 (371)	RN	2.1	3.20	8.04
0.5	7	13 (372)	RN	2.5	4.55	16.26
1.2	6.2	14 (373)	RN	3.6	3.95	12.25
2	8.5	15 (374)	RN	2.2	2.85	6.38
2.2	7	16 (375)	RN	1.0	3.30	8.55
2.5	7	17 (376)	RN	2.4	2.80	6.16
2.5	8	18 (377)	RN	2.4	2.80	6.16
2.4	8	19 (378)	RN	3.1	3.20	8.04
0.9	6.5	20 (379)	RN	2.3	4.70	17.35
1.5	9.7	21 (380)	RN	2.5	2.70	5.73
3	9.5	22 (381)	RN	2.5	3.70	10.75
3.5	8.5	23 (382)	RN	2.5	2.80	6.16
3.5	7.5	24 (383)	RN	1.4	3.30	8.55
5	8	25 (384)	RN	3.0	3.75	11.04
5	8.3	26 (385)	RN	3.0	3.70	10.75
5	8	27 (386)	RN	3.5	3.60	10.18
7	5	28 (387)	RN	3.3	5.00	19.63
3.5	4.5	29 (388)	RN	1.7	4.30	14.52
3.5	4.5	30 (389)	RN	2.3	4.70	17.35
3.5	4.5	31 (390)	RN	2.4	6.50	33.18
5.5	0.5	32 (391)	RN	2.0	4.80	18.10
6.2	1.5	33 (392)	RN	2.7	4.00	12.57
6.2	1.5	34 (393)	RN	2.7	4.60	16.62
6.5	3	35 (394)	RN	3.0	4.40	15.21
6.5	5.5	36 (395)	RN	2.2	4.00	12.57
9	5.5	37 (396)	RN	3.6	5.00	19.63
9.2	4	38 (397)	RN	2.3	5.00	19.63
9.1	4	39 (398)	RN	2.2	3.60	10.18
8.5	3.2	40 (399)	RN	2.3	3.20	8.04
9	6	41 (12)	RN	3.8	3.30	8.55
8	7	42 (13)	RN	3.0	3.60	10.18
6.5	7.5	43 (14)	RN	3.2	2.60	5.31
6	8	44 (15)	RN	2.8	3.60	10.18
6	8	45 (16)	RN	2.2	4.20	13.85
6	8	46 (17)	RN	2.7	4.95	19.24
6	9.5	47 (18)	RN	2.2	3.50	9.62

7	9.5	48 (20)	RN	2.8	3.00	7.07
9.3	8	49 (21)	RN	2.6	2.90	6.61
9.5	7	50 (22)	RN	3.5	2.95	6.83
9.5	6	51 (23)	LA	5.8	6.70	35.26
9.5	1	52 (24)	LA	5.1	11.00	95.03
9.5	1	53 (25)	LA	5.9	9.05	64.33
9.5	1	54 (26)	LA	4.9	10.20	81.71
9.5	1	55 (27)	LA	7.3	20.00	314.16
9.5	0.2	56 (28)	LA	7.3	9.40	69.40

Rey 1, plot 1 seedlings

13/5/06 **Lat. North:** 08 25 19.0

Long. West: 078 51 32.6

Plot (a,b,c)	Sub. Plot #	POSITION X	POSITION Y	Sapling #	Dbh If needed	Species	Height (cm). (from sediment surface)
1		8.2	3.1	1		RN	40
1		8.8	3.2	2		RN	50
1		9.8	2.6	3		RN	70
1		4.7	4	4		RN	28
1		2	5.2	5		RN	33
1		0.3	4.8	6		RN	35

Rey 1, plot 2

13.5.06 N 08 25 17.6 W 078 51 34.7 12.30-13.50

POSITION X	POSITION Y	Tree No.	Species	Tree height	Diameter at Breast Height (cm)	Basal Area (cm2)
8.2	8.5	1 (29)	LA	3.8	5.00	19.63
7.5	9.5	2 (30)	LA	3.8	3.70	10.75
8	8	3 (31)	LA	3.1	4.20	13.85
3.5	7.5	4 (32)	RN	1.8	3.50	9.62
4	9	5 (33)	RN	1.5	3.80	11.34
3.5	8.5	6 (34)	RN	1.5	3.70	10.75
2.3	7	7 (35)	RN	1.8	3.20	8.04
2.2	9.5	8 (36)	P	2.8	6.05	28.75
1.8	4.6	9 (37)	P	2.0	3.80	11.34
1.5	4	10 (38)	RN	3.9	3.99	12.50
3.3	4.5	11 (39)	RN	3.7	3.90	11.95
1	3	12 (40)	RN	3.8	3.70	10.75
2	2.2	13 (41)	RN	4.8	4.20	13.85
1.3	2	14 (42)	P	7.1	9.40	69.40
0.5	1.7	15 (43)	RN	4.2	6.65	34.73
2	1.5	16 (44)	RN	4.2	4.80	18.10
2.5	0.5	17 (45)	RN	4.6	5.98	28.09
4	1.5	18 (46)	P	7.6	11.70	107.51
6.5	0.5	19 (47)	RN	2.7	4.10	13.20
7.2	0.2	20 (48)	RN	2.7	4.40	15.21
8.5	0.1	21 (49)	RN	2.5	3.40	9.08

8.5	0.1	22 (50)	RN	2.5	3.50	9.62
7.9	0.5	23 (51)	RN	1.7	3.80	11.34
7.5	2.2	24 (52)	RN	2.1	2.80	6.16
7.5	2.2	25 (53)	RN	3.3	3.70	10.75
7.5	3	26 (54)	LA	8.3	12.60	124.69
7.5	3	27 (55)	LA	8.5	9.80	75.43
6.5	3	28 (56)	LA	9.2	9.30	67.93
6.5	3	29 (57)	LA	7.9	11.90	111.22
6.5	3	30 (58)	LA	7.9	21.60	366.44
7.5	3	31 (59)	LA	4.4	20.70	336.54
7.5	3	32 (60)	LA	3.1	6.00	28.27

Rey 1, plot 2 seedlings

13/5/06 **Lat. North:** N 08 25 17.6

Long. West: W 078 51 34.7

Plot (a,b,c)	Sub. Plot #	POSITION X	POSITION Y	Sapling #	Dbh If needed	Species	Height (cm). (from sediment surface)
2		1.2	1.5	1		RN	40

Rey 1, plot 3

14.5.06 N 08 24 42.4 W 078 51 36.1 09.00-10.50

POSITION X	POSITION Y	Tree No.	Species	Tree height	Diameter at Breast Height (cm)	Basal Area (cm2)
3.3	3.9	1 (61)	LA	2.0	4.30	14.52
3.6	4.1	2 (62)	LA	2.6	6.80	36.32
3.4	3.8	3 (63)	LA	4.4	8.10	51.53
3.9	3.9	4 (64)	LA	2.8	2.60	5.31
3.4	3.6	5 (65)	LA	3.8	5.90	27.34
3.5	2	6 (77)	RN	2.4	3.80	11.34
5	3.5	7 (71)	RN	2.5	3.30	8.55
5.5	3	8 (69)	RN	2.3	4.70	17.35
5.5	3.2	9 (75)	RN	2.2	3.90	11.95
6.5	3.2	10 (72)	RN	2.7	4.40	15.21
3.4	3.6	11 (86)	RN	2.5	3.80	11.34
4.5	4.2	12 (68)	RN	2.3	3.70	10.75
3.2	6.5	14 (73)	LA	3.8	5.80	26.42
3.2	6.5	15 (70)	LA	3.4	4.50	15.90
3.2	6.5	16 (81)	LA	7.5	7.70	46.57
3.2	6.5	17 (82)	LA	6.9	6.60	34.21
3.2	6.5	18 (76)	LA	6.9	8.20	52.81
3.2	6.5	19 (66)	LA	6.0	5.80	26.42
3.2	6.5	20 (76)	LA	6.5	8.40	55.42
3.2	6.5	21 (67)	LA	2.5	6.40	32.17
3.2	6.5	22 (83)	LA	1.6	3.10	7.55
2	6.5	23 (84)	RN	2.3	3.10	7.55
2.72	6.5	15 (73)	LA	2.9	4.71	17.40

Rey 1, plot 3 seedlings

14/05/2006 **Lat. North:** N 08 24 42.4

Long. West: W 078 51 36.1

Plot (a,b,c)	Sub. Plot #	POSITION X	POSITION Y	Sapling #	Dbh If needed	Species	Height (cm). (from sediment surface)
3		8.1	9.5	1		LA	7
3		5.86	9.32	2		RN	87

Rey 1, plot 4

14.5.06 N 08 24 46.2 W 078 51 18.9 11.20-12.35

POSITION X	POSITION Y	Tree No.	Species	Tree height	Diameter at Breast Height (cm)	Basal Area (cm2)
3	1	1 (86)	RN	2.3	2.90	6.61
3	1	2 (87)	RN	2.5	3.40	9.08
9	3	3 (88)	RN	3.1	3.90	11.95
9	5	4 (89)	RN	3.0	2.70	5.73
6	4.5	5 (90)	RN	3.8	5.90	27.34
4.2	4.9	6 (91)	RN	2.6	5.50	23.76
2.5	3.3	7 (92)	RN	3.4	9.40	69.40
3.1	5.7	8 (93)	RN	2.2	5.00	19.63
3	4	9 (94)	RN	2.6	4.80	18.10
2.5	3.3	10 (95)	RN	2.6	4.80	18.10
0.3	4	11 (96)	RN	2.0	4.00	12.57
0.7	6.2	12 (97)	RN	2.2	3.00	7.07
2	7.2	13 (98)	RN	2.4	3.10	7.55
2.1	8.5	14 (99)	RN	2.4	2.80	6.16
3	9	15 (100)	RN	2.5	2.80	6.16
5.3	9.8	16 (853)	RN	2.2	2.70	5.73
5.8	8.5	17 (854)	LA	3.9	6.20	30.19
8.2	8	18 (855)	RN	2.7	4.90	18.86
8	6.8	19 (856)	RN	2.6	4.00	12.57
7	6.2	20 (857)	RN	2.5	4.10	13.20
9.8	8	21 (896)	RN	1.5	3.20	8.04
1.5	9.9	22 (858)	RN	2.1	2.90	6.61
1	9.4	23 (859)	RN	2.3	3.20	8.04
0.05	9.4	24 (860)	RN	2.6	2.50	4.91

No seedlings were present in Rey, plot 4.

