The Prospect of Win Wins from REDD+; A Case Study in the Okapi Wildlife Reserve

Mark Ilan Abrahams

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Acronyms

FAO- Food and Agriculture Organisation

OWR- Okapi Wildlife Reserve

DRC- Democratic Republic of Congo

ZA- Zone Agricole (agricultural zone)

DBH- Diameter at breast height

WSG- Wood specific gravity

AGB- Above ground biomass

WCS- Wildlife Conservation Society

CEFRECOF- Centre de Formation et de Recherche en Conservation Forestiere

Abstract

REDD+ has been touted as not only a climate change mitigation strategy, but also a boon for biodiversity conservation. The degree to which the latter is true depends partially on the strength of concurrence between biodiversity conservation priority areas and high carbon stocks. Carbon stock assessments and tree diversity assessments were carried out within the agricultural mosaic of Epulu, and nearby primary forest areas to test for such concurrence.

A random stratified sampling plan was implemented in order to ensure representation of the main disturbance classes; primary forest, active fields, and inactive disturbed areas. Plots were studied for trees, saplings, lianas and palms. The Shannon index was calculated for trees and allometric equations were applied to all plant sources to determine carbon stock.

Quantification and analysis of plots by class and carbon source revealed 1. The overwhelming importance of trees, especially large trees, in the carbon stock (trees represented over 90% of carbon per plot on average) 2. The importance for both diversity and carbon of primary forests 3. The potential for biodiversity and carbon savings if disturbed areas are cleared instead of primary forests (a carbon saving of over 75 tonnes per hectare). These results were supported by linear regressions of carbon against diversity which showed a significant positive correlation between the two. Similar analysis of only primary forest plots however, showed the opposite trend. Monodominant forest had significantly higher carbon and lower diversity than mixed forest. A regression of carbon against diversity showed a non-significant negative correlation.

The message for REDD+ is mixed. At the project scale there seems to be potential win-wins for carbon and biodiversity conservation. At the landscape level however, lower diversity forests will be prioritised by REDD+ unless conservationists can present a strong case for compromise.

Word Count

12305

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Joel Masselink (GIS specialist for WCS) and Jean-Remy Makana (head of the WCS DRC botanical programme) provided both crucial data and technical input. Joel is responsible for the landcover classification on which plot sampling was based. He was also the person who met me on my arrival in Beni and (along with Ashley Vosper) was virtually my guide to DRC. Jean-Remy helped formulise the survey methodology and provided the reference material such as wood specific gravity database with which the data was analysed.

The field survey team consisted of the highly able botanists Floribert Bujo, who was always calm and inquisitive and Jacqus Mukenzi who even worked on the weekend. Agricultural extension worker Mustafa Saidi, who also acted as scribe when no botanist was available. Technicians Abena Abeli and Collin Kenge Baenanji, whose knowledge of the forest amazed me.

Site Director Jean Joseph Mapilanga, Director of WCS (Epulu) Robert K. Mwinyihali, Assistant Director of WCS (Epulu) Baraka Othep and the local scientific committee all supported my research whilst in Epulu.

The Geoeye Foundation provided satellite imagery. Due to logistical difficulties I was not able to access it in time to include in this project.

Enough thanks cannot be given to my hallmates, Silwoodians, family and friends for keeping me sane.

1 Introduction

1.1 Problem to be Addressed and its Importance

In the broadest sense, this research project is concerned with the usefulness of harnessing the value of ecosystem services attributable to biodiversity to raise funds for its conservation. Specifically, what should conservation professionals expect from (and how should they approach) REDD+? REDD+ promises substantial funding ($1.2 -$10 billion pa, Miles and Kapos 2008) for the conservation and sustainable management of forests, in order to safeguard the carbon dioxide that might otherwise be released through their removal or degradation.

Biodiversity conservation is currently chronically underfunded (Balmford and Whitton 2003), necessitating harsh prioritisation. The prospect of REDD+ funding is therefore a huge opportunity for global forest conservation. It is however questionable if forests likely to be conserved for their carbon are also those most important to conserve for their biodiversity. If not, the huge opportunity will be wasted. Admittedly, any large scale conservation of natural forests is likely to have large benefits for biodiversity. In the context of inadequate, effectively zero sum funding, preserving less biodiverse forests at great expense would leave more important forests under-protected. This issue is exacerbated if a) The protection of large swathes of forest reduces supply of timber and agricultural land, such that higher biodiversity but less protected forests come under even greater pressure b) The REDD mechanism itself creates perverse incentives to replace natural forests with high carbon monocultures.

This research project takes the Okapi Wildlife Reserve (OWR) in the Democratic Republic of Congo (DRC) as a detailed case study of carbon and biodiversity values in shifting agriculture and primary forest areas. By exploring the relationship between these values it hopes to contribute to the understanding of what REDD+ might mean for biodiversity, and how it should be approached.

1.2 Aims and Objectives

1.2.1 Overall aim

Using the OWR as a case study; to explore the potential For REDD+ initiatives to create win-win scenarios at 1. The local (project area) and 2. The landscape level, in which the conservation and sustainable management of forests for the carbon stock they represent, also has optimal outcomes for biodiversity conservation.

In order to meet the above aim, this project will complete the objectives below.

1.2.2 Objectives

1. The creation of a landcover classification by Joel Masselink of the agricultural zone (ZA, zone agricole) of Epulu, on which a sampling methodology ensuring representation of the main disturbance classes (primary forest, active fields, and disturbed areas) can be based.
2. The Collection of data on different plant sources of above ground carbon per plot. Assessment of the carbon stock per plot of each source. Use of tree data to ascertain tree diversity per plot. Comparison of the diversity and carbon stock per disturbance class and primary forest type.
3. The comparison of carbon losses and tree diversity reduction under two scenarios a) conversion of primary forest for agriculture b) conversion of disturbed areas for agriculture. Based on the above, quantification of potential REDD+ funding resulting from prevention of carbon emissions.
4. Irrespective of disturbance class, to determine if carbon stock per plot and tree diversity per plot are correlated a) across the entire study area and b) between primary forest plots.

If a) Carbon and diversity losses are both reduced when disturbed rather than primary forest areas are converted for agriculture and b) tree diversity positively correlates with high carbon stock, then we might expect prima facie that the preservation of carbon stocks under REDD+ will be promising at the project level and facilitate biodiversity conservation.

If a) The primary forest type with higher diversity also has higher carbon and b) high diversity positively correlates with high carbon stock, then we might expect prima facie for

REDD+ to produce win-wins at the landscape level, in which the forests preserved for their high carbon are also highly important for biodiversity.

2 Background

2.1 Funding Biodiversity Conservation- Intrinsic Value vs. Ecosystem Services

There is debate amongst conservationists concerning the most appropriate strategy for raising funds for biodiversity conservation. Some argue that appealing to rational self interest by pointing out the many benefits brought by biodiversity, would motivate governments and the population at large to provide the necessary funds. People will not care enough about biodiversity to actually pay for it unless tangible benefits to them can be demonstrated. A popular approach has been to quantify these benefits in terms of ecosystem services, and couch funding in terms of a rational investment, which is generously repaid (Constanza et al 1987).

Where biodiversity performs functions useful to people other than those in proximity to it, Payment for Ecosystem Services (PES) schemes have been used as a way of compensating people who would otherwise bear the costs of conserving it.

Opposing conservationists argue that 1. the value of biodiversity is near impossible to quantify 2. Any attempted quantification will undervalue it and that 3. It would be more effective to appeal to people's love of the natural world and appreciation of its intrinsic value, in order to elicit funds. They point out that many species do not perform functions obviously useful to people, and that focusing on ecosystem services will erode their protection (McCauley 2006).

2.2 The Role of REDD

Climate change mitigation is seen as an area where forest conservation can be championed in the name of global human self-interest. Climate stability can be viewed as an ecosystem service partly provided by the world's forests. The carbon stored in plant material would be released if those forests were cleared, contributing to global climate change. Indeed, emissions from deforestation contribute "nearly 20% of global greenhouse gas emissions" (UN-REDD, 2009). As the effects of climate change are likely to be destructive and costly

(Stern 2006), it has been proposed that funds be made available to prevent the emissions from forest clearance, hence Reduced Emissions through Deforestation and Degradation or REDD. These funds would be used to compensate developing countries for the cost of not deforesting.

Forests are initially of interest in climate change mitigation due not to their biodiversity per se, but the large carbon-based biomass they represent. It is possible however that the large areas of high biomass forest at risk of clearance due to development, which REDD seeks to preserve, are the same highly diverse forests that conservationists fight to protect. This is particularly likely as the highly diverse tropical rainforests, are mostly to be found in developing countries.

2.3 REDD+

There is some confusion over the meaning of the "+" in REDD+. According to the UN-REDD programme website

> "REDD+" goes beyond deforestation and forest degradation, and includes the role of conservation, sustainable management of forests and enhancement of forest carbon stocks.

This opens the possibility for developing countries to be paid for projects such as afforestation and sustainable timber extraction, insofar as these activities result in greater carbon sequestration than under policies that would otherwise have been pursued. These are seen as increasingly important in a more crowded and anthropogenically modified world, where simply excluding people from nature is not an option. It also explicitly acknowledges the role of conservation. The potentially congruent interests alluded to in the previous section have been much discussed as a result.

2.4 Regional Context

Africa hold 30% of the world's tropical forest (Makana et al 2011), and has the highest predicted population growth over the next century (United Nations 2004). The combination of a large forest resource and a fast expanding population entail a high threat of deforestation. The UN-REDD 2008 framework document suggests that in Africa, the largest cause of deforestation is conversion of forests to small scale permanent agriculture (with the intensification and expansion of shifting agriculture far less important).

2.5 Study Site

The village of Epulu lies within the Okapi Wildlife Reserve in North Eastern DRC (figure 2.1). The reserve protects 1.35 million hectares of the Ituri forest (Makana et al 2011). Makana and Thomas (2006) characterise the region as having a fairly flat topography (elevation 750 m to ~950 m above sea level), mean annual rainfall of 1725 mm, a dry season from December to February and a stable annual average daily temperature of 23-25.5 °C. The area is classified under the WWF biome and ecoregions as tropical moist broadleaf forest (Olson 2001).As described by Makana et al 2011, the Ituri forest is composed of two climax forest types in addition to swamp forest in riparian areas. The two climax forest types are 1. Semi-deciduous mixed forest dominated by *Cynometra alexandri* C.H. Wright and *Julbernardia seretii* Troupin and 2. Evergreen monodominant forest in which *Gilbertiodendron dewevrei* (De Wild.) J. L´eonard comprises >50% of the canopy. The local name for Gilbertiodendron dewevrei is Mbau, which is also the name of the monodominant forest type characterised by it.

Within the reserve, land is zoned according to permissible level of human use (Brown 2009). Each village has an agricultural zone allotted according to the size of the community (figure 2.2). In this zone, forest is permitted to be cleared for agriculture, though riparian areas are theoretically set aside. Agricultural zones are surrounded by hunting zones, delineated in part according to traditional tribal boundaries of the Mbuti and Efe Pygmy groups. In this zone, traditional hunting and gathering of non-threatened species is permitted, theoretically for local consumption. The reserve centres on a core conservation zone in which (again theoretically) no hunting is permitted.

The agricultural zone of Epulu is a patchwork of active fields, disturbed/regenerating areas of various ages and primary forest islands, surrounded by an arc of heretofore unconverted primary forest. Swidden or “slash and burn” agriculture is practiced. Vegetation is cleared and burned to enrich the soil. It is then farmed until reduced soil fertility (due to rapid mineralisation and nutrient leaching typical of tropical regions) and high pest and disease burden necessitate abandonment (Wilkie and Curran 1993).

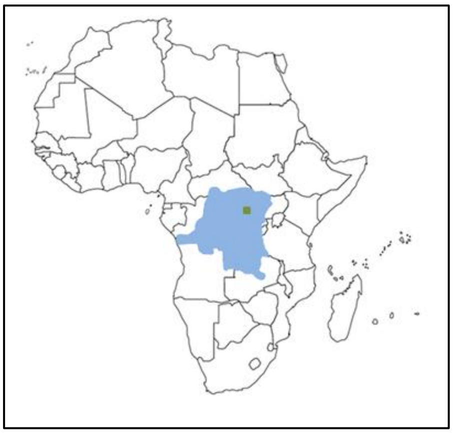

Figure 2.1- A map of Africa showing the Democratic Republic of Congo and the location of the Okapi Wildlife Reserve

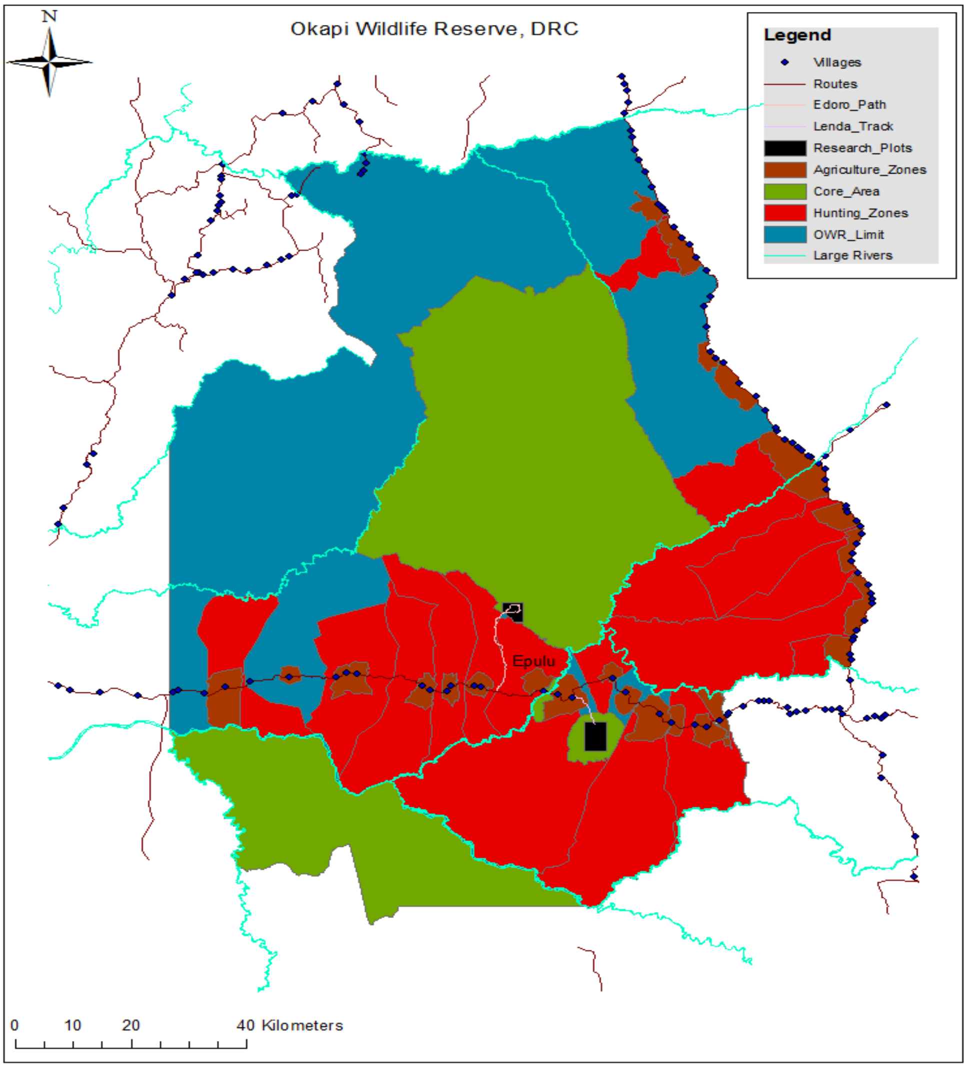

Figure 2.2 A map of the Okapi Wildlife Reserve, showing the major land use zones, location of Epulu, Lenda and Edoro.

