Fall 2012

A Comparison of Qualitative and Quantitative Ecological Assessment Methods of Mangroves in Southwestern Madagascar

Sondra Winders
SIT Study Abroad

A comparison of qualitative and quantitative ecological assessment methods of mangroves in Southwestern Madagascar

Sondra Winders

SIT Madagascar: Biodiversity and Natural Resource Management

Project Advisor: Benjamin Taylor

Academic Director: Jim Hansen

Fall 2012

For those who like to be beside the seaside

ACKNOWLEDGEMENTS

I would like to acknowledge Honko Mangrove Conservation and Education, Blue Ventures and SIT Madagascar: Biodiversity and Natural Resource Management. Together, they provided the materials and means necessary to complete this project, as well as guidance and support throughout. I would like to specifically thank my advisor, Ben Taylor, without whom this project would not have been possible. I also cannot forget to mention the Blue Ventures Blue Carbon team of Trevor Jones, Samir Gandhi, Zo Andriamahenina and Holy Andriamitantsoa for all their help and hard work.

Table of Contents

Table of Figures

List of Tables

ABSTRACT

Mangroves are unique, tropical, intertidal forests that, among many other important functions, serve as large carbon sinks for the sequestration of atmospheric CO_2. This project qualitatively assessed the mangrove forest of Honko Mangrove Conservation and Education (Tulear, Madagascar) in conjunction with Blue Ventures for a proposed Plan Vivo carbon stock project. The qualitative results were then compared with quantitative measurements in order to determine the most effective method of ecological assessment. Sixty-three stands of mangrove forest covering 9.72km^2 were identified and mapped. Level of harvest, species composition, density, canopy cover, dominant height, dominant DBH, forest condition and composition were compared between the studies. Qualitative results agreed with quantitative measurements in species composition, dominant height, dominant DBH and forest condition. While there were some differences between level of harvest classifications, density, canopy cover and composition, neither method was determined to be superior to the other. Qualitative and quantitative data both support and correct each other and it is recommended that quantitative data be combined with qualitative observation to avoid oversight in future carbon stock assessments.

INTRODUCTION

Mangroves

The term ‘mangrove’ refers to both the trees and woody shrubs that occupy tropical intertidal forest communities and the communities themselves (Tomlinson, 1986). Mangrove ecosystems are characterized by fluctuating tides, high salinity levels, low-oxygen concentrations and the high temperatures of the tropics (Hogarth, 2007). Through adaptations such as spatial zonation, salt balance, aerial roots and vivipary, 73 species of mangrove are able to exist in these tropical, extreme, ever-changing environments (Appendix I) (Spalding, Kainuma, & Collins, 2010). These species play important roles in stabilizing the soil, protecting against coastal erosion, creating habitat and breeding ground for many different marine and terrestrial organisms, performing biofiltration services and acting as primary photosynthetic producers in these complex and productive ecosystems (Appendix I) (Hogarth, 2007; Spalding, Kainuma, & Collins, 2010).

Mangroves in Madagascar

Globally, mangroves cover an estimated 152,000km^2, of which 2% are found in Madagascar (Roger & Andrianasolo, 2003). Nearly 98% of this habitat occurs along the western side of the island where they are less exposed to high wave energy (Roger & Andrianasolo, 2003; Spalding, Kainuma, & Collins, 2010). The most extensive mangroves are found along the northwestern coast of Madagascar, where the climate is more humid, while in southwestern Madagascar, where the dry season can last seven to nine months, mangroves are more sparsely distributed and rarely reach 6m in height (Spalding, Kainuma, & Collins, 2010).

Uses and Threats

Mangroves play important socio-economic roles, providing wood for building, firewood and charcoal production for local communities, and serving as lucrative fisheries for crabs, shrimp and fish (Hogarth, 2007). However, human use of mangroves has led to significant exploitation of the resources they provide, resulting in widespread deforestation (Hogarth, 2007). Over the last 50 years, mangroves have been reduced by 30-50% (Donate et al., 2011). The annual loss of mangroves averages 1-2%, exceeding rates of loss of terrestrial forests (Jones, 2012). Mangroves also face the threats of global climate change. Consequences of increased global temperatures, including sea level rise and ocean acidification, will negatively affect the balance of coastal ecosystems such as mangroves (Hogarth, 2007).

Mangroves as carbon sinks

The increasing amount of CO_2 in the atmosphere and its contribution to the effects of climate change (IPCC, 2007) has led to an increased interest in the importance of mangroves as carbon sinks. Mangroves remove CO_2 from the atmosphere through photosynthesis, perhaps reducing the problems associated with greenhouse gases and global warming (Kathiresan & Qasim, 2005). Mangroves are among the most productive ecosystems on earth and maintain a high standing biomass compared with many other forests of the wet tropics (Appendix I) (Spalding, Kainuma, & Collins, 2010). While mangroves cover a relatively small area globally and have a lower physical stature than most adjacent tropical moist forests, their biomass is comparable to higher-canopy terrestrial forests due to their larger proportion of below-ground biomass (Spalding, Kainuma, & Collins, 2010). The organic-rich sediment held in these ecosystems also plays a role in carbon sequestration, having been found to account for 49-98% of carbon storage in these systems (Donato et al., 2011). Because of the costal environment of mangroves, they have been dubbed “blue carbon” sinks as they gain attention from climate and conservation communities.

With the amount of carbon stored in forests, it should come as no surprise that deforestation is a major contributor to greenhouse gas emissions, currently accounting for 8-20% of CO_2 emissions annually (Spalding, Kainuma, & Collins, 2010; Donato et al., 2011; Pendleton, et al., 2012). Studies suggest that deforestation of mangroves alone accounts for 10% of CO_2 emissions despite the fact that mangroves account for just 0.7% of tropical forest area (Donato et al., 2011; Pendleton, et al., 2012) Preventing further forest loss will reduce projected CO_2 increases, an idea that has led to programs such as the United Nation's Reducing Emissions from Deforestation and Forest Degradation and to Enhance Carbon Stocks (REDD/REDD+), and Payments for Ecosystem Services (PES). Such programs use political, legal and economic means to encourage countries to maintain existing forest areas (Spalding, Kainuma, & Collins, 2010). More than 40 countries are developing national REDD+ strategies and policies and hundreds of PES projects have been initiated in the tropics (Alongi, 2011).

Honko Mangrove Education and Conservation/Blue Ventures

Mangroves in southwestern Madagascar are particularly threatened by deforestation, especially those surrounding the populated city of Tulear (Spalding, Kainuma, & Collins, 2010). Based just north of Tulear, a Belgian Non-Governmental Organization (NGO) Honko Mangrove Conservation and Education aims to prevent the loss of mangrove forest in this area. Founded in 2007, Honko works toward achieving this goal through efforts to replant deforested areas and the promotion of alternative livelihoods for Malagasy ethnic groups living in the area (Honko, 2011). Blue Ventures, an English NGO based in Tulear, also works with local communities to conserve marine and coastal environments. Through initiatives involving ecotourism, sustainable fisheries management, aquaculture and blue carbon they strive to protect biodiversity and alleviate poverty in the Tulear region (Blue, 2012).

Plan Vivo Foundation

One example of how Honko and Blue Ventures work with local communities to conserve threatened mangrove forest and coastal environments is through the Plan Vivo Foundation. A registered Scottish charity, Plan Vivo uses payments for ecosystem services to encourage projects supporting rural smallholders, or owners of small subsistence farms, and community groups with improved natural resource management worldwide (Plan, 2008). Projects that quantify and monitor climate services, can gain 'Plan Vivo Certificates" which generate funding for projects, activities and payments for ecosystem services (Plan, 2008). Presently, Honko and Blue Ventures are initiating a Plan Vivo project based on carbon crediting with the Vondron'Olona Ifotony (VOI) of Honko, a local association of villages (Taylor, 2012). The VOI holds the land rights to the mangroves in the Honko area and includes the five villages surrounding Honko: Ambondrolava, Ambotsibotsike, Belalanda, Belitsake and Tanambao (Taylor, 2012). By protecting the mangroves of Honko, the VOI will receive payment for the amount of carbon the forest produces, which can then be reinvested in the community (Taylor, 2012). This will be the second Plan Vivo project ever to focus on mangroves in the world (Taylor, 2012).

Objective

This study qualitatively assessed and classified the mangrove forests of Honko in terms of stature and level of harvest, in conjunction with Blue Ventures for the proposed Plan Vivo carbon stock project. Quantitative measurements of the mangroves were then taken in order to determine the more effective method to inform future Plan Vivo assessments.