Rey 1, plot 5

14.5.06 N 08 24 37.7 W 078 51 24.8 13.00-14.15

POSITION X	POSITION Y	Tree No.	Species	Tree height	Diameter at Breast Height (cm)	Basal Area (cm2)
1.5	8.5	1 (863)	LA	7.7	13.05	133.76
1.5	8.5	2 (862)	LA	7.0	16.25	207.39

1.5	8.5	3 (861)	LA	3.7	10.70	89.92
1.5	8.5	4 (864)	LA	6.7	14.50	165.13
8	9.5	5 (895)	P	10.7	11.50	103.87

Rey 1, plot 5 seedlings

14/05/2006

Lat. North: N 08 24 37.7

Long. West: W 078 51 24.8

Plot (a,b,c)	Sub. Plot #	POSITION X	POSITION Y	Sapling #	Dbh If needed	Species	Height (cm). (from sediment surface)
5		9.8	1.8	1 (1794)		LA	80
5		8.8	2	2 (1705)		RN	81
5		8.7	1.2	3 (1791)		RN	58
5		7.7	2.2	4 (1751)		RN	94
5		7.5	1.9	5 (1743)		LA	12
5		7.8	2	6 (1752)		LA	10
5		7.6	2	7 (1778)		LA	14
5		7.5	1.7	8 (1741)		LA	12
5		6.7	1	9 (1754)		LA	12
5		6.5	1.1	10 (1746)		RN	69
5		5.6	0.9	11 (1713)		RN	50
5		5.5	1	12 (1789)		LA	19
5		5	1	13 (1781)		RN	50
5		2.1	2.2	14 (1787)		RN	50
5		0.5	2.2	15 (1736)		RN	76
5		1	1.8	16 (1730)		RN	52
5		1.3	0.7	17 (1793)		RN	53
5		1.5	1.2	18 (1709)		RN	83
5		1.9	2	19 (1779)		RN	63
5		2	2	20 (1703)		RN	65
5		2.1	2.1	21 (1706)		RN	61
5		1.1	2.1	22 (1726)		RN	56
5		3	1.2	23 (1740)		RN	46
5		4	1.2	24 (1792)		RN	47
5		4	2	25 (1768)		LA	15
5		4.1	1.7	26 (1702)		RN	54
5		4.1	1.7	27 (1747)		RN	55
5		4.1	1	28 (1784)		LA	15
5		4.2	2	29 (1750)		LA	15
5		6.8	1.2	30 (1759)		RN	100
5		6.75	1.3	31 (1729)		LA	17
5		6.6	1.4	32 (1776)		RN	58
5		6.8	1.3	33 (1780)		LA	11
5		6.9	1.3	34 (1717)		LA	17
5		7	1.4	35 (1770)		LA	15
5		7.5	1.8	36 (1737)		LA	17
5		7.5	1.9	37 (1756)		LA	15
5		7.7	2	38 (1777)		LA	16

5		7.7	2.5	39 (1783)		RN	66
5		5.5	2.8	40 (1708)		RN	54
5		4	3	41 (1782)		LA	15
5		8	2.8	42 (1732)		RN	18
5		7.6	3.1	43 (1772)		RN	14
5		5.5	3	44 (1773)		LA	38
5		9	4	45 (1758)		RN	86
5		9.7	4	46 (1798)		RN	77
5		3.4	6	47 (1721)		LA	57
5		3.5	6	48 (1716)		RN	43
5		1.5	8	49 (1748)		RN	65
5		7.6	1.9	50 (1786)		RN	35
5		9.6	8	51 (1739)		RN	54
5		9.6	8	52 (1775)		RN	58
5		9.8	8	53 (1745)		RN	58

7.6.4 Rey 2

Rey 2, plot 1

15.5.06 N 08 16 09 W 078 55 46 9.50-11.50

POSITION		Tree No.	Species		Diameter	Basal
X	Y			Tree height	at Breast Height (cm)	Area (cm2)
6	1	1 (1710)	RN	3.5	2.80	6.16
6	1	2 (1711)	RN	3.4	2.60	5.31
5	1	3 (1718)	RN	3.5	2.50	4.91
4.5	1	4 (1771)	RN	2.6	2.50	4.91
4.5	1	5 (1766)	RN	3.7	2.80	6.16
4.5	1	6 (275)	RN	3.8	3.50	9.62
4.15	0.6	7 (264)	RN	2.5	2.80	6.16
4.25	0.7	8 (280)	RN	2.6	2.55	5.11
3.4	1	9 (266)	RN	3.0	2.80	6.16
3.2	0.9	10 (271)	RN	2.7	3.10	7.55
0.8	1	11 (279)	RN	2.9	3.50	9.62
0.8	1	12 (290)	RN	2.5	2.50	4.91
0.5	1	13 (269)	RN	2.5	2.50	4.91
2.5	1.8	14 (278)	RN	2.7	2.90	6.61
4	1.5	15 (277)	RN	2.9	2.50	4.91
5.5	1.5	16 (299)	RN	2.8	2.50	4.91
5.2	3	17 (273)	LA	4.6	4.05	12.88
9.7	3.2	18 (256)	RN	3.4	2.70	5.73
9.7	3.2	19 (272)	RN	2.8	2.80	6.16
9.7	3.2	20 (274)	RN	3.8	3.20	8.04
9.8	3.2	21 (288)	RN	2.1	2.50	4.91
9	5.2	22 (268)	LA	3.1	2.55	5.11
9	5.5	23 (281)	LA	3.3	2.80	6.16
9	5.8	24 (286)	LA	4.1	4.20	13.85
9.5	6.4	25 (265)	LA	3.6	2.50	4.91

9	6.8	26 (295)	LA	4.0	2.50	4.91
8.8	5.7	27 (298)	LA	4.2	2.90	6.61
8.6	5.65	28 (282)	LA	3.6	2.70	5.73
8.6	5.65	29 (17)	LA	4.1	2.80	6.16
8	5.6	30 (163)	LA	4.3	4.85	18.47
8	5.8	31 (1998)	LA	2.1	2.90	6.61
7.5	6.2	32 (1092)	LA	4.3	2.80	6.16
7	6.2	33 (1098)	LA	3.3	2.50	4.91
7	4	34 (1100)	LA	2.9	3.70	10.75
5.6	4.6	35 (1093)	LA	2.4	2.80	6.16
6.5	5.6	36 (726)	LA	3.5	2.80	6.16
5	5	37 (805)	LA	3.7	3.10	7.55
4.8	5	38 (970)	LA	4.2	5.40	22.90
3.8	3.5	39 (179)	RN	2.0	2.50	4.91
3.8	3.5	40 (165)	LA	2.9	2.60	5.31
3.8	3.5	41 (183)	RN	2.5	3.60	10.18
0.1	3.55	42 (171)	LA	4.1	4.40	15.21
0.25	4.5	43 (160)	LA	4.4	3.80	11.34
1	5.1	44 (184)	RN	2.8	3.90	11.95
1.3	5.1	45 (175)	LA	3.5	2.90	6.61
5	6	46 (166)	RN	3.2	3.00	7.07
6	7	47 (177)	LA	3.3	2.50	4.91
6.8	6.5	48 (168)	LA	1.7	2.50	4.91
6	8	49 (205)	LA	3.6	4.20	13.85
7.5	8	50 (208)	LA	3.1	3.20	8.04
7.5	6.5	51 (161)	LA	4.2	2.80	6.16
8	7	52 (182)	LA	3.5	2.50	4.91
8.5	6.3	53 (167)	RN	2.6	2.60	5.31
8	7	54 (168)	LA	4.4	2.90	6.61
9	7.5	55 (210)	RN	4.0	2.90	6.61
8.5	8	56 (744)	LA	3.6	2.50	4.91
8.5	8.5	57 (185)	LA	2.8	2.90	6.61
9	9.3	58 (169)	LA	3.9	2.60	5.31
10	9.5	59 (867)	LA	4.9	3.70	10.75
8	9.7	60 (698)	RN	1.9	2.60	5.31
7.5	9.8	61 (866)	LA	4.7	2.80	6.16
7.5	9.8	62 (868)	LA	4.9	3.00	7.07
1.4	7	63 (870)	RN	2.9	2.70	5.73
0.5	7.5	64 (894)	RN	2.8	2.50	4.91
3.5	6	65 (871)	RN	3.9	3.40	9.08
3	6.5	66 (893)	RN	3.8	2.30	4.15
1.2	9.3	67 (872)	RN	2.9	3.70	10.75
2.3	9	68 (891)	RN	3.2	2.90	6.61
3	8.2	69 (892)	RN	3.3	4.10	13.20
3	8.5	70 (890)	LA	2.4	6.20	30.19
3	8.5	71 (889)	LA	7.2	6.50	33.18
2.8	8	72 (73)	RN	3.0	4.10	13.20
2.38	9	73 (874)	RN	3.9	2.80	6.16
4	10	74 (875)	RN	3.4	4.00	12.57

3.2	7	75 (876)	LA	4.7	7.90	49.02
0.5	6.5	76 (877)	LA	5.5	4.30	14.52

Rey 2, plot 1 seedlings

15/05/2006

Lat. North: N 08 16 09
Long. West: W 078 55 46

Plot (a,b,c)	Sub. Plot #	POSITION X	POSITION Y	Sapling #	Dbh If needed	Species	Height (cm). (from sediment surface)
1	1 (1.4,6)	20	30	1 (1742)		RN	32
1	1	19	39	2 (1761)		RN	47
1	1	60	20	3 (1731)		RN	17
1	1	80	12	4 (1722)		RN	27
1	1	64	30	5 (1797)		RN	26
1	1	64	30	6 (1774)		RN	19
1	1	72	42	7 (1738)		RN	20
1	1	4	50	8 (1733)		RN	59
1	1	90	50	9 (1763)		RN	38
1	1	88	50	10 (1728)		RN	41
1	1	19	75	11 (1749)		RN	33
1	1	98	60	12 (1720)		RN	41
1	1	23	87	13 (1757)		RN	26
1	1	70	98	14 (1701)		RN	32
1	1	70	98	15 (1788)		RN	40.5
1	1	60	30	16 (1767)		RN	89
1	1	60	30	17 (1765)		RN	77
1	1	50	100	18 (1753)		RN	74
1	1	45	100	19 (1735)		RN	85
1	1	81	30	20 (1707)		RN	49
1							
1	2 (5.5,6)	25	12	1 (1760)		RN	100
1	2	48	14	2 (1764)		RN	100
1	2	80	14	3 (1727)		RN	30
1	2	84	34	4 (1785)		RN	89
1	2	84	34	5 (1719)		RN	64
1	2	54	34	6 (1790)		RN	43
1	2	54	34	7 (1762)		RN	87
1	2	88	63	8 (1796)		RN	32
1	2	14	74	9 (1723)		RN	47
1	2	47	52	10 (1704)		RN	77
1	2	15	42	11 (1744)		RN	96
1	2	24	84	12 (1714)		RN	22
1							
1	3 (0.1,1.2)	41	92	1 (1725)		RN	100
1	3	40	55	2 (1755)		RN	37.5
1	3	22	38	3 (1769)		RN	81
1	3	34	16	4 (1799)		RN	45
1							
1	4 (8.4,8.7)	30	13	1 (277)		RN	72
1	4	68	20	2 (274)		RN	47
1	4	61	70	3 (271)		RN	79
1	4	66	17	4 (275)		RN	70
1	4	51	60	5 (276)		RN	29
1	4	71	70	6 (272)		RN	74
1	4	66	14	7 (256)		RN	69

1	4	20	45	8 (691)		RN	34
1	4	50	40	9 (1031)		RN	31
1	4	50	30	10 (104)		RN	41
1	4	34	80	11 (144)		RN	36
1	4	36	82	12 (1116)		RN	71
1	4	10	80	13 (0)		RN	61.5
1	4	10	80	14 (279)		RN	88.5
1	4	98	98	15 (270)		RN	86
1							
1	5 (2.1,4.8)	60	37	1 (615)		RN	33.5
1	5	62	62	2 (481)		RN	53
1	5	38	57	3 (204)		RN	89

Rey 2, plot 2

15.5.06 N 08 16 10 W 078 55 44 13.00-15.00

POSITION		Tree No.	Species		Diameter	Basal
X	Y			Tree height	at Breast Height (cm)	Area (cm2)
9.5	4.5	1 (901)	P	10.5	11.00	95.03
6	5.5	2 (902)	P	6.1	15.50	188.69
6	5.5	3 (903)	P	5.4	5.60	24.63
4.5	6	4 (904)	P	6.5	11.50	103.87
4.5	7	5 (905)	P	5.8	6.80	36.32
1.75	8.8	6 (906)	P	5.9	7.10	39.59
1.75	8	7 (907)	P	8.7	15.10	179.08
2.5	5	8 (908)	RN	5.6	8.55	57.41
2.4	4	9 (909)	LA	10.9	22.65	402.93
6	4	10 (910)	P	3.4	4.45	15.55
6	4	11 (911)	P	6.5	12.20	116.90
8	1.5	12 (912)	LA	8.5	26.50	551.55
8	1.5	13 (913)	LA	6.9	22.70	404.71
9	0.1	14 (914)	RN	4.0	8.00	50.27
8	1.5	15 (915)	RN	2.2	3.30	8.55
8	1.5	16 (916)	RN	2.2	3.30	8.55
4.5	1	17 (917)	P	6.9	12.55	123.70
3.2	1.75	18 (918)	RN	6.4	6.55	33.70
0.3	1.75	19 (919)	RN	2.0	4.15	13.53
6	1	20 (920)	RN	5.1	5.15	20.83

Rey 2, plot 2 seedlings

15/05/2006

Lat. North: N 08 16 10
Long. West: W 078 55 44

Plot	Sub.	POSITION		Sapling #	Dbh	Species	Height (cm). (from
(a,b,c)	Plot #	X	Y		If needed		sediment surface)
2		2	5.7	1 (255)		RN	44
2		8.5	6.8	2 (253)		RN	46
2		9	1.8	3 (472)		RN	26
2		8.5	2.2	4 (1734)		RN	36

