THESIS

ASSESSMENT OF GULLELE BOTANIC GARDENS CONSERVATION STRATEGY IN ADDIS ABABA, ETHIOPIA

RESEARCH FROM THE PEACE CORPS MASTERS INTERNATIONAL PROGAM

Submitted by

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ABSTRACT

ASSESSMENT OF GULLELE BOTANIC GARDENS CONSERVATION STRATEGY IN ADDIS ABABA, ETHIOPIA

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Monitoring of current and future conditions is critical for a conservation area to quantify results and remain competitive against alternative land uses. This study aims to monitor and evaluate the objectives of the Gullele Botanic Gardens (GBG) in Addis Ababa, Ethiopia. The following report advances the understanding of existing understory and tree species in GBG and aims to uncover various attributes of the conservation forest. To provide a baseline dataset for future research and management practices, this report focused on species composition and carbon stock analysis of the area. Species-specific allometric equations to estimate above-ground biomass for *Juniperus procera* and *Eucalyptus globulus* are applied in this study to test the restoration strategy and strength of applied allometry to estimate carbon stock of the conservation area. The equations and carbon stock of the forest were evaluated with the following hypothesis: Removal of *E. globulus* of greater than 35cm DBH would impact the carbon storage (Mg ha-1) significantly as compared to the overall estimate. Conservative estimates found *E. globulus* accounted for 68% of the total carbon. Results of both the carbon stock and species composition analyses were used to delineate forest stands with a Geographic Information System. Ultimately, the strategy of GBG to restore native stand structure and understory species to the area will be advanced by the organization of forest stands delineated by this study.

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I extend sincere appreciation to my committee for their patience and dedication.

Melinda Laituri
Paul Evangelista
Jessica Davis
Robert Sturtevant

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PREFACE

The following thesis research was developed over the course of three years, two of which were spent in service with the Peace Corps Masters International program (PCMI). As a volunteer and masters' student at Colorado State University in the PCMI program, I served with both the Ethiopian Wildlife Conservation Authority (EWCA) and the Gullele Botanic Garden (GBG) in Addis Ababa Ethiopia. The collaborative projects with these organizations focused on capacity development with geospatial technology to improve the efficacy of natural resources management methods in Ethiopia. The thesis is organized into the following chapters:

1) A literature review on modeling carbon dynamics in forest ecology based on allometric equations. This informed the methods of field collection and data analysis for forest and vascular plant understory inventories in the GBG forest. Native species allometry such as *Juniperus procera* and the exotic species of *Eucalyptus globulus* were given preference in this review, due to the management strategy of restoring a native forest in place of exotic *E. globulus* trees.

2) A technical report of the results of Carbon stock and understory vegetation analysis of GBG. In September and October of 2012 forest attributes including density and species composition were collected in 28 plots and 271 point samples from the 621 hectare forest. Baseline analysis of plot uniqueness and species composition are reported. To examine the strategy of complete type change to a native stand, the carbon stock of *E. globulus*, as compared to native species assessment of the carbon stock was estimated with species-specific allometric equations identified in chapter 2. The following original hypothesis (A), and subsequent calibrated hypothesis (B), examined the Carbon stock assessment with the goal of identifying the contribution of larger individual trees to the total:

A) Removing old growth *E. globulus* of greater than 35cm DBH would impact the carbon storage (Mg ha^{-1}) significantly as compared to the overall estimate.

B) Removing larger DBH classes of *E. globulus* greater than 30cm DBH would impact the carbon storage (Mg ha^{-1}) significantly as compared to the overall estimate.

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Eq. 1 *Total Belowground Carbon Allocation*

$$\boldsymbol{TBCA} = \frac{\boldsymbol{Fs} + \boldsymbol{Fe} - \boldsymbol{Fa} + \Delta(\boldsymbol{Cs} + \boldsymbol{Cr} + \boldsymbol{Cl})}{\Delta \boldsymbol{t}}$$

Eq. 2 *Cluster Basal Area*

$$= \frac{\sum_{n=1} trees * prism\ factor\ (20)}{Point\ samples\ taken\ (9)}$$

Eq. 3 *Tukey's HSD Q score*

$$HSD = Q\ score * \sqrt{\frac{MS\ within}{n}}\ ;\ 4.4\sqrt{\frac{2031}{374}} = 10.3 \text{ Tukey's statistic}$$

Eq. 4 *Plot Uniqueness*

$$1 - \frac{\sum Species\ proportional\ frequencies\ of\ total\ plots}{Plot\ species\ richness}$$

Chapter 1

Introduction

The following literature review grounded and informed research conducted on the conservation forest at the Gullele Botanic Gardens (GBG) in Addis Ababa, Ethiopia. The primary focus of this review is forest biomass measurement techniques as they relate to spatial estimation of carbon sequestration. To begin the focus is contextualized with background on the role of tropical forests in the global carbon sequestration budget. Additional sections include a summary of geographically relevant tree species literature, an explanation of role of forestry in Ethiopia and a review of nested vegetation sampling methods. While the functions and values of forest carbon sequestration are detailed in the literature (Chave et al., 2005; Benitez et al., 2007), a gap exists in the assessment of fine scale conservation projects and their ability to sequester carbon through targeted management. Sequestration estimates are made at the landscape and regional scales, leaving fine scale agroforestry and afforestation projects unexamined. Methods to assess aboveground sequestered carbon and the general ecological condition of the botanic garden conservation area were informed based on the following.

Carbon sequestration in forests

Sequestration of Carbon (C) in forest biomass remains the primary terrestrial ecological process by which C is temporarily accumulated (Nair et al., 2009, WGBU, 1998). Particular attention has been paid to the impact of deforestation on the C cycle and the related environmental externalities. The conversion of forests to other land use, to meet demands of developing economies, places tropical forests at the base of the global C equation (Lemma et al. 2006, Silver et al., 2000). Studies estimate that tropical deforestation is the leading cause of species extinction and contributes to 25% of total anthropogenic released atmospheric C (IPCC 2001, Thomas et al., 2004). The role of forests is examined in the literature for the services they provide to ecosystems, nutrient cycling, wildlife species and local economies (Pohjonen, 1991; Nascimento et al., 2001; Guo et al., 2002).

Forest conservation management applications for biomass

Carbon cap-and-trade programs attract scrutiny and skepticism because of a lack of standardized assessment of C storage and reliable monitoring programs across projects (Kuyah et al., 2012). Enforcement and the efficacy of policies designed to preserve natural C storage come into question when addressing cap and trade programs (Montagu et al., 2005). Due to the heterogeneous structure of forests and forest ecology at the global scale a standardized method to identify C sequestration across projects will be met with a suite of caveats and limitations. For this reason, research and conservation projects continue to recommend a site specific focus and scope (Ketterings et al., 2001). Conservation and climate change mitigation literature focuses on modeling C sequestration in agroforestry and reporting the results as compared to empirical studies of current C measurements to identify the impact these projects have on the global C budget (Nilsson et al., 2005).

Agroforestry and afforestation projects are often linked as endeavors with high potential for natural sequestration of C (Vitousek, 1991; Albrecht et al. 2003; Arroja et al., 2006). Sequestration projects with the highest potential are concentrated in developing countries, where forest resources remain in demand and therefore under the highest threat of unsustainable exploitation (Rokityanskiy et al., 2007). Creating and enhancing C sinks in the biosphere was listed as the primary strategy for reduction of CO_2 in developing economies (Albrecht et al., 2003). This was established by the United Nations Framework Convention on Climate Change (UNFCCC) in the Kyoto protocol. Forest sequestration of C has the potential to store 3 Pg (Petagram 10^{15} metric tons) of C annually, which accounts for more than rangelands and terrestrial sediments combined. Together these three sinks account for nearly 60% of total potential storage across terrestrial biomes (DOE, 1999).

Forest biomes store C via multiple processes. At the scale of individual trees C is stored in various locations in the tree biomass (Giardina et al., 2002). Forest sequestration studies may be grouped into the following subjects of C sequestration: soil and belowground sequestration verses aboveground biomass (AGB).

Sequestration in forest soils

Carbon is stored in soils directly and indirectly. Direct soil sequestration occurs when atmospheric and inorganic CO_2 compounds are restructured into other C based molecules such as carbonates, through chemical reaction. Alternatively, C is stored indirectly as plants accumulate C in biomass through the process of photosynthesis (Nair et al., 2009). This translates into either belowground biomass (BGB) or litter decomposition, which stores C in the soil (Ashagire et al., 2005). Total belowground C allocation (TBCA) is accounted for by the following equation as adapted from Forrester et al. (2006)

$$\textbf{\textit{Eq. 1}} \qquad \boldsymbol{TBCA = \frac{Fs+Fe-Fa+\Delta(Cs+Cr+Cl)}{\Delta t}}$$

Where F_s is the efflux of C from the soil surface in the form of CO2; Fe the C exported from the site (erosion, leaching or CH_4 efflux); F_a the C in litter fall; C_s the soil organic C; C_r the root C; C_l the forest floor litter C, and t is the time(Giardina and Ryan, 2002).