METHODS

Site Overview

Honko is located in southwestern Madagascar, 12km north of Tulear in the village of Ambondrolava (23°15’37”S, 43°37’49”E). The mangrove forest covers approximately 500ha, surrounding a small inlet channel that runs north to south. Seven species of mangrove representing five families have been identified at this site (Table 1, Appendix III). The average spring tidal amplitude for the Tulear region is 3.24m (Spalding, Kainuma, & Collins, 2010). The average temperature from October to March is 28°C and 23°C from April to September (Climate, 2004). The rainy season typically lasts from December to February and averages 71mm of precipitation, while the dry season averages 21mm (World, 2012).

Table 1. Species of mangrove found in Honko.

Family	Scientific Name
Avicenniaceae	*Avicennia marina*
Combretaceae	*Lumnitzera racemonsa*
Meliaceae	*Xylocarpus granatum*
Rhizophoraceae	*Bruguiera gymnorrhiza*
Rhizophoraceae	*Ceriops tagal*
Rhizophoraceae	*Rhizophora mucronata*
Sonneratiaceae	*Sonneratia alba*

Qualitative Fieldwork

Stands and sub-stands of mangrove forest were identified using up to date SPOT (Systèm Pour l’Observation de la Terre) Satellite Imagery and direct observation (Appendix I). Each stand was qualitatively assessed for:

- Level of harvest (intact, degraded, deforested, (re)planted)
- Dominant species (>60%)
- Density (low, medium or high)
- Canopy Cover (closed >60%, open 30-70%, or very open <40%)
- Number of stories (1,2 or 3)

- Dominant tree height (stunted <5m, short <5m, medium 5-10m, tall >10m)
- Dominant tree diameter at breast height (DBH) (<5cm, >5cm, >10cm)
- Forest stature (height and DBH combined – small, I1, I2, large)
- Forest age (dying/dead, mature, young, pioneer, regeneration)
- Forest condition (healthy <30%, some death 30-70%, mostly dead >70%)
- Micro-relief (flat, depression or mixed-variable)
- Composition (homogeneous, mostly homogeneous, middle, mostly heterogeneous or heterogeneous).

Levels of harvest were determined based on the ratio of stumps to living trees in a stand (Table 2). In the presence or dominance of stumps, observations were based on live standing trees. Height and DBH measurements were taken for two or three trees representing the dominant class in each stand using a hypsometer and diameter tape to ensure accuracy of estimations. Each stand was mapped using a Garmin etrex 20 GPS unit.

Table 2. Ratios of classification for level of harvest labels applied to stands.

Level of Harvest	Classification
Intact	>90% trees live/standing
Degraded	<90% stumps/standing dead >10% trees live/standing
Deforested	Dominated by stumps/standing dead <10% trees live/standing
Re-planted	Dominated by seedlings with some trees

Quantitative Fieldwork

Three adjacent stands were chosen representing each of the levels of harvest (Figure 1). Three, 2m wide belt transects were laid running east to west within each stand. Each transect started inland and ran the width of the stand towards the channel. Transects were chosen randomly along 10m intervals spanning the north-south length of each stand starting at 0m. Any tree whose trunk fell within the belt transect was measured for height with a hypsometer, distance along the transect using a 30m transect tape, distance from the transect to the left or right with a 2m tailor's tape and the species name was recorded. If a stump fell within the transect, its location was recorded.

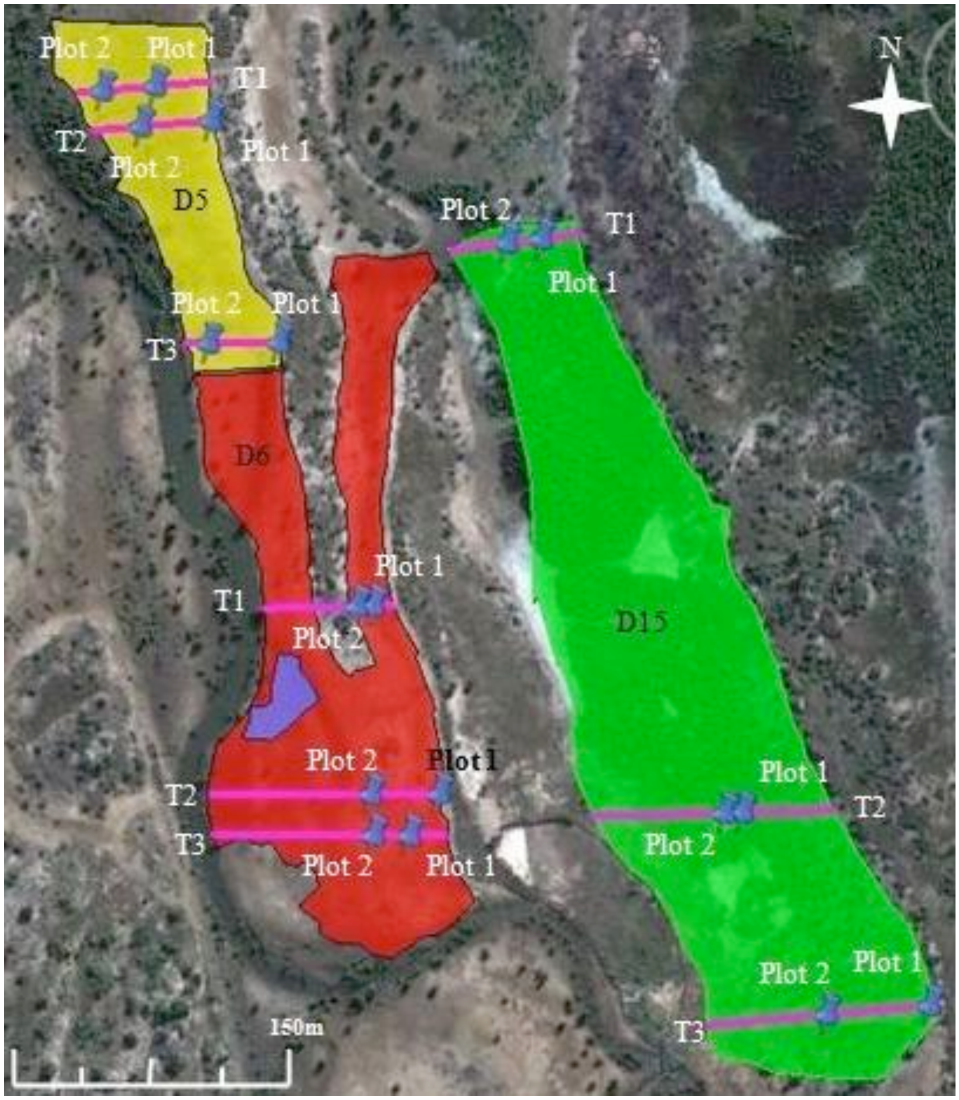

Figure 1. Map of three stands used in quantitative study with location of transects and plots.

The location of two 10m^2 plots were randomly chosen from 10m intervals along the length of the transect and laid to the south of each transect. Within each plot, the X (east to west) and Y-axis (north to south) location and the species of each tree were recorded and circumference at breast height (CBH) measurements were taken using a tailor's tape. If the tree did not reach breast height the CBH was measured at 30cm (Kauffman & Donato, 2012). If the tree was multi-stemmed, the most dominant stem was measured. If the trunk of the tree branched off before reaching breast height, the point just before the branching occurred was measured. Densiometer readings were taken in the north-east, center and south-west of each plot to measure canopy cover. The location and occurrence of stumps were also recorded.

RESULTS

Qualitative

A total of 63 stands and 28 sub-stands were identified covering an area of 9.72km^2 (Figure 2, Figure 3Figure 4Figure 5 Figure 6). Of those, 31 stands were labeled intact. Intact stands accounted for 5.9km^2 of the total area assessed, while a total of 10 stands making up 2.4km^2, were degraded. Four stands and 0.6km^2 of the total area were deforested. There were 18 re-planted stands, covering an area of 0.9km^2. In total, 61% of the area assessed was intact and 9% was re-planted. Degraded and deforested areas covered 24% and 6% of the area, respectively, and were mainly located in the southern region of the forest. Stands D5, D6 and D15 were chosen for the quantitative study because they represented the three levels of harvest in one area (*see Figure 1*). The qualitative results for these three stands are summarized by categories compared in the quantitative study in Table 3.

Table 3. Summary table of qualitative results for the three stands and categories compared in the quantitative study.