Rey 2, plot 3

16.5.06 N 08 16 22 W 078 55 37 10.10-11.50

POSITION		Tree No.	Species		Diameter	Basal
X	Y			Tree height	at Breast Height (cm)	Area (cm2)
8	1	1 (789)	P	6.5	22.20	387.08
5.5	2	2 (898)	P	8.0	22.00	380.13
1	2	3 (897)	P	8.2	27.10	576.80
2.5	3.5	4 (1085)	RN	3.4	7.80	47.78
1	4.5	5 (1981)	P	7.6	20.80	339.79
1.5	8.3	6 (1084)	RN	4.4	4.20	13.85
6	7	7 (1082)	RN	6.8	7.10	39.59
5.5	9	8 (1081)	RN	4.5	4.90	18.86
3.5	9.5	9 (1087)	RN	2.5	3.00	7.07
5	4	10 (1080)	RN	6.9	5.70	25.52
7.7	9	11 (888)	RN	6.4	8.20	52.81
8	7.7	12 (887)	RN	3.6	4.90	18.86
9	5	13 (878)	RN	6.1	22.20	387.08

Rey 2, plot 3 seedlings

16/05/2006

Lat. North: N 08 16 22
Long. West: W 078 55 37

Plot	Sub.	POSITION		Sapling #	Dbh	Species	Height (cm). (from
(a,b,c)	Plot #	X	Y		If needed		sediment surface)
3		3.2	2.8	1 (1700)		RN	28
3		6.3	7	2 (1695)		RN	20
3		7	8	3 (1698)		RN	39
3		8	9.2	4 (1692)		RN	31
3		8.7	9.7	5 (1696)		RN	20
3		9	9.7	6 (1693)		RN	36
3		3	7.5	7 (1657)		RN	45
3		8	7.5	8 (1694)		RN	50

Rey 2, plot 4

16.5.06 N 08 16 23 W 078 55 37 12.00-13.14

POSITION		Tree No.	Species		Diameter	Basal
X	Y			Tree height	at Breast Height (cm)	Area (cm2)
1	0.2	1 (1079)	P	2.9	4.00	12.57
1	9	2 (1074)	LA	9.5	10.40	84.95
4.5	7.5	3 (1072)	P	6.1	6.60	34.21
1.8	9.5	4 (992)	LA	5.4	3.40	9.08
5	7	5 (1077)	LA	7.9	12.55	123.70
6.5	7	6 (1076)	LA	11.5	15.20	181.46
6.5	7	7 (994)	LA	10.2	21.30	356.33
7.5	8.6	8 (1075)	P	5.3	6.75	35.78
8.5	9	9 (1069)	P	4.3	3.50	9.62
6.5	7	10 (993)	P	7.0	7.75	47.17
8.5	8.5	11 (1070)	P	4.9	4.20	13.85
9.2	8	12 (1078)	P	4.4	3.10	7.55

10	6.6	13 (1073)	P	3.8	3.30	8.55
9.5	5.5	14 (1071)	RN	4.0	3.00	7.07
7.8	4.2	15 (991)	P	3.2	3.30	8.55

Rey 2, plot 4 seedlings

16/05/2006

Lat. North: N 08 16 23
Long. West: W 078 55 37

Plot (a,b,c)	Sub. Plot #	POSITION X	POSITION Y	Sapling #	Dbh If needed	Species	Height (cm). (from sediment surface)
4	1 (5,5)	81	76	1 (1699)		RN	84
4	1	33	81	2 (1697)		RN	100
4							
4	2 (6.3,1)	54	49	1 (1652)		RN	86
4							
4	3 (2,2.6)	22	17	1 (1654)		RN	100
4							
4	4 (1.55,0)	37	41	1 (1650)		RN	51
4							
4	5 (0.2,7.2)	13	40	1 (1658)		LA	89
4	5	13	43	2 (1655)		LA	84
4	5	95	14	3 (1690)		RN	90

Rey 2, plot 5

16.5.06 N 08 16 11 W 078 55 34 13.45-15.00

POSITION X	POSITION Y	Tree No.	Species	Tree height	Diameter at Breast Height (cm)	Basal Area (cm2)
9.6	3.2	1 (978)	P	10.4	19.70	304.81
9	4	2 (977)	P	7.4	11.20	98.52
7	5	3 (976)	P	4.5	4.50	15.90
9.5	5	4 (975)	P	1.8	2.55	5.11
9.2	6.2	5 (974)	P	3.0	2.90	6.61
9.9	5.2	6 (973)	P	5.7	4.51	15.98
8	5.2	7 (972)	P	5.2	5.30	22.06
6.8	8	8 (971)	P	12.0	18.00	254.47
8.2	9	9 (970)	P	7.4	16.30	208.67
5.5	8	10 (696)	P	4.0	3.15	7.79
3.8	8.1	11 (896)	P	4.8	3.40	9.08
2.9	8	12 (967)	P	4.1	4.40	15.21
2.8	7.9	13 (966)	P	5.4	4.85	18.47
2.9	7.65	14 (965)	P	5.1	4.15	13.53
1.8	6.2	15 (964)	P	12.0	21.75	371.54
4.5	5.6	16 (963)	P	2.8	4.60	16.62
4	3	17 (882)	P	9.0	13.10	134.78
1.9	1	18 (883)	P	11.9	20.30	323.65
4.5	6.5	19 (962)	RN	6.5	7.20	40.72
4.9	2.5	20 (961)	P	2.2	2.80	6.16
4.9	4.5	21 (960)	P	5.2	3.90	11.95
9.6	8.7	22 (959)	P	7.1	6.80	36.32

4	9.3	23 (958)	P	10.2	16.40	211.24

Rey 2, plot 5 seedlings

16/05/2006

Lat. North: N 08 16 11
Long. West: W 078 55 34

Plot (a,b,c)	Sub. Plot #	POSITION X	POSITION Y	Sapling #	Dbh If needed	Species	Height (cm). (from sediment surface)
5	1 (2.37,1.1)	23	46	1 (1691)		RN	63
5							
5	2 (5.1,0.8)	87	3	1 (1659)		RN	87.5
5							
5	3 (1.8,8.5)						
5							
5	4 (3.1,6.5)						
5							
5	5 (6.5,3.2)						

7.6.5 San Jose

San Jose, plot 1

17.5.06 N 08 14 52 W 079 06 24 12.00-13.24

POSITION X	POSITION Y	Tree No.	Species	Tree height	Diameter at Breast Height (cm)	Basal Area (cm2)
9	2.2	1 (944)	RN	26.0	27.60	598.28
9	2.7	2 (732)	RN	40.0	66.00	3421.19
6.2	7	3 (1731)	RN	17.0	14.40	162.86
6.2	8	4 (806)	RN	5.9	4.20	13.85
0.5	8	5 (78)	RN	8.1	6.25	30.68
0.8	7	6 (181)	RN	6.4	5.00	19.63

San Jose, plot 1 seedlings

17/05/2006

Lat. North: 08 14 52
Long. West: 079 06 24

Plot (a,b,c)	Sub. Plot #	POSITION X	POSITION Y	Sapling #	Dbh If needed	Species	Height (cm). (from sediment surface)
1		9.3	8.3	1 (1662)		RN	85

San Jose, plot 2

17.5.06 N 08 14 51 W 079 06 24 13.24-14.58

POSITION X	POSITION Y	Tree No.	Species	Tree height	Diameter at Breast Height (cm)	Basal Area (cm2)
1.5	2	1 (852)	RN	9.9	8.40	55.42
3	5	2 (900)	RN	22.0	55.00	2375.83
7	1.8	3 (987)	RN	6.1	4.20	13.85
7.7	4.6	4 (997)	RN	6.2	4.10	13.20

6.9	4	5 (996)	RN	5.8	#REF!	#REF!
8.4	6	6 (988)	RN	6.9	6.00	28.27
8	9	7 (985)	RN	7.2	6.30	31.17
5	9	8 (986)	RN	6.0	4.90	18.86

San Jose, plot 2 seedlings

17/05/2006 **Lat. North:** N 08 14 51

Long. West: W 079 06 24

Plot (a,b,c)	Sub. Plot #	POSITION X	POSITION Y	Sapling #	Dbh If needed	Species	Height (cm). (from sediment surface)
2		1.5	1.1	1 (209)		RN	63
2		5.8	2	2 (998)		RN	78
2		5.8	3	3 (664)		RN	75
2		8.5	3	4 (983)		RN	90
2		8.5	3.2	5 (984)		RN	70
2		8.3	4	6 (1090)		RN	98
2		8.3	5	7 (995)		RN	90
2		8.5	0.8	8 (999)		RN	80
2		9.2	5.5	9 (990)		RN	50

San Jose, plot 3

17.5.06 N 08 14 52 W 079 06 25 15.00-15.25

POSITION X	POSITION Y	Tree No.	Species	Tree height	Diameter at Breast Height (cm)	Basal Area (cm2)
5	7.5	1 (879)	RN	6.0	5.00	19.63

San Jose, plot 3 seedlings

17/05/2006 **Lat. North:** N 08 14 52

Long. West: W 079 06 25

Plot (a,b,c)	Sub. Plot #	POSITION X	POSITION Y	Sapling #	Dbh If needed	Species	Height (cm). (from sediment surface)
3		2.1	2.2	1 (980)		RN	95
3		1.2	2.3	2 (981)		RN	59

San Jose, plot 4

17.5.06 N 08 14 54 W 079 06 24 15.27-16.01

POSITION X	POSITION Y	Tree No.	Species	Tree height	Diameter at Breast Height (cm)	Basal Area (cm2)
2	1	1 (953)	RN	16.0	17.00	226.98
5.4	8.5	2 (957)	RN	21.0	17.60	243.28
8.1	4.9	3 (952)	RN	19.0	29.30	674.26

No seedlings were present in San Jose, plot 4.

San Jose, plot 5

17.5.06 N 08 14 54 W 079 06 24 15.30-16.15

POSITION	Tree No.	Species		Diameter	Basal

X	Y			Tree height	at Breast Height (cm)	Area (cm2)
3	4.5	1 (945)	LA	1.3	3.50	9.62
4.5	8	2 (943)	RN	1.5	3.50	9.62
6.8	6.8	3 (934)	RN	3.2	3.30	8.55
7.5	8.8	4 (940)	RN	3.8	3.30	8.55
7.8	7.9	5 (938)	RN	3.8	3.80	11.34
8	6	6 (937)	RN	3.8	3.40	9.08

San Jose, plot 5 seedlings

17/05/2006

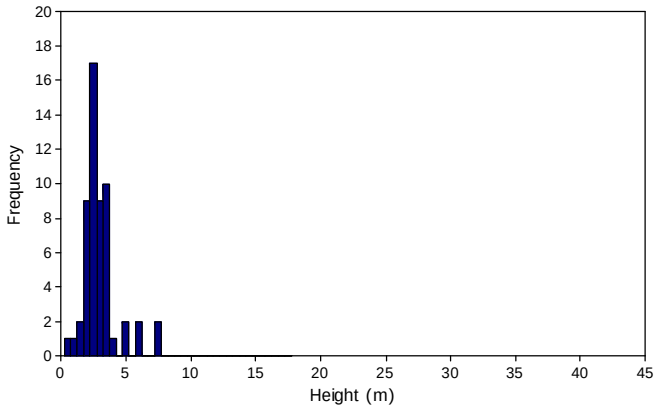
Lat. North: N 08 14 54

Long. West: W 079 06 24

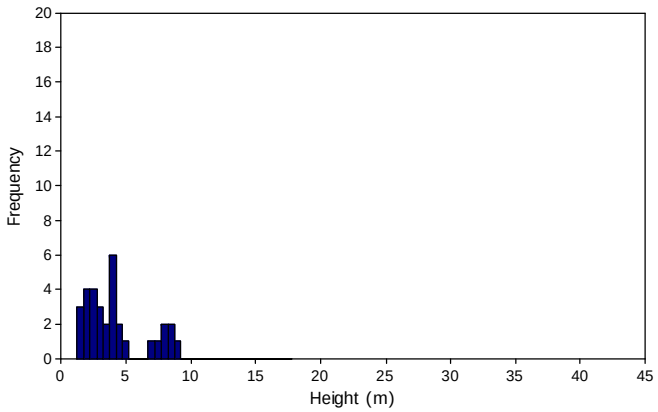
Plot (a,b,c)	Sub. Plot #	POSITION X	POSITION Y	Sapling #	Dbh If needed	Species	Height (cm). (from sediment surface)
		2.2	7.4	1 (974)		RN	95
		6	8.4	2 (942)		RN	55
		5	4	3 (933)		RN	40
		7	7	4 (935)		RN	40
		8	8	5 (939)		RN	95