Two long term research sites have been set up to the North West and South East of Epulu. To the North West, the Edoro site consists of two ten hectare plots encompassing mostly mixed forest. To The South East, the Lenda site has two ten hectare plots consisting of mostly Mbau forest. Both Lenda and Edoro are divided into a grid of 20m by 20m plots which are extensively surveyed for trees, saplings and lianas every 5 years (Makana et al 2011).

2.6 Key Literature and Reference Material

2.6.1 REDD win-wins

- Harvey et al 2009 “Opportunities For Achieving Biodiversity Conservation Through REDD” gives a broad outline of the design features of REDD under discussion, and different approaches that could be taken to integrate biodiversity conservation. Its main conclusion is that it should be ensured that “REDD is included in the new global climate agreement and maximizes the area of tropical forest conserved.” It argues that, given the urgent need for tropical forest conservation, it is more important to implement a robust REDD framework (with safeguards to avoid incentivising replacing natural forests with plantations) as soon as possible, rather than become bogged down in detailed wrangling over maximising biodiversity benefits.
- Strassburg et al 2009 “Global Congruence Of Carbon Storage And Biodiversity In Terrestrial Ecosystems” use global datasets to examine the congruence between species richness and carbon stock. They find high, but patchy correlation, in which many highly diverse areas would be well protected, but others would be ignored by a carbon-only approach to REDD. Their global focus somewhat obscures the carbon-biodiversity relationship for areas actually eligible for REDD funding.
- Venter et al 2006 “Harnessing Carbon Payments to Protect Biodiversity” show that a REDD mechanism concerned only with cost-effectively reducing carbon emissions produces suboptimal benefits for biodiversity. A slight reduction in carbon benefits per expenditure would be rewarded with high benefits for biodiversity. The use of species area relationships to characterise biodiversity ignores the nuance of conservation prioritisation.
- The Secretariat of the Convention on Biodiversity, in their 2009 technical report “Forest Resilience, Biodiversity, and Climate Change” argues that biodiversity is

crucial at multiple scales for maintaining forest resilience. The ability of forests to store carbon in the face of climate change is compromised if they have been simplified (or replaced by simple plantations), such that forest conservation without biodiversity conservation is misguided.

2.6.2 Carbon Stock Assessment

- Gibbs et al 2007 in "Monitoring and estimating tropical forest carbon stocks: making REDD a reality" review biome average, ground-based and remote sensing methods for estimating national forest carbon stocks. Included is an overview of biome average and national carbon stock estimates. They conclude that biome averages are easy to use, but involve high uncertainty, ground based surveys can be conducted with low technology and give accurate results (and will always be necessary to ground-truth other methods), but satellite based estimates will become more important in future as technology and expertise increase.
- Chave et 2005 "Tree allometry and improved estimation of carbon stocks and balance in tropical forests" was based on a large pan-tropical dataset, and provides robust allometric equations for tree biomass estimation. Alternative equations are presented depending on forest type and on whether data for height and DBH, or only DBH are available. The equations are not valid for palms and lianas, only for trees within the DBH range 5-156cm. No guidance is provided on how the biomass of larger trees should be estimated.
- The Intergovernmental Panel on Climate Change (IPCC) taskforce on National Greenhouse Gas Inventories produce the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (2006). This is a comprehensive set of standards used to estimate and report carbon stocks. It outlines a tiered approach in which estimates can be made with varying degrees of precision.

2.6.3 The Okapi Wildlife Reserve

- Makana et al 2011 "Demography And Biomass Change In Monodominant And Mixed Old-Growth Forest Of The Congo" presents an analysis of long term tree and sapling data from research plots at Lenda and Edoro, especially regarding the changes to mixed and monodominant forests. Their methods are five yearly censuses of forest plots and calculation of above ground biomass using allometric equations from Chave et al 2005. They report an increase in the monodominant forest and increased presence of Mbau in the mixed forest. They note that as Mbau invades mixed forest, biomass increases at the expense of diversity. This study is restricted to primary forests, not making any comparisons with areas of high anthropogenic disturbance.

- Wilkie et al 1998 “Modelling The Sustainability Of Subsistence Farming And Hunting In The Ituri Forest Of Zaire” analyse the different effects of shifting agriculture and hunting on forest cover and faunal abundance in Ituri. They use human population censuses, predicted growth rates and bushmeat consumption figures, alongside forest cover and wildlife abundance figures to explore these effects. They conclude that deforestation is not as important an issue for conservation as defaunation due to overhunting. Their paper was published in 1998, at the start of the second Congo war, a period of violent upheaval. The relative calm and improved infrastructure in the last few years calls into question some of their assumptions.

3 Methods

3.1 Constraints

Due to logistical and budgetary constraints, it was possible to conduct just over six weeks of active surveys between 16th May and 29th June 2011. A botanist was available for four of these. This limited the survey location, number of survey plots and what it was possible to survey in each plot.

It was only possible to survey within the agricultural zone of Epulu, and the research area of Lenda. Studying other agricultural zones would have been time consuming and required transport between towns that was available only sporadically. Studying plots further into the core reserved zone was unmanageable due to the presence of elephant poachers active in the region, and due to the additional cost of providing food for the other four team members. This spatial limitation reduces the generalisability of the results, but was unavoidable given the time and resources available.

To reduce survey time per plot, lianas and saplings were only surveyed in one subplot, increasing the variability of the results for these components of the carbon stock assessment. It was not possible to carry out a carbon stock assessment for leaf litter, soil, deadwood and crops. These would have required the application of techniques such as litter traps, soil sample analysis, and destructive weighing of herbaceous vegetation that were unfeasible (and for crops, inappropriate) in this context.

3.2 Study area

Fieldwork for this study took place in the Okapi Wildlife Reserve, Democratic Republic of Congo. Additional data had been collect by Jean Remy at Lenda and Edoro in 2007.

Joel Masselink, the GIS specialist for WCS DRC, created a land cover classification map of the Epulu area. Land cover classes were primary forest, active field and disturbed areas. He used high a resolution SPOT5 image of the ZA from 2009 to make an initial map which was then ground truthed. From this, a final map of was created to enable randomised plot selection (see appendix for further details).

Using a random stratified sampling approach (Gardener et al, 2010), 90 plot locations within Epulu were chosen, 30 in each of the three land cover classes (see figure 3.1). The plots were at least 80m apart which was sufficient to ensure independence due to the heterogeneous nature of the habitat. Surveys were conducted as close to the location of the predefined plots as possible.

Eight additional plots were chosen within Lenda from pre-existing survey locations. Four were randomly chosen from monodominant forest and four were from mixed forest.

Three plots were used as a pilot study to finales the data collection protocol and to familiarize the survey team with it. An additional three plots had methodological problems and therefore, they have been excluded from all analysis.

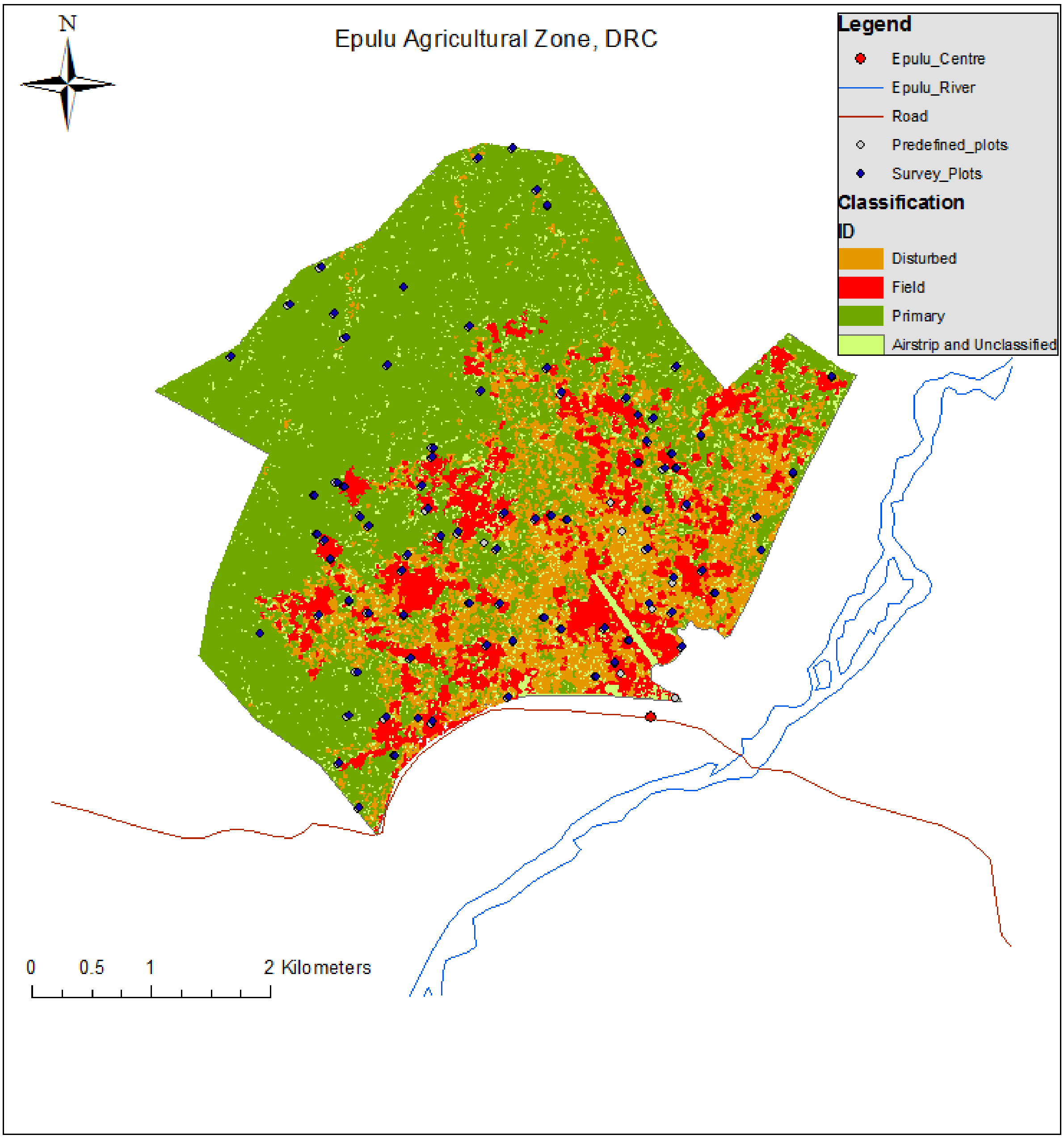

Figure 3.1- A map of the Agricultural Zone of Epulu. Unsupervised satellite image classification was carried out by Joel Masselink. The three land cover classes, primary forest, active fields and disturbed areas, were used as the basis for random stratified sampling. The predefined plots that are not accompanied by a survey plot are the ones excluded from the analysis or not surveyed.

3.3 Class Identification

The land cover class of each predefined plot was ground truthed using the local knowledge of members of the survey team. The survey team included Mustafa, the agricultural extension worker for Epulu with an intimate knowledge of the area. The botanists Flory and Jacqus and the technicians Abena and Collin were also reliable in this respect. Class was determined based on the known disturbance history. Forest plots that had not been cleared within memory were classed as primary forest. Plots that were still being harvested from were classed as active fields. Plots for which the age since active cultivation was known were aged. These were mostly young fallows. Fallows younger than 4 years were grouped with active fields for the purpose of initial analysis. Plots that had been cleared for cultivation previously, but too long ago to be able to age (about 10 years +) were classed as secondary forest.

The above three classes were used as 'lax' categories. The lax classes are composed of primary forest, fields (including both active fields and fallows younger than four years) and the disturbed class which encompasses all other plots. In order to gain precision, a further subset of 'strict' classes were defined and used in certain aspects of the analysis. The strict grouping made the following four modifications).

1. Only the primary forest plots within the ZA were included in the primary class. The eight Lenda plots were excluded in case they were different enough to affect the carbon estimate.
2. Only fields active at the time of survey were included in the field class. Young fallows were excluded to account for the possibility that they may have regenerated sufficiently to inflate the carbon estimate of that class.
3. Only secondary forests and old fallows were included in the disturbed class. Plots that Mustafa identified as young or intermediate fallows would not have regenerated sufficiently for them to be eligible for re-clearing. Likewise other types of disturbed plot such as those with their understorey cut or in the process of being cleared, would not give an accurate estimate of a plot in its pre-clearance state.
4. Swamp forest plots were excluded. They are unlikely to be converted to agriculture or have as much carbon as other primary forest.

3.4 Plot Design and Data Collection

Plot size and layout was chosen in order to be comparable with existing research by Jean-Remy and the Smithsonian Institute in the OWR at Lenda and Edoro (see map in background). Plots were 20m by 20m aligned north to south and these were further split into 16 subplots of 5m by 5m. Splitting the plots in this way was advantageous because it helped make tree surveys more manageable. Each subplot could be thoroughly surveyed before moving on, without missing individuals or double counting. Subplot junctions were used as systematic points for canopy measurements (Newton 2007). In addition, the subplots facilitated subsampling of sapling, liana and other data which would be too time consuming to sample in the entire plot.

In all plots (see figure 3.2), the following was measured: species and diameter at breast height (DBH) of all trees over or equal to 10cm DBH; species and height of all palms; DBH of all standing dead trees over or equal to 10cm DBH.

At every corner/ subplot intersect, canopy cover was measured. In subplot 1,1 the DBH of all trees was measured, including those between 1cm and 10cm DBH (these were termed "saplings" in later analysis) and the species and DBH of all lianas greater or equal to 2cm DBH.

In four pre-chosen subplots (1,4; 3,3; 4,4; 4,1), the following additional data was collected: characteristics of understory; presence of invasive species; height of herbaceous layer; characteristics of groundcover; soil texture; depth of leaf litter; diameter of fallen woody debris. For complete details of data collection, see appendix.

As illustrated by the below diagram, different measurements were taken in subplots and intersects. For further details of the data collection protocol, see appendix.