Estimates value soil sinks as twice as large (1580 x 10^{15}g of C) as the atmosphere (750 x 10^{15} g) or living terrestrial vegetation (610 x 10^{15} g) (Schimel D.S., 1995). Carbon, being a crucial bio-nutrient is commonly measured to assess soil fertility. Inquiry into the ability of soils to store C has led to the adaptation of fertility measurements by researchers to assess sequestration potential of forest soils. Researchers interested in the role of natural resource management on sequestration of C in forest soils are eager to identify methods to improve soil C capacity (Giardina et al., 2002) or management techniques to avoid loss of C in soil (Ashagire et al., 2005).

In a meta-analysis of soil C sequestration, Jonson et al., (2001) proposed there is a minimal initial loss of soil C after a forest timber harvest. In a plantation, harvest timber biomass is removed leaving belowground biomass in soil. This belowground biomass accounts for additional C stored in soil; however, the temporary impact to soil C levels is less clear (Johnson et al., 1991). Predicting the impact of forest harvests at a given site is problematic based on uncertainties associated with temporal and spatial variability of C soil measurements (Nave et al., 2010). Overall the impact of a harvest on the soil is negative if the species does not coppice or if the area is clear cut without reforestation measures in place (Bruijnzeel 2004). Live biomass replacement above and belowground and the loss of leaf litter deposits further restrict sequestration in belowground stock post-harvest (Kuyah et al., 2013).

Sequestration in plant biomass

The ecological role of forests in the global C cycle is commonly explained through estimates of biomass (Perez-Cruzado and Rodriguez- Soalleiro, 2011). The accumulation of C through the process of photosynthesis is the key biological driver converting atmospheric C in CO_2 into solid state C (Cox et al., 2000). Interest in the primary productivity and allocation of acquired C has led to discovery of significant variance across species and environments (Kitajima 1994). While a host of methods are employed in the scientific literature to estimate C in forest biomass (Lefsky et al. 1999; Riano et al., 2004; Naesset et al., 2008), methods based on species dependent allometric equations (Kohyama 1987; Ketterings et al., 2001, Chave et al., 2005, Kuyah et al., 2012) receive preference due to their applicability across forest management projects at varying spatial scales.

Destructive sampling

Estimation through destructive sampling and related regression analysis is the most accurate method to identify individual tree biomass (Parresol, 1999, Perez-Cruzado and Rodriguez- Soalleiro, 2011). Destructive methods require the felling of trees and subsequent measurement of tree fractions to inform regression models. Laborious and destructive as the method explicitly states, it is appropriate for empirical studies capable of acquiring a representative sample of a tree species to generate regional stand models (Ketterings et al. 2001**;** Kuyah et al., 2012). This requires compensation to land owners for trees destroyed in the study. This method attracts attention to a project and depending on the objectives of a study may ultimately be too invasive to a local community (Djomo et al., 2010). To account for differences across individual trees, or in the case of regional estimate, various species and fine scale environmental heterogeneity, the sample sizes of destructive studies range from 30 trees for localized estimates (Pohjonen 1991**,** Kirby et al., 2007) to 2,410 various species in a biome level comparison (Chave et al., 2005). The final step of empirical studies to develop allometric equations through destructive sampling is to ground the equations in an expression of confidence and model limitations. Models may account for the limitations by explaining the standard error of the biomass estimates as compared to destructive samples (Pohjonen 1991), developing a clear line of caveats for the equations (Antonio et al., 2007), and geographic or ecological limitations in the proposed models (Chave at al., 2005).

Belowground Biomass (BGB)

Depending on the species and environmental conditions, as much as 30% of plant primary production may be stored belowground (Giardina et al., 2002). Methods to estimate BGB and C storage are labor intensive and riddled with uncertainty due to the exclusion of major components such as root respiration and mycorrhizal respiration and turnover (Ekblad and Hoberg, 2001). Variance is also explained as a result of species-specific adaptations and differences in tree physiology. Micro-climate and site-specific soil attributes contribute to significant portions of BGB allocation. In the case of *E. globulus* spp. 21% of allocation is likely to exist below ground. However, a high variance of allocation is associated with water availability and spatial heterogeneity of soil nutrients (Kuyah et al., 2013) thus reducing the confidence in belowground models at regional scales.

Destructive methods to measure belowground biomass require a heavy investment to remove all biomass of a representative sample of trees. This includes both above and belowground biomass as the belowground biomass is not easily estimated by aboveground attributes such as root collar, Diameter at Brest Height (DBH) and height (Giardina et al., 2002). Soil layers as well as the tree are destroyed in the process, which may not be practical for conservation studies focused on threatened species (Kirby et al., 2007) or environmentally sensitive areas (Djomo et al., 2010).

Aboveground Biomass (AGB)

The efficiency of stand level estimates using allometric models is markedly superior when compared to destructive sampling techniques (Ketterings et al., 2001; Ansley et al., 2012). However, development of regional and global estimates of C with allometric based AGB models is limited due to high levels of variance (Chave et al., 2005). Estimating the sequestration of projects at a scale less than 1,000 hectares is not always feasible; however, aggregation of these projects demonstrates the significant role they play in globally sequestered C. Specifically the fine-scale agroforestry projects offer sustainable, replicable, and positive results throughout an incalculable number of examples (Kirby et al., 2007; Kuyah et al., 2012, 2013).

Allometry in biomass estimation

Allometric equations provide efficient estimates for stand level biomass (Garcia et al., 2012). Relying on sound equations previously derived by a rigorous destructive sampling method is a less invasive alternative to a full empirical study. However, acknowledgement of the limitations of each equation as it relates to a specific species or geographic location must accompany allometry based studies (Henry et al., 2009). Estimation of forest biomass with allometric equations in a stepwise process is detailed by Ketterings et al. (2001) in the following order:

(1) choosing a suitable functional form for the allometric equation;

(2) choosing suitable values for any adjustable parameters in the equation;

(3) field measurements of the input variables such as diameter at breast height (DBH), and;

(4) using the allometric equation to give the aboveground biomass of individual trees and summation to develop estimate per area.

Uncertainty exists as to how well an equation can estimate forest biomass due to a lack of standardized models that convert individual tree measurements into volume and biomass or both (Chave et al., 2005). Species-specific equations are costly arduous undertakings due to the destructive sampling necessary to produce robust regression values across a spectrum of DBH values. However, their significant improvement to accuracy of biomass estimates has led forest management research to prefer specialized equations by species (Kuyah et al., 2013) over generalized alternatives (Kirby et al., 2007), which attempt to estimate across a mixed species composition.

While many studies stress the importance of reducing error by employing site-specific equations (Pohjonen, 1991; Ketterings et al., 2001; Henry et al., 2009), others have demonstrated the possibility to build generalized equations to estimate regional biomass across multiple sites (Chave et al., 2005; Montagu et al., 2005; Kirby et al., 2007). These equations are developed through a multiple site analysis of one or more species. This process compounds the issue of labor intensive destructive sampling; however, once tested for accuracy, the models allow for regional assessments requiring only basic survey measurements such as DBH.

Application of allometric equations to survey metrics

Common forest stand exams or inventories provide the exogenous variables such as DBH and tree height (H) for allometric equations to model species-specific endogenous parameters (Perez-Cruzado et al., 2011). Iterations of the base equation (B) = $\boldsymbol{\alpha}D^b$ for B biomass, species wood density $\boldsymbol{\alpha}$, diameter D and field parameters b have been adapted to serve multiple purposes of biomass studies. For both specific and general estimates, it is recommended to rely on a single equation to estimate the entire biomass of the tree as complete tree models exhibits fewer errors across the sum of tree fractions (Feller, 1992). Depending on the research questions and scale of study, the single tree biomass estimates are applied to density measurements of trees per hectare (TPHA) to assess stand level attributes (Djomo et al., 2010). It is appropriate to scale up the process for dominate stands or plantations where only one species' allometry is in question. While more generalized formulas designed to estimate mixed species forests with high diversity exist (Kirby et al., 2007; Chave et al., 2005), the accuracy of these equations is suspect due to high allometric variance across species. The accuracy of allometric equations improves when regional, climatic and species-specific equations are available (Kuyah et al., 2013).

In keeping with the recommendations, species-specific allometric equations were identified and selected for relevance to the research in Gullele. Table 2 is a synthesis of selected allometry literature with particular focus directed towards *E. globulus* and *J. procera.* The forest in the central Ethiopian highlands surrounding Addis Ababa is comprised of exotic species of *E. globulus* and mixed *J. procera* stands, which remain as a relic or historic native juniper range. The following equations demonstrate the diversity in compositions, applications and results of allometry-based biomass estimation research. Further, the equations are characteristic of allometric literature, which favors plantation species over threatened species with conservation value.

Table 1. Summary of selected allometric studies relevant to this research.