7.7 Analysis of data for all plots
7.7.1 Adult height data, Rey 1

Plot 1



Plot 2



Plot 3

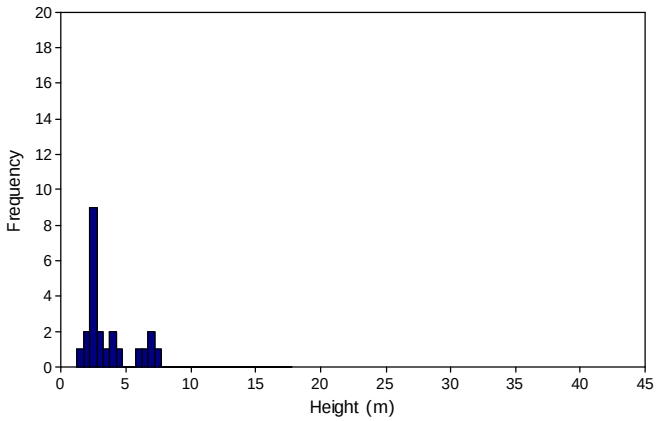
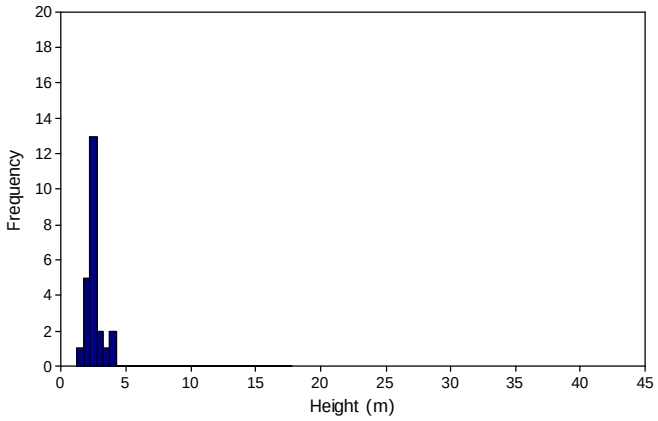


Figure 7.18 Histograms to show distribution of adult height classes in Rey 1, plots 1-3.

Plot 4



Plot 5

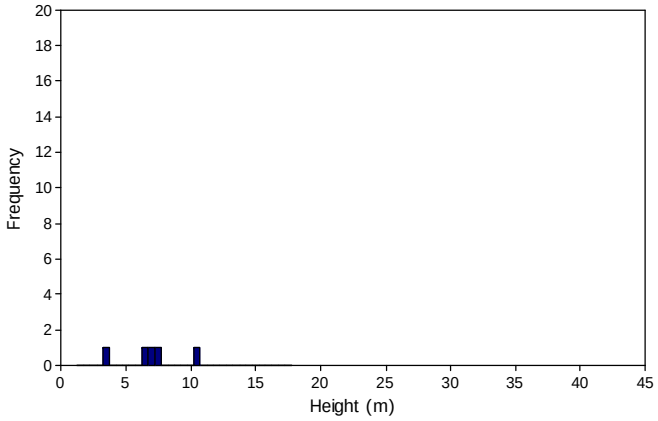
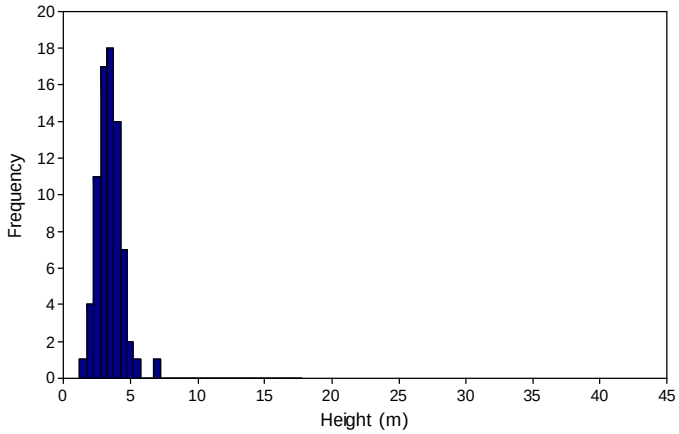


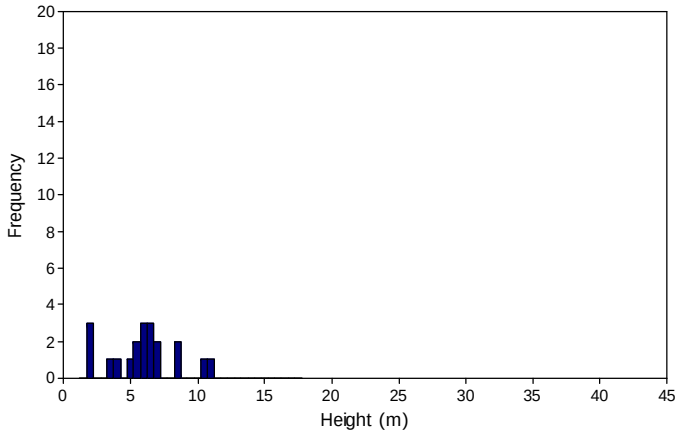
Figure 7.19 Histograms to show the distribution of adult height classes in Rey 1, plots 4 and 5

7.7.2 Adult height data, Rey 2

Plot 1



Plot 2



Plot 3

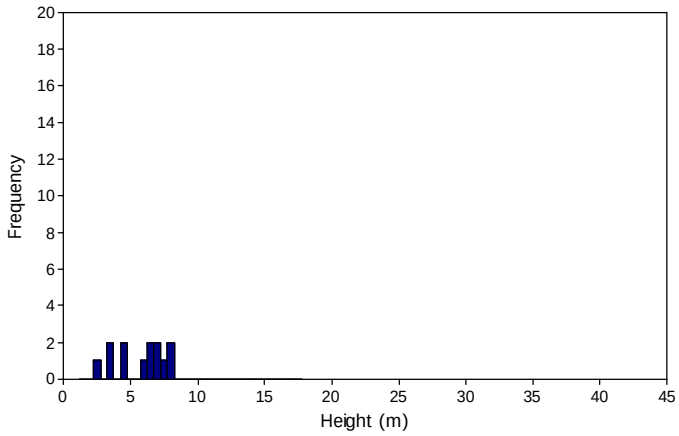
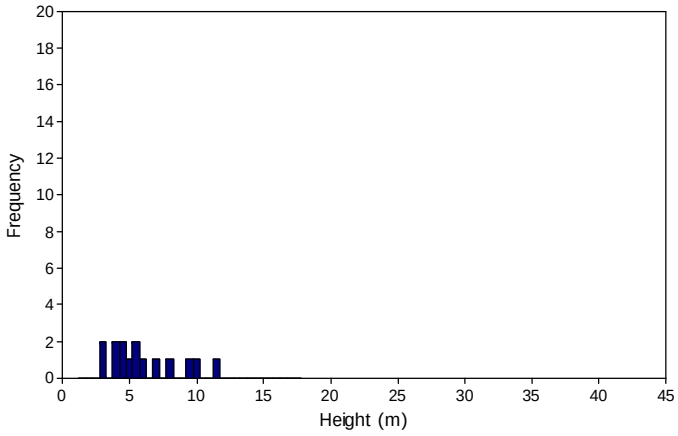


Figure 7.20 Histograms to show the distribution of adult height classes at Rey 2, plots 1-3

Plot 4



Plot 5

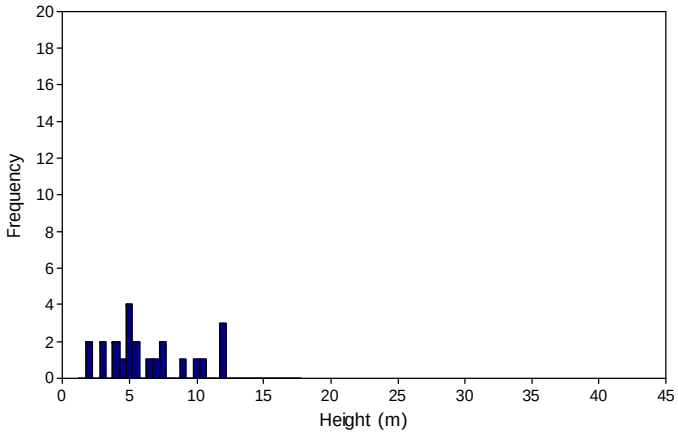
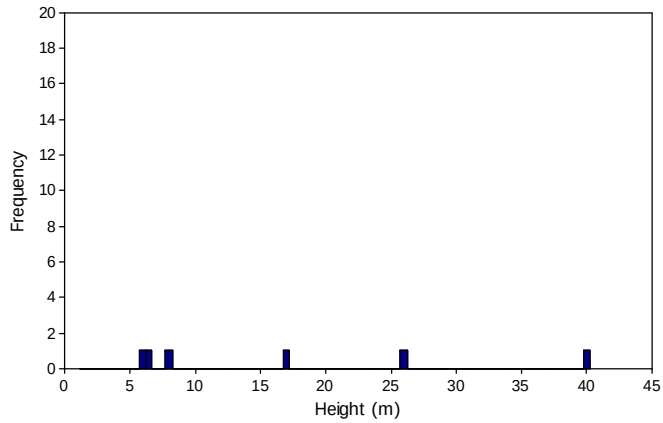


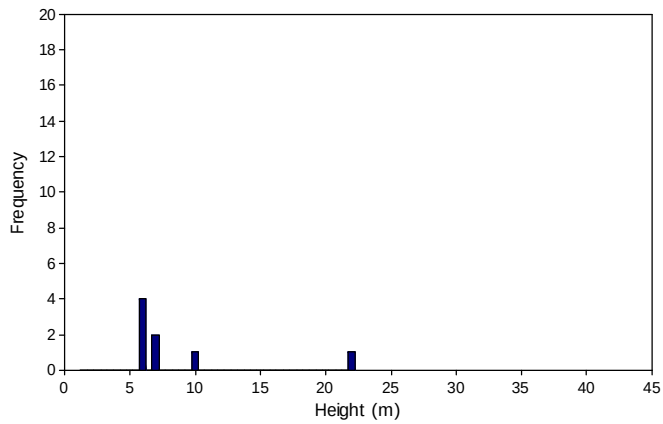
Figure 7.21 Histograms to show the distribution of adult height classes at Rey 2, plots 4 and 5

7.7.3 Adult height data, San Jose

Plot 1



Plot 2



Plot 3

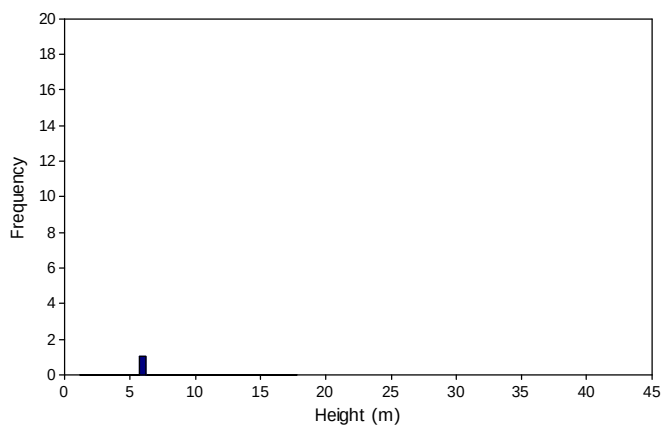
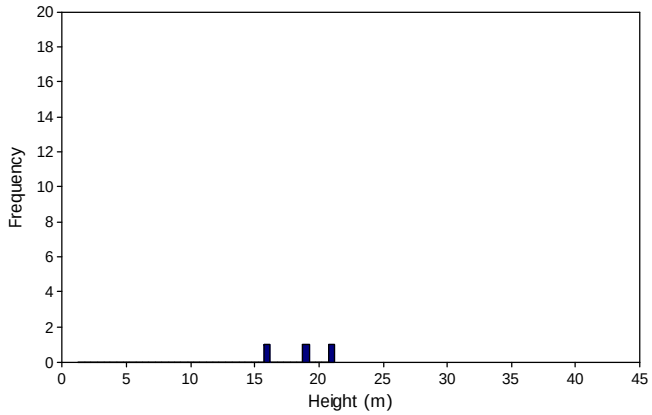