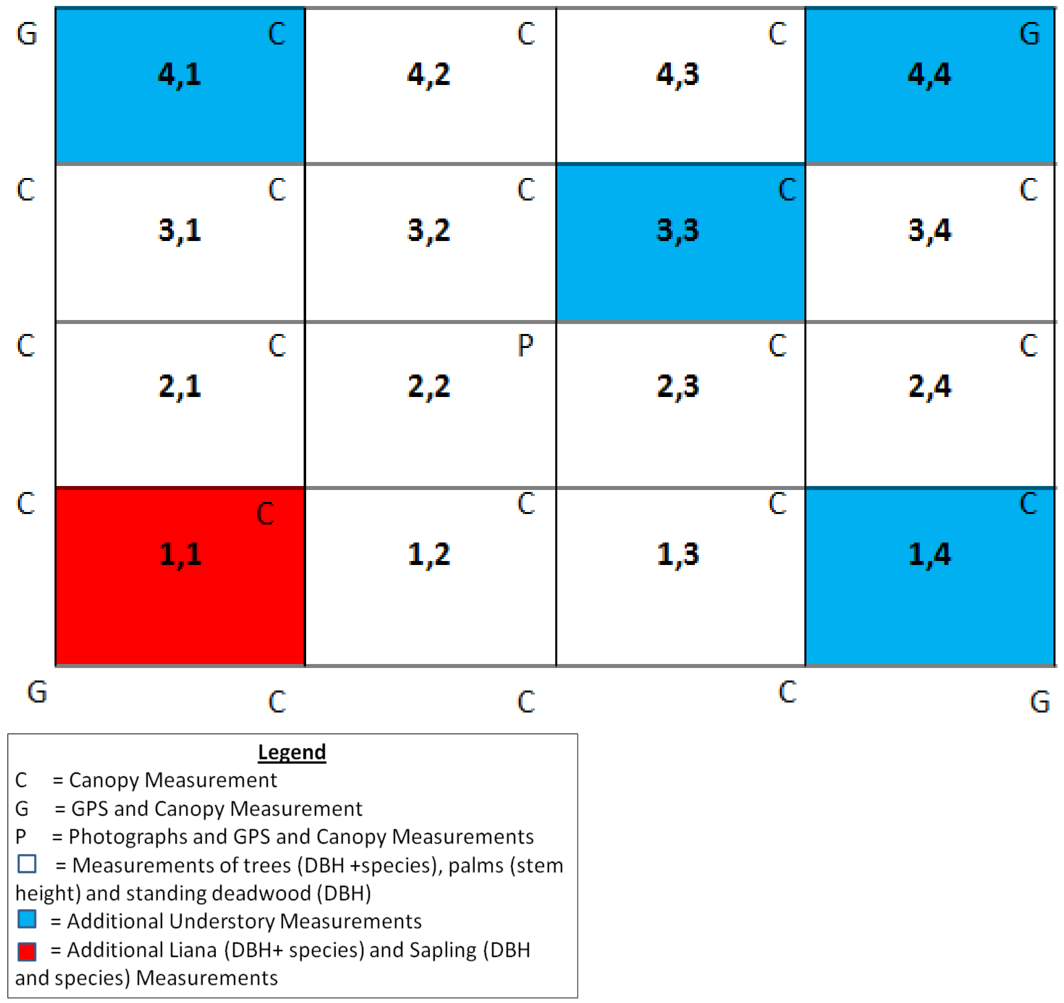

Figure 3.2 - Diagram of survey plot layout showing subplots and data collected

3.5 Tree Identification and Confirmation

Both the diversity and carbon stock assessments require identification of tree species. The Shannon Weiner diversity index requires it directly, as it is based on relative abundance of each species per plot. The carbon stock assessment requires it indirectly, as the allometric equation is based partly on wood specific gravity, which in turn is determined by tree species.

62 plots were surveyed with a botanist (botanists alternated by fortnight), such that tree species could be identified in the field. Data entered from survey sheets was checked by the botanists for mistakes. During the final two survey weeks however, no botanist was available, so 31 plots were surveyed without one. For these plots, technicians identified tree species with local names. Local names were referenced against species, genus or family

where possible, using a database of local and species names provided by Jean-Remy. The record of local and species names made by the botanists during earlier fieldwork was also used as a reference. There were several problems with this procedure.

1. Local names were sometimes spelled slightly differently, but are considered the same. For example njanjude and mjunbube.
2. Local names that are very similar can refer to totally different species. Kombi refers to *Myrianthus arboreus*, whereas kombo refers to *Musanga cecropioides*.
3. Some species such as Cassia spectabilis seem to have no local name.
4. Some local names refer to more than one species. Kabu can refer to *Apodytes dimidiate*, *Ochna afzelia* or *Scottellia klaineana* var*. Klaineana*.
5. Some species have more than one local name. Njilolo and silingwa both referred to *Cleistopholis patens*.

In some cases it was difficult to determine if the tree had simply been misidentified. In an attempt to overcome these problems, a total of 60 samples were taken during surveys, of trees whose local name did not match a species. These were given to the herbarium for drying and later identification. No identification has been forthcoming however.

For the purposes of the carbon stock assessment, the most specific level of identification that could confidently be made was used, be this to species, genus or family level. Otherwise identity was left as indeterminate.

For the diversity assessment, in plots where no botanist was present, three assessments were made based on different assumptions 1. Minimum species = assume that all local names for which a species is unknown correspond to the same species. 2. Maximum species = assume that each instance of a local name with no known species refers to a different species 3. Intermediate species = assume that each local name refers to one and only one species. The intermediate species assumption was used for later analysis. The results of the minimum and maximum species assumptions are in the diversity assessment (see appendices).

3.6 Statistical Analysis

Statistical analysis was carried out using Microsoft Excel, R version 2.13.0 (R Development Core Team 2011) and ArcGIS version 9.1.

3.6.1 Tree diversity

The Shannon-Weiner diversity index is a common and robust method for calculating the level of biodiversity. This particular index was chosen so that the data would be comparable with similar analyses carried out in the OWR.

To calculate the Shannon index per plot the following formula was used

$$H' = -\sum_{i=1}^{S} (pi \ln pi)$$

Where

- n_i = the abundance of species i
- S = the number of species
- N= The total number of trees
- p_i = the relative abundance of each species. ($\frac{ni}{N}$)

3.7 Wood Specific Gravity

Wood specific gravity was attained for all tree species using three references. The first two were lists of tree species in the Ituri and DRC region, with WSG to species, genus or family level. The third was a global database of WSG. Lists were referred to in order of specificity, with the Ituri list taking priority over the DRC list, which took precedence over the global list. The global list was used to calculate average values per genus or family (based on individuals of other species surveyed in their genus or family) where these could not be found elsewhere. Where WSG could not be found at family level, or the tree identity was indeterminate, the average WSG of all samples was used.

For example, if the individual in question had the species code GREESU, standing for *Greenwayodendron suaveolens*, the Ituri reference list would be checked first, returning,

wsg	idlevel	site	sp	genus	species	fam
NA	NA	congo	GREESU	Greenwayodendron	suaveolens	Annonaceae

The DRC reference list would then be checked, returning

family	genus	species	wsg
Annonaceae	Greenwayodendron	suaveolens	0.57088
det_level	wsg_species	wsg_genus	wsg_family
FAM	NA	NA	0.57087634

Such that the global database did not need to be checked, and the WSG was recorded as 0.57088 determined to family level.

3.8 Carbon Stock Estimation

To estimate carbon stocks in trees and saplings, the wet forest and the moist tropical forest equations were used for the sake of comparison (Chave et al 2006). For palms, a regression equation was used (Frangi and Lugo 1985). For lianas, equations from Chave et al 2003 and Schnitzer et al 2006 were compared.

Table 3.1 - equations used in the carbon stock estimation. [AGB]est= Estimate of above ground biomass in kg; P= Wood specific gravity in grams per cubic meter (oven dry mass divided by green volume); D= Diameter at breast height in cm.; H= Stem height in meters; D_130= Diameter at 130cm from the root in cm

Carbon Source	**Equation**
Trees and saplings (moist forest)	$[AGB]est = p \times \exp(-1.499 + 2.148 \ln(D) + 0.207(\ln(D))^2 - 0.0281 (\ln(D))^3)$
Trees and saplings (wet forest)	$[AGB]est = p \times \exp(-1.239 + 1.980 \ln(D) + 0.207(\ln(D))^2 - 0.0281(\ln(D))^3)$
Palms	$[AGB]est = 4.5 + 7.7 \times H$
Schnitzer Lianas part 1	$D\_130 = 0.070 + 1.02 (D)$
Schnitzer Lianas part 2	$[AGB]est = \exp[-1.484 + 2.657 \ln(D)]$
Chave Lianas	$[AGB]est = \exp[0.0499 + 2.053 \ln(D)]$

The above equations have differing levels of uncertainty.

- Trees and saplings (wet and moist forest) - 19.5% standard error in estimating biomass at the stand level
- Schnitzer Lianas part 1 - $R^2>0.88$
- Schnitzer Lianas part 2- $R^2 = 0.694$
- Chave Lianas- not reported

Palms- Frangi and Lugo (1985) report an r^2 of 0.90. The equation was formulated for *Prestoea montana* rather than for Raphia and Oil palms (*Raphia gentiliana* and *Elaeis guineensis*). However, as equations have not been developed for palms in the study region, Frangi and Lugo's equation is used unmodified.

As lianas and saplings were only measured in one subplot, the resulting ABG was multiplied by 16. This introduces additional uncertainty due to variation in sapling and liana density within plots. All above ground biomass estimates were multiplied by the carbon conversion factor. This was 0.47, the standard recommended by IPCC good practice guidelines 2006

3.9 Comparing Carbon by Class and Source

The level of carbon within each plot was calculated and the proportion of that carbon which was made up by each source (trees, saplings, lianas and palms) was expressed as a percentage.

As the data is non-parametric, Kruskal Wallis tests were performed to determine if the level of carbon in each source differed significantly within each class and if the level of carbon within each class differed significantly within each source.

3.10 Comparing Reductions in Carbon and Diversity From Conversion To Agriculture

As trees were the largest and least variable component of carbon per plot, the analysis focused only on tree carbon only. The differences in average tree carbon per plot between the primary class and the field class and between the disturbed class and the field class were calculated using both lax and strict class groupings. Wilcoxon rank sum tests were conducted to determine if these differences were significant. To determine how much more carbon is lost when primary forest rather than disturbed areas are converted to agriculture, the difference between the above differences was calculated.

3.11 The Correlation Between Carbon and Diversity Across the Disturbance Gradient

In order to determine if tree diversity and carbon stocks are correlated, a linear model was run using data from the 93 plots surveyed. In model 1, the response variable was tree diversity and the explanatory variable for tree carbon. Only tree carbon was considered as the other carbon sources were too unreliable.

3.12 Comparing the Carbon and Diversity of Mixed and Monodominant Forests

Primary forests were split into two subcategories- monodominant and mixed. Due to a lack of monodominant forest in the survey sites at Epulu, data from the research plots at Lenda and Edoro was used to compare mixed and monodominant forests. There were 19 mixed forest plots within the ZA, so 19 mixed and 19 monodominant plots were chosen at random from the Lenda and Edoro sites for the sake of comparison.

Kruskal-Wallis and Wilcoxon tests were used to compare differences in tree diversity and tree carbon stock between monodominant and mixed forest outside of Epulu, monodominant and mixed forests inside of Epulu and mixed forests both inside and outside of Epulu. In model 2, the response variable was primary forest diversity and the explanatory variable for tree carbon. Only the 19 mixed primary forest plots surveyed in the ZA, plus the 38 additional plots from Lenda and Edoro.

3.13 Generalised Linear Models

To explore further the relationship between carbon, diversity, and other variables, generalised linear models with a Gaussian error family specified were used. A generalised linear model was run on AGB (log-transformed to a normal distribution) against plot class, the presence of invasives, canopy score, stem density and tree diversity. Model simplification was employed where firstly the full model was fitted and the least significant terms were removed. This was repeated until only significant terms ($p<0.05$) remained in the model

3.14 Sources of Error and Uncertainty

At every stage of research there are sources of error and uncertainty. As Watson et al (unpublished) stress in “Uncertain Emission Reductions from Forest Conservation: REDD in the Bale Mountains Eco-Region, Ethiopia” attempting to quantify these is crucial in order to realistically evaluate REDD projects. Table 3.2 summarises some of these errors and the attempts to quantify or mitigate them. For more detail on constraints, see appendix.

Table 3.2 Summary of sources of error and uncertainty

Source of Error/ Uncertainty	**Effect**	**Response**
Sample size	Small plot size and number introduce sampling error. Sample may not be representative	Standard errors reported
Sampling strategy	Spatial autocorrelation due to plot proximity violates assumptions of observation independence.	Minimum plot proximity incorporated into sampling strategy
DBH measurement	Inaccuracies due to vines, slope, irregular trunk shape and human error	Unquantified
Species identification - botanist	Potential misidentification of tree species, leading to inaccurate determination of WSG	Unquantified
Species identification- technicians	Potential misidentification of tree species, leading to inaccurate determination of WSG	Unquantified
Local name/species name	Uncertainty about the species corresponding to local names leading to inaccurate determination of WSG and inaccurate diversity score	Minimum, maximum and intermediate diversity values per plot recorded
Plot classification	Plots may be classed by the very features under examination	Classless analysis (regression) to validate class based analysis
Data entry	Errors correctly reading and recording data	Error checking with botanists
WSG per species	Lack of adequate samples per species leading to imprecise WSG	Unquantified
Allometric equations	Equations predict ABG based on relationships observed in samples. These samples may be unrepresentative and the equations only account for a proportion of the observed variance.	Associated error reported where available. Alternative allometric equations tested where available
Aggregation of plot data per class	Sample mean may not match population mean	Standard errors reported with the mean where possible
Lack of re-sampling	Class based comparison used as a surrogate for change over time. Potential bias and inaccuracy	Alternative class groupings tested
Statistical tests	type 1 and type 2 errors	p values reported

4 Results

4.1 Landcover Classification

Joel's landcover classification proved highly accurate (see table 4.1 below), enabling fairly even sampling of the three main classes of interest.

For plots he classified as primary forest, there were three instances in which the plot was actually an old fallow or secondary forest. There were five instances where the plot had been disturbed in some way (for example the understorey had been cut in preparation for agricultural conversion); for one of these it was uncertain if the plot had been disturbed before or after the satellite image was taken.

For plots he classified as disturbed there was the highest uncertainty and error. This is not surprising as the disturbed class is the most variable, being intermediate between active field and primary forest. In two instances the plot was actually primary forest. In four instances the plot was an active field and it was uncertain if it had been disturbed or active when the image was taken.

Active fields were the most accurately determined class, probably due to the distinctive reflective signature of bare ground present in active fields. In two instances, plots were disturbed and it was unclear if they had been active when the image was taken. In 14 instances, plots had lapsed into fallows since the image was taken.

Table 4.1 an assessment of the accuracy of Joel Masselink's land cover classification.

Assessment	**Predetermined Class**		
	Primary	Disturbed	Active
Total	29	30	26
% correct	72	77	38
% outdated but correct	14	3	54
% uncertain	3	13	8
% incorrect	10	7	0
% Accuracy	86	80	92

4.2 Overall Characteristics of Disturbance Classes

The following is a crude characterisation of the disturbance classes based on the understorey assessments carried out.

4.2.1 Primary Forest was characterised by

- Closed, high canopy overshadowing a sub canopy. Occasional canopy gaps were caused by tree fall, more prevalent in mixed than Mbau forest.
- Almost total absence of invasive plants. Only one primary forest plot included any of the identified invasives and that was at the border with a disturbed area.
- An open, sapling dominated understorey, especially in Mbau forest. Ground herbs tended to be sparse and of limited variety, including *Palisota manniii* and *Palisota ambigua*, *Sarcophrynium*, *Ataenidia conferta*, and even under the densest canopy, *Leptaspis cochleata*. Large epiphytes were evident high in trees and large vines were more prevalent in mixed forest.
- Relatively thick leaf litter, especially in Mbau forest.
- A litter- dominated groundcover.

4.2.2 Disturbed Areas were characterised by

- High variability overall, with plots in various stages of succession.
- A mix of canopy types ranging from none, to closed low canopy and higher canopies with gaps.
- Frequent presence of invasive plants, *Lantana camara, Sida acuta* and (most prevalent) *Chromolaena oderata*. In some instances these totally dominated fallows.
- Often a dense, herb dominated understorey. The highest diversity of ground herbs was found in this class, including *Palisota mannii* and *Palisota ambigua*, *Megaphrynium, Sarcophrynium, Afromomum sanguineum, Desmodium adscendens, Marantochloa, Piper umbellatum* and *Anchomanes giganteus*. Left over crop species included banana, chilli, manioc and papaya. Some fallows were dominated by palms. Vines of various sizes were present and epiphytes were often evident on palm stems.
- Variable leaf litter thickness
- A plant/litter dominated groundcover.