Reference	Location/ Species	Research Questions	Equations or models	Results
Perez Cruzado et al., 2012	Western Spain / *Eucalyptus nitens*	Estimate biomass, evaluate bias across estimators and ability of crown ratio to improve accuracy	$Wi = b_1 \cdot x_{1_{\ldots}} X_n^{b_n+1}$ With 34 total parameters tested	Inclusion of Height increased accuracy of biomass of wood but not other tree fractions. Crown ratio can accurately predict certain tree fractions
Kirby et al., 2007	Eastern Panama/ 129 morphospecies 87 of which were linked to species and 11 to genus	Assessment of above and belowground biomass of managed forest, agro-forest and pasture land for C sequestration	Exp[3.965+2384 ln(BD)] saplings ≥1BD, <5cmDBH (combination of 7 external models and 1 in situ) 0.47 default proportion biomass = C	Total estimated C by land use (Mg ha^{-1}) Forest: 335.1± 34.6 Agro-forest 144.7± 2.3 Pasture 45.7± 2.6
Kuyah et al., 2013	Western Kenya/ *Eucalyptus grandis, camaldulensis, and saligna*	Develop mixed species allometric biomass equations *Eucalyptus* in Kenya and determine biomass distribution between AGB and BGB	Ln(B)= a + b x ln(DBH)+ c xln(H)	*Eucalyptus* dominated agricultural landscapes stock 11.7 ± 0.01 Mg ha^{-1}
Ketterings et al., 2001	Western Indonesia Mixed species of tropical forest	Examine estimate error associated with choosing suitable values for adjusting parameters in allometric equations	Variance estimates: $V_{tree} = \varphi B D_i{}^2 = \varphi a^2 D_i{}^{2b}$ $V_{estimate}(D_i) = (\underline{_{Bi}})\ (Vaa + a^2 \ln(Di)\ {}^2V_{bb} + 2a\ln(D_i)V_{ab})$	B(kg per tree) = $0.066D^{2.59}$ Site specific wood density, and diameter vs. height parameters reduce estimate errors

Reference	Location/ Species	Research Questions	Equations or models	Results
Pohjonen 1991	Central Ethiopia/ *Juniperus procera*	Determine volume equations and tables for *Juniperus procera*	$\ln(v*) = -2.741 + 1.92\, x \ln(d) + 0.902\, x \ln(h)$ * Volume for trees over 7 dbh in decimeters	Standard errors of logarithmic equations were above 10%. However, errors were reduced in two input models D,H (Diameter and Height)
Zewdie et al., 2009	Central Ethiopia/ *E. globulus*	Assess the relationship between AGB and tree diameter and height across chronosequence of coppice shoot age and cutting cycles	V= $0.12(D)^{0.39}(H)^{2.08}$	Total ABG by forest stand age: (Mg ha^{-1}) 1: (10.6) 4: (32.2) 5: (69.7) 7: (92.8) 9: (152.6)
Antonio et al., 2007	Costal Portugal/ *E. globulus*	Develop set of complimentary equations to estimate AGB across regional boundaries	Total AGB = sum of complimentary tree fraction equations reliant on various parameters and based on $V = k1Da1Hb1$ ABG= $W_w + W_b + W_l + W_{br}$ ABG= stem + stem bark+ leaves + branches	1)Inclusion of height improves predictive ability significantly 2) Regional applications of equations are reliable if height and age structure of the stand are taken into account.
Perez Cruzado et al., 2011	Western Spain / *Eucalyptus nitens & E. globulus*	Estimate biomass, evaluate bias across estimators and ability of crown ratio to improve accuracy	Total AGB (Mg Ha^{-1}) = $b^7 * d_g^{b8} * H_0^{b9} * N^{b10}$ Where d_g is a relation of the QMD to TPHA and height, H_0 is the mean height, and N is stems ha^{-1}	Additions of model parameters improved the fit of the data significantly with an AGB maximum accumulation prediction of 13.4 Mg ha-1

Reference	Location/ Species	Research Questions	Equations or models	Results
Montagu et al., 2005	Western Australia/ *Eucalyptus pilularis*	Examine the influence of site specific characteristics on allometric relationships across seven sites to develop a generalized equation for regional biomass assessment	General: AGB= $AGB = \exp(-3.270 + 2.707 * \ln(dbh + 1)) * (0.971)$	The variable of DBH was found to be most effective when predicting a generalized model across 7 contrasting size and the regional scale
Walsh et al., 2008	NSW Australia/ *Eucalyptus* species: *E. camaldulensis* *E. melliodora* *E. albens* *E. microcarpa* *E. polyanthemos* *E. siderozylon* *E. crebra* *E. botryoides* *E. globulus*	To examine C sequestration potential of *Eucalyptus* spp. plantations in low rainfall areas using predictive growth models as compared to published estimates.	$AGB = \exp(-3.270 + 2.707 * \ln(dbh + 1)) * (0.971)$	Potential productivity within and between eucalypt species is variable. Species specific habitat ranges and drought tolerance thresholds were identified to aid in risk analysis when planting eucalypt species in adverse conditions.
Chave et al., 2005	Various Tropical Forest tree species in Australia, Brazil, French Guiana, Guadeloupe, India, Indonesia, Malaysia, Mexico and Venezuela.	To test the assumption that a single pan-tropical allometry can be used in AGB estimation procedures.	$\mathrm{Ln(ABG)}=a+b+\ln(D)+c(\ln(D))^2 +d(\ln(D))^3 +\beta_3 \ln(\rho)$	A consensus of broad estimates for tropical forest biomass was reached; however, overestimates of 0.5 to 6.5% occurred when averaged across stands.
Fernandez-Puratich et al., 2013	Various Mediterranean fruit tree species: *Olea europea*	Develop biomass volume allometric equations for fruit tree production.	$V\ (m^3) =-0.03642+0.00324(DBH)$	Unused biomass produced in fruit tree orchards represents a significant resource.

Alternative methods of AGB estimation

Advancements in forest survey methods have kept pace with innovations and applications of remotely sensed data analysis. Although the metrics and research questions remain the same as traditional stand exams, advancement in remote sensing techniques do not require time consuming and expensive destructive sampling (Naesset et al., 2008). Further, remotely sensed data can be analyzed across spatial and temporal scales more effectively than traditional methods due to the significant reduction in field data required (Garcia et al., 2009). Active and passive remote sensing samples are useful in determining forest stand attributes. While active sampling is the process of tasking satellites, aerial surveys or other sensors and formats of data collection, passive methods rely on imagery collected on a continuous basis from satellites. An example of passive data retrieval is the Landsat constellation, which relies on a uniform method of capture and dispersal of data. Passive data retrieval on platforms such as the Terra and aqua satellites provide information collected from hyper-spectral sensors which is useful for landscape scale estimates of ecological metrics such as leaf area index and evapotranspiration (Sun et al., 2010). Passive remote sensing data have been used to estimate both above and belowground biomass (Leboeuf et al., 2007).

Issues occur with passive sampling of vegetation exhibiting a density over 100Mg/ha^{-1} as passive sensors tend to underestimate biomass due to limited saturation capabilities as a function of pixel resolution and limited canopy penetration(Cohen et al., 1992). These studies must be corroborated by field validation, which points to the issue of a closed canopy in dense multistory tropical forests. In the case of passive sensors, with medium resolution, a dense forest canopy will be generalized to a single pixel value corresponding to a general forest spectral signature rather than individual trees or species-specific signatures. Therefore the density of forests limits application of remote sensing to estimate biomass of individual trees and thus a larger area of interest (Sun et al., 2010). Advancements in active sensors such as LiDAR (Light Detection and Ranging) and SAR (Synthetic Aperture Radar) provide a solution to the dense vegetation issue (Lefsky et al. 1999; Riano et al., 2004). However, a major drawback to analysis of high resolution remote sensing data is the cost of site specific active sampling with techniques such as airborne LiDAR. Further, these technologies require specialized skills using GIS and image analysis software, which may be outside the scope of fine scale analysis (Dunn et al., 1999; Aanestad et al., 2007).

Plantation and conservation tree species in Ethiopia

Eucalyptus species

Eucalyptus species are a preferred plantation forestry species. As a crop, *Eucalyptus spp.* produce a high yield with low nutrient and cost input requirements (Perez-Cruzado et al., 2011). Demand for a hardwood species with favorable growth yield and adaptability to a range of environments has driven the spread of *Eucalyptus* plantations across the world (Fritzsche et al., 2006; Zewdie et al., 2009; Kuyah et al., 2013). As early as 1895, *Eucalyptus* spp. were imported to Africa and specifically Ethiopia, to address the issue of fuel wood shortages (Pohjonen et al., 1990). The same demand and natural resource pressure causing high rates of deforestation in developing economies contributes to the increased use of *Eucalyptus* spp. The use of *Eucalyptus* spp. as short rotation woody crops is a common solution due to the minimal labor required to manage the species and the relative success of the species to adapt to new conditions (Perez-Cruzado et al., 2011). In nutrient poor soils *E. globulus* demonstrated a mean annual increment (MAI) of 6.5m^3 ha^{-1}(Forrester et al., 2004) and in more fertile soils the MAI has a range between 8 and 45m^{3}ha^{-1} (Bennett et al., 1997; Hingston and Galbraith, 1998). Depending on soil nutrients and site-specific characteristics, the popular management technique of harvest and coppice is possible in a short rotation cycle ranging between 7 and 12 years (Madeira et al., 2002).