Figure 7.22 Histograms to show the distribution of adult height classes at San Jose, plots 1-3

Plot 4



Plot 5

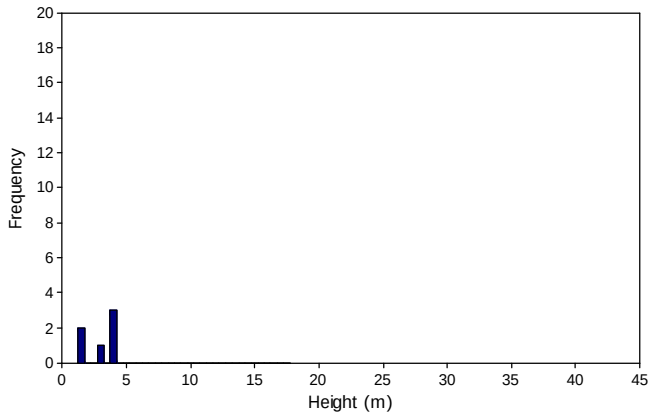
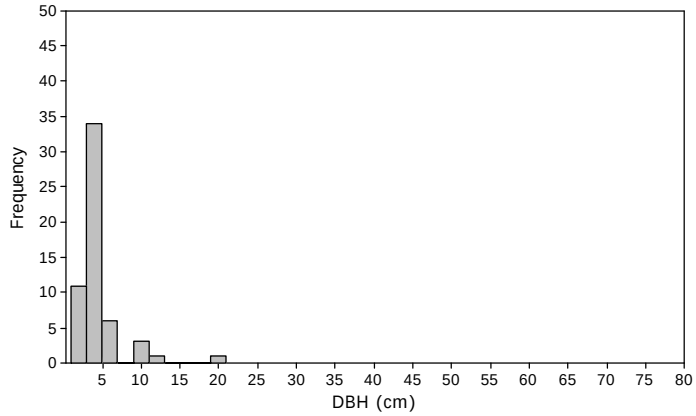


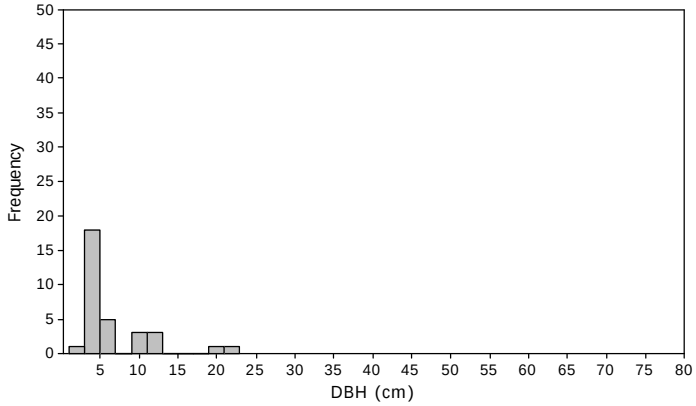
Figure 7.23 Histograms to show the distribution of adult height classes at San Jose, plots 4 and 5

7.7.4 Adult DBH data, Rey 1

Plot 1



Plot 2



Plot 3

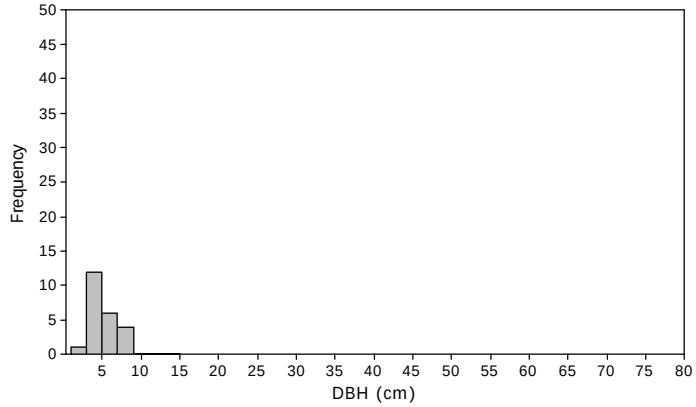
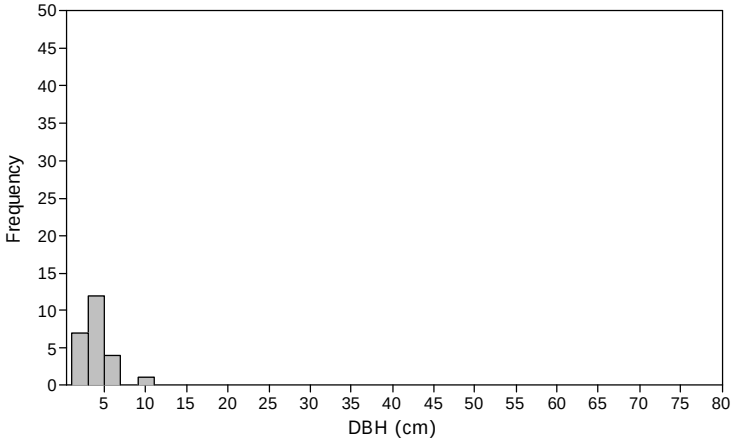


Figure 7.24 Histograms to show distribution of adult DBH classes greater than 2.5cm in Reyes 1, plots 1-3.

Plot 4



Plot 5

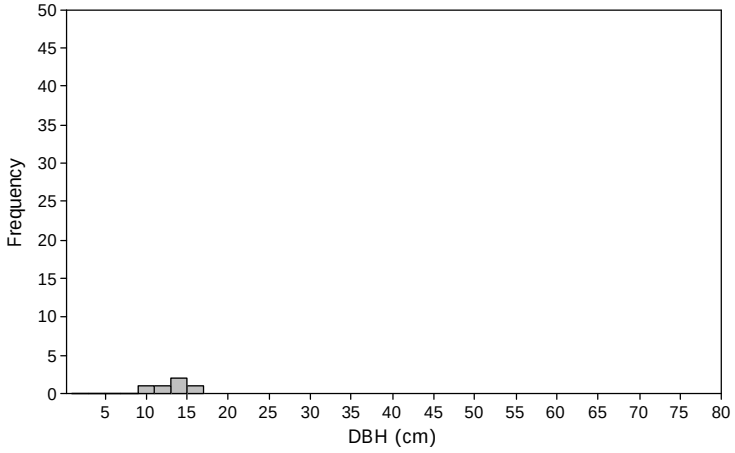
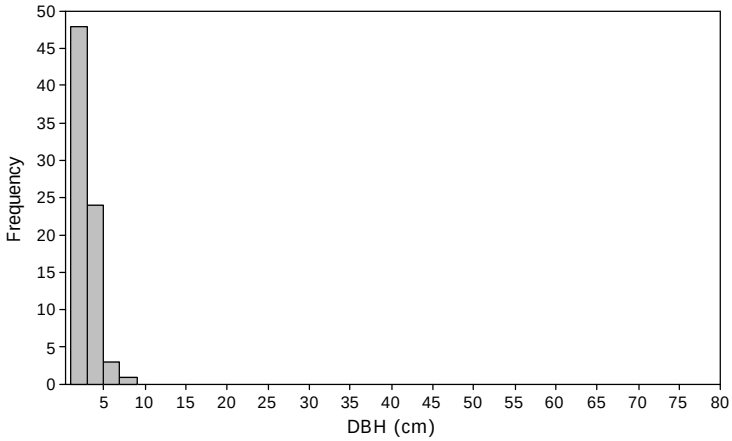


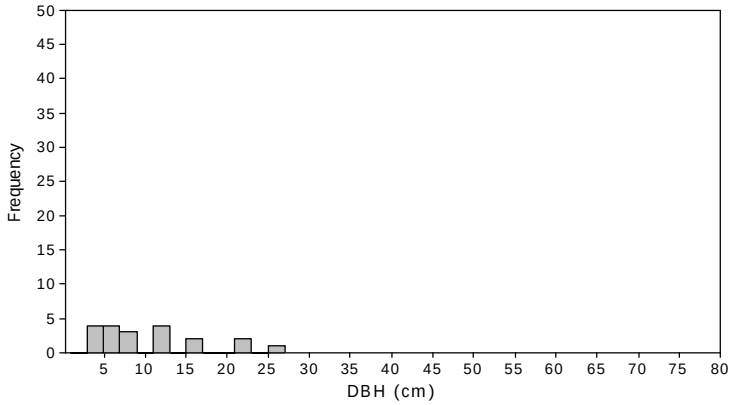
Figure 7.25 Histograms to show the distribution of adult DBH classes greater than 2.5cm in Reyes 1, plots 4 and 5.

7.7.5 Adult DBH data, Rey 2

Plot 1



Plot 2



Plot 3

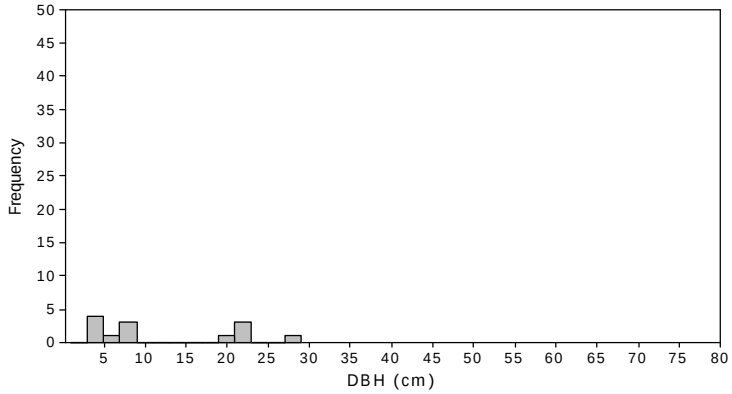
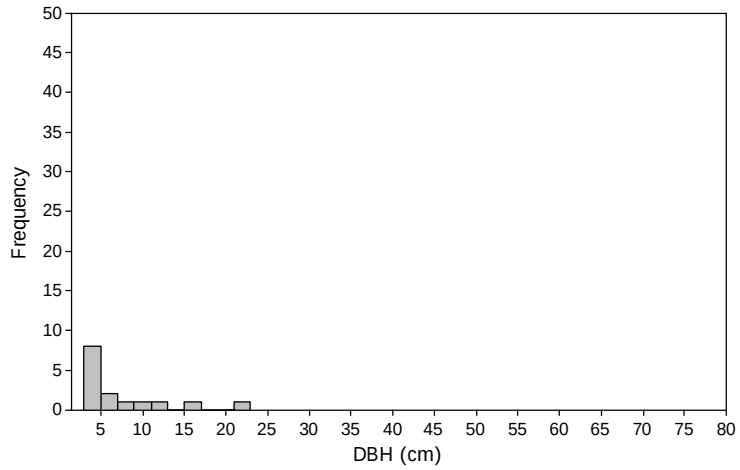


Figure 7.26 Histograms to show distribution of adult DBH classes greater than 2.5cm in Rey 2, plots 1-3.