- The higher incidence of biting ants, dense undergrowth, spines and thorny vines made this the least pleasant class to survey in.

4.2.3 Active fields were characterised by

- No canopy other than the occasional tree and dense herbs.
- Frequent presence of invasive plants, *Lantana camara, Sida acuta* and (most prevalent) *Chromolaena oderata*.
- An open, crop dominated understorey. Non-crop herb diversity was low, but included *Cyathula prostrata, Bidens pilosa, Physalis angulata* and *Stachytarpheta indica*. Crops included manioc, tarrow, chilli, tomato, banana, papaya, peanut, haricot beans, squash, sweet potato and maize.
- Superficial leaf litter if any.
- A plant dominated groundcover with far more bare ground and fallen deadwood than the other classes.

4.3 Wood Specific Gravity and DBH

WSG only varied within a small range. The lowest WSG recorded on the database was 0.205 for *Musanga Cecropiodes* and the highest was 0.985 for *Harungana madagascariensis*. However, DBH varied within a large range. The smallest stems in the tree class were 10cm DBH, whilst the largest were over 150cm DBH. Therefore, in the determination of the AGB of a tree, the DBH was much more important than the WSG (see figure 4.1).

Brown. (2002) suggests that allometric equations relying on DBH alone can explain 98% of the variation in biomass per tree. It is for these reasons that errors in species identification (and hence WSG) were relatively unimportant for the carbon stock assessment.

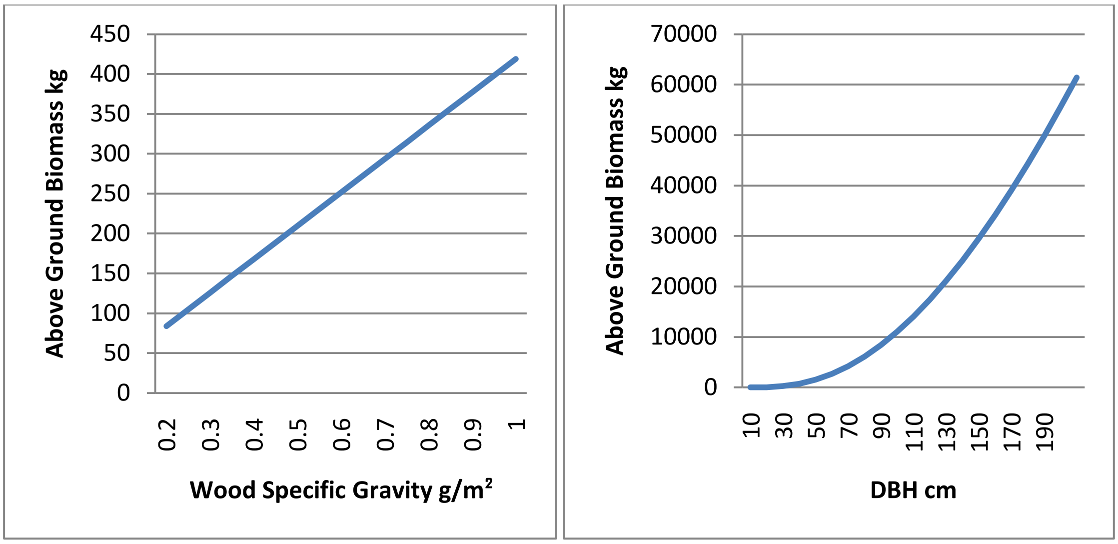

Figure 4.1 Left- Keeping DBH constant, and increasing WSG results in a linear increase in AGB. Right- Keeping WSG constant and increasing DBH results in a non-linear increase in AGB.

4.4 Components of the Above Ground Carbon Stock

In all classes the largest carbon source was trees, followed by saplings. In the disturbed and field classes, the next largest sources were palms, followed by lianas, with almost no lianas in active fields. In primary forest by contrast there were no palms. Other than lianas (the mean carbon per plot of which was not significantly different between classes) all sources were significantly different by class and within each class (see tables 4.2 and 4.3).

Table 4.2: Kruskal Wallace tests to determine if carbon sources were significantly different between classes, and whether each carbon source was significantly different within each class.

1	All Classes			2	All Sources		
	chi^2	Df	p		chi^2	df	p
All Sources	25.7928	2	<0.001	All Classes	265.93	171	<0.001
Trees	27.4732	2	<0.001	Primary	98.7441	62	<0.01
Saplings	27.3227	2	<0.001	Disturbed	107.4652	77	<0.05
Lianas	3.4762	2	>0.05	Field	60.5257	33	<0.01
Palms	16.006	2	<0.001				

Table 4.3: Mean Above Ground Carbon Per Plot in kg Organised By Class and Source followed by the proportion of carbon per plot represented by each source, per class, all with standard errors.

	All Classes		**Primary**		**Disturbed**		**Field**	
Source	**Carbon**	**SE**	**Carbon**	**SE**	**Carbon**	**SE**	**Carbon**	**SE**
Trees	5353.32	697.52	8126.58	1263.73	5017.65	1142.01	2379.04	855.84
Saplings	100.80	13.10	167.88	25.07	106.85	19.078	10.10	7.31
Lianas	18.40	8.67	9.66	4.40	37.74	22.18	3.12	3.06
Palms	15.08	4.69	0	0	31.14	10.32	6.80	3.10
	All Classes		**Primary**		**Disturbed**		**Field**	
Source	**%**	**SE**	**%**	**SE**	**%**	**SE**	**%**	**SE**
Trees	92.95	1.59	95.59	1.61	89.03	2.88	95.92	2.89
Saplings	4.55	1.26	3.70	1.07	8.09	2.78	0.33	0.23
Lianas	0.54	0.24	0.71	0.61	0.78	0.36	0.02	0.02
Palms	1.96	1.00	0	0	2.10	0.64	3.73	2.89

4.5 Comparing Carbon By Class

Carbon is significantly different by class, using either lax or strict class assumptions. Primary forests have significantly more carbon, followed by disturbed areas and the field class has the lowest carbon. There are extreme outliers in the data (figure 4.2).

Table 4.4: Mean carbon per plot kg and standard error, organised by class, using both lax and strict class assumptions

Class Assumptions	**Lax**		**Strict**	
Class	**Tree Carbon**	**Standard error**	**Tree Carbon**	**Standard error**
primary	8126.58	1263.73	8486.21	1790.40
disturbed	5017.65	1142.01	4910.56	1489.40
field	2379.04	855.84	382.35	141.16

Table 4.5: Wilcoxon tests comparing the different classes

Class Assumptions	**Lax**		**Strict**	
class	W	p	W	p
Primary vs. Field	719	<0.001	249	<0.001
Disturbed vs. Field	642	<0.01	201	<0.001
Primary vs. Disturbed	228	<0.001	284	<0.01

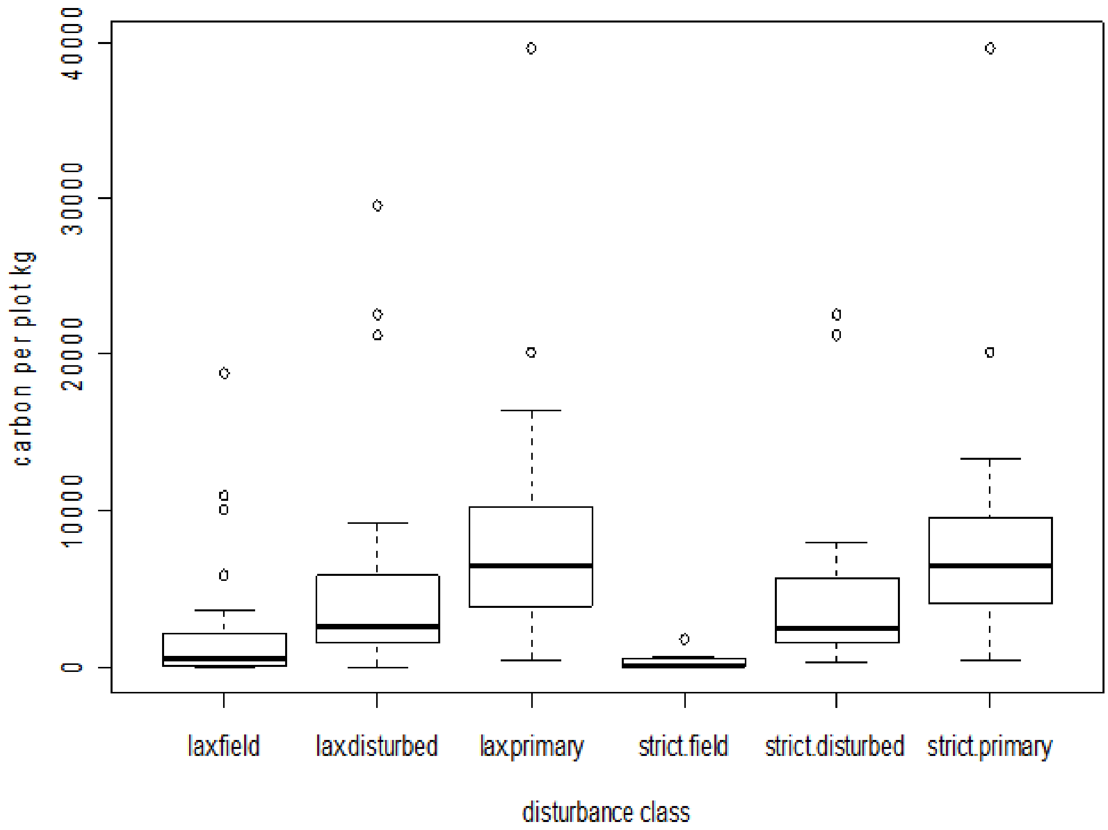

Figure 4.2: Carbon per plot in both lax and strict land cover classes is extremely variable

4.6 Comparative Carbon Losses Due to Conversion To Agriculture

Nearly twice as much carbon is lost when primary forest rather than disturbed areas are converted. These comparative losses can be thought of as potential savings if primary forest conversion were avoided. The strict class assumptions are more robust, and show an even greater difference, hence the potential for even greater savings.

Table 4.6: Tree carbon lost due to different land use changes

Class Assumptions	Lax	Strict
Kg per plot carbon lost Primary converted to field	5747.54	8103.86
Kg per plot carbon lost Disturbed converted to field	2638.61	4528.21
% carbon lost primary to field	70.73	95.49
% carbon lost disturbed to field	52.59	92.21
How much more is lost when converting primary rather than secondary forest? Kg per plot	3108.93	3575.65
How much more is lost when converting primary rather than secondary forest? tons per hectare	77.72	89.39
How many times more carbon is lost when converting primary rather than secondary?	1.90	1.80

4.7 Carbon Accounting

It was estimated that between 77 and 89 tonnes of carbon per hectare could be saved through avoiding primary forest conversion to agriculture. One tonne of carbon is equivalent to 3.67 tonnes of carbon dioxide (Miles et al 2009). Butler et al 2009 cite values of between \$4.65 and \$52.44 per tonne of avoided carbon dioxide emissions depending on different pricing scenarios. 1106.6 hectares of primary forest were deforested within the reserve between 2005 and 2010 (see appendices). We can therefore perform simple carbon accounting (see table 4.7).

Table 4.7: Estimates of the potential value of carbon saved through avoided deforestation.

Tonnes of carbon per hectare saved through reconverting disturbed areas – minimum	77.72
Tonnes of carbon per hectare saved through reconverting disturbed areas – maximum	89.39
Conversion factor between carbon and carbon dioxide	3.67
Tonnes of carbon dioxide per hectare saved through reconverting disturbed areas - minimum	285.23
Tonnes of carbon dioxide per hectare saved through reconverting disturbed areas - maximum	328.06
Carbon dioxide price $ per tonne - minimum	4.65
Carbon dioxide price $ per tonne - maximum	52.44
Value $ per hectare of carbon dioxide saved- minimum	1326.33
Value $ per hectare of carbon dioxide saved- maximum	17203.53
Hectares of primary forest deforested within the reserve between 2005- 2010	1106.6
Hypothetical total $ value of carbon dioxide saved (2005-2010)- all OWR – minimum	1454120.54
Hypothetical total $ value of carbon dioxide saved (2005-2010)- all OWR – maximum	18954372.87

4.8 Comparing Tree Diversity per Class

For both lax and strict class assumptions, the tree diversity of the classes is significantly different. The primary forest class has the highest diversity, followed by the disturbed class and the field class has the lowest diversity. Using stricter class assumptions reduces the spread of the data per class, especially for the field class, and reduces outliers.

Table 4.8: Mean tree diversity by class

lax	mean	se	**strict**	mean	se
field	0.502828958	0.101117089	field	0.168567377	0.08437173
dist	1.718812198	0.092944981	dist	1.791385774	0.075463456
prim	2.085738593	0.099122091	prim	2.202253765	0.061147728

Table 4.9: Wilcoxon output displaying a comparison of mean tree diversity

Class assumptions	lax		strict	
Test results	W	p	W	p
Primary vs. disturbed	771	<0.001	331	<0.001
Disturbed vs. field	55	<0.001	216	<0.001
Primary vs. field	805	<0.001	264	<0.001

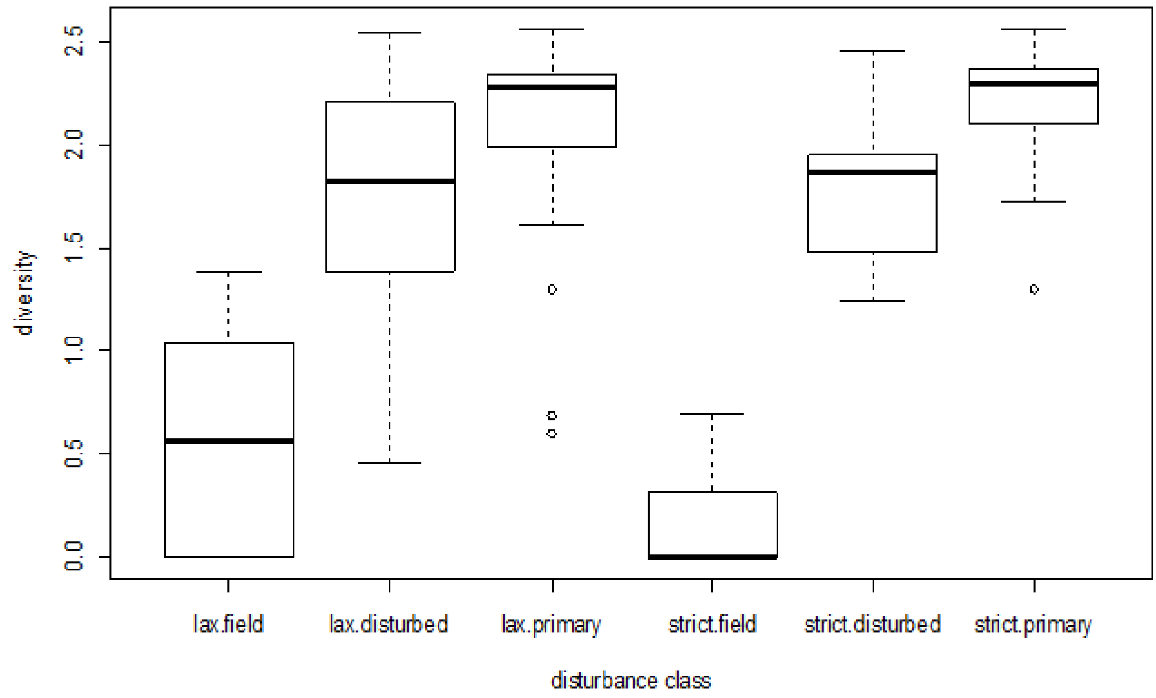

Figure 4.3: Diversity per class

4.9 Comparing Carbon and Diversity Amongst Primary Forest Types

Tree carbon and tree diversity were significantly different by forest type. Comparison of the three groups against each other using Wilcoxon tests showed that monodominant forests have significantly higher carbon and lower diversity than mixed forests. Though the mixed forests at Epulu were slightly higher carbon and lower diversity than those at Edoro, the difference was not significant. Overall, the differences in diversity were more significant than differences in carbon.