When included in a mixed species plantation of nitrogen fixing species, *Eucalyptus* spp. benefit from improved nutrient cycling (Binkley et al., 1992) However, while a species with a relatively high growth rate, *Eucalyptus* spp. are subject to interspecies competition (Forrester et al., 2004). *Eucalyptus* species are associated with environmental and social externalities when exotic to an ecosystem (Kidanu et al., 2005; Alem et al., 2009). Specifically, *Eucalyptus* may negatively impact the water table, soil nutrient levels and litter composition (Almeida et al., 1990). In some cases of understory interactions, *Eucalyptus* spp. can suppress native vegetation, which help control runoff and improve water retention rates (Descheemaeker et al., 2006). Where restoration and conservation of water and soil resources are top priority, a management plan of stand replacement to accelerate native succession is recommended to restore biodiversity and normal functioning ecosystems (Zhou et al., 2002). While the impacts of stand replacement in the short term are destructive to soil composition, nutrient levels, habitat and understory species (Bruijnzeel, 2004), management may observe long-term ecological benefits such as improved niche habitats for local wildlife (Cornish and Vertessy, 2001). However, a final consideration for practitioners is the likelihood of *Eucalyptus*, as an exotic pioneer species to compound the difficulty in achieving a diverse stand and later stages of succession. In the case of *Eucalyptus,* continuous control methods are necessary, within the first three to five years, to achieve acceptable rates of control for higher levels of restoration success (Bean and Russo, 1993).

Juniperus procera

Originating in Africa, J*. procera* is distributed throughout the continent and is known as the African pencil cedar. The species is found in mountainous regions throughout its' native distribution from Zimbabwe to the Arabian Peninsula within an elevation range of 1,750 and 3,200 m asl (Pohjonen, 1992; Legesse, 2010). This vast geographic range is explained in part by the precipitation range of the species. *Juniperus procera* forests persist between 1,000 and 1,400mm but individual trees can be found between 300-2,000 mm annual precipitation (Louppe et al., 2008). Under favorable conditions healthy trees can reach 60cm in DBH and 35m in height within 100 years of growth (Kigomo, 1985).

Juniperus procera is native to Ethiopia and is spatially distributed in the highlands and central plateaus of the country as shown in Figure 1 (Fetene et al., 2001). A similar pattern of loss, fragmentation and variance outside of historic ranges exists in Ethiopia, where the estimated original range of the species has been reduced from 50×10^6 to 3×10^6 ha (Pohjonen, 1992; Legesse, 2010). Fire and climate change mitigation research on the historical range of variability of Mount Kilimanjaro have shown significant loss of *J. procera* despite efforts to conserve the species in this habitat (Hemp 2005). An analogous history of fire and land use change in Ethiopia results in a loss of native range of *J. procera* across the country (Pohjonen, 1992; Louppe et al., 2008).

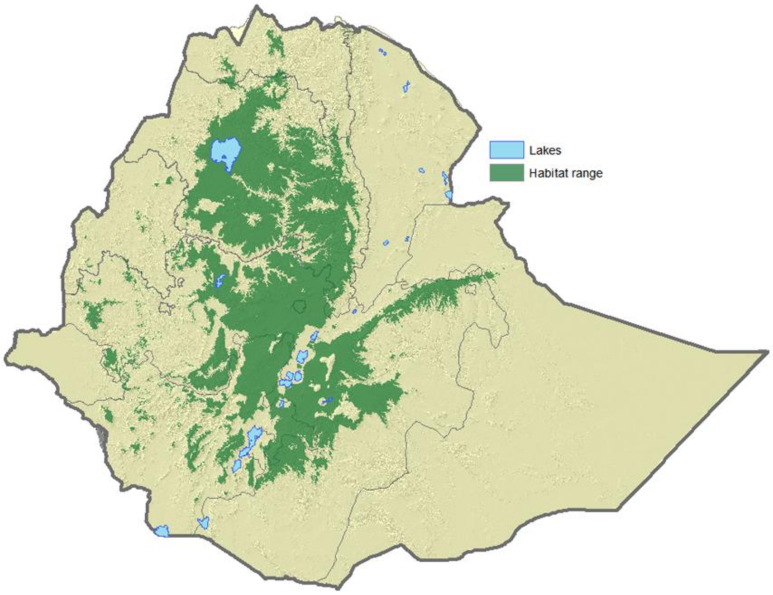


Figure 1. Range of *J. procera* in Ethiopia adapted from elevation range and precipitation range identified in Pohjonen (1992) and Louppe et al., (2008), respectively.

In Ethiopia, stands and individual trees of this species are considered relics compared to historic distributions. Pressure on *J. procera* timber resources in Ethiopia and habitat loss has limited research on the species.

Removal of larger DBH class trees and overgrazing restricts studies to non-representative sample sizes of irregular trees. For the volume equations of *J. procera* presented by Pohjonen (1991), a sample of 75 trees were destructively sampled from Menagasha state forest. An accurate representation for a national biomass model was not possible at the time of the study because deforestation had isolated full DBH classes of the species to old growth protected forests: Menagasha, Bale Mountains National Park and Gara Ades.

Management of *J. procera*

Growth rates of *J. procera* are slow relative to exotic timber plantation species typically utilized in Ethiopia (Pohjonen et al., 1992). Timber suitable for machine timber is possible with a growth cycle between 70 and 100 years. Annual yields of *J. procera* are variable and dependent on site specific available nutrients and sunlight (Sharew et al., 1996). A range of 3.5 to 13 m^3ha^{-1} year-^{1} with a mean growth rate of 7.5m^3 $ha^{-1}year^{-1}$ limits the plantation potential for this species when compared to exotics such as *E. globulus*, which boast a growth rate of 50m^3 $ha^{-1}year^{-1}$ on identical sites (Louppe et al., 2008).

While shade intolerant, *J. procera* is capable of competition with non-native species such as *Eucalyptus* spp., when provided sufficient light (Sharew et al., 1996; Legesse 2010). In the case of arid regions and restoration projects, a soil terrace system and rain water harvesting report positive impacts on growth rates of this species. Growth of *J. procera* is significantly higher in terrace systems as compared to abandoned terrace systems, which on average show 12% of the basal area of terraced plantations. Further, methods of terracing compound the benefits of soil retention seen in reforestation projects using *J. procera* (El Atta et al., 2010). However, when considering soil conservation with *J. procera* it is important to account for the acidic litter produced by the juniper, which can lower soil pH levels and limit the potential for intercropping in agroforestry projects (Kerfoot, 1961).

A recent discovery related to *J. procera* is the potential for trees located in specific conditions to contribute to the fields of dendrochronology and dendroclimatic studies (Wils et al., 2011). While generally an unlikely geography to study seasonality, the rainy season patterns of sub-equatorial Ethiopia are captured in the growth ring physiology of *J. procera* (Sass-Klassen et al., 2008). Interest in a transitioning climate has driven efforts to identify and decode the historic records of biotic and abiotic climate stenographers. The role of *J. procera* in dendrochronology is unique due to its location. Conifer species, which display annual growth rings in temperate biomes record plentiful data. However, the tropics are poorly understood as a climatic region. The limited number of tropical climate records and increasing interest in this region as a location of high C storage potential combine to add conservation value to *J. procera* (Legesse, 2010).

While revealing the composition and stand attributes of a forest are crucial for understanding the biomass of a forest, the health and ecology will only be understood through an effort to collect information on the understory vegetation. In the case of Gullele Botanic Garden, a baseline sampling effort of the understory vegetation was necessary to better explain the conditions of the forest ecology under the dominance of *E. globulus*. Future sampling efforts of similar method may be employed to examine the effect of the GBG management strategy to replace *E. globulus* with a native species forest stand.

Vegetation sampling

The value of species and biodiversity is well documented ecological research. As noted in the broad consensus monograph led by Hooper et al. (2005), “More species are needed to insure a stable supply of ecosystem goods and services as spatial and temporal variability increases, which typically occurs as longer time periods and larger areas are considered”. The compilation suggests that ecosystems with higher diversity are likely to show both improved resilience and resistance and thus lower vulnerability to the impacts of climate change.

A vegetation inventory to collect data on species richness, diversity and abundance is an ideal compliment to a forestry inventory. Vegetation communities throughout a forest are important indicators in the overall health of a local ecology. A suite of methods such as quadrat and fixed radious sampling to measure and inventory vascular understory plants are utalized in the literuature (Stohlgren et al., 1995; Rapson et al., 1997); however, for the puropose of this review the methods of the intinsive modified Whittaker were selected.

The intensive modified Whittaker adapted by Barnett and Stohlgren (2003) has advantages of recovering greater species richness due to its size and rectangular structure (see Stolgren et al. 1994,1998). The structure is better designed to capture rare species and avoid spatially autocorrelated bias commonly identified in transect methods (Paker, 1951; Daubenmire, 1959). Additionally, plot size and construction lend themselves to rapid sampling times per plot depending on the density of the vegetation in question. This realative decrease in field sampling allows for increased plot frequency across a landscape or environmental gradient, as compared to other methods. A final dynamic benefit of this sampling method is the direct application to geospatial analysis.

The intenisve modified Whittaker sample plots account for a total of 100 m^2 and include four nested sub plots of 1 m^2 and a central plot of 10 m^2 the sampels capture information at multiple spatial scales. Accounting for the various spatial scales enables the research team to analyze the vegetation data for correlations across the landscape with ancillary and remotely sensed data. With a georeference for the plot using a Global Positioning System (GPS) the plots may be entered into a Geographic Information System for spatial analysis (Chong et al., 2001). Spatial distribution estimates are possible based on correlations identified in geospatial analysis and ecosystems modeling techniques based on various methods of regression (Elith et al., 2008).