CATEGORY	D5	D6	D15
Level of Harvest	Degraded	Deforested	Intact
Species Dominance	*A. marina*	*A. marina*	*A. marina*
Density	Low	Low	Medium
Canopy Cover	Very Open	Very Open	Open
Dominant Height	<5m	<5m	<5m
Dominant DBH	<5cm	>10cm	<5cm
Forest Condition	Healthy	Healthy	Healthy
Composition	Middle	Mostly Homogeneous	Heterogeneous

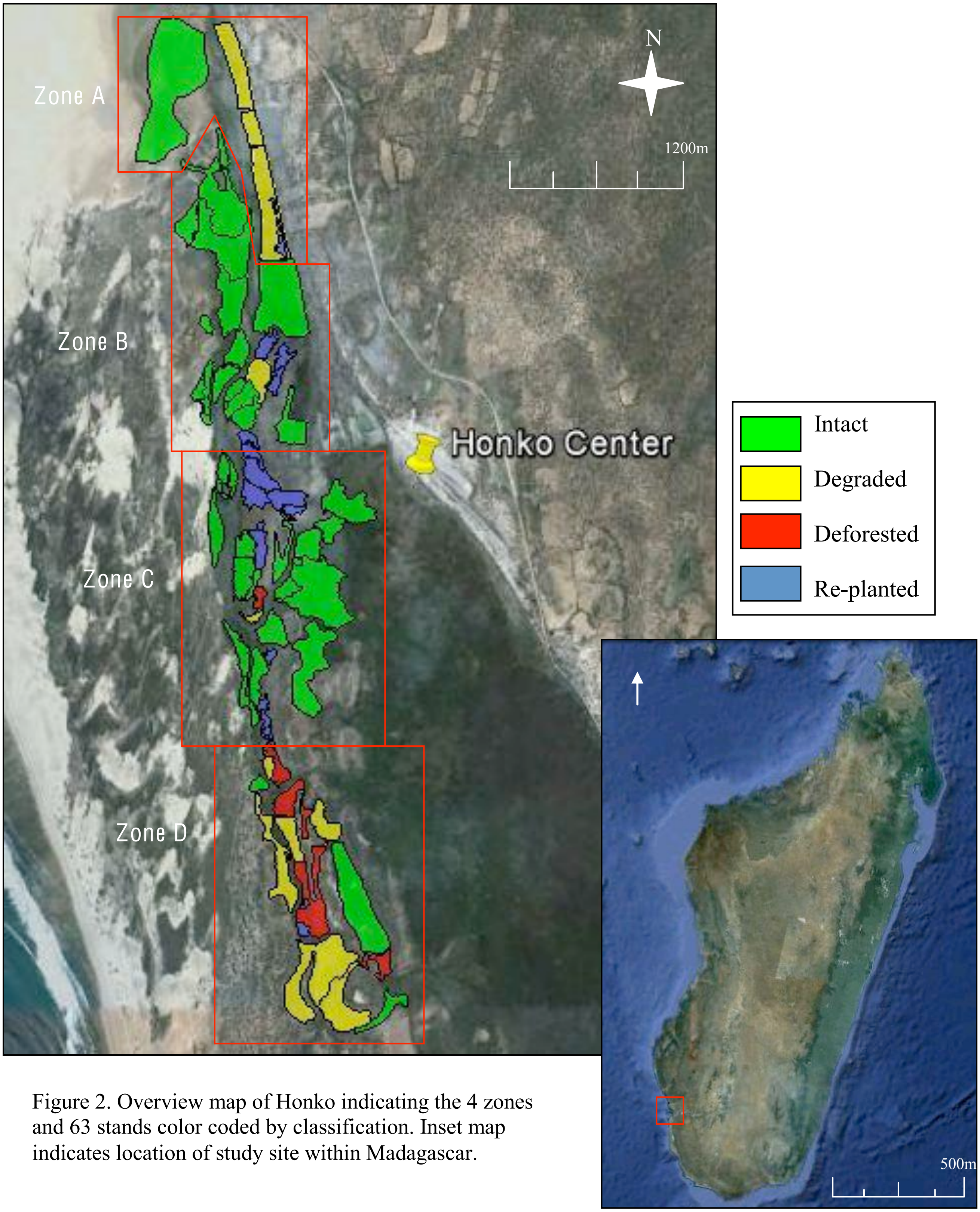

Figure 2. Overview map of Honko indicating the 4 zones and 63 stands color coded by classification. Inset map indicates location of study site within Madagascar.

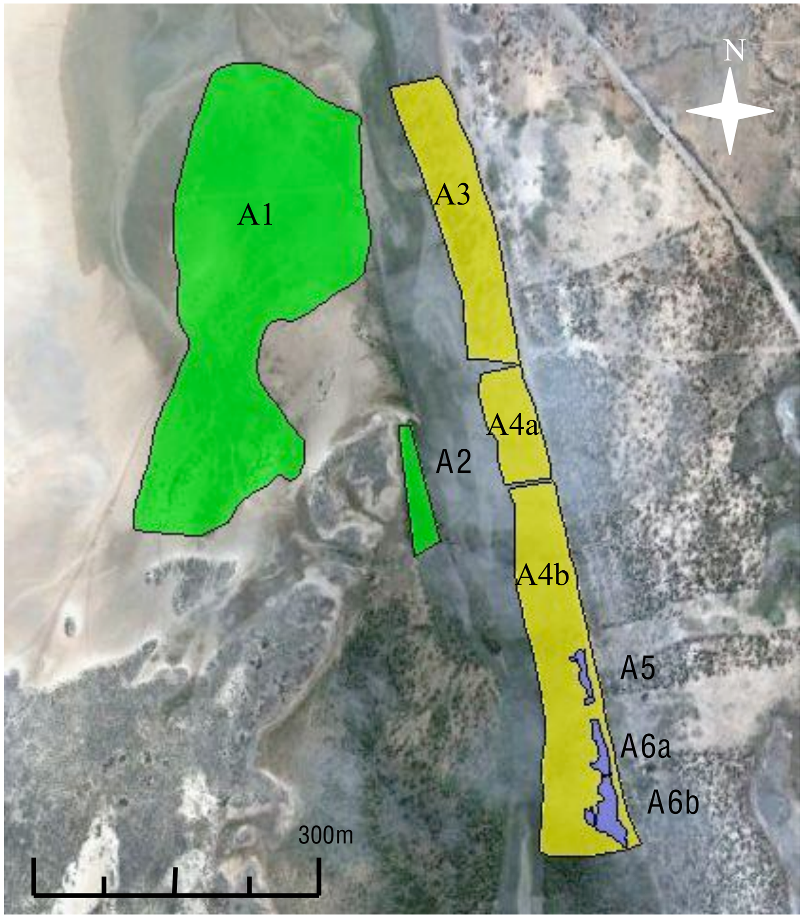

Figure 3. Map showing stands in Zone A of Honko labeled and color coded according to classification. Green = intact; Yellow = degraded; Blue = re-planted.

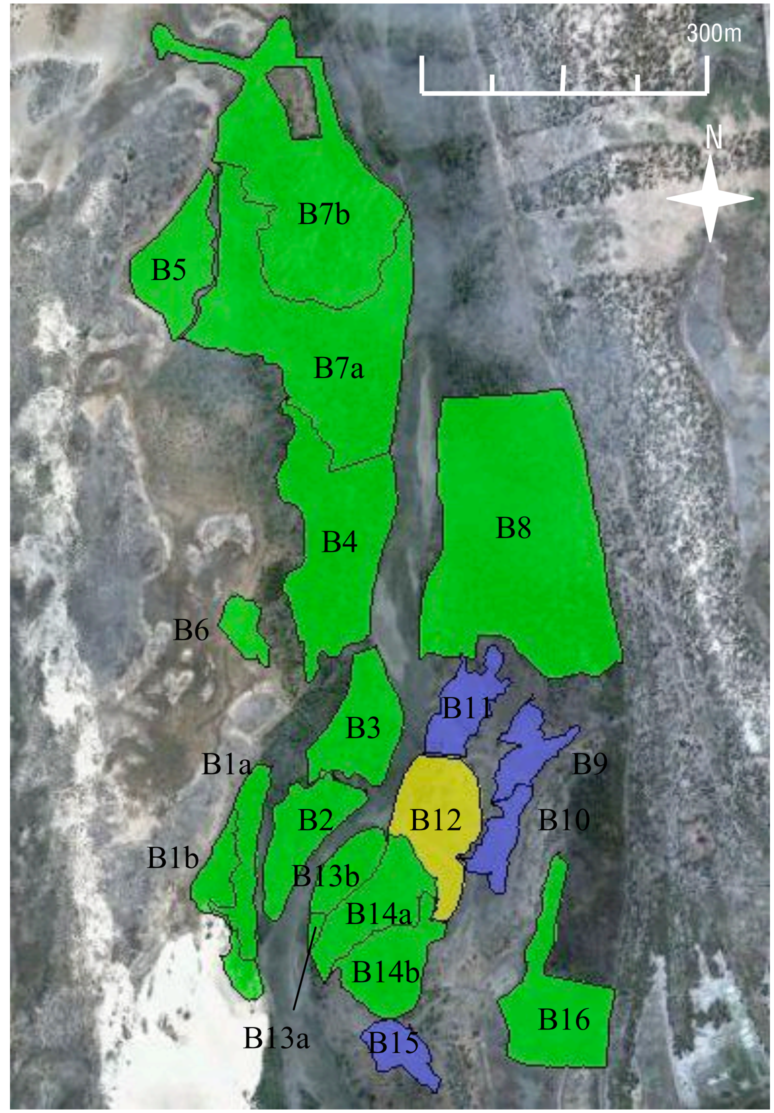

Figure 4. Map showing stands in Zone B of Honko labeled and color coded according to classification. Green = intact; Yellow = degraded; Blue = re-planted.