Table 4.10: Comparison of primary forest plots for carbon and diversity

	carbon	**se**	**diversity**	**se**
mixed	7379.487854	959.3426222	2.175151572	0.079772313
mono	11330.1128	1020.088417	1.308281583	0.130185191
ZA	8693.788477	1970.661988	2.172875081	0.067495791

Table 4.11- Results of significance tests for monodominant and mixed forests

Kruskal Wallis tests	chi²	df	p	Kruskal Wallis tests	chi²	df	p
Tree Carbon by forest type	10.0369	2	<0.01	Tree Diversity by forest type	24.3962	2	<0.001
Wilcoxon Tests	W	p		Wilcoxon Tests	W	p	
mono vs. mixed	282	<0.01		mono vs. mixed	38	<0.001	
mono vs. ZA	266	<0.05		mono vs. ZA	31.5	<0.001	
mixed vs. ZA	182	>0.05		mixed vs. ZA	173	>0.05	

4.10 Linear Models of Carbon against Diversity

In model 1 there is a highly significant positive correlation between diversity per plot and carbon per plot. This validates the comparison made between disturbance classes. The fit of the model is poor due to the fact that the carbon data is not normally distributed (R^2=0.131).

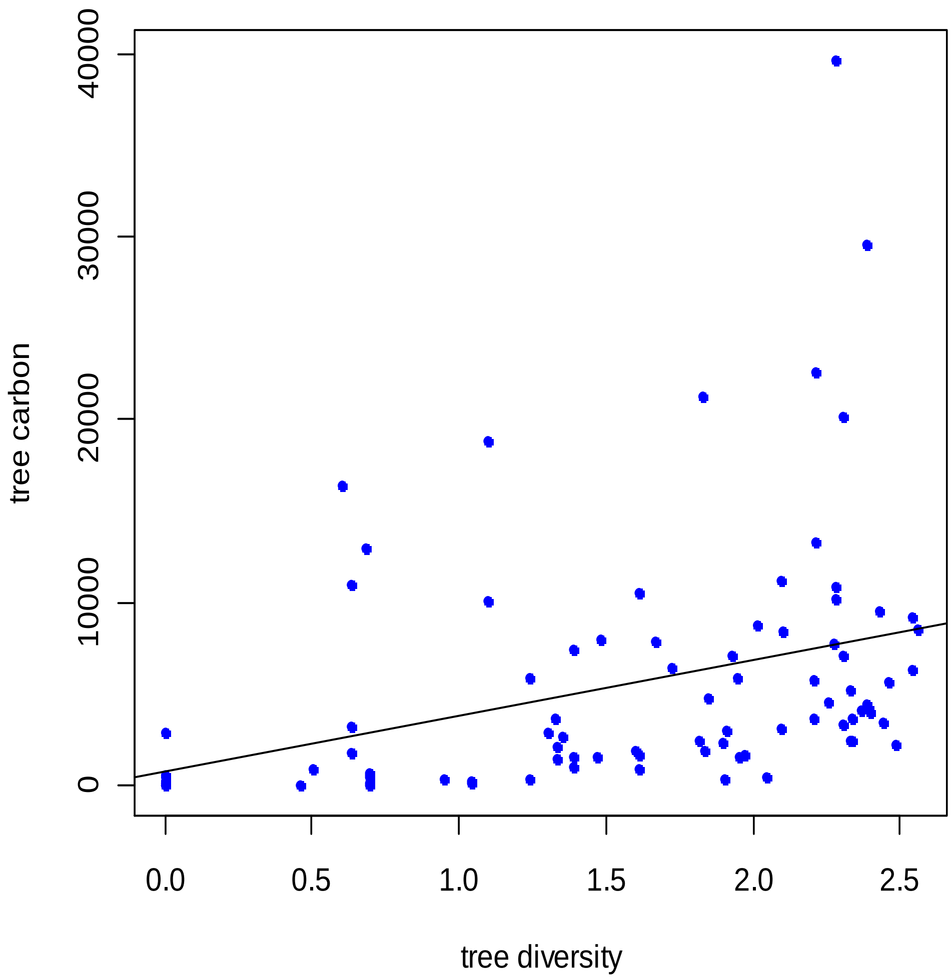

Figure 4.4: The correlation between tree diversity and tree carbon across plots in all disturbance classes.

Model 2- Using the 19 mixed forest plots within the ZA and the 38 selected from Lenda and Edoro. Once only primary forest plots are considered, the correlation between tree diversity and tree carbon looses significance. For primary forests, we cannot say that diversity and carbon are correlated.

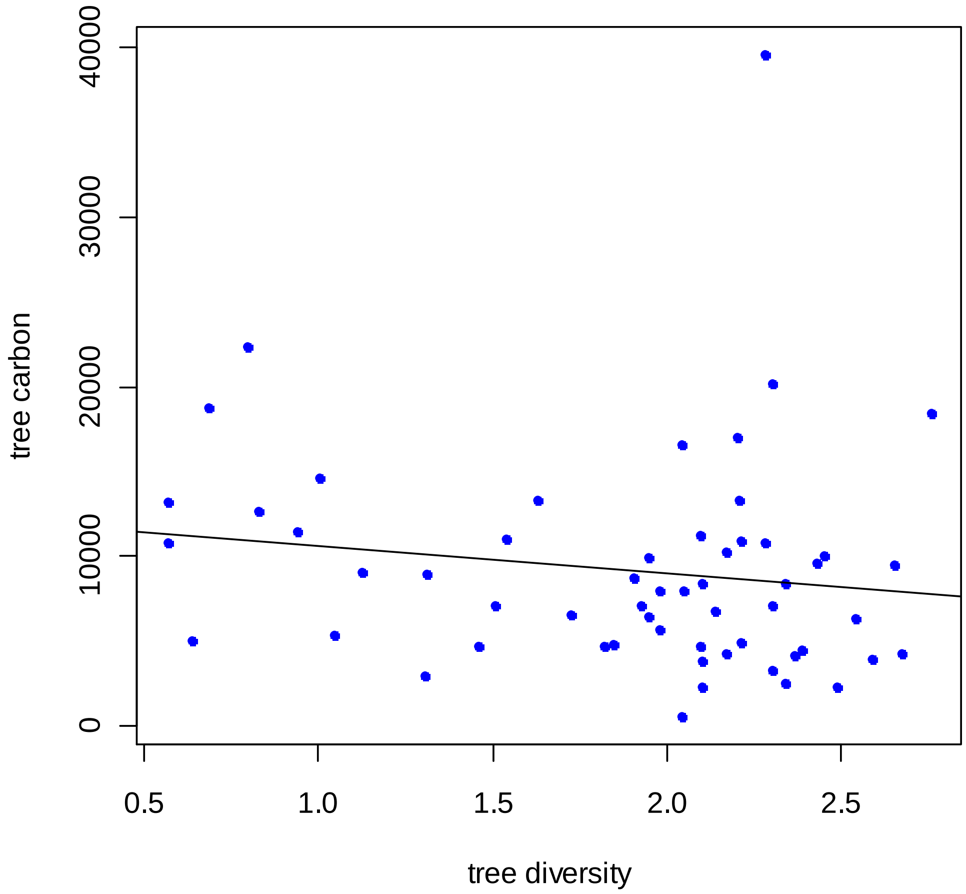

Figure 4.5: Tree diversity against tree carbon only considering primary forest plots.

Table 4.12: model outputs

Model number	Residual standard error	df	Multiple R-squared	Adjusted R-squared	F-statistic	df	p
1	6271	90	0.1405	0.1309	14.71	1 and 90	<0.001
2	6342	55	0.02261	0.004834	1.272	1 and 55	>0.05

4.11 Generalised Linear Model

The only variables which significantly explain carbon were tree diversity ($p<0.001$) and canopy score ($p<0.01$). Model fit was poor however, with a null deviance of 343.99 on 91 degrees of freedom and a residual deviance of 167.15 on 89 degrees of freedom.

5 Discussion

5.1 The Importance of Large Trees

The analysis of the relative importance of WSG and DBH demonstrated that the largest trees have by far the largest AGB. As very large trees are uncommon, and my plot and sample size were relatively small, such trees strongly affected my results.

For instance, the plot with the sixth highest carbon I surveyed (based on trees alone) was plot 86 (survey order 91), which had 18824kg of Carbon. This was identified by Mustafa as a four year old fallow. Compare this to plot 54 (survey order 74), a primary mixed forest plot with 515kg of Carbon, less than a 36^{th} of the amount. Plot 54 however had a large canopy gap caused by tree-fall, another phenomenon affecting my results. Plot L3 (order 38) was a primary monodominant forest with no canopy gap, but only 1857kg Carbon, less than a tenth that of plot 86. The difference is almost entirely due the presence of the large tree pictured below left. The tree was an *Entandrophragma cylindricum* of 149.4cm DBH; representing 14277kg of carbon.

Chave et al (2005) note that estimating the biomass of large trees via allometric equations is difficult due to the effects of weathering and crown dominance. Furthermore, due to their patchy distribution, they add high variability to carbon stock estimation. This was evident in this study especially due to the limited number and small size of plots surveyed.

Figure 5.1: Left - Plot 84. Abena climbs a large *Entandrophragma cylindricum* in subplot 4,4, whilst Mustafa shields his survey sheet from the rain. Right- Plot L3. A primary monodominant forest plot. The latter had less than a tenth of the carbon of the former.

5.2 Comparing Allometric Equations

5.2.1 Trees

Applying the moist forest allometric equations to the tree data produced results which were on average 1.5 times higher per plot (standard deviation 1.00) than those using the wet forest equation. Chave et al (2005) mention that models which did not account for forest type overestimated AGB, but did not explain why. Potentially it could be due to a combination of different species composition in wetter areas, and the effects of habitat on individual trees. The Ituri forest is classed as a moist forest. To quote Chave et al (2005)

> Forests where evapotranspiration exceeds rainfall during more than a month (climatological average over many years), but less than 5 month were classified as 'moist forests'. These are forests with a marked dry season (one to 4 months), sometimes with a semi-deciduous canopy, and corresponding to ca. 1,500–3,500 mm/year in rainfall for lowland forests.

Given the potential effect of climate upon stand level AGB, hence carbon, one might expect climate change to alter the carbon content of large swathes of forest. Makana et al (2011) note that AGB has slowly increased in their study plots with the advance of Mbau forest. Whether this is linked to climate is uncertain.

5.2.2 Lianas

Applying the Chave et al (2003) equation to lianas produced results 2.17 times higher than those using the Schnitzer (2006) equations. As the Schnitzer paper is more recent, has Chave, J. as a co-author, and incorporates a correction for where on the liana the diameter is measured, it was used over the Chave et al equation. Even if the higher estimate of liana carbon were used, lianas would still represent less than 2% of total above ground carbon irrespective of class.

5.3 Results in Context

The results obtained in this study broadly agree with research carried out previously and elsewhere. For example it was found that.

1. Trees are by far the largest component of the above ground carbon stock in all classes.

Even in active fields this study found that 95% of carbon was to be found in trees. Henry et al 2008 reported lower values of 81% and 55% at different sites. Their sites were somewhat different from the Congolese ones in that they had hedgerows, the contribution of which was reported separately as 13% and 39%. Combining the hedgerow with the tree values gives figures similar to those from this study. Their study was rare in that it disaggregated sources of carbon. Like this study however it measured perennial vegetation, but not annual crops. Presumably the relative importance of tree carbon would be reduced if annual crops had been measured.

2. Carbon stock is higher in primary forest than active fields and disturbed areas.

Silver et al 2000 study presents a literature review showing that AGB increases at 6.2 Mg per hectare per year in the first 20 years and 2.9 Mg per hectare per year in the first 80 years.

3. Diversity is higher in primary forest than active fields or disturbed areas.

Numerous studies have confirmed that biodiversity (measured in a variety of ways) is higher in primary forests than secondary or other disturbed or cultivated areas. Kessler et al 2005 conclude this for tree species richness in Indonesia. Turner et al 1997 conclude it for tree species richness in Singapore. Barlow et al 2007 give a more complex picture for more comprehensive measures of biodiversity, but ultimately confirm the central importance of primary forests.

4. High carbon and biodiversity generally correlated across the disturbance gradient

This is in a sense predicted by the preceding two points. Strassburg et al (2009) global study found a similar correlation of high biomass and biodiversity amongst different biomes.

5. Monodominant forest has higher carbon but lower diversity than mixed forest.

Makana et al (2011) and Hart (1990) reach the same conclusion. Makana et al also mentions that monodominant forests at other sites (Douglas fir and Redwood forests of the USA)tend to have high biomass.

What made this study unique is that a) It quantified and compared the carbon represented by different classes and sources in the context of a shifting agriculture mosaic and b) It analysed these findings, along with tree diversity in the context of REDD+.

5.4 Limitations and Assumptions

In addition to the aforementioned constraints there were several key research limitations

5.4.1 Plot classification; a surrogate for change over time.

To determine the changes undergone in the process of converting an area for agriculture, one ought to study a single plot over time, rather than comparing different plots at one point in time. This is for two reasons:

1. It is possible that the areas converted for agriculture are in some way different to those that are not, introducing bias. It may be for example that one reason islands of primary forest remain in the ZA is due to their high density of large, hard wooded trees which cannot easily be felled. Had those areas been converted, perhaps they would have higher residual carbon than the active fields studied here.

2. Re-surveying plots would allow accurate determination of the age of the plot since conversion. As previously mentioned, plot age and class in this study were based on the

known disturbance history of the plot, as determined by the experienced survey team. In practice it is difficult to ascertain if plot classification was done solely on the basis of known disturbance history, or if plot characteristics such as tree size were also being used as cues. If the latter is true then it introduces circularity into the analysis. If primary forests are being defined by the presence of large trees, shown here to have high carbon, and the difference in carbon per plot of the different classes is being analysed, then the primary forest class is being defined on the basis of what it is supposed to explain, namely carbon. A long running study would avoid this circularity by objectively aging plots.

To improve the reliability of the results this research project accounts for the potential problems with class identification by using two types of analysis; class based and classless. In class-based analysis, plots were organised into classes (be these disturbance or forest types), the mean carbon and tree diversity of which were compared with Kruskal Wallis and Wilcoxon tests. In classless analysis, linear models were run of carbon against diversity per plot. Both analyses resulted in the same conclusions, namely that primary forests have higher carbon and diversity.

5.4.2 Biodiversity estimates based on tree diversity.

This study aims to determine if REDD+ can achieve biodiversity conservation aims. Attempting to address this issue by focusing on tree diversity involves two assumptions. First, that tree diversity is an adequate proxy for wider diversity. Second, that alpha diversity is an adequate basis for conservation prioritisation.

Barlow et al 2007 point out the difficulties in using indicator taxa to measure biodiversity. As Redford 1992 warns in “The Empty Forest” high tree cover can mask faunal poverty. Nonetheless, tree diversity is both a valuable component of biodiversity in its own right, and it has been found to correspond to wider biodiversity, particularly in the context of Ituri. Chapman et al (1999) report low primate encounter rates in monodominant forest. Melletti et al (2006) report higher utilisation of mixed than monodominant forests by forest buffalo. In the OWR, megafauna have been found to preferentially frequent the more diverse mixed forests over monodominat forests.