Plot 4



Plot 5

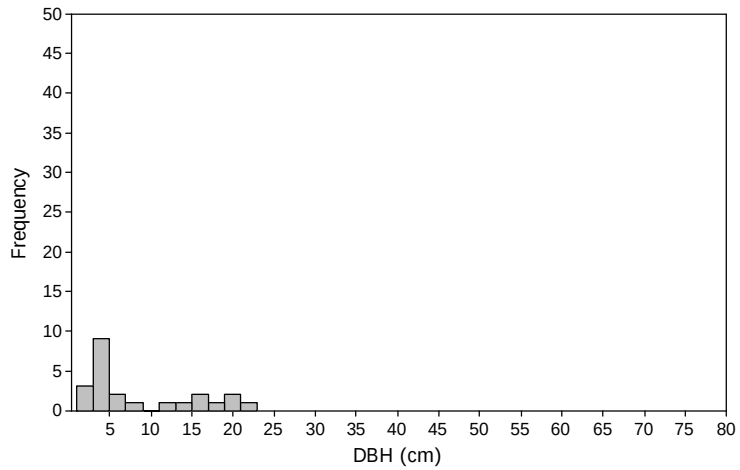
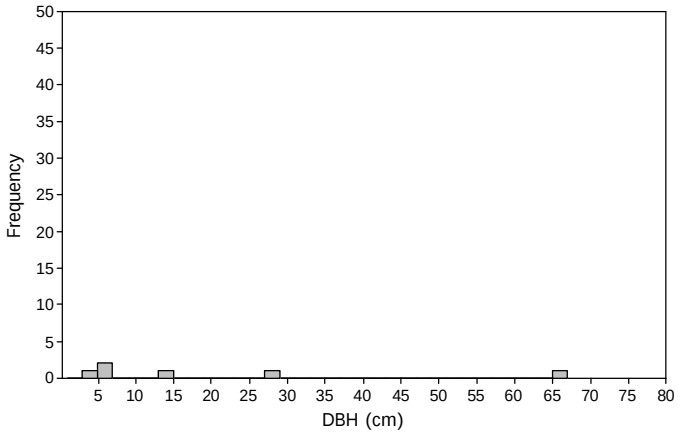


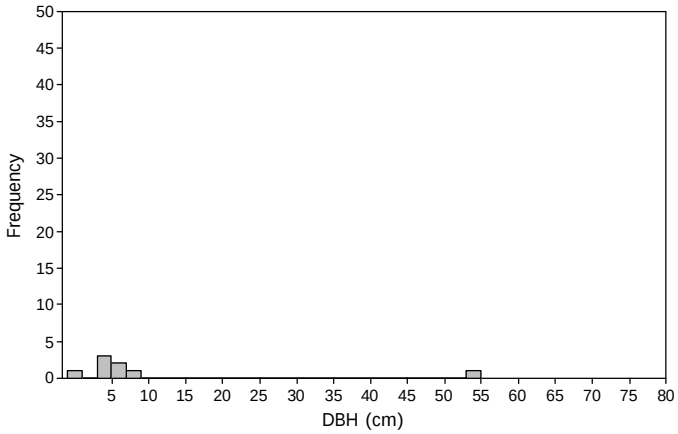
Figure 7.27 Histograms to show the distribution of adult DBH classes greater than 2.5cm in Rey 2, plots 4 and 5.

7.7.6 Adult DBH data, San Jose

Plot 1



Plot 2



Plot 3

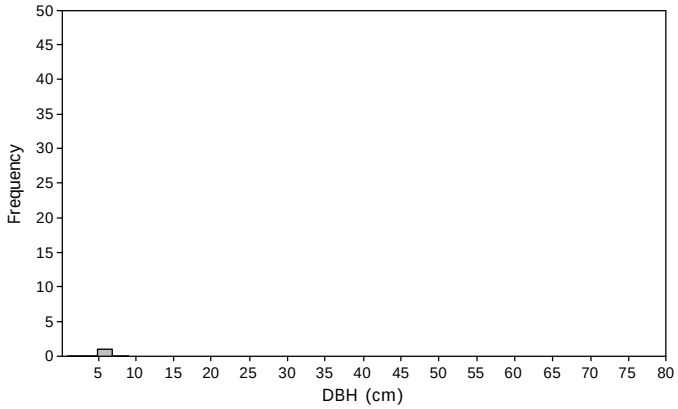
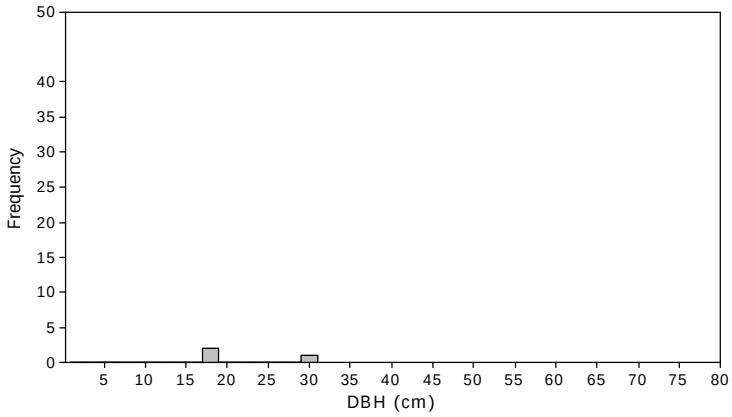


Figure 7.28 Histograms to show distribution of adult DBH classes greater than 2.5cm in San Jose, plots 1-3.

Plot 4



Plot 5

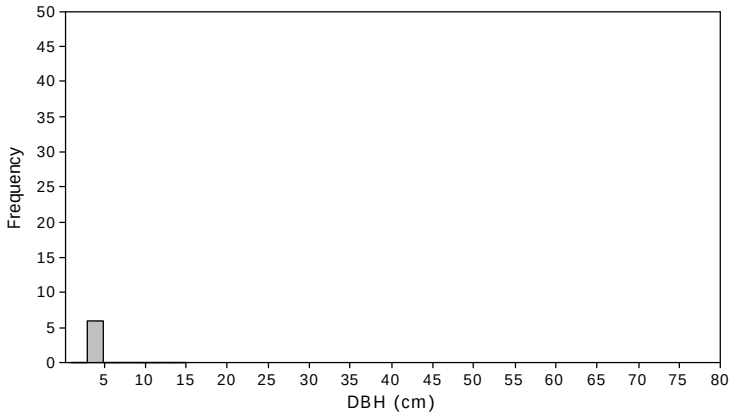


Figure 7.29 Histograms to show the distribution of adult DBH classes greater than 2.5cm in San Jose, plots 4 and 5.

7.7.7 Adult species composition, Rey 1

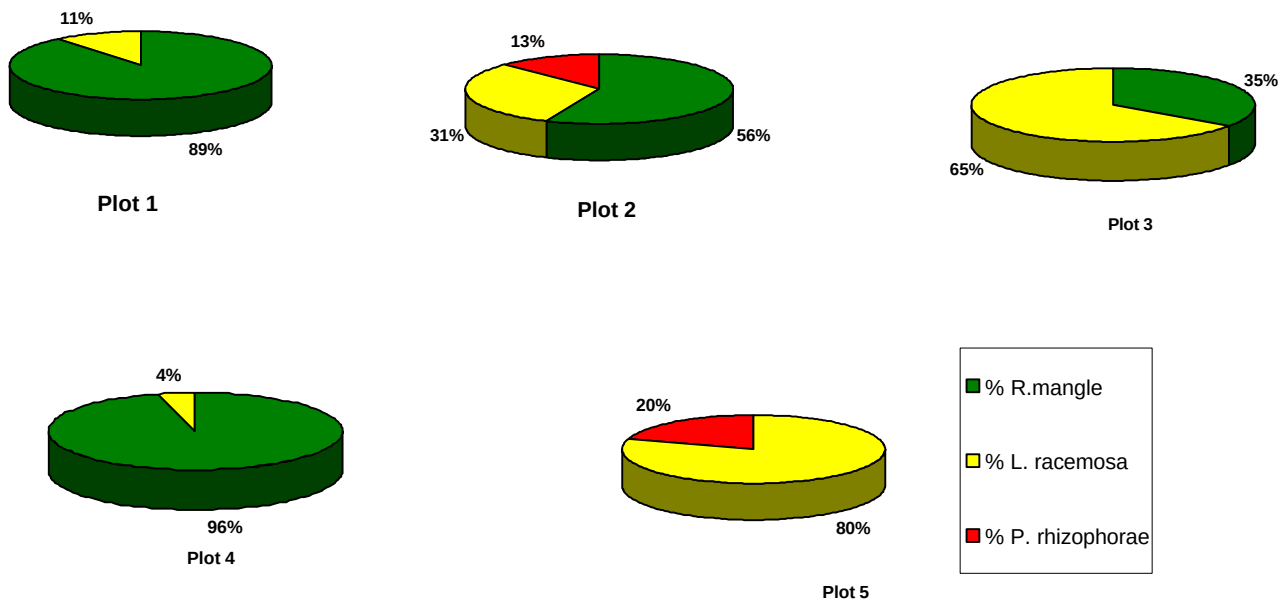


Figure 7.30 A comparison was made of the species composition of adult trees in each of the five sub plots at Rey 1. Results are expressed as the number of species in each plot as a percentage of the total number of trees in the plot.

7.7.8 Adult species composition, Rey 2

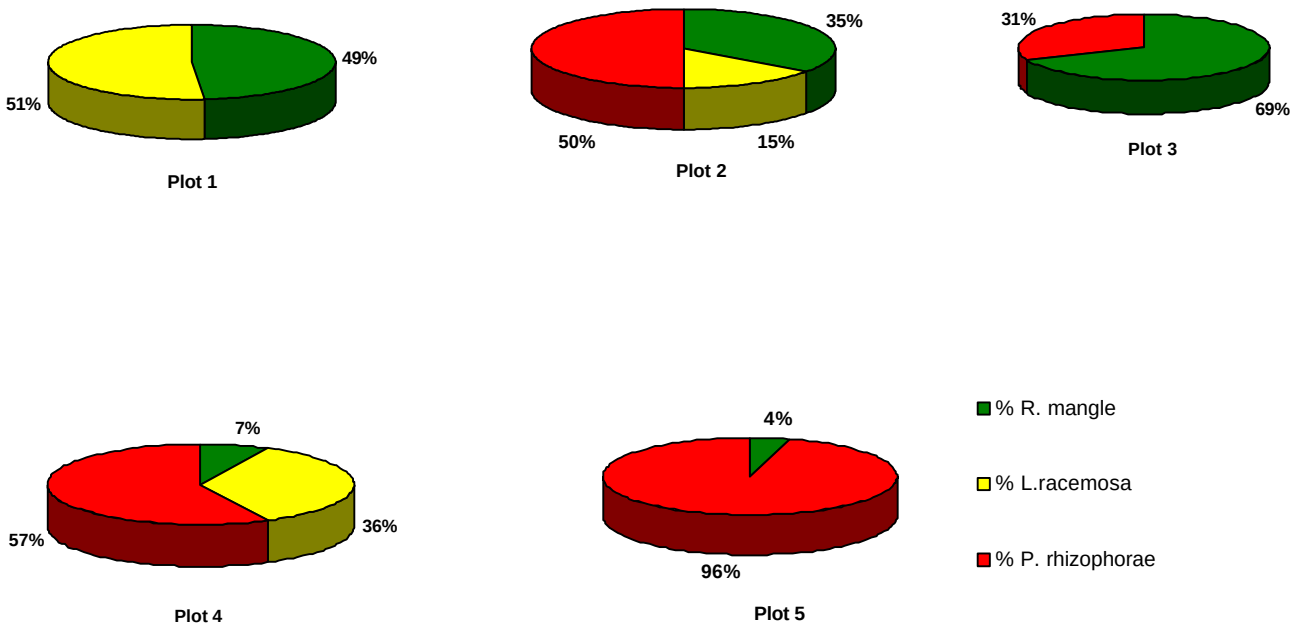


Figure 7.31 A comparison was made of the species composition of adult trees in each of the five sub plots at Rey 2. Results are expressed as the number of species in each plot as a percentage of the total number of trees in the plot.