Discussion

Heightened awareness of the global C budget is reshaping funding programs from agencies such as the European Union and Food and Agriculuture Organization (FAO) of the

Unitited Nations. A demand for accurate estimates of C sequestration and continued monitoring of sequestration has increased globally (Flachsland et al., 2009). Landscape models to predict C storage concentrations in areas of tropical rainforest with the highest potential for sequestration are a popular subject of forest C estimation literature (Ketterings et al., 2001; Chave et al., 2005; Kirby et al., 2007). However, given additional evidence of the global benefit of fine scale forestry projects and agroforestry, a rift in the literature is beginning to emerge (Kirby et al., 2007; Zewewdie et al., 2009).

Insuffiicent attention has been paid to fine scale conservation projects attempting to estimate C stocks and potential sequestration. Chief among the concerns for these projects are affordable and practical methods to assess C as it relates to managment (Kuyah et al., 2013). Conservation projects in developing economies are dependent on external sources for emperical research funding. To ensure consistent support for conservation projects, a suite of practical examples of C stock estimation is nesseccary. Management authorities may initially emulate and adapt these case studies with the ultimate goals of access to funding and informed management decisions. Finally, for the purposes of the Gullele Botanic Garden, the C stock and understory vegetation inventories will provide future research and manegment endavors with comparison data. Inventory data and resulting analyses may be built upon and used to supply future projects with funding, insight and, at a fundamental level, baseline statistics to assess the progress of forest transition to native species composition.

Chapter 2

Introduction

Gullele Botanic Garden (GBG), the first of its kind in the horn of Africa, was officially established on July 7th 2010 by Addis Ababa city proclamation 18/2005 E.C. The forest of Gullele, on the northern edge of the city was selected for the benefits associated with the location (Figure 2). The area has significant environmental value because it lies on both the upper urban watershed for the Akaki River and the expanse of the metropolitan area. The conservation area is projected to be an economically competitive alternative to urban expansion and serve as a destination for ecotourism. The social impacts of the project are expected to take many forms including educational outreach, public works projects and the establishment of the gardens as a center for research.

To prioritize future goals and objectives for the area, the government of Addis Ababa agreed on the following four mandates, for GBG: (1) Native Species Conservation, (2) Education, (3) Ecotourism, and (4) Research. To realize these mandates, the gardens must identify existing natural resources and adapt best conservation management practices to their needs and capacity.

From 2010-2012, I designed and implemented the following research with GBG staff members Birhanu Belay, Wondye Kebede and Soloman Getahun as part of my study within Peace Corps Masters' International (PCMI) program. The research project was conducted with particular focus on the native species conservation and research mandates.

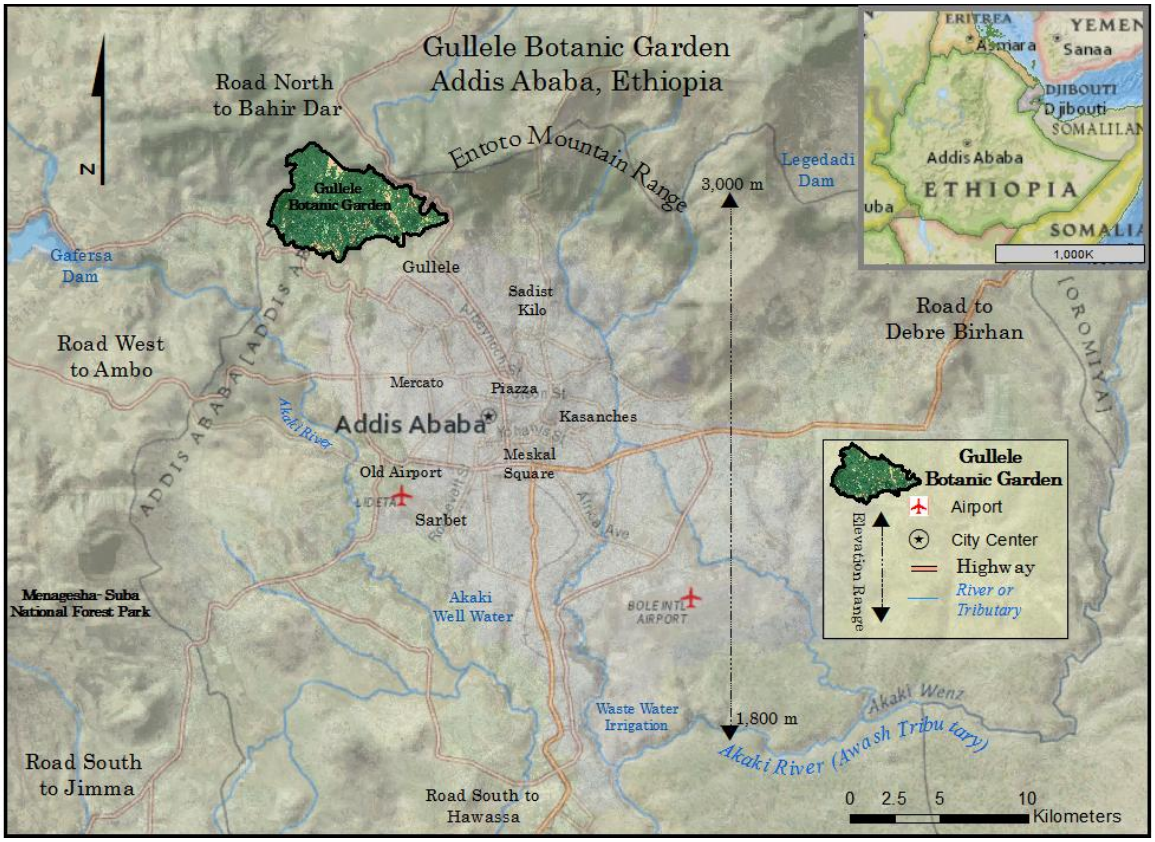


Figure 2. Location of Gullele Botanic Garden and water sources in Addis Ababa (Map adapted from Van Rooijen & Taddesse 2009)

Purpose of Research

The team worked to meet the following objectives: (1) build a spatial inventory of the tree and understory plant species present in the 612 hectares of conservation forest protected by the Gullele Botanic Garden; (2) provide a baseline analysis of species composition and C stock of the aboveground biomass to serve as a case study for future research by students and professionals; and (3) examine the conservation strategies to facilitate restoration of native species and plant communities.

To meet these objectives, the team:

1) Reviewed literature pertinent to the forest restoration management strategy

2) Estimated aboveground biomass and C equivalency of the forest using allometric equations

3) Identified areas of forest homogeneity through spatial analysis of tree density, species composition, and basal area to delineate forest stands

Finally, overall, the primary focus of this research was to quantify the impact to the C budget of the forest when *E. globulus* is removed from the forest.

Background

The capital city of Addis Ababa is approaching a crossroads in the new millennium. Population growth and environmental pressures from rapid industrialization in Ethiopia continues to grow beyond the city's capacity to meet the demand for natural resources (Abiye et al., 2009). The outward expansion of the urban area threatens groundwater sources with overuse and pollution (Alemayehu et al., 2005). Forest health and species native to the central highlands directly adjacent to the city remain under threat of land use change due to human population growth and natural resource exploitation (Legesse 2010; Zewdie et al., 2013). A clear view of the issues led the government of Addis Ababa to conserve a section of the city's northern forest and watershed of Gullele. The opportunity to conserve the forest in Addis Ababa is unique. This fact is not lost on the developers of the project who will include a botanic garden at the center, complete with an onsite nursery and arboretum.

The project is charged with the ambitious goal of collecting, propagating and preserving endemic Ethiopian flora in the conservation area. This will include plant and tree species from five agro-ecological zones present in Ethiopia depicted in Figure 3. The

Gullele Botanic Garden will showcase the exceptional diversity of Ethiopia and serve as an open-ended case study for forest restoration projects in the region.

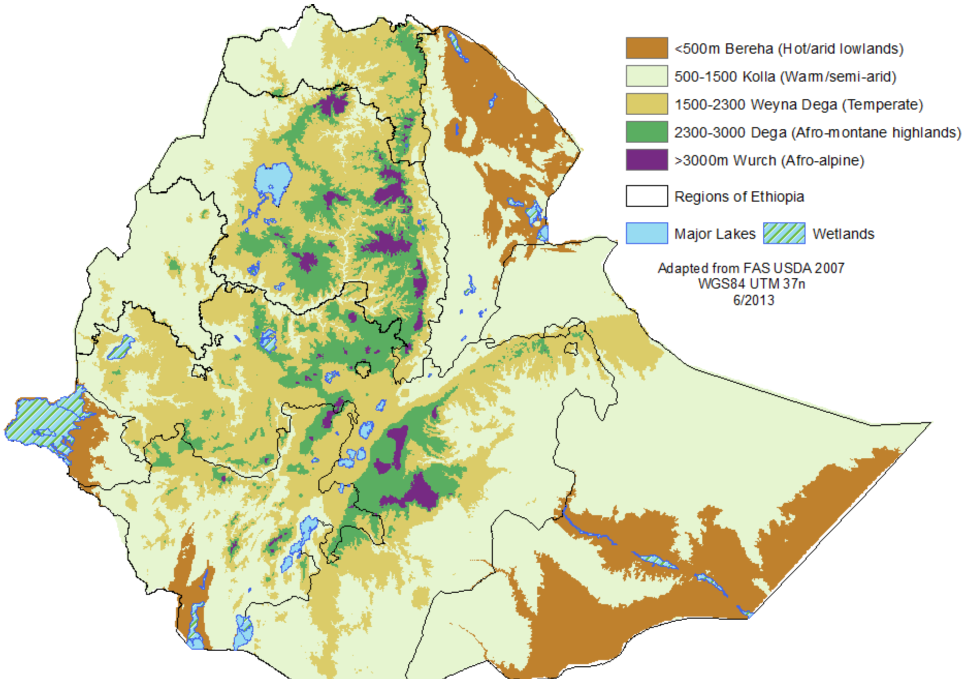


Figure 3. Elevation-based Agro-ecological zones of Ethiopia.