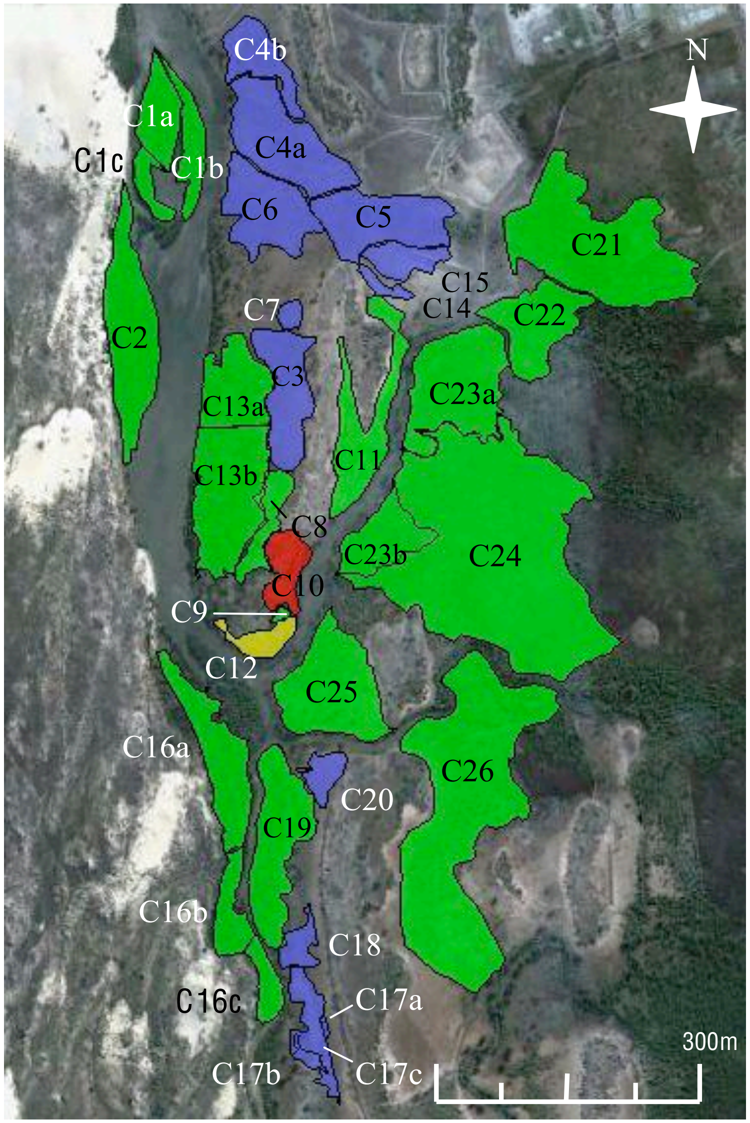

Figure 5. Map showing stands in Zone C of Honko labeled and color coded according to classification. Green = intact; Yellow = degraded; Red = deforested; Blue = re-planted

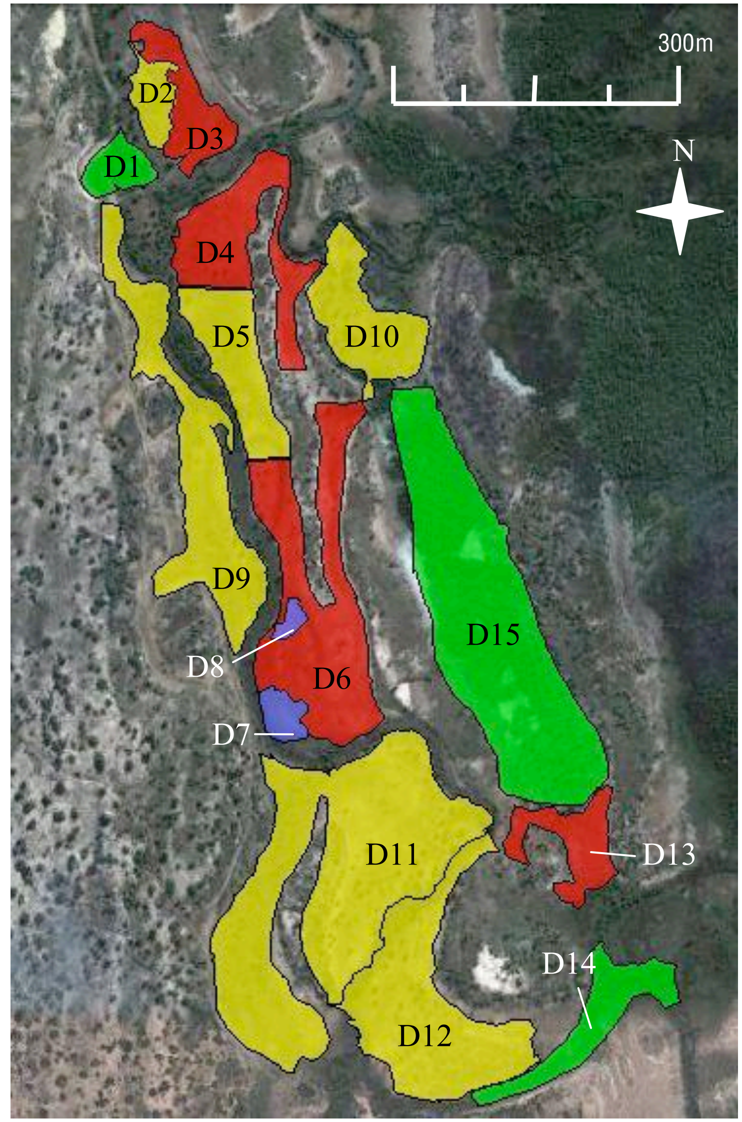

Figure 6. Map showing stands in Zone D of Honko labeled and color coded according to classification. Green = intact; Yellow = degraded; Red = deforested; Blue = re-planted.

Quantitative

Level of Harvest

Based on species data collected from the transects, stand D5 consisted of approximately 66% stumps vs. 32% live trees (Figure 7). Stand D6 had a similar ratio, but with a higher proportion of trees: 61% stumps to 39% live trees. Stand D15 had the highest proportion of live trees with and 47% stumps and 51% live trees. Based on the qualitative classification ratio, all three of these stands are degraded.

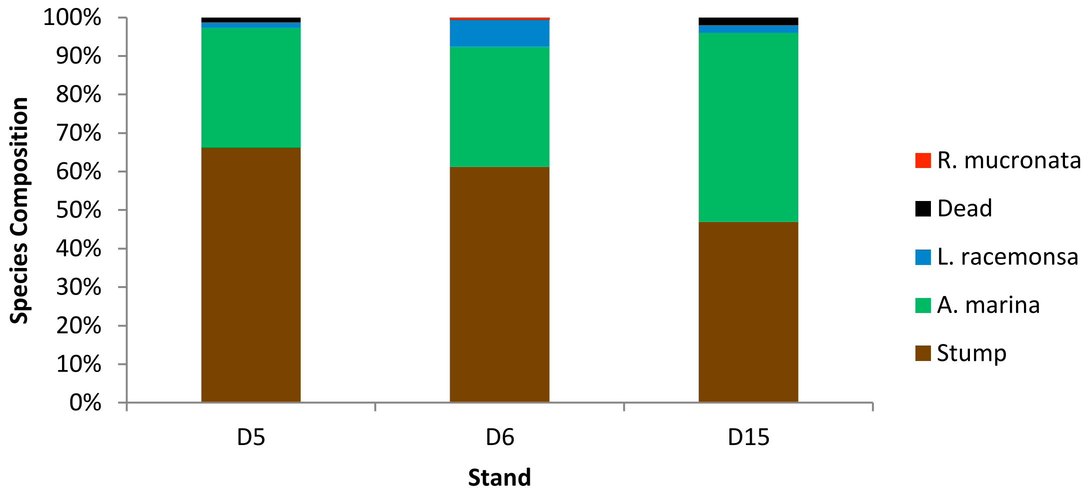

Figure 7. Percent species composition of each stand.