7.7.9 Adult species composition, San Jose

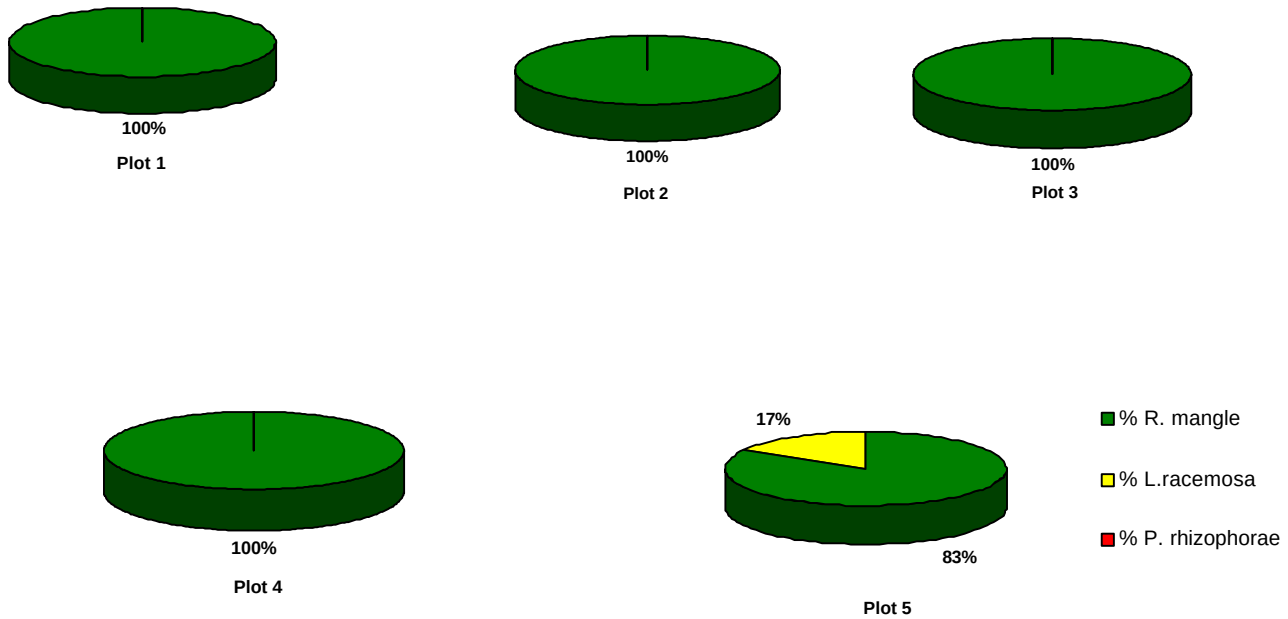
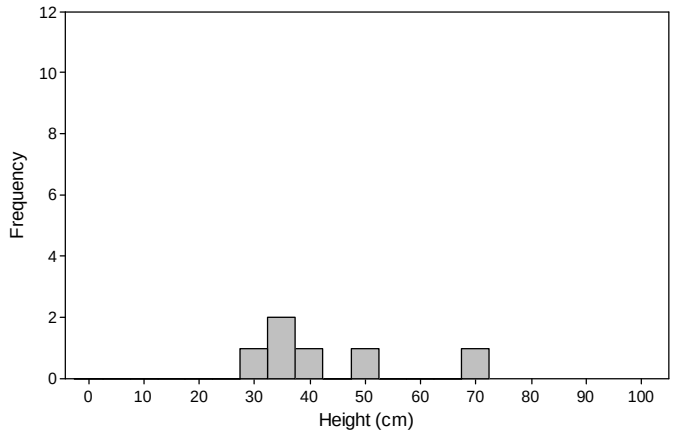


Figure 7.32 A comparison was made of the species composition of adult trees in each of the five sub plots at San Jose. Results are expressed as the number of species in each plot as a percentage of the total number of trees in the plot.

7.8 Seedling data
7.8.1 Seedling height data, Rey 1

Plot 1



Plot 2

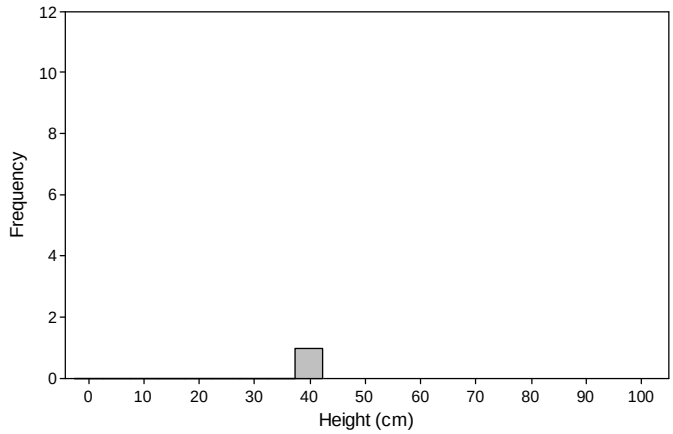
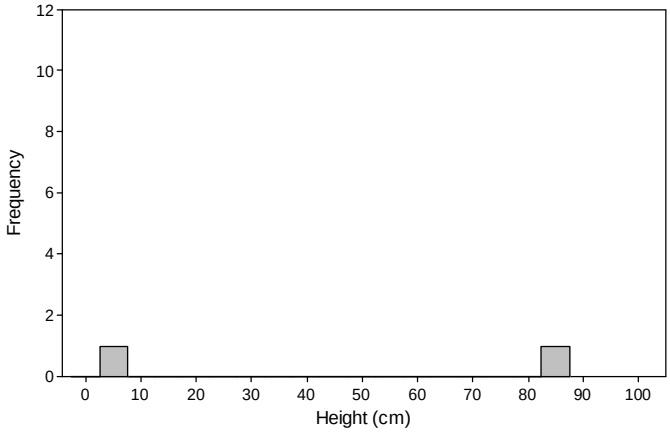


Figure 7.33 Histograms showing distribution of seedling height in Rey 1, plots 1 and 2.

Plot 3



Plot 5

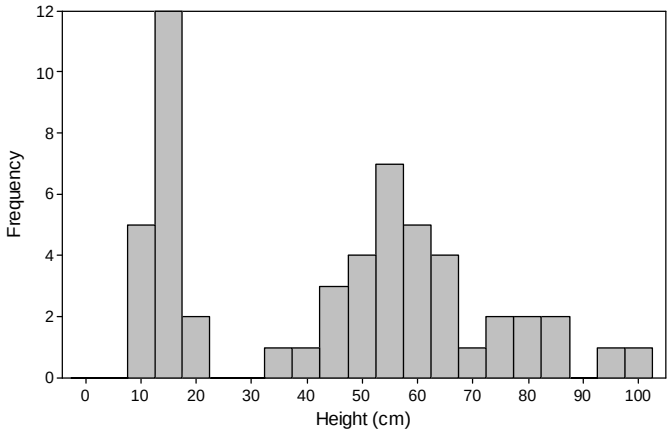
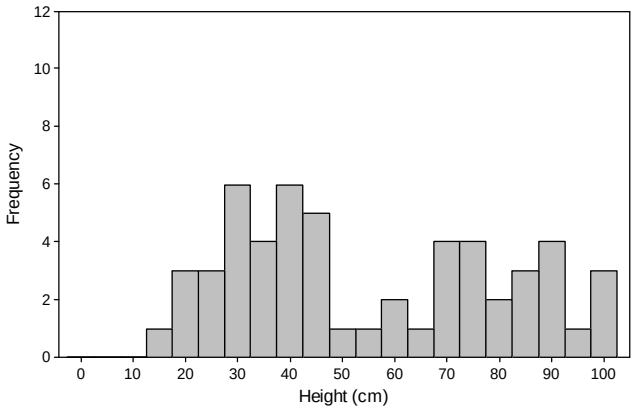


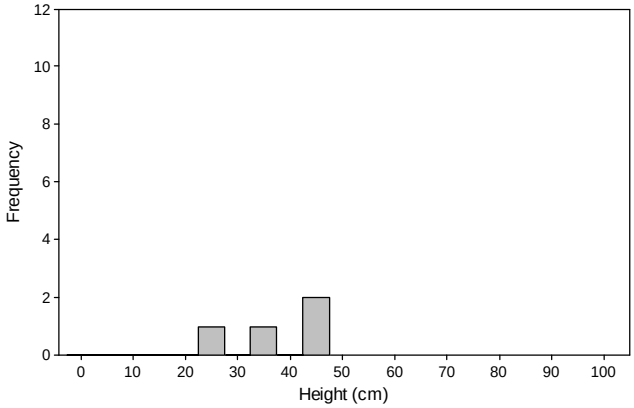
Figure 7.34 Histograms showing distribution of seedling height in Rey 1, plots 3 and 5. Note; there were no seedling in Reyes 1, plot 4.

7.8.2 Seedling height data, Rey 2

Plot 1



Plot 2



Plot 3

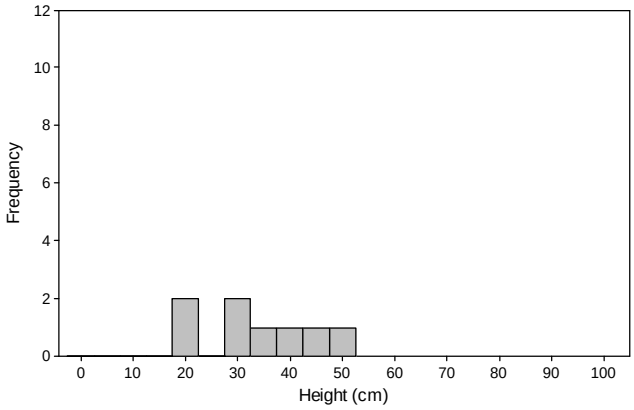
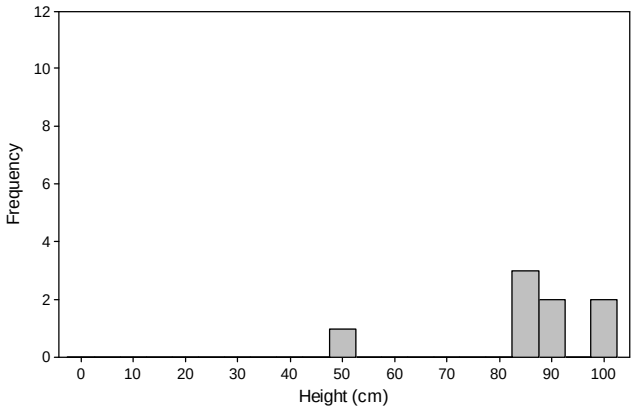


Figure 7.35 Histograms showing distribution of seedling height in Rey 2, plots 1-3.

Plot 4



Plot 5

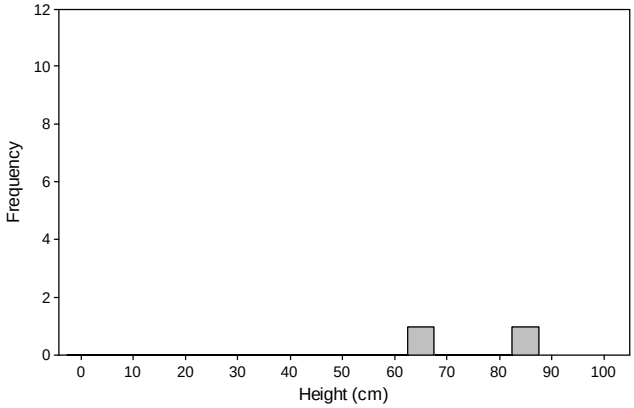
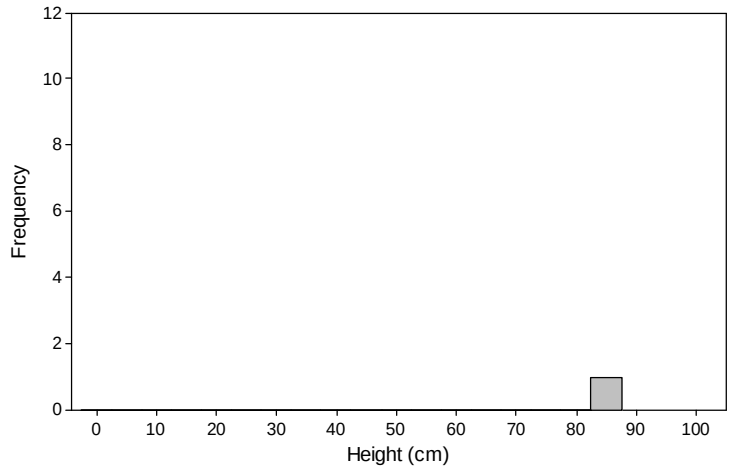


Figure 7.36 Histograms showing distribution of seedling height in Rey 2, plots 4 and 5.