Conservation prioritisation is a voluminous area of research in its own right, which it is beyond the scope of this study to address. Alpha diversity is only one aspect to consider alongside endemism, threat level, monetary cost and evolutionary distinctness. These are addressed in Strassburg et al (2009).

5.4.3 A wide variety of forest uses were not studied

REDD+ explicitly goes beyond forest preservation to sustainable use. The only form of use examined here is shifting agriculture, the sustainability of which is debatable. other forms of use that would potentially come under REDD+ include community based natural resource management (CBNRM), hunting and gathering, selective timber extraction, or any form of extractive activity whose goal was long term sustainable use of forests. The OWR and surrounding Ituri region would be a fruitful site for such studies, as it includes CBNRM, forestry, and hunting.

5.4.5 Lack of Undisturbed Site

Ideally this research project would have studied primary forest plots sufficiently far from human settlements to guarantee a high level of intactness. This would have enabled the creation of a baseline of carbon and diversity against which other plots could be compared. In practice, there is no part of the OWR entirely beyond the reach of hunters whose activities will have some impact on the forest. Studying plots in the research site at Lenda, and using data from previous surveys at Lenda and Edoro, is an adequate compromise.

5.5 Strengths

Previous studies of above ground biomass and tree diversity in the region have focused on primary forest and logged forest. Using stratified random sampling within the relatively small ZA of Epulu, this study was able to collect data from the entire disturbance range. This allows quantification of carbon losses due to agricultural conversion, and the analysis of a broader range of carbon and diversity values.

5.6 Future Research

5.6.1 Technical Issues With Carbon Stock Assessment

- Harmonisation of data concerning the WSG of trees would improve the accuracy of carbon stock estimates. As WSG only has a relatively minor impact on above ground biomass however, and destructive sampling of trees is fairly costly, this should not be a priority.

- Allometric equations which account for very large trees are needed. Although these trees are rare, their effect on carbon stock assessment is disproportionately large. Relevant issues to address would be to account for the effects of age and weathering.
- Non-tree sources of carbon are comparatively under-researched. Area or species-specific equations have been created for palms, but more universally applicable developments are rare. Such equations would ideally be based on measurements easily made in the field such as stem height and species for palms, and DBH and species for lianas. The comparison of different sources of above ground carbon showed that non-trees are far less significant in terms of carbon representation, suggesting that such research is not a priority. There is however a danger that this becomes a self-fulfilling prophecy, in which the underdeveloped carbon estimation techniques produce results in which we have little confidence, leading us to conclude that developing better techniques is not a priority.
- Estimates for crop biomass (biomass of cropland not including non crop carbon) are lacking. Where destructive sampling is inappropriate for estimating crop biomass, generic estimates would give a more complete picture.

5.6.2 REDD+ Local

- In order to accurately determine carbon losses due to agricultural conversion, repeat assessments must be made of the same plots before and after conversion. These measurements should be made for a range of primary forest and already disturbed plots if the aim is to quantify carbon that could be saved through avoiding conversion of primary forest.
- Studying non-agricultural sources of deforestation and degradation such as mining and firewood collection, would allow for a more comprehensive mitigation strategy.
- Social research into the drivers of primary forest conversion over disturbed areas is crucial for formulation of appropriate responses. If immigrant pressure is the cause, then it may be feasible to encourage local chiefs not to sell their land. If however local expansion is the cause, then changes to agricultural practices would have to be considered.

- Slash and mulch is being promoted within the OWR as an alternative to slash and burn. Quantifying the carbon and biodiversity benefits of this approach could be an appealing addition to a REDD+ project. Such benefits may include: 1) Lower or slower emissions inherent in the process of mulching compared to slash and burn 2) Reduced deforestation due to increased field longevity 3. Lower mortality of large trees within active fields.

5.6.3 REDD+ Global

- Studying the relationship between spatial prioritisation of biodiversity conservation and high carbon stocks at the appropriate scale is a priority. A study by Strassburg et al (2009) , although useful, is too large scale. Deserts and Polar Regions, along with forested regions in developed countries are highly unlikely to be candidates for REDD+. For example according to Keith et al (2009) the forests with the highest carbon stock are "Australian temperate moist *Eucalyptus regnans* forests" and cool temperate moist forests far outstrip tropical wet forests in carbon storage. As these are generally found in developed countries however, they are of little concern for REDD+. Focusing on high carbon regions in developing countries would give a clearer picture of the likelihood that REDD+ can produce win-wins. Venter et al 2009 has the appropriate focus on potential REDD areas, but lacks the nuance of conservation prioritisation (for example for threatened or endemic species) of the Strassburg (2009) paper. Once such research has been undertaken, it should be clearer which areas will most urgently require non-REDD+ funding.
- This and other studies indicate that if REDD+ focuses exclusively on maximising carbon savings per investment, then forests of lower biodiversity conservation priority will be preserved for their carbon, leaving high priority forests at risk. If this is to be avoided then conservationists should muster the most convincing argument they can, that REDD+ should compromise on some carbon for the sake of biodiversity. Research into the indirect carbon benefits of highly biodiverse forests, such as their stability, should be built upon.

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5.7 Aim 1- The Prospects for REDD+ win-wins at the Project Level

Results presented here indicate that, if existing disturbed areas (rather than primary forest) were converted to agriculture, then above ground carbon stocks as well as tree diversity would benefit. This is encouraging, as it suggests that prima facie, REDD+ funding could be employed to encourage reconversion of already disturbed areas and discourage agricultural expansion into primary forest, at a benefit to biodiversity.

The carbon accounting showed that carbon savings could be worth between $1326.33 and $17203.53 per hectare, and between $1454120.54and $18954372.87 over the entire OWR in a five year period. The greatest source of uncertainty in this calculation is the price of avoided carbon dioxide emissions per hectare. The viability of a REDD+ scheme would in part depend if these funds outweigh the cost to farmers of forgoing the conversion of primary forest.

5.7.1 Achieving Carbon Savings

How carbon savings might be achieved depends on why primary forests are currently being converted. The following examples are relevant both to Epulu, and in other shifting agriculture settings.

5.7.1.1 Labour saving

It may be that cutting trees in a primary forest is less labour intensive and unpleasant than clearing dense fallow areas , which are full of thorns and biting ants (photos). In this scenario REDD+ funds could compensate farmers for the additional labour required in clearing disturbed areas. This scenario seems unlikely as Wilkie and Curran (1993) and Wilkie et al (1998) report that farmers preferentially clear disturbed areas, rather than having to fell large trees in primary forests.

5.7.1.2 Immigrant pressure

It may be that people from outside the reserve are buying land to farm, thus fuelling expansion into primary forest areas. REDD+ funds could compensate villagers or village chiefs for not engaging in this practice. Anecdotal evidence suggests that this practice does occur, and that land is sold cheaply such that the necessary funds may not be very high. This scenario may suffer effort displacement, where immigrants would simply deforest elsewhere, though this may be preferable to deforestation within the reserve. It should be noted that higher carbon emissions savings would be expected under this scenario, as total deforestation would be reduced, rather than shifting deforestation from one class to another.

5.7.1.3 Local expansion

Growing local pressure on primary forests could be due to a combination of

1. Population growth leading to greater demand for food,
2. Increased ability to farm, due to rising living standards (and subsequent access to better equipment).
3. Increased ability to sell agricultural produce due to better access to markets.

In this "local expansion" scenario we assume that the disturbed land is at its capacity (given prevailing technology and agricultural practices) such that expansion into primary forest is necessary. Even if this is not currently the case, it is likely to become so in future given population trends. It would arguably be inappropriate to pay villagers not to farm if they were doing so to subsist and/or improve their livelihood. The opportunity costs are likely to be too high for this to be a viable option in any case. A potential solution to this problem would be to alter the prevailing technologies/agricultural practices. For example:

Reducing the fallow period-This could mean that less land was required in the cultivation cycle. On its own, this is not an option. The premise of local expansion is that land is already at its capacity. It assumes that fallow lengths cannot shorten without increasing problems with persistent weeds, disease and soil infertility.

Increasing yield per area- Intensifying agriculture by introducing higher yielding crops, more powerful tools, chemical fertilisers and pest control could reduce the land required under cultivation at any one time. Large trees that are currently too difficult to cut could be removed, reducing the unusable space in fields. These measures would sacrifice the limited carbon and biodiversity potential of active fields, for the sake of controlling their area (quote). This strategy assumes that the newfound technology would not simply be used to convert the same or even more primary forest to agriculture. Such techniques and technologies are also associated with a) the high carbon and pollution cost of fertiliser, and

b) agricultural monocultures with low pest and disease resilience, which are thereby vulnerable to large scale failure.

Increased field longevity- Measures that result in soils retaining fertility for longer, such as replacing slash and burn with slash and mulch, could reduce regularity with which new fields need to be opened. Such measures would have the additional benefit of increasing the biodiversity and carbon value of active fields by decreasing the fire-induced mortality of large trees. Using the same simple calculations performed in table 4.7, the single large tree in figure 5.1 would be worth between $244 and $2747 in avoided emissions alone (though this assumes a carbon value of zero if it were dead, which is unwarranted). In tropical areas, where heavy rainfall leaches fertility rapidly from soil, and weed and pest species increase quickly, this approach would be challenging.

5.8 Aim 2- The Prospects for REDD+ win-wins at the Landscape Level

The analysis of primary mixed and monodominant forest indicates that (at least within the context of Ituri) primary forests with the highest above ground carbon are not those with highest tree diversity. As discussed earlier, high carbon monodominant forests are generally not preferred by megafauna and it might be expected that they have lower biodiversity overall.

Reducing Emissions through Deforestation and Degradation is, as the name suggests, primarily about carbon. The benefits to biodiversity are an additional bonus, but not core to requirements. If it is assumed that REDD+ funders and policy makers want to maximise the carbon saved with the funds available, and that the cost of conservation is the same per area of mixed or monodominant forest, then we should expect monodominant forest to be preferentially conserved. This would leave the more biodiverse mixed forests vulnerable to deforestation and degradation.

Conservationists could console themselves with the thought that reducing carbon emissions is ultimately beneficial for biodiversity. The Millennium Ecosystem Assessment (2005) presents climate change as a very rapidly increasing threat to all biomes. It drives habitat change and range shifts. As mentioned earlier however, it is possible that REDD+ could become a driver of biodiversity loss. If safeguards are not put in place to prevent 1.

Displaced pressure due to reduced access to forests and 2. Perverse incentives to replace natural forests with plantations, then highly diverse forest will suffer.

Taking a more proactive stance, conservationists can take two broad approaches. They can try to secure funding for biodiversity conservation (either through REDD+ or elsewhere) based on the intrinsic value of biodiversity. Alternatively, they can make the case that biodiversity has extrinsic value other than just as a source of biomass. The purported tendency of highly biodiverse ecosystems to remain stable in the face of change, providing a higher certainty of carbon storage, would be a convincing case for compromise within REDD+.

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Appendices

Appendix A- Satellite Image Classification- Joel Masselink

DESCRIPTION OF SATELLITE IMAGE DATA:
Data: SPOT 5 image © CNES 2009, Distribution Spot Image S.A., France, all rights reserved
Capture date: 24 March 2009
Spatial Resolution: 10 m

This SPOT 5 multispectral satellite image was provided to Wildlife Conservation Society by Spot Image, a division of France's Centre National d'Etudes Spatiales (CNES). This image was provided for free to WCS through Spot Image's *Planet Action* initiative, specifically for the project "Mapping agri-expansion in Okapi Wildlife Reserve", which WCS is currently leading. The core mission of *Planet Action* is "to support local projects acting on Climate Change-related issues by providing geographic information and technology to NGOs, universities, research centers".

DESCRIPTION OF SATELLITE IMAGE CLASSIFICATION:
Four spectral bands were used for the image classification:

- red (band 2),
- near infrared (band 3),
- short-wave infrared (band 4),
- Normalized Differential Vegetation Index (NDVI)

The NDVI image was made from an image transformation of bands 2 and 3. Band 1 (green) was not used for the classification because it was deemed to provide little additional spectral information.

Classification was performed using an unsupervised technique called clustering. This technique calculates basic image statistics, and then groups pixels into "clusters" which are statistically alike. The method of clustering used for this classification was "broad" which resulted in 29 original clusters. Then these clusters were manually reviewed and combined into real-world land cover classes based an available ground-truth data and analyst's knowledge of the landscape's geography. These were combined to yield the final three land-cover classes: intact forest, disturbed and cleared.

GENERATION OF STRATIFIED SAMPLING PLAN:
The final land cover classification was then filtered to eliminate isolated groups of pixels – therefore any group of less than 10 contiguous pixels was filtered out. Then, a stratified random sample was generated by creating 30 points in each of the three land cover classes. These were adopted as the SW corner of the 90 plots to-be-surveyed.

Appendix B- Image Classification Training Exercise

A training exercise within the agricultural zone was carried out with Joel, myself, a botanist (Florybert Bujo) and the Agricultural Extension Worker (Mustafa) on 10/05/11. Using a provisional landcover classification created by Joel. We navigated to areas thought to be primary forest islands, active fields, disturbed areas, and the limits of the active fields. We took GPS locations, photographs and notes. These were used to refine the final land cover classification. I had intended to make a full reconnaissance of the ZA in a similar manner, delineating active fields and the boundary of the primary forest. The training exercise showed that this would be too time consuming. This was due to 1. The difficulty of moving quickly, particularly through dense fallows and 2. The spatially heterogeneous and fine grained nature of the ZA (active fields and fallows are closely intermingled, without clear boundaries).

Appendix C- Deforestation In The Okapi Wildlife Reserve

A preliminary analysis of deforestation rates in the Okapi Wildlife Reserve was performed using a coarse satellite-data derived deforestation dataset produced for the Central African Regional Program for the Environment (CARPE). Delimited agricultural zones cover 4.9% or 67,500 hectares of the Okapi Wildlife Reserve, which is the only area where human alteration of forests is permitted. During the period of 2000-2010, the total area deforested was 3195 ha or 4.7% of the total area of the agricultural zones (0.2% of the total area of the reserve).

This deforestation was almost equal between primary and secondary forest, with 1592.2 ha (49.8% of total deforestation) of primary forest lost and 1602.7 ha (50.2% of total deforestation) of secondary forest lost. However, when two time periods are compared: 2000-2005 and 2005-2010, the deforestation rate increased by 59% from the first period (1235.5 ha) to the second period (1959.4 ha). This increased deforestation is disproportionately located in the primary forest in agricultural zones located along the National Road 4, which traverses the Okapi reserve east-west. This roads re-opening in 2007 has facilitated immigration and improved market access, resulting in increased deforestation. Therefore monitoring of land distribution and agricultural practices is of huge importance.

	FOREST LOSS (Hectares)	
Forest Type	**2000-2005**	**2005-2010**
Primary	485.6	1106.6
Secondary	749.9	852.8
Total	**1235.5**	**1959.4**

Appendix D- Data Collection Protocol

Survey Team

- Myself- Responsible for taking gps points, canopy measurements, photographs, understorey characteristics and overall responsibility for the team
- Jacqus Mukenzi/Floribert Bujo- Botanist- Responsible for identifying tree species, palm height and overall responsibility for tree measurement
- Mustafa Saidi - Agricultural extension worker- responsible for locating plots, determining their class/age since active cultivation, plot set up and dbh measurement
- Kolin Kenge/Abena Abeli- technicians- Responsible for identifying the local name of trees, climbing trees a) if a sample needs to be taken for a tree of unknown species b) in order to measure DBH above buttress roots, plot set up and dbh measurement.