Species Dominance

Of the living trees, stand D5 was dominated by *Avicennia marina* (96%), with *Lumnitzera racemonsa* accounting for the other 4% of the composition (*see Figure 7*). While D6 was also dominated by *A. marina* (80%) it had the highest species diversity of the three stands analyzed. *L. racemonsa* accounted for 18% of trees and *Rhizophora mucronata* 1%. More similar to D5, D15 was 97% *A. marina* and 3% *L. racemonsa*.

Density

The density of living trees was calculated using plot data. D5 had a density of 1.02 trees/m^2. No living trees were recorded in D6, resulting in a density of 0 trees/m^2. D15 had the highest density at 1.22 trees/m^2. A one-way analysis of variance (ANOVA) showed no significant difference between the three stands ($p>0.05$) (Table 4).

Table 4. Summary statistics of one-way analysis of variance test.

Sources of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	P-value
Between Groups	2	4.98	2.49	1.36	0.29
Within Groups	12	21.9	1.83		
Total	14	26.89			

Canopy Cover

All three stands had very open canopy cover. D5 had a canopy cover of 10.81%, while D6 had the lowest percentage of canopy cover at 0.16%. D15 had the highest percentage of canopy cover (18.9%).

Dominant Height

Of the trees measured in D5, D6 and D15, 100% were under <5m in height (Figure 8).

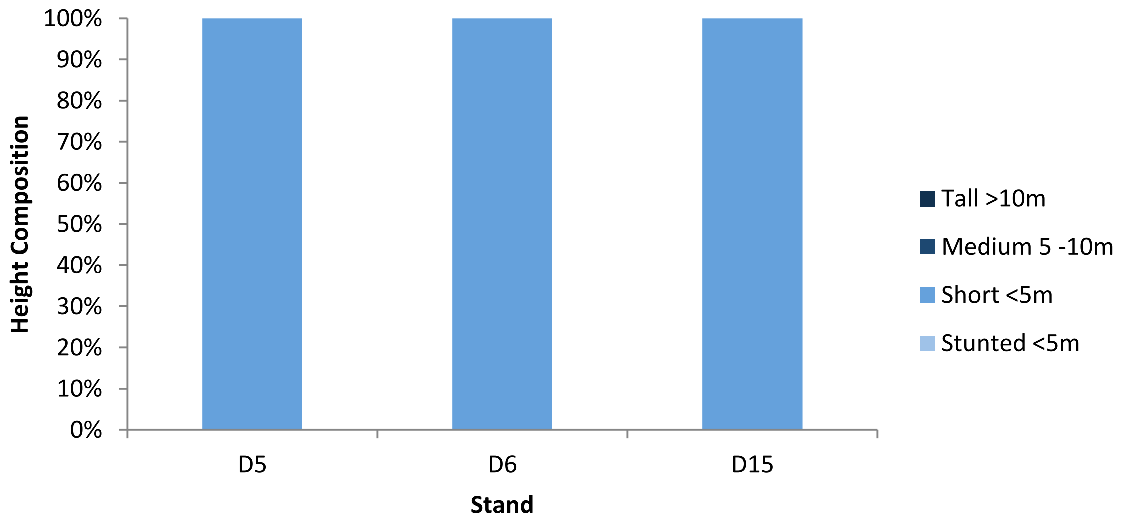

Figure 8. Height composition of each stand by percentage.

Dominant DBH

The dominant DBH for D5 and D15 was <5cm (89% for both) (Figure 9). No living trees were recorded in plots for D6, so no DBH measurements were taken for that stand.

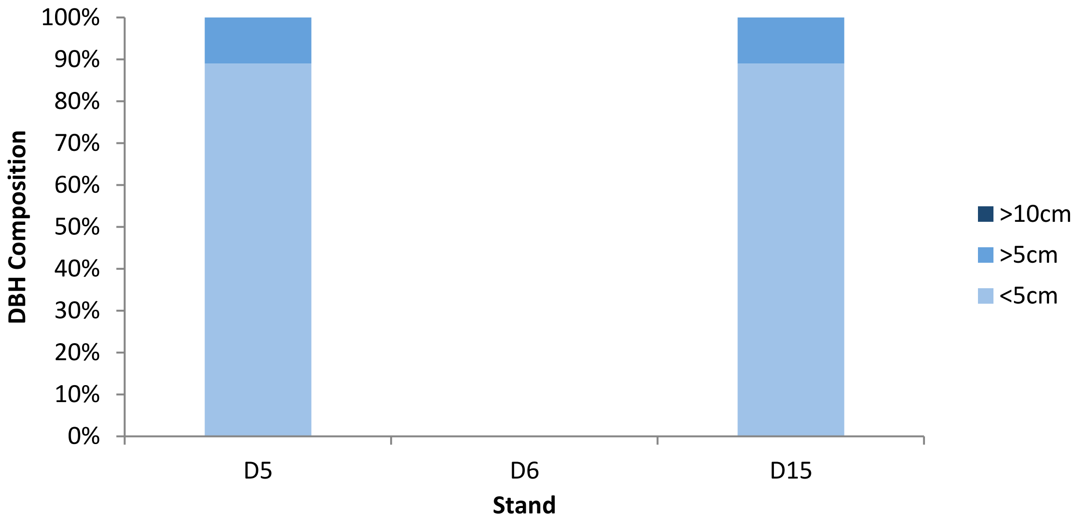

Figure 9. DBH composition of each stand by percentage.

Basal area for each stand was calculated from DBH values (Appendix I). The percent contribution of each species to basal area was calculated (Figure 10). For D5, *Ceriops tagal* made up 9% of the basal area, while *A. marina* made up 91%. In stand D15, *A. marina* accounted for 97% of the basal area and *L. racemonsa*, 3%.

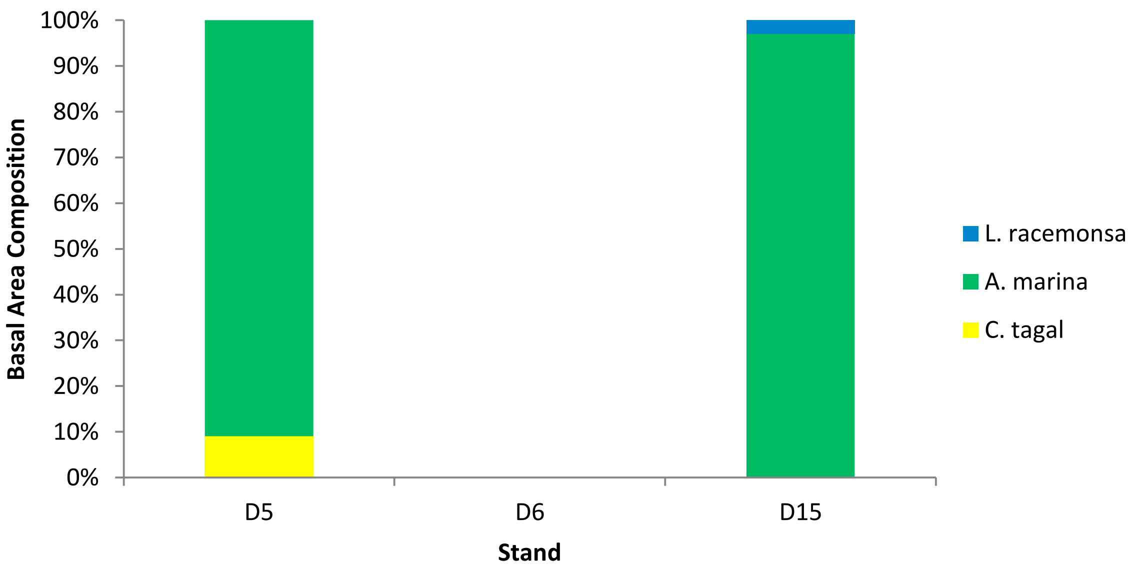

Figure 10. Species composition of the basal area of each stand by percentage.

Forest Condition

Stands D5, D6 and D15 were all considered healthy. For stand D5, 0.1% were standing dead trees. D6 had 1.3% dead trees, while D15 had 2% (*see Figure 7*).

Composition

Table 5. Results of quantitative analysis of stand composition by transect.