The topography of Ethiopia is diverse and translates into impressive plant diversity across the agro-ecological zones. Beginning at -125 m BSL in the Danakil depression and reaching 4,533 m ASL at the summit of Ras Dajen peak, Ethiopia has an elevation range of 4,658 meters. Within this range, hot spots of plant and animal diversity are found in the xeric, afro-alpine and cloud forest ecosystems (IUCN 2011). Monitoring and protecting these species is an arduous task given the remoteness of some populations, and pressure from people and changing land-use. Further, agencies with insufficient capacity to protect entire hot spot areas are typically the only effort to conserve at risk species. These factors contribute to list Ethiopia as a category 1 country in terms of threatened biodiversity. This category is assigned based on a ranking in the top 20% of countries under threat of future plant species endangerment and a ranking in the bottom 20% in terms of governance quality (Giam et al., 2010). Conservation of plant species and related natural heritage of Ethiopia is at stake for the Gullele Botanic Gardens.

A final objective of the gardens will replace exotic tree species with tree species native to Ethiopia. Imported in 1894, for use in plantations, *E. globulus* is now ubiquitous throughout Ethiopia. *Eucalyptus* species were selected for plantations in Ethiopia because of favorable attributes such as adaptability, durability, coppice regeneration and rapid growth rate (Pohjonen et al., 1990). The forests of Gullele and Entoto (Figure 4) on the northern ridge of Addis Ababa are sites of the first plantations in the nation and retain a history of plantations and legacies of native forest (Zewedie et al., 2009; Pohjonen, 1992).

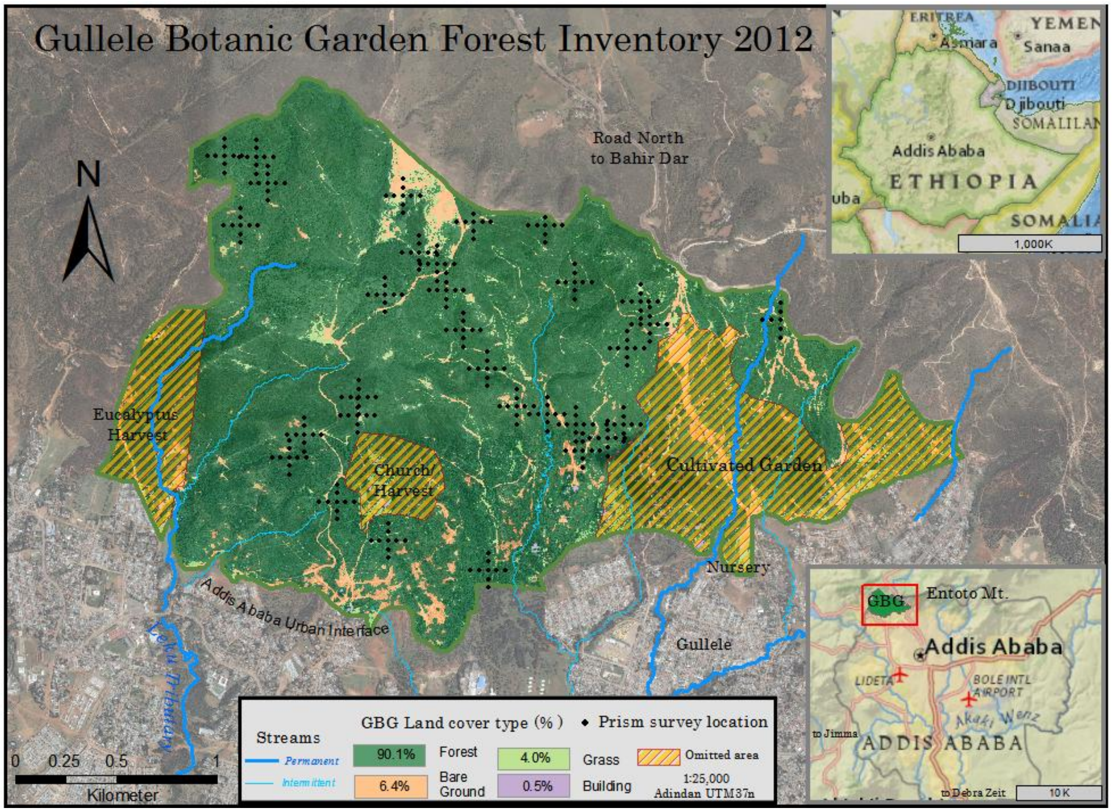


Figure 4.Location of GBG in the Gullele and Entoto highlands of Addis Ababa, Ethiopia

This plantation legacy has produced deviant forest stands with heterogeneous species composition and uneven age classes. The restoration management strategy will address this issue and with a type conversion to remove and replace *E. globulus* with native tree species. The long-term strategy of forest type conversion will serve as an opportunity to examine the impacts, both positive and negative, of forest restoration in the Afromontane or Dega ecosystem.

The forest restoration strategy is twofold: (1) harvest and control growth of *E. globulus* and (2) plant a variety of native and threatened tree seedlings which are produced in a nursery onsite. Seedlings will ideally out-shade and ultimately out-compete the *E. globulus*, which is known as a foster effect. Interest in this type conversion technique has prompted studies locally in Ethiopia (Stobl et al., 2011) and at the global scale. Results show exotic plantation species may foster shade tolerant native species such as the *Podocarpus falcatus*. If successful, the end result of the shelter effect will produce a native species structure once the *E. globulus* is overtaken (Lemenih et al., 2004).

The less destructive strategy of native succession is associated with potential benefits to the local ecology (Kasenene, 2007; Freier et al., 2010). However, the timetable of native succession is unclear as experimental stands of *E. globulus* and *P. falcatus* remain active. Partial coppicing and removal of *E. globulus* from these stands have shown positive results on the growth rate of *P. falcatus* (Stobl et al., 2011). *Eucalyptus* spp. are harvested and allowed to coppice after 7-8 years of established growth. If seedlings are well established, this management strategy may produce a cohort of native species to compete with the *E. globulus* coppice. While forest productivity is not a primary objective of the

Gullele Botanic Garden, the plan is in effect to physically remove and control the *E. globulus*. This has implications for a number of environmental variables including soil health, understory vegetation composition and wildlife habitat.

Forest Carbon

In the context of the global budget, forest C is viewed as a critical component of mitigating the impacts of climate change. The interest in forest C has directed research to explore all options, including plantations and conservation of natural forests. Expected outcomes of conservation (Kirby et al., 2007) and plantation (Perez-Cruzado et al., 2012) forestry are not equivalent; however, the role of forests on the global C budget at multiple spatial scales is clear (Johnson et al., 2001). Carbon storage in forest biomass remains the primary process of temporary accumulation (Nair et al., 2009; WGBU, 1998). Conversely, the release of C through deforestation contributes to 25% of total anthropogenic C emissions (IPCC, 2001; Thomas et al., 2004).

Interest in C sequestration strategies has led to proposals for economic cap and trade programs at the international scale. These programs fall on a spectrum of feasibility and practicality. A lack of standardized methods for site sequestration limits confidence in many of these programs (Chave et al., 2005; Kirby et al., 2007). However, models such as "Reducing Emissions from All Land Uses" (REALU or REDD++) which aim to monitor emission reduction and sequestration at the landscape scale are taking hold (Kuyah et al., 2012). To fill the gap of C estimates and build confidence in cap and trade programs, conservation projects must monitor and report current and projected sequestration

(Flachsland et al., 2009). In the case of GBG, estimates of C stock prior to the removal of *E. globulus* and restoration of the native forest are a valuable baseline statistics to establish.

The physical removal and subsequent control of *E. globulus* is associated with negative externalities requiring further examination. Increased soil erosion (Girmay et al., 2009; Girma et al., 2010) and dramatic disturbance to the hydrologic cycle (Kidanu et al., 2005) are well documented outcomes of harvest and control strategies. A third implication is the loss of tree biomass and thus C stored in the forest. Beyond the clear loss of aboveground biomass to the total C stored in the forest, other C in soils and belowground is lost when physical or chemical controls are put in place to halt the growth of *E. globulus* (Freier et al., 2010).

Efforts to measure forest C sequestration have developed a host of estimation techniques and objectives. Sequestration studies may be grouped into the following aspects of C sequestration: soil and belowground sequestration vs. aboveground biomass (Nair et al., 2009). The most common method to estimate C in plantation and conservation forests is the development of allometric equations to estimate tree biomass. Species specific tree biometrics such as height (H) and Diameter at Breast Height (DBH) are input into equations that estimate the amount of C stored in aboveground biomass of a single tree. These values are fit to surveys of forest density that estimate C at multiple spatial scales. Allometric equations for *E. globulus, J. procera* and various other species found in the garden are applied in this study to estimate the present C stock.