Equipment
compass, gps, 2 x machete, 10 decameters, 3 tape measures, calipers, clinometer/scope, pen knife, data sheets, pens/pencils, 1.3m DBH stick,

Choosing/Finding plots

- In advance, choose groups of 3 or 4 plots close enough together to be surveyed in one day.
- Use Mbuti guides, Extension Worker advice and GPS to find plot sites.
- The GPS location is the SW corner of the plot. NB- GPS inaccurate. Navigate until it begins to spin.
- Agricultural extension worker to determine plot class based on known disturbance history.

Marking out plots

- If the plot is in an **unexpected class** (meant to be primary forest, but now an opened field) then complete the survey and make a note.
- If the plot encompasses an **unwanted class** (e.g. if it is meant to be a primary forest plot, but there is the corner of an in use field) and it is possible to move the plot slightly so that this can be excluded, then do so systematically. Try 5m, then 10m, then 20m move N, S, E or W only, shortest distance possible. Record the move and new gps location. If this is done, ensure you do not overlap another survey plot.
- Put stakes in the corners of the plot and every 5m point round the exterior. Use compass to ensure that the sides run N-S and E-W.
- If possible, do not hack around the plot with a machete as this will affect the survey.
- Run decameters around the exterior of the plot and marking out the 5x5 subplots. For large trees, if the tree is >=50% inside the plot then include it. If not, exclude it.
- If there is a large tree at the point where the corner should be, then run tapes up to the tree from both sides. If more than half of the tree is in the plot, include it, if not, exclude it.

The SW Subplot 1,1

- For all trees 1-10cm DBH and >=10cm DBH, record species and DBH.
- **Species** using botanist.
- Technician should determine the local name and the botanist the scientific name.
- The technician should collect a sample for the herbarium if the species is unknown.
- **Dbh** should be measured at 1.3m above ground.
- If the tree has a buttress, then 50cm from the top of the buttress. If on a slope measure from the uphill side. If the tree branches low down, measure each stem separately. If the tree branches higher up, measure as a single stem If there is a stem protrusion at 1.3m, measure above or below as appropriate. Dbh should be measured with calipers if 1-4cm dbh, tape measure if larger.
- For all **lianas** >=2cm diameter record DBH and species

- For all **palm trees**, record species and estimate height (to top of stem)
- For all **standing dead trees** >= 10cm DBH record dbh.

All other 5x5m Subplots

- For all trees >=10cm DBH, record species and DBH.
- **Species** using botanist.
- Technician should determine the local name and the botanist the scientific name.
- The technician should collect a sample for the herbarium if the species is unknown.
- **DBH** should be measured at 1.3m above ground.
- If the tree has a buttress, then 50cm from the top of the buttress. If on a slope measure from the uphill side. If the tree branches low down, measure each stem separately. If the tree branches higher up, measure as a single stem. If there is a stem protrusion at 1.3m, measure above or below as appropriate. Dbh should be measured with a tape measure.
- For all **palm trees**, record species and estimate height (to top of stem)
- For all **standing dead trees** >= 10cm dbh record dbh

Overall

- Take 5 **GPS locations** (latitude, longitude and altitude), one at each corner and in the middle of the plot. Include the associated error using the "average" function.
- At every corner and subplot intersect (25 total) use the scope to record **vegetation vs sky**. Ensure plum rests against protractor and scope so that you are looking directly up. Record whether vegetation is seen through more than 50% of the scope

Home Made Canopy Scope

- At the middle of the plot (NE corner of subplot 2,3) ...

- take **photographs** facing N E S and W that capture the vertical layers. Record the number of the photograph. The photograph should encompass all vertical strata, from leaf litter to canopy. Take multiple if necessary, starting at canopy. These are for reference later in case of odd data.
- **Canopy-** Look in all directions. Is there 1. a distinct layer at a consistent height above 20m composed of the crowns of trees? 2. a canopy where the crowns of trees are of mixed heights? 3. A canopy composed of trees below 20m? 4. Is the canopy broken by a large (>25%) gap/s? 5 No continuous canopy, occasional trees/open sky.
- **Emergents-** if there is a distinct canopy, are there tall trees that extend through the top of the highest canopy layer? Y/N.
- **Subcanopy** – Are there trees >=5cm DBH whose crowns are entirely below the canopy?
- Do they form a distinct layer of consistent height?

Vertical Structure

- In four pre-chosen subplots, 1,4. 3,3. 4,4 and 4,1
- **Understorey**- What vegetation characterises the understorey (woody/herbaceous vegetation)? Is it characterised by particular species? Note the presence of invasive plants.
- What is the **Average Height** of the herbaceous layer?
- Is the understorey thick/closed/hard to move through or sparse/open/easy to move through.
- **Groundcover-** Excluding ground taken up by trees >=5cm DBH, estimate to the nearest 10%, what % of the ground is covered by leaf litter, bare soil, water, plants, fallen deadwood.
- **Soil Texture**- Is the soil sandy, clay, or other? Take a small amount from the centre of the plot, moisten and rub it between your fingers. Use the Ontario Institute of Pedology (1985) finger assessment. Gritty = sandy. Smooth= silty. Sticky= clay.
- How thick is the **Leaf Litter**? None= occasional pieces of debris form no layer. Superficial= bare ground can still be seen through the litter layer. Thin= Litter must be moved aside in order to see bare ground, but less than 2cm deep. Thick= Litter is more than 2cm deep.
- **Fallen Dead Wood**- Record the diameter to the nearest cm of the thickest stem of fallen woody debris (>2.5cm diameter)

Appendix E- Fieldwork Data Sheets

<table>
<tr><td colspan="6">SW Subplot 1,1 record Trees >=1cm dbh. Lianas >= 2cm dbh. Palms with stem . Dead trees >= 10cm dbh.</td></tr>
<tr><td colspan="6">Plot Number : Botanist:</td></tr>
<tr><td colspan="6">Notes; dead, liana, palm, strangler, broken, regrown, stem on ground,</td></tr>
<tr><td>Plant number</td><td>Stem number</td><td>local name</td><td>species</td><td>Dbh/ Height</td><td>notes</td></tr>
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<table>
<tr><td colspan="7">All other subplots record... Trees >= 10cm dbh, Dead trees >= 10cm dbh, Palms with stem</td></tr>
<tr><td colspan="7">Plot Number: Botanist:</td></tr>
<tr><td colspan="7">Notes: dead, palm, strangler, broken, regrown, stem on ground,</td></tr>
<tr><td>Subplot</td><td>plant number</td><td>stem number</td><td>local name</td><td>species</td><td>Dbh/ Height</td><td>Notes</td></tr>
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Plot Number:	Date:	Time:
Moved SW corner?	Distance:	Direction:
Predetrmined Class:	De Facto:	

Notes (Nearby large trees/land uses. Reason for move. General veg.:

	Lat	Long	Alt	Error
SW				
SE				
NE				
NW				
Mid				

Middle of Plot- Canopy Assessment-					
Photos: N	W	E	S		
Canopy-	closed	mixed height	gaps>25%	below 20m	none
Emergents?					
Subcanopy (>=5cm dbh overshadowed)?		Distinct layer?			

Canopy Openness- Sky vs Veg. 25 points. Each Intersect				
			vis	
		Pic/gps		

N

GPS 4,1 VIS	4,2	4,3	VIS 4,4 GPS
3,1	3,2 GPS/PHOTO	GPS/PHOTO 3,3 VIS	3,4
2,1	2,2 GPS/PHOTO	GPS/PHOTO 2,3	2,4
GPS 1,1	1,2	1,3	VIS 1,4 GPS

W S E

Subplot 1,4. Understorey character:	
Openness.	
Average herbacious height:	
Groundcover nearest 10% (plant/lit/soil/wat/DW):	
Deadwood largest diameter >2.5cm:	
Soil texture:	Litter.

Subplot 3,3. Understorey character:	
Openness.	
Average herbacious height:	
Groundcover nearest 10% (plant/lit/soil/wat/DW):	
Deadwood largest diameter >2.5cm:	
Soil texture:	Litter.

Subplot 4,4. Understorey character:	
Openness.	
Average herbacious height:	
Groundcover nearest 10% (plant/lit/soil/wat/DW):	
Deadwood largest diameter >2.5cm:	
Soil texture:	Litter.

Subplot 4,1. Understorey character:	
Openness.	
Average herbacious height:	
Groundcover nearest 10% (plant/lit/soil/wat/DW):	
Deadwood largest diameter >2.5cm:	
Soil texture:	Litter.

Appendix F- Canopy Assessment

order surveyed	canopy cover	type	emergents	subcanopy	layer	score
	scope points veg seen	None=0 low/gaps=1, low=2, mixed= 3, gaps=4, closed=5	trees through canopy. No=0, yes=1	trees >= 5cm DBH overshadowed. No=0, yes=1	No=0, yes=1, part= 0.5	cover x (type +emerge +sub+ layer+1)?
1	12	0	0	0	0	12
2	25	4	0	0	0	125
3	23	5	0	1	0.5	172.5
4	24	4	0	1	0	144
5	4	0	0	0	0	4
6	21	3.5	0	0	0	94.5
7	23	4	0	0	0	115
8	10	0	0	0	0	10
9	5	0	0	0	0	5
10	0	0	0	0	0	0
11	25	2	0	0	0	75
12	23	1	0	0	0	46
13	25	4	0	0	0	125
14	24	4	0	1	0	144
15	15	4	0	0	0	75
16	12	0	0	0	0	12
17	9	0	0	0	0	9

18	3	0	0	0	0	3
19	21	0	0	1	0	42
20	20	0	0	0	0	20
21	18	0	0	0	0	18
22	24	2	0	0	0	72
23	0	0	0	0	0	0
24	24	5	0	1	0	168
25	25	5	0	1	0.5	187.5
26	4	0	0	0	0	4
27	8	0	0	0	0	8
28	20	1	0	0	0	40
29	17	0	0	0	0	17
30	20	0	0	0	0	20
31	22	1	0	0	0	44
32	11	0	0	0	0	11
33	19	0	0	0	0	19
34	8	0	0	0	0	8
35	25	5	0	1	0.5	187.5
36	25	5	0	1	0.5	187.5
37	25	5	0	1	0.5	187.5
38	25	5	0	1	0.5	187.5
39	24	5	0	1	0.5	180
40	24	5	0	1	0.5	180
41	24	5	0	1	0.5	180
42	25	5	0	1	0.5	187.5
43	25	3	0	1	0.5	137.5
44	20	0	0	0	0	20
45	15	0	0	0	0	15
46	24	5	0	1	0.5	180

47	23	3.5	0	1	0	126.5
48	24	4	0	1	0	144
49	1	0	0	0	0	1
50	23	5	0	1	0.5	172.5
51	22	4	0	1	0	132
52	7	0	0	0	0	7
53	14	4	0	0	0	70
54	23	4	0	1	0.5	149.5
55	17	0	0	0	0	17
56	20	0	0	0	0	20
57	24	2	0	0	0	72
58	23	3	0	0	0	92
59	7	0	0	0	0	7
60	25	5	0	1	0.5	187.5
61	23	5	0	1	0.5	172.5
62	10	0	0	0	0	10
63	12	0	0	0	0	12
64	25	2	0	0	0	75
65	23	4	0	1	0	138
66	11	0	0	0	0	11
67	8	0	0	0	0	8
68	13	0	0	0	0	13
69	23	3.5	0	0	0	103.5
70	16	0	0	0	0	16
71	25	5	0	1	0.5	187.5
72	24	5	0	1	0.5	180
73	24	5	0	1	0.5	180
74	23	0	0	0	0	23
75	25	5	0	1	0.5	187.5

76	24	4	0	1	0	144
77	25	5	0	1	0	175
78	23	5	0	1	0.5	172.5
79	25	3.5	0	1	0	137.5
80	25	5	0	1	0.5	187.5
81	23	2	0	0	0	69
82	19	4	0	0	0	95
83	22	1	0	0	0	44
84	3	0	0	0	0	3
85	21	2	0	0	0	63
86	24	2	0	0	0	72
87	5	0	0	0	0	5
88	17	0	0	0	0	17
89	6	0	0	0	0	6
90	16	0	0	0	0	16
91	8	0	0	0	0	8
92	7	0	0	0	0	7
93	23	2	1	0	0	92

Appendix G- Understorey Assessment

order	openness	average herbaceous height m	plant	litter	bare	water	DW	deadwood mm	soil	litter
	1=v closed. 2=closed. 3=mid. 4=open. 5=vopen.		Groundcover %						1=sand. 2=other. 3=clay	0=none. 1=superficial. 2=thin. 3=thick
1	2	2	25	75	0	0	?	41.5	1	?
2	?	0.25	27.5	72.5	0	0	?	58.25	1.5	?
3	4	0	20	80	0	0	?	147.25	1.5	?
4	2	1	27.5	45	17.5	10	?	141.25	1.75	?
5	2.5	1.375	85	2.5	12.5	0	?	140	1.5	?
6	4	1.125	60	40	0	0	?	193.25	1.5	3
7	2.25	1.375	20	80	0	0	?	109	1	?
8	3	1.75	90	7.5	2.5	0	?	60	1	?
9	5	0.875	35	25	40	0	?	377.5	2	?
10	3	1.75	82.5	15	2.5	0	?	80	3	?
11	3.5	1	45	55		0	?	65.5	1.25	?
12	3.33	0.75	25	75		0		154	1	3
13	3.75	0.75	32.5	67.5		0		58.5	1.25	3
14	3	0.375	30	57.5	7.5	0	5	227.5	1.25	2
15	4.25	0.25	25	75		0		232.25	1	3
16	2	2	40	47.5		0	12.5	342.75	1	1
17	4.25	1.25	82.5	2.5	15	0		100	2.25	0.25
18	3.5	1.375	47.5	27.5	25	0		105	1.5	1

19	3	1.75	37.5	47.5		0	15	310	1.25	3
20	2.5	1.375	22.5	77.5		0		110	1	2.75
21	1	2.333333333	92.5	7.5		0		0	1	0.5
22	3.5	0.625	40	60		0		53.25	1.25	3
23	4	1.25	55	2.5	12.5	0	30	333.75	3	0.75
24	4.75	0	32.5	60	2.5	0	5	163.25	3	2.25
25	4	0.375	22.5	70		0	7.5	214.5	3	2
26	3.25	2.375	82.5	2.5	15	0		0	1	0.25
27	2.5	1.75	92.5	7.5		0		0	1	0.5
28	4	0.5	20	67.5	12.5	0		53.25	1	1.75
29	3	2	77.5	17.5	2.5	0	2.5	127.25	1.75	0.75
30	2.75	0.875	65	32.5		0	2.5	115	1.5	1.75
31	3.5	0.875	27.5	70		0	2.5	64	1.25	2.75
32	3	1.333333333	67.5	32.5		0		55	1	1.5
33	1.75	3.25	27.5	72.5		0		25	1.75	2.75
34	3	1.125	72.5	25		0	2.5	65	2	1
35	4	0.6875	17.5	80	2.5	0		106.25	1.5	3
36	4.25	0.0625	10	87.5		0	2.5	127.5	2.25	3
37	4	0.5	15	75		0	10	362.5	2.75	3
38	4	0.3125	10	85		0	5	167.5	2.5	3
39	4.25	0.3125	10	90		0		62.5	2	3
40	3.75	0.5	13.33333	76.66667		0	7.5	184.25	3	2.5
41	3.5	0.4375	15	80	5	0		97.5	3	2.5
43	4.25	0.5	15	85		0		92.5	3	2.5
43	3.5	0.5625	20	75		0	5	137.5	3	2.5
44	2.25	1.75	65	35		0	0	87.5	1.25	2.25
45	3.25	1.5	55	40		0	5	171.25	1.25	2.75
46	3.75	0.3125	10	87.5		0	2.5	90	1.5	3
47	2.5	1.375	37.5	62.5		0	0	115	1.25	2.5