Stand	Transect	Species Composition	Density (tree/ m^2)	Mean Tree Height (m)
D5	T1	48% Stumps 48% *A.marina* 3% Dead trees	0.09	2.15
	T2	69% Stumps 28% *A. marina* 3% *L. racemonsa*	0.06	2.02
	T3	89% Stumps 11% *A. marina*	0.02	0.3
D6	T1	100% Stumps	0	0
	T2	59% Stumps 41% *A. marina*	0.4	0.6
	T3	55% Stumps 33% *L. racemonsa* 5% *A. marina* 5% Dead trees 3% *R. mucronata*	0.1	0.5
D15	T1	66% *A. marina* 28% Stumps 5% Dead trees 2% *L. racemonsa*	0.5	2.76
	T2	85% Stumps 15% *A. marina*	0.04	2.92
	T3	53% *A. marina* 43% Stumps 3% *L. racemonsa*	0.3	2.58

When comparing quantitative data between transects within stands, some variation was found (Table 5). The percentage of species composition made up of stumps between D5 varied considerably (Figure 11). The densities of the three transects were all low with little variance, while the mean heights of two of the transects were very different from the third. Because of the variance in species composition between the transects and differences in height in one of the transects, this stand can be classified as having a 'middle' composition, being not quite heterogeneous and not quite homogeneous.

Within stand D6, the percentage of species composition made up of stumps was 100% in one transect and around 50% in the other two (Figure 12). The density of the two transects containing trees were relatively similar and the mean heights were approximately the same. However, the trees present in the two transects are confined to a small area along the channel.

Because of this and because only one transect differs from the other two, this stand is mostly homogeneous.

For stand D15, the percentage of species composition made up of stumps varied greatly between the three transects (Figure 13). The densities were all low and the mean heights varied little. Because only the species composition varied between transects, this stand should be classified as mostly homogenous rather than heterogeneous.

DISCUSSION

Level of harvest

Based on observed qualitative data, D5 was determined to be a degraded area, D6 was a deforested area and D15 was intact. However, quantitative sampling throughout the stands revealed that based on the proposed ratios of stumps to living trees, all three stands were actually degraded. Observationally, these areas were very different. The D6 deforested area was almost completely bare and dominated by large stumps with a few mature *A. marina* interspersed throughout (Figure 15, Appendix II). Although the quantitative data shows that 39% of the stand was made up of live trees, the data is slightly skewed. An abundance of small, regenerated *A. marina* and *L. racemonsa* was found at the end of transect 2 and 3 directly adjacent to the inlet channel (*see Figure 12*). This small area of trees was significant enough to change the level of harvest when quantitatively analyzed. However, when directly observed, it was clearly not the dominant stature of the entire stand. In this instance, the qualitative method provides more perspective on the quantitative results.

The ratio of living trees to stumps could also have been affected by the presence of a lower density of larger stumps, indicating that the original forest had a fairly low density of trees. Stand D15, perceived to be intact, was also determined to be degraded. This stand was composed of larger, less dense *A. marina* often interspersed with grass and reeds (Figure 16, Appendix II). Therefore, the quantitative classification could again be affected by the lower density of trees in the stand.

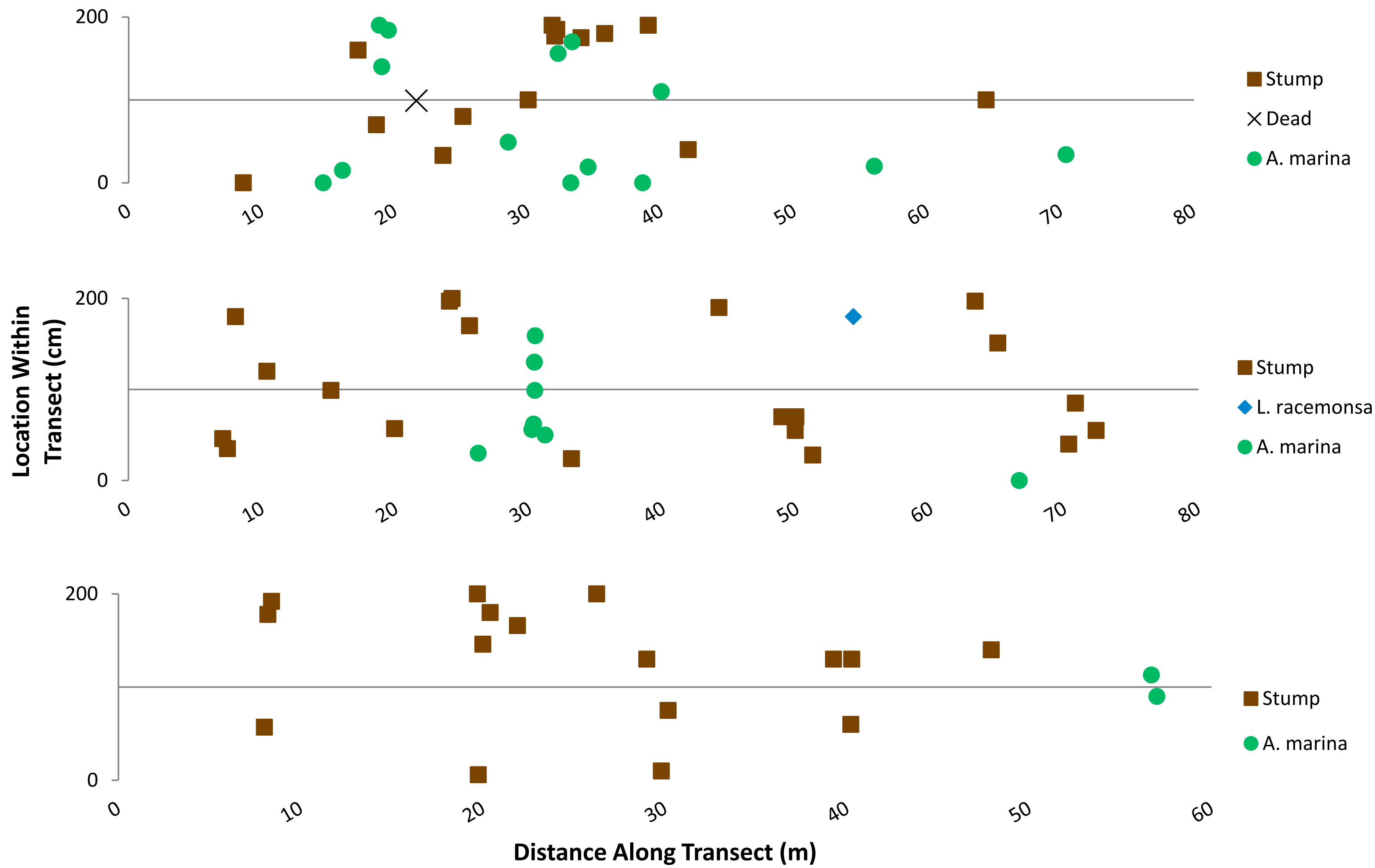

Figure 11. Graphs showing species distribution along transects 1, 2 and 3 (from top to bottom) in stand D5.