Questions regarding fine scale C storage of conservation forests remain unanswered by the literature. The impact of forest type change with a focus of native species restoration on understory vegetation and plant communities in the afromontane ecosystem is not well documented. The need to establish baseline data on the issues related to the restoration strategy provided the impetus to question how changes in forest types will affect aboveground C storage. The site C budget was examined by testing the following hypothesis against the species-specific allometric models: removal of *E. globulus* trees greater than 35 cm in DBH would significantly impact forest C stock (Mg ha^{-1}) as compared to the overall estimate. This research question was developed with the intent of challenging the strategy of total removal of *E. globulus* from the landscape. The hypothesis serves the secondary function of an assessment of the sensitivity of various *E. globulus* allometric models to the wide variance in individual tree attributes across the conservation forest. Upon initial review of the data collected, a second hypothesis was developed to test for a significance of total trees below 30cm DBH. The research questions were identified and developed based on both the needs of GBG management and the geographic attributes of the protected area.

Study Site

The Entoto Mountain range in Addis Ababa dictates the elevation gradient of Gullele and influences a sharp increase in precipitation supporting the forest along the northern rim of the capital city. The forest of Gullele has a reputation for containing historically significant trees in the city, which is part of the motivation to preserve the location. The gardens are comprised of 621 ha of conservation forest and approximately 100 ha of cultivated gardens, which are located on the northern periphery of the capital city Addis Ababa. The southern boundary of the gardens is located at 9.1˚ S, and 9.06˚N, 38.74˚E, and 38.7˚W make up the extent of the boundary from north, east, and west, respectively. The dry evergreen afro-montane forest is dominated by *E. globulus.* An assortment of native species and *E. globulus* forest is present throughout the elevation range of the garden between 2,538 – 2,890 m ASL. The area is topographically diverse given the extent; slopes in the garden range from 0 to 40° with a mean of 11.7° (GBG, 2008). The conservation area contributes to the headwaters of the Akaki River (Figure 2 and 4), which transects Addis Ababa from north to south. The northern hills of the region receive 1,196 mm of precipitation annually with an average temperature of 15.9°C. Historically, seasonal precipitation is bimodal with a short rainy season beginning in March and ending before June. The long rainy season is present from June to mid-September (World Clim, 2009). The remaining six months constitute only 16% of total annual rainfall (Conway et al., 2004).

Influence of site topography on management

At the landscape scale, reforestation projects in tropical regions show positive results in areas of high elevation (Figure 5) and steep slopes (Crk et al., 2009). A number of factors may contribute to the success of reforestation in these areas including the following: limited access to remote forests where natural regeneration is sheltered from the impacts of human resource use. Isolation from roads and villages limits the impact of harvesting, fuel wood collection and livestock grazing. This may relate, in some capacity, to the situation at GBG. However, the urban interface of Addis Ababa will limit the success of reforestation due to the heavy use of resources including livestock and illegal harvesting within the boundary of GBG. The slopes and topography of the forest may also complicate the efforts to maintain seedlings because water resources are unevenly distributed throughout the conservation area. Dams to redistribute water resources are located on the eastern permanent stream in GBG; however, most of this reservoir is allocated towards irrigation of the cultivated gardens and not seedlings or saplings.

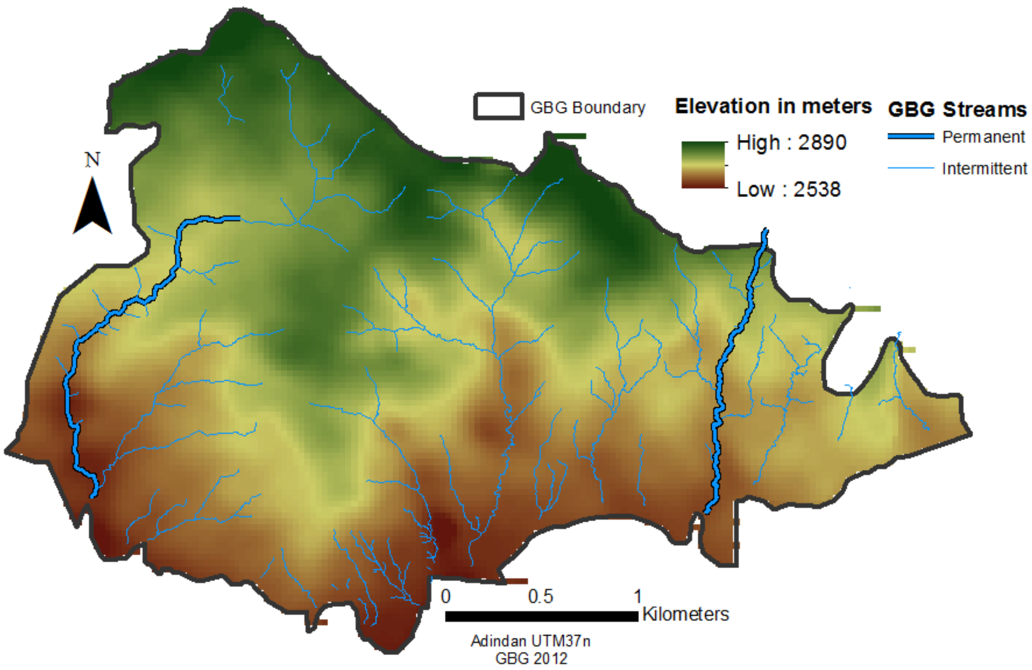


Figure 5. Elevation in meters of Gullele Botanic Garden.

Access to water for seedling maintenance may be difficult for the central region of the garden. In an effort to improve survival rates of seedlings throughout the area terracing has been undertaken. In arid environments methods of terracing are beneficial when reforesting an area with *J. procera* and similar afro-alpine species (El Atta et al., 2010). Terracing throughout the garden will have positive externalities of limiting soil erosion in areas of high slope (Figure 6) as well as support water retention.

Customized irrigation regiments and soil amendments are necessary to establish threatened plant species, historically distributed throughout Afro-montane and Afro-alpine regions. It is advisable to utilize forest stands to organize soil amendments, plantation cycles, and maintenance schedules. Stand attributes such as mean slope, elevation and dominate aspect will also be beneficial for planting species with topographic and specific resource requirements such as shade tolerance. The workflow and results of a procedure to identify and delineate forest stands of homogenous attributes at GBG is included in the results section as well as Appendix I.

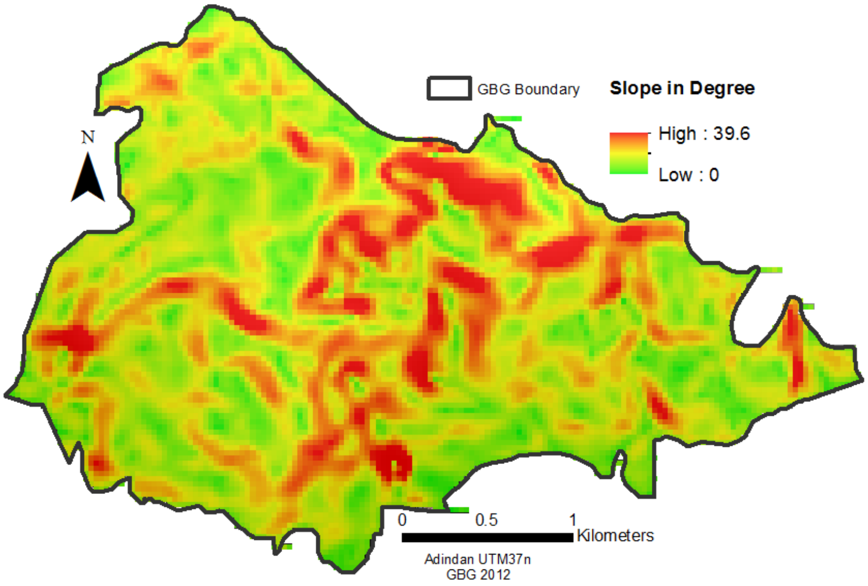


Figure 6. Slope of Gullele Botanic Garden in degrees.

The forest and cultivated gardens have primarily south facing slopes. While the geographic location of 9°N or approximately 1,000 kilometers north of the equator reduces the influence of aspect on plant growth as compared to higher degrees of latitudes, a noticeable differences remains. Steep slopes and high elevation in the forest will influence the success rate of seedlings and the overall ecosystem restoration efforts at GBG. The diverse topography poses a set of challenges and opportunities for cultivation and restoration of native species.

The extensive traditional ecological knowledge networks throughout Ethiopia, in addition to the academic support from institutions such as Addis Ababa University and

Wendo Genet College of Natural Resources, will continue to influence management practices at GBG. Experimental stands in the hills of Entoto and Wendo Genet, located in the Central Rift Valley of Ethiopia, are rich with a research history detailing previous successes and failures when working with indigenous species restoration and propagation (Zewedie et al., 2009; Legesse, 2010; Strobl et al., 2011). Drawing from the knowledge base and available research, it is possible for GBG to remain informed on how best to structure experimental stands designed to restore native forest to Gullele. Projects such as the *Podocarpus falcatus* shelter tree study by Strobl et al. (2011) and the restoration efforts in Entoto with *Hagenia abyssinica* demonstrate positive potential and will provide guidelines for GBG to follow (Legesse, 2010).