48	2.5	1.875	37.5	60		0	2.5	77.5	1	1.75
49	5	1.125	42.5	7.5		0	0	70	1.5	0.5
50	3.75	0.3125	12.5	85		0	0	120	1.25	2.75
51	3	1.125	37.5	55		0	5	80	1	2.25
52	2	2.25	53.33333	30		0	16.66667	267.5	1.5	1
53	2.75	0.75	40	17.5		0	27.5	250	1.75	2.25
54	3.25	1.125	25	65		0	10	130	1	2.25
55	2.5	1.75	40	40		0	20	295	1.25	1.25
56	2.75	1.625	25	45		0	12.5	225	1.75	2.5
57	3.25	1.125	25	75		0	0	65	1.5	1.5
58	3.25	1.625	60	22.5	17.5	0	0	142.5	2.5	1.5
59	3.5	1.125	92.5	2.5	0	0	5	85	2	0.5
60	3.5	1.125	27.5	67.5	0	0	5	240	2.5	3
61	3.25	0.5	17.5	77.5	5	0	0	175	1.75	3
62	2.5	2.125	95	5	0	0	0	90	1.25	1.75
63	2	2.125	92.5	2.5	0	0	5	252.5	1.25	0.75
64	3.25	2.125	20	62.5	0	0	15	270	2	3
65	3	0.5625	37.5	45	0	0	17.5	140	1.75	2.25
66	3.5	1.125	77.5	15	5	0	2.5	142.5	2	0.75
67	3	1.125	57.5	20	12.5	0	10	110	1.5	0.75
68	1.5	2.75	70	20	0	0	10	197.5	1.25	1.5
69	2.75	1.25	32.5	52.5	0	0	15	495	2.25	2
70	2.75	1.5	87.5	7.5	5	0	0	70	1.75	1
71	4	0.5	12.5	85	0	0	2.5	107.5	2.25	1.75
72	3.75	0.4375	7.5	85	0	0	7.5	140	1.75	3
73	3.5	0.9375	17.5	72.5	0	0	10	142.5	2	2
74	2.75	0.5	22.5	72.5	2.5	0	2.5	202.5	2	2
75	3.5	0.375	20	80	0	0	0	130	1.75	2.25
76	2.75	1.625	22.5	67.5	0	0	10	377.5	1.5	2

77	4.25	0.375	12.5	87.5	0	0	0	122.5	3	2.75
78	3.5	0.5625	12.5	70	2.5	0	10	137.5	1	2.25
79	3.25	0.625	17.5	77.5	0	0	5	247.5	2.5	1.75
80	3.25	0.4375	22.5	72.5	0	0	5	87.5	1	2.25
81	2.75	0.125	17.5	70	2.5	0	0	50	2.25	2.5
82	2.5	1.75	82.5	5	0	0	12.5	222.5	1.5	2.25
83	3.25	1.625	60	35	0	0	5	125	2	1.25
84	3.25	1.125	90	7.5	0	0	2.5	140	2	1
85	3.25	1.5	30	70	0	0	0	36.25	1.25	2
86	3.75	1	17.5	82.5	0	0	0	147.5	2	2.75
87	3.25	2.25	47.5	5	22.5	0	25	262.5	2.25	0.5
88	2.25	2.25	36.66667	43.33333	0	0	22.5	387.5	2	2
89	3.25	1.125	77.5	7.5	12.5	0	2.5	110	1.25	0.75
90	2.25	2.375	65	30	0	0	3.333333	150	1.5	1.5
91	3.75	0.625	65	22.5	0	0	12.5	285	2	1.666666667
92	3.333333333	1.375	92.5	5	0	0	2.5	145	1.5	1
93	3.25	1.125	22.5	72.5	0	0	0	280	1.25	2.5

Appendix H- Tree Diversity Per Plot

order	individuals per plot	richness. species per plot (mid)	richness min	richness max	shannon diversity index per plot (mid)	shannon min	shannon max	evenness (mid)	evenness min	evenness max
1	5	2			0.5004			0.7219		
2	14	8			1.9085			0.9178		
3	15	11			2.3035			0.9606		
4	5	5			1.6094			1		
5	2	2			0.6931			1		
6	19	12			2.3332			0.9389		
7	19	11			2.2148			0.9236		
8	3	3			1.0986			1		
9	1	1			0			1		
10	1	1			0			1		
11	14	10			2.2056			0.9579		
12	21	8			1.3907			0.6688		
13	9	7			1.831			0.941		
14	19	12			2.3057			0.9279		
15	15	11			2.3035			0.9606		
16	1	1			0			1		
17	2	2			0.6931			1		
18	1	1			0			1		
19	7	7			1.9459			1		
20	10	8			1.973			0.9488		
21	10	2			0.4605			0.6644		
22	22	8			1.8964			0.912		
23	1	1			0			1		
24	23	13			2.3895			0.9316		
25	17	11			2.2824			0.9518		
26	2	2			0.6931			1		
27	4	4			1.3863			1		
28	11	5			1.4681			0.9122		
29	15	8			1.599			0.769		

30	5	5			1.6094			1		
31	0	0			0			0		
32	6	4			1.2425			0.8962		
33	5	3			0.9503			0.865		
34	2	2			0.6931			1		
35	15	11			2.3035			0.9606		
36	16	3			0.6019			0.5479		
37	24	12			2.2793			0.9173		
38	10	7			1.8344			0.9427		
39	9	3			0.6837			0.6224		
40	17	14			2.5578			0.9692		
41	12	9			2.0947			0.9534		
42	12	10			2.2539			0.9788		
43	16	12			2.3394			0.9414		
44	6	4			1.2425			0.8962		
45	9	2			0.6365			0.9183		
46	15	12			2.4308			0.9782		
47	16	10			2.014			0.8747		
48	14	13			2.54			0.9903		
49	2	1			0			1		
50	13	9			2.0981			0.9549		
51	14	12			2.441			0.9823		
52	0	0			0			0		
53	11	11			2.3979			1		
54	9	5			1.3031			0.8097		
55	5	4			1.3322			0.961		
56	19	12			2.3332			0.9389		
57	18	6			1.351			0.754		
58	13	12			2.4583			0.9893		
59	1	1			0			1		
60	11	8			1.8462			0.8878		
61	12	11			2.3694			0.9881		
62	1	1			0			1		
63	3	2	2	3	0.6365	0.6365	1.0986	0.9183	0.9183	1
64	17	10	7	10	1.9504	1.6242	1.9504	0.8471	0.8347	0.8471
65	15	11	9	12	2.3384	2.0611	2.4308	0.9752	0.9381	0.9782

66	3	2	2	2	0.6365	0.6365	0.6365	0.9183	0.9183	0.9183
67	4	4	3	4	1.3863	1.0397	1.3863	1	0.9464	1
68	6	4	4	4	1.3297	1.3297	1.3297	0.9591	0.9591	0.9591
69	19	7	7	7	1.4801	1.4801	1.4801	0.7606	0.7606	0.7606
70	1	1	1	1	0	0	0	1	1	1
71	16	9	9	10	1.9274	1.9274	2.014	0.8772	0.8772	0.8747
72	17	11	10	11	2.2824	2.2008	2.2824	0.9518	0.9558	0.9518
73	20	13	9	13	2.3889	1.9865	2.3889	0.9314	0.9041	0.9314
74	9	8	6	9	2.0432	1.5811	2.1972	0.9826	0.8824	1
75	16	9	8	9	2.1007	2.014	2.1007	0.9561	0.9685	0.9561
76	15	13	11	13	2.4883	2.2686	2.4883	0.9701	0.9461	0.9701
77	16	11	6	14	2.274	1.3307	2.5666	0.9483	0.7427	0.9725
78	21	10	7	10	1.7225	1.4584	1.7225	0.7481	0.7495	0.7481
79	14	13	10	13	2.54	2.144	2.54	0.9903	0.9311	0.9903
80	12	10	9	10	2.2103	2.0947	2.2103	0.9599	0.9534	0.9599
81	16	12	9	13	2.3933	1.977	2.48	0.9631	0.8998	0.9669
82	8	6	6	6	1.6675	1.6675	1.6675	0.9306	0.9306	0.9306
83	8	7	7	7	1.9062	1.9062	1.9062	0.9796	0.9796	0.9796
84	2	2	1	2	0.6931	0	0.6931	1	1	1
85	10	6	2	9	1.6094	0.8018	2.164	0.8982	1.1568	0.9849
86	21	9	6	19	1.8139	1.1282	2.8876	0.8255	0.6297	0.9807
87	1	1	1	1	0	0	0	1	1	1
88	4	3	3	3	1.0397	1.0397	1.0397	0.9464	0.9464	0.9464
89	1	1	1	1	0	0	0	1	1	1
90	5	4	3	4	1.3322	1.0549	1.3322	0.961	0.9602	0.961
91	3	3	3	3	1.0986	1.0986	1.0986	1	1	1
92	4	3	3	3	1.0397	1.0397	1.0397	0.9464	0.9464	0.9464
93	27	12	11	13	2.204	2.082	2.204	0.887	0.8682	0.8593

Appendix I- Regression of Carbon and Diversity For all Plots

Order	Diversity	Carbon	Carbon.log
1	0.500402424	952.0302027	6.85859676
2	1.908535282	3017.231536	8.01209498
3	2.303488495	20166.8617	9.911796026
4	1.609437912	10542.96303	9.263213905
5	0.693147181	52.77831908	3.966100483
6	2.333196714	2467.499708	7.810960653
7	2.214810368	22592.27324	10.02536323
8	1.098612289	10064.45472	9.21676516
9	0	421.5867729	6.044025623
10	0	100.9172909	4.614301279
11	2.205598359	3714.940531	8.220117949
12	1.390682628	1565.475278	7.355944749
13	1.831020481	21301.36327	9.966526353
14	2.305657338	7139.998748	8.87346788
15	2.303488495	3359.762121	8.119625453
16	0	609.2506688	6.41222979
17	0.693147181	127.316429	4.846675555
18	0	27.81252261	3.325486373
19	1.945910149	5868.137718	8.677292608
20	1.973001406	1640.972793	7.403044512
21	0.460517019	60.9972266	4.110828398
22	1.896430164	2391.578993	7.779709093
23	0	235.2565458	5.460676603
24	2.389460282	29578.3442	10.29479776
25	2.282374376	39662.84811	10.58817021
26	0.693147181	624.7213317	6.437305681
27	1.386294361	1052.239066	6.958675616
28	1.468139939	1526.168459	7.330515598
29	1.599014712	1951.311697	7.57625709
30	1.609437912	855.6506611	6.751862187
31	NA	NA	NA
32	1.242453325	5839.518424	8.672403611
33	0.950270539	357.3396397	5.878686701
34	0.693147181	660.9192238	6.493631629
35	2.303488495	3292.023317	8.099257645
36	0.601923972	16370.67865	9.703247127
37	2.279289868	10181.19664	9.228297832
38	1.83437197	1857.303212	7.526880828
39	0.683738906	12964.98247	9.470007346
40	2.55779386	8520.624585	9.050244925
41	2.094729048	3108.91824	8.042030112
42	2.25385759	4577.018184	8.428803013
43	2.339371734	3711.489168	8.219188468
44	1.242453325	390.6606916	5.967839387
45	0.636514168	3269.872114	8.092506154
46	2.430791329	9582.575213	9.167701646
47	2.014035524	8713.117329	9.072584908
48	2.540036304	9229.026049	9.130108802
49	0	127.3583817	4.847005015
50	2.098147389	11198.09035	9.323498538
51	2.441015278	3405.469068	8.133137968
52	0	0	0
53	2.397895273	3954.75083	8.282672877
54	1.303092404	2926.712117	7.981634928
55	1.33217904	2095.694999	7.647640519
56	2.333196714	5271.066822	8.569988054
57	1.351039416	2638.353904	7.87791048
58	2.45831133	5687.243315	8.645980931
59	0	20.42476537	3.016748153
60	1.846220219	4797.7585	8.475904109
61	2.36938212	4136.065846	8.327500336
62	0	2903.179837	7.973561911
63	0.636514168	10930.93767	9.299352366
64	1.950409497	1616.968286	7.388308247
65	2.338371705	2499.280402	7.82375813
66	0.636514168	1829.387123	7.511736284
67	1.386294361	7413.257476	8.911025227
68	1.329661349	3630.639773	8.197164158
69	1.480112097	7939.926196	8.979659259
70	0	53.48495456	3.979400391
71	1.927392126	7111.449115	8.869461316
72	2.282374376	10807.77789	9.288021329
73	2.388889715	4487.296348	8.40900565
74	2.043191871	515.1842939	6.244524689
75	2.100678921	8443.132845	9.041108709
76	2.488327743	2255.128149	7.720962079
77	2.273965716	7757.360403	8.956397401
78	1.72246804	6491.10847	8.778188592
79	2.540036304	6336.832975	8.754134392
80	2.210253578	13331.85667	9.497911689
81	2.393312123	4194.46926	8.341522094
82	1.667461933	7851.926462	8.96851419
83	1.906154747	361.0181465	5.888928224
84	0.693147181	438.5012907	6.083362755
85	1.609437912	1724.216663	7.452528118

86	1.813882115	2462.21072	7.808814892
87	0	128.8883474	4.858946505
88	1.039720771	215.5014626	5.372967696
89	0	15.690229	2.753038162
90	1.33217904	1442.685772	7.274261775
91	1.098612289	18823.84347	9.842879615
92	1.039720771	123.1074977	4.813057939
93	2.204019024	5810.515593	8.667424588
94	1.948053346	6383.748213	8.761510698
95	1.508955779	7047.44705	8.86042071
96	2.758100484	18476.34246	9.824246407
97	2.654251219	9479.509228	9.156887825
98	2.675181145	4268.164024	8.358939043
99	2.102865772	3806.028975	8.244341661
100	2.450396283	10071.78584	9.217493313
101	1.979204517	5630.479284	8.635949848
102	1.458411971	4731.915286	8.462085323
103	2.048882828	7912.744843	8.97623001
104	0.63903186	5027.058625	8.522590326
105	1.981096754	8002.701732	8.98753448
106	0.826405322	12644.22048	9.444955511
107	0.937155853	11473.01238	9.347752807

108	1.907283999	8709.847377	9.072209547
109	1.127483235	9018.245214	9.10700505
110	0.567060931	13173.66945	9.485975378
111	1.043793881	5360.993478	8.586904587
112	0.566085739	10834.28697	9.290471104
113	2.17111553	4232.988127	8.350663436
114	2.588573163	3870.593583	8.261163155
115	2.0992928	2308.430525	7.744323146
116	2.13833306	6768.453813	8.820027952
117	2.340339101	8437.491583	9.040440338
118	1.820075975	4675.073399	8.450000142
119	2.200663189	16971.05815	9.73926471
120	2.172927092	10283.19023	9.238265824
121	2.212256611	4854.824622	8.487728257
122	0.79631164	22317.52261	10.01312742
123	1.311431337	8914.726886	9.095459895
124	1.540305825	11068.55652	9.311863622
125	1.002718265	14668.90551	9.593485261
126	0.683738906	18774.57071	9.840258611
127	2.212109415	10875.11376	9.294232317
128	2.094889682	4657.742843	8.446286241
129	2.043191871	16608.70281	9.717682103