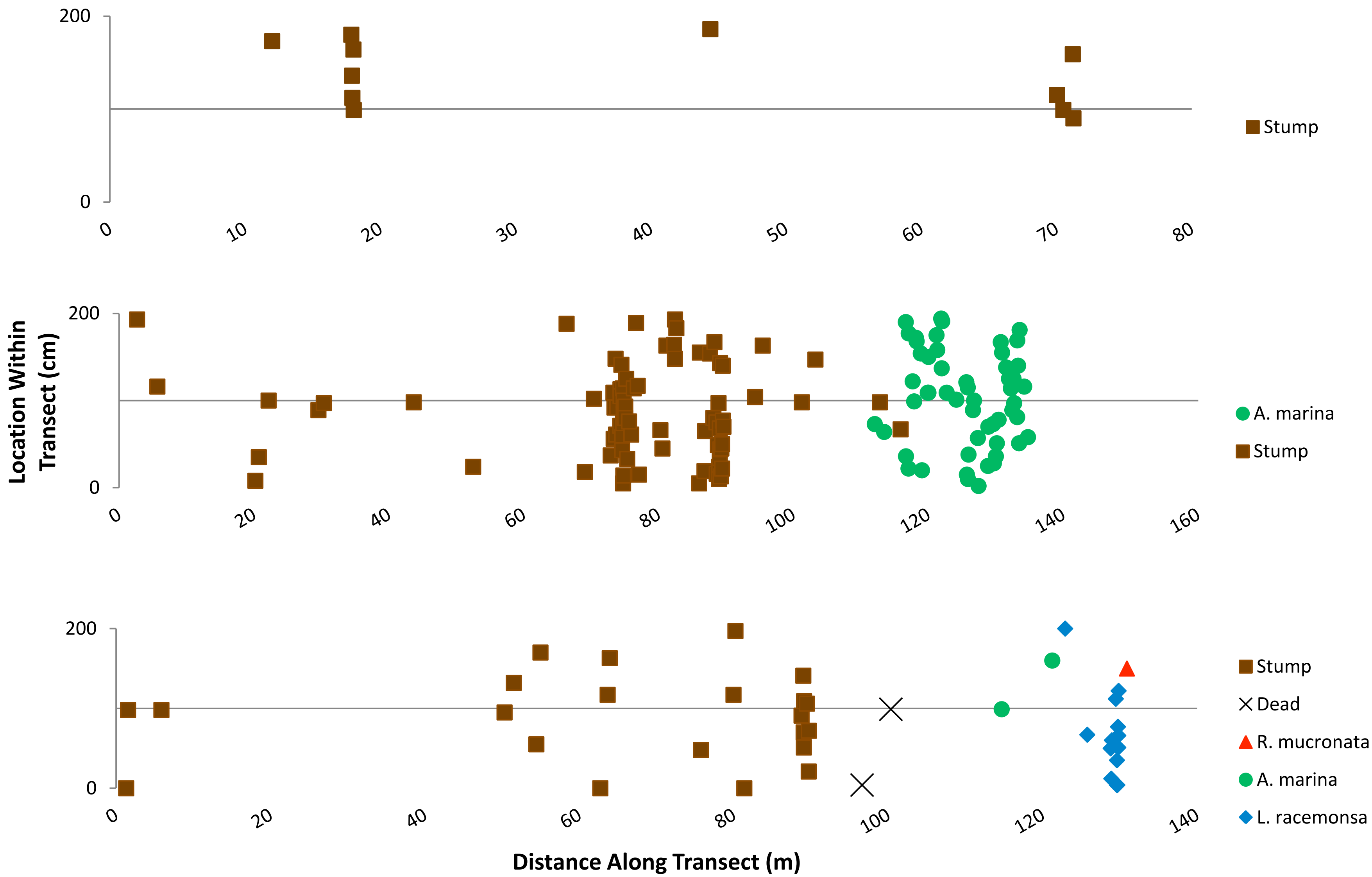

Figure 12. Graphs showing species distribution along transect 1, 2 and 3 (from top to bottom) in stand D6.

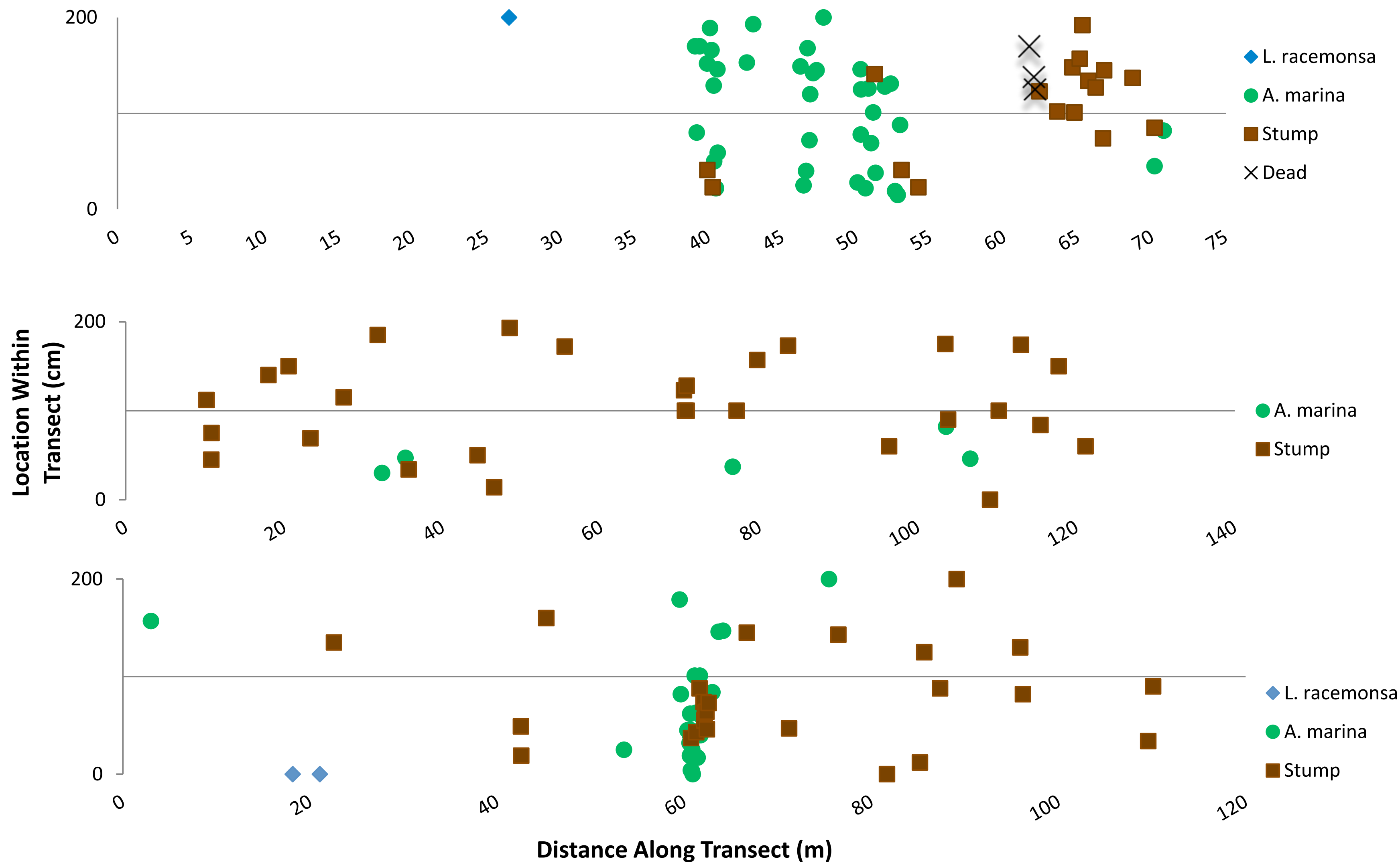

Figure 13. Graphs showing species distribution along transects 1, 2 and 3 (from top to bottom) in stand D15.

Species Dominance

Qualitative data of species dominance agreed with quantitative data on species composition. Due to the low species diversity in these areas, it was not as difficult to observationally determine a dominant species.

Density

D5 and D6 were observationally determined to have low density of trees, while D15 was said to be of medium density. However, quantitatively, there was no significant difference between the densities of the stands. The lack of difference in the density of the stands was probably due to the location and the species composition of the stands. The stands were all located in the same area in the southern portion of the forest, far from the head of the channel (*see Figure 2*). There the mangrove forest begins to thin and becomes interspersed with reeds and grass as there is not as much tidal influence. Had these stands been compared to stands in the northern section of the forest, there may have been a greater variance between densities.

The fact that the dominant species was *A. marina* may also affect the density of the stands. In most forests, density is negatively correlated with DBH and tree size, because population growth is usually density-dependent for reasons such as intra- and inter-specific competition (Fangliang & Duncan, 2000). Since mature *A. marina* can grow to a large size in both height and DBH with a wide span of pneumataphores around their base, mature *A. marina* stands may be less dense than other younger stands or stands of different tree species. The lower density of the stands is probably also linked to degradation in the area, especially in the most intact stand, D15. There were a large number of cut stumps throughout the stand, which, had they been standing trees, would have increased the density of the stand.

Canopy Cover

Quantitative canopy cover data agreed with qualitative data for stands D5 and D6. However, D15, originally said to have 'open' canopy cover, was found to be 'very open.' This difference is most likely linked with the difference in density classification. A higher perceived density may lead to a higher perceived canopy cover. Therefore, the quantitatively determined lower density classification is linked with the quantitatively lower canopy cover.

Dominant Height

The dominant height measurements were all <5m, supporting the qualitative results. However, as mentioned before, the trees measured in stand D6 were not in the observed dominant class of living trees estimated in the qualitative study. Therefore, it is unclear whether or not the observations of this stand are truly accurate. However, a deforested area will not be the most effective carbon sink, so the measurements of what few trees remain are not essential to the carbon stock assessment.

Dominant DBH

The quantitative data for dominant DBH matches the qualitative data for stand D5 and D15 of <5cm. However, no DBH data was collected for stand D6 because no live trees were found in the plot locations, so the accuracy of observations is again unknown.