7.8.3 Seedling data, San Jose

Plot 1



Plot 2

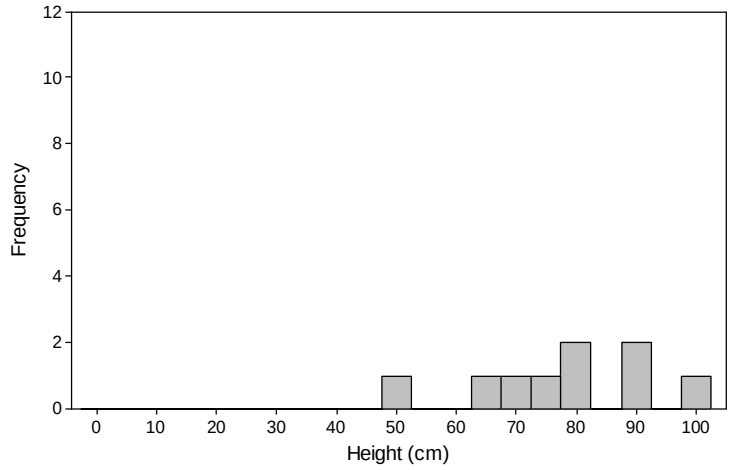
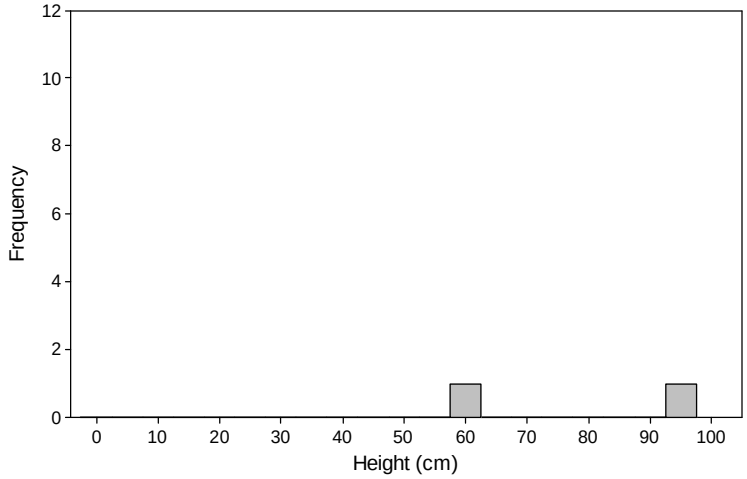


Figure 7.37 Histograms showing distribution of seedling height in San Jose, plots 1 and 2.

Plot 3



Plot 5

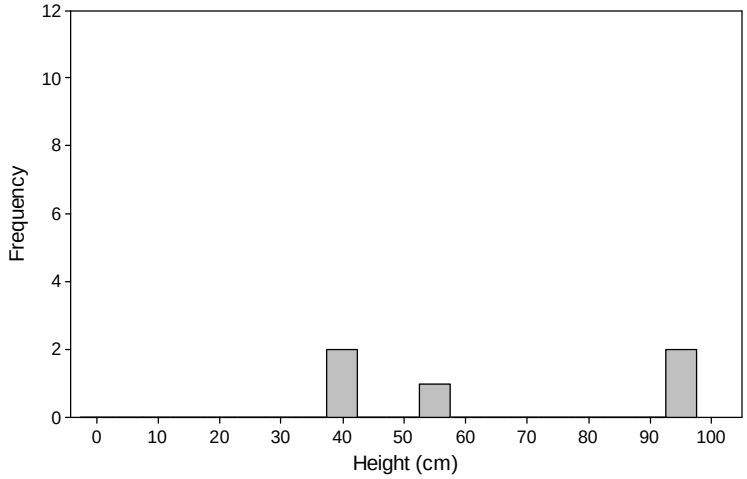


Figure 7.38 Histograms showing distribution of seedling height in San Jose, plots 3 and 5. Note; there were no seedling in San Jose, plot 4.

7.8.4 Seedling species composition, Rey 1

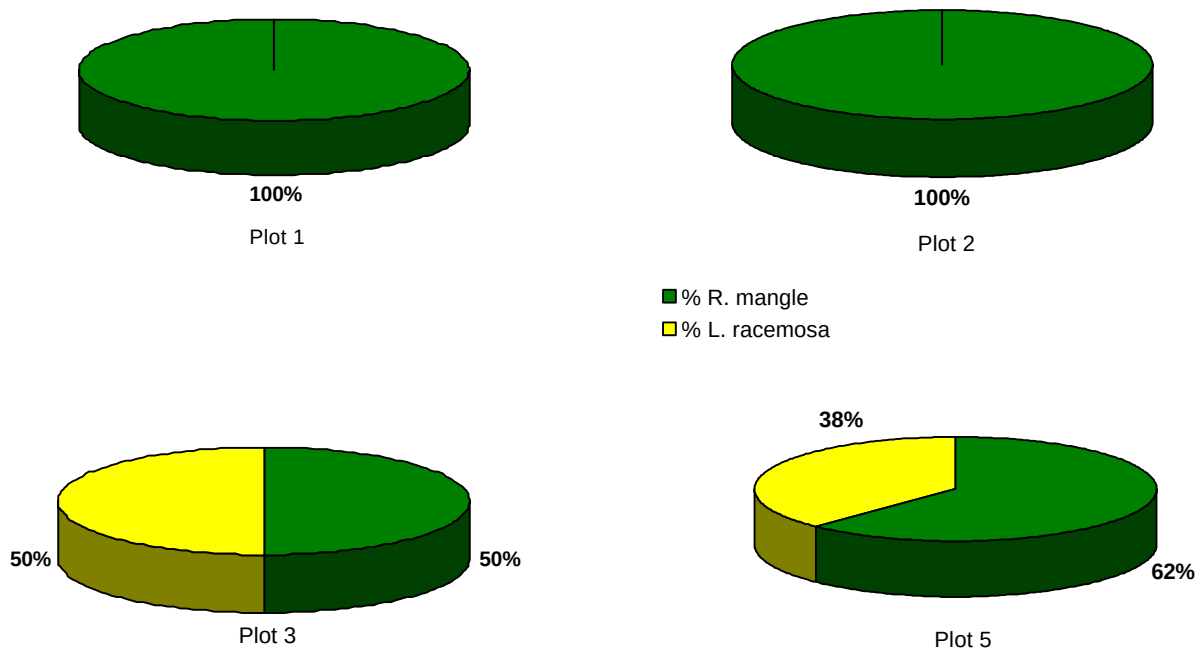


Figure 7.39 A comparison was made of the species composition of seedling trees in each of the five sub plots at Rey 1. Results are expressed as the number of species in each plot as a percentage of the total number of trees in the plot. In all plots the total number of seedlings were measured. Note; there were no seedlings in plot 4.

7.8.5 Seedling species composition, Rey 2

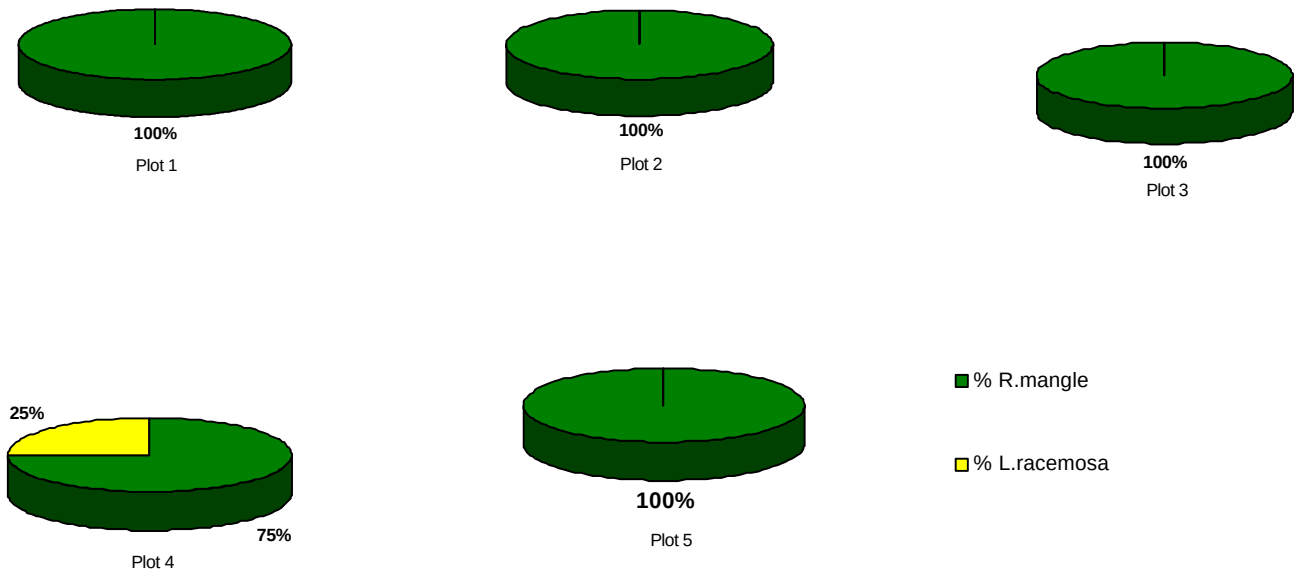


Figure 7.39 A comparison was made of the species composition of seedling trees in each of the five sub plots at Reyes 2. Results are expressed as the number of species in each plot as a percentage of the total number of trees in the plot. At Reyes 2 seedlings were measured within 5x1m2 quadrats in sub plots 1,4 and 5. All seedlings were measured in sub plots in 2 and 3.

7.8.6 Seedling species composition, San Jose

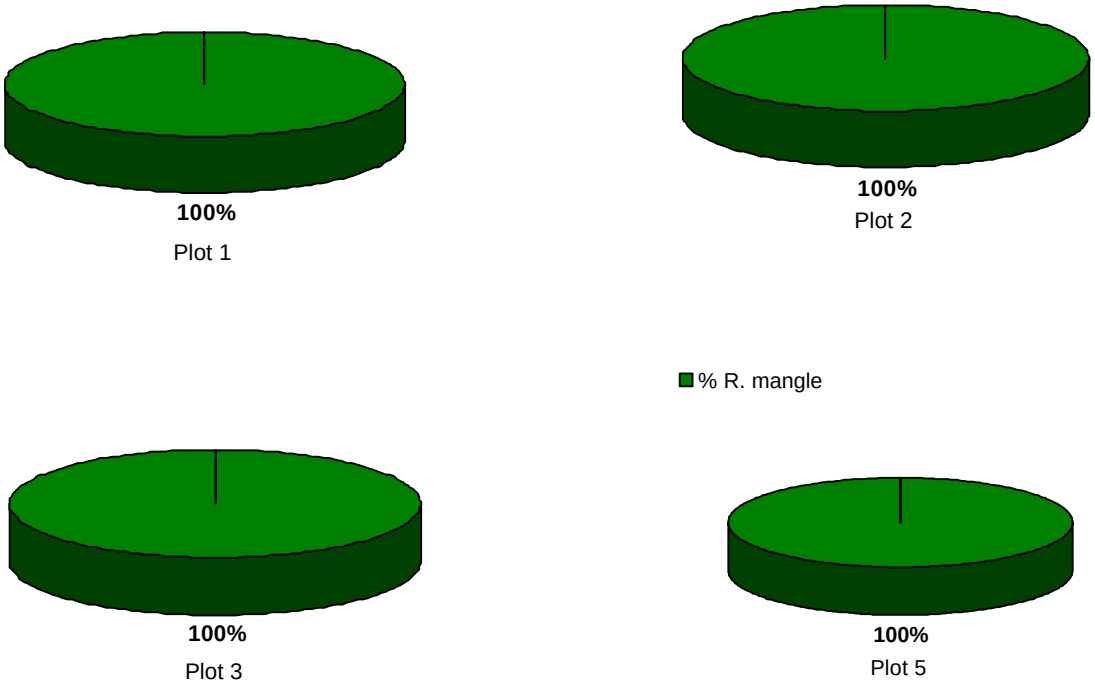


Figure 7.40 A comparison was made of the species composition of seedling trees in each of the five sub plots at San Jose. Results are expressed as the number of species in each plot as a percentage of the total number of trees in the plot. In all plots the total number of seedlings were measured. Note; there were no seedlings in plot 4.