Often, one restriction of qualitative analysis is that the dominant species identified is not necessarily dominant in contribution to biomass. For example, there may be large trees of what appears to be the dominant species, but more, smaller trees of another species that actually contribute more to basal area. In terms of species composition to basal area for these stands, the dominant species was the dominant contributor to basal area. These quantitative findings support the accuracy of the qualitative method of data collection.

Forest Condition

While Honko has been affected by the felling of trees for human use, the overall health of living trees has not been an issue. The quantitative data collected on the conditions of the forest agreed with the qualitative data.

Composition

In terms of the composition of the forest, stand D5 was determined to have a middle composition, while stand D6 was mostly homogenous and stand D15 was heterogeneous based on direct observation. The quantitative data agreed with the composition results for stands D5 and D6 but differed in classifying D15 as mostly homogenous instead of heterogeneous.

Qualitative composition data included more than just species, density and tree height. Observed composition included all stand attributes including DBH, which was only measured in plots and therefore not representative of the entire stand, and micro-relief, which was not assessed in the quantitative analysis. Because more factors were included in the qualitative analysis of composition than in the quantitative, the qualitative observation may have been better able to determine the composition of more of the stand than the quantitative data could provide, giving it advantages over the quantitative method in this case.

CONCLUSION

Overall, qualitative method of ecological assessment provided fairly accurate results when compared with quantitative measurements. By comparing the same factors in both studies, it becomes clear that neither method should be left on its own. Qualitative observations will differ depending on the person doing them, but quantitative measurements should not be blindly done nor blindly accepted. Qualitative results are either supported or corrected by the quantitative measurements and vice versa. Quantitative data collection should always be checked with qualitative observation to ensure the most accurate results are reached.

This project recommends to Plan Vivo and future carbon stock assessments that quantitative measurements be taken in addition to qualitative measurements when doing primary forest evaluations to efficiently obtain accurate data and avoid oversight. Future recommendations for studies include monitoring the Plan Vivo carbon stock project's social and environmental effects in the Honko area in the coming years after its implementation.

WORKS CITED

Alongi, D. (2011). Carbon payments for mangrove conservation: ecosystem constraints and uncertainties of sequestration potential. *Environmental Science and Policy*.

Blue Ventures (2012). *About Us*. Retrieved November 24, 2012, from Blue Ventures: www.blueventures.org

Biology. (2008, July 2). *Biomass*. Retrieved December 1, 2012, from Biology Online: http://www.biology-online.org/dictionary/Biomass

Climate Zone (2004). Retrieved November 26, 2012, from Climate-zone.com: http://www.climate-zone.com/climate/madagascar/fahrenheit/tulear.htm

Donato, D., Kauffman, J., Murdiyarso, D., Kurianato, S., Stidham, M., & Kanninen, M. (2011). Mangroves among the most carbon-rich forest in the tropics. *Nature Geoscience*, 1-5.

Fangliang, H., & Duncan, R. (2000). Density-dependent effects on tree survival in an old-growth Douglas fir forest. *Journal of Ecology, 88* (4), 676-688.

Hogarth, P. (2007). *The Biology of Mangroves and Seagrasses.* Oxford: Oxford University Press.

Honko (2011). *About Us*. Retrieved November 24, 2012, from Honko Mangrove Conservation & Education vzw: www.honko.org

IPCC. (2007). Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp.

Jones, T. (2012, October 18). Personal Communication.

Kathiresan, K., & Qasim, S. (2005). *Biodiversity of Mangrove Ecosystems.* Hindustan Publishing Company.

Kauffman, J., & Donato, D. (2012). Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in mangrove forests. *Working Paper 86* . Bogor, Indonesia.

Plan Vivo (2008). *The Plan Vivo Standards.*

Pendleton, L., Donato, D., Murray, B., Crooks, S., Jenkins, W., Sifleet, S., et al. (2012). Estimating global "blue carbon" emissions from conversion and degradation of vegetated coastal ecosystems. *PLoS ONE , 7* (9).

Pywell, N. (2003, October 7). *Glossary of Forestry Terms*. Retrieved December 1, 2012, from Department of Natural Resources: http://www.dnr.state.md.us/forests/gloss.html#s

Roger, E., & Andrianasolo, M. (2003). Mangroves and Salt Marshes. In S. Goodman, & J. Benstead (Eds.), *The Natural History of Madagascar* (pp. 209-210). Chicago: The University of Chicago Press.

Spalding, M., Kainuma, M., & Collins, L. (2010). *World Atlas of Mangroves.* London: Earthscan.

Taylor, B. (2012, November 27). Personal Communication.

Tomlinson, P. (1986). *The Botany of Mangroves.* Cambridge: Cambridge University Press.

World Weather Online (2012). *Tulear (TLE) Weather - Monthy Averages*. Retrieved November 24, 2012, from World Weather Online: http://www.worldweatheronline.com/v2/weather-averages.aspx?q=TLE

APPENDIX

I. Glossary

Aerial roots – due to the poorly oxygenated soil in mangrove environments, mangroves have developed above-ground roots with numerous tiny pores called lenticels in order to maximize gas exchange (Hogarth, 2007).

Basal Area – the sum of the cross-sectional areas of trees approximately 1.3m above the ground for a given area (Pywell, 2003).

Biofiltration – the natural process of living material capturing and biologically degrading pollutants and other nutrient runoff.

Biomass – the mass of living biological organisms in a given area or ecosystem at a given time (Biology, 2008).

Photosynthetic primary production – the process by which plants make organic compounds from atmospheric CO_2 using light as a source of energy.

Salt balance – mangroves deploy a variety of means to cope with a high salinity environment including salt exclusion, tolerance and excretion (Hogarth, 2007).

Spatial Zonation – different species of mangroves have adapted to inhabit different zones of a tidal flat seaward to landward due to factors that vary spatiall such as tidal range and substrate (Tomlinson, 1986).

Stand – a group of forest trees of sufficiently uniform species composition, age, and condition to be considered a homogeneous unit for management purposes (Pywell, 2003).

Sub-stand – a group of forest trees of sufficiently uniform species composition, age and condition different from that of a stand, but not significantly enough to be classified as its own homogenous unit.

Vivipary – a phenomenon in some species of mangrove, where the growing embryo remains on the parent tree after pollination and is dependent on it for a period that can last many months. When the propagule leaves the parent, it is a seedling and not a seed or a fruit (Hogarth, 2007).

II. Stand Identification

Figure 14. Picture depicting stand D5 of Honko, degraded mangrove.

Figure 15. Picture depicting stand D6 of Honko, deforested mangrove.

Figure 16. Picture depicting stand D15 of Honko, intact mangrove.

III. Species Identification

Figure 17. Example of *Avicennia marina* at Honko.

Figure 18. Example of *Brugueria gymnorrhiza* at Honko.

Figure 19. Example of *Ceriops tagal* at Honko.

Figure 20. Example of *Rhizophora mucronata* at Honko.

Figure 21. Example of *Lumnitzera racemonsa* at Honko.

Figure 22. Example of *Sonneratia alba* at Honko.

IV. Instructions

Spherical Densiometer: Model – A

(An instrument for measuring forest overstory density)

Hold instrument level, 12” – 18” in front of body and at elbow height, so that operator’s head is just outside of grid area. Assume four equi-spaced dots in each square of the grid and systematically count dots equivalent to quarter-square canopy openings. Multiply the total count by 1.04 to obtain percent of overhead area not occupied by canopy. The difference between this and 100 is an estimation of overstory density in percent. (Assuming each dot to represent one percent is often accurate enough.) Make four readings per location – facig North, East, South and West – record and average.

Robert E. Lemmon, FOREST DENSIOMETERS
10175 Pioneer Ave
Rapid City, SD 57702-4753
(605) 343-9211

Vertex IV and Transponder T3

Calibrate: Use a measuring tape to meausre the exact distance of 10m between the transponder and the Vertex front. Press ON to start the Vertex instrument. Step in the menu to CALIBRATE and press ON. The instrument will calibrate to 10m and automatically turn off when ready.

Height measuring with transponder: Start the transponder T3 and place it on/towards the object to measure. *Note that transponder should be placed at the T.HEIGHT(transponder height) that has been set).* Walk a suitable distance from the object – for optimal result accuracy, a distance equal to the approximate height.

1. Press ON to start the Vertex and aim at the transponder. Keep pressing ON until the cross hair sight goes out momentarily. Now release ON. The Vertex ha measured the distance, the angle and horizontal distance to the transponder.
2. Aim at the height to measure with the sight cross hairs blinking. Press ON until the cross hair disappears. The first height is locked and displayed. Repeat until all heights on the object are measured.

Haglöf Sweden AB
Box 28
88221 Långsele, Sweden
+46 620-255 80