Material and Methods

Inventories of forest stand characteristics and understory vegetation were taken in the forested area of GBG in September and October of 2012. For the purposes of examining attributes linked to conservation value, for both tree and understory species in the forested area, a nested vegetation sampling method was combined with a point sample forest inventory. This combination maximized data collection in the field. The following methods were carried out in the context of the larger research framework in Figure 7.

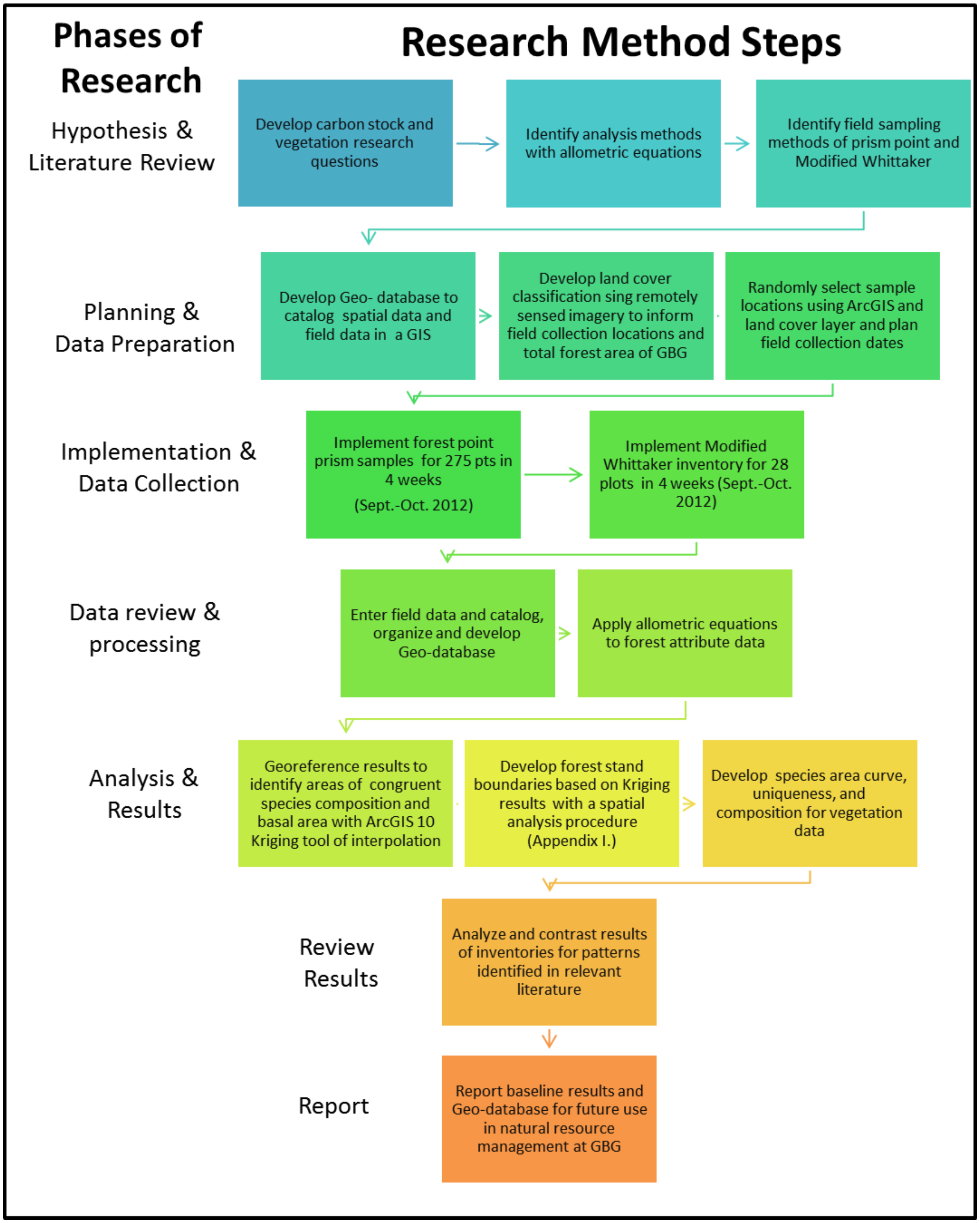


Figure 7. Flow chart of research process organized by phases and subdivided steps.

The intensive modified Whittaker vegetation sampling method designed by Barnett and Stohlgren (2003) provided the foundation for understory vascular plant species sampling (Figure 8). The design attributes of nested sub plots and a reduction in plot area (100 m^2) allowed for a higher plot frequency across the landscape as compared to traditional (1000 m^2) modified Whittaker plots (Stohlgren et al., 1995). Species attributes of height, percent cover, and plot canopy cover were recorded. Ancillary data collected at each plot included slope, aspect, elevation and Universal Transverse Mercator location collected by GPS. A total of 28 plots were randomly positioned throughout the conservation forest using the ArcGIS 10 tool “create random points”.

The centroid of each Modified Whittaker plot provided an anchor point for the forest inventory samples. Starting from the anchor, two samples were taken at intervals of 50 and 100 meters following each of the four cardinal azimuths for a total of nine point samples per Modified Whittaker plot or “cluster” (Figure 8). Clusters of nine prism points were then attached to the centroid of each random point using a tool developed in Python programing language (Appendix III).

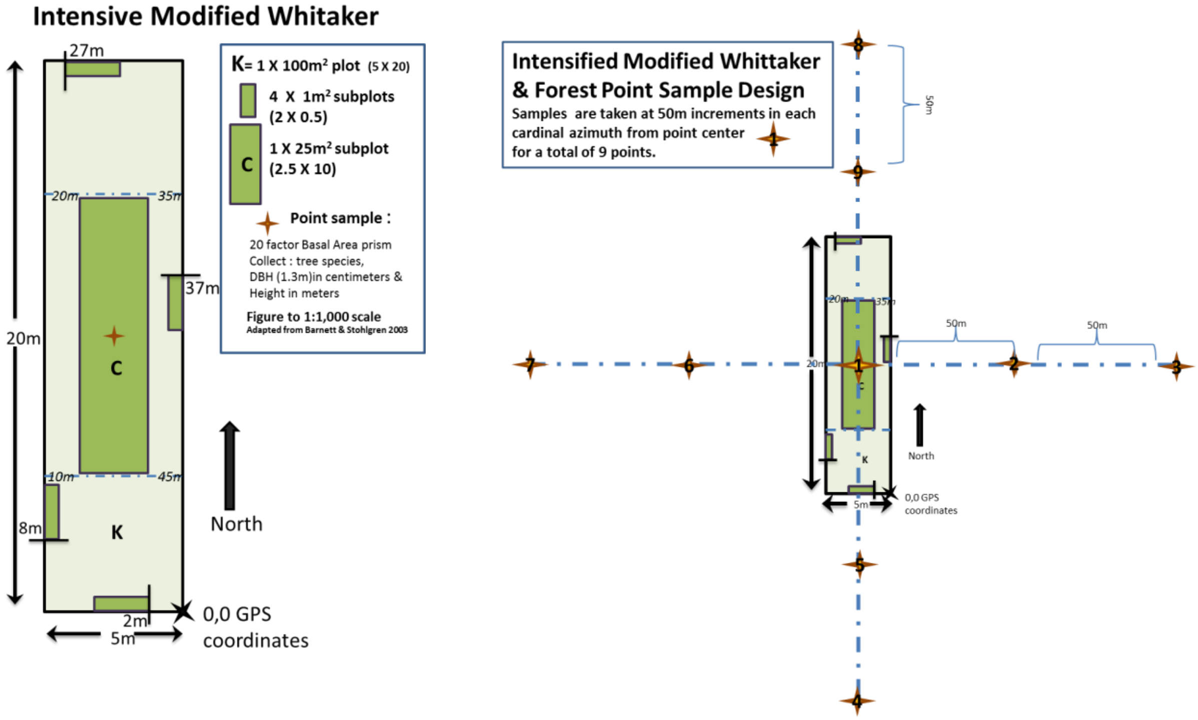


Figure 8. Diagram of Intensive Modified Whitaker and forest prism point adapted from Bashkin et al. (2003).

Forest measurements and area estimation

A total of 275 variable radius forest inventory plots were conducted with a 20 Basal Area factor prism. Tree species along with the attributes of diameter at breast height (D) (DBH; equal to 1.3 meters high over the bark) and tree height (H) were recorded with a hypsometer laser range finder for 763 sample trees. Point samples from four locations were rejected due to violation of study site's boundary topology. The sample area was defined as within the GBG boundary, but not within the areas excluded. Exclusion areas were based on ground-truth validation of visual boundaries and the land cover classification developed in ArcGIS 10 supervised image classification tool.

The forest inventory metrics were geo-rectified against Spot and QuickBird imagery of the forest and entered into a geodatabase (Appendix IV) using the Adindan datum and

Universal Transverse Mercator projection for analysis in a Geographic Information System (GIS). Spot imagery data from 2006 and 2008 were classified into land cover values using ArcGIS 10 image classification in a supervised classification. Training data for the spot image was developed through the supervised process of identifying areas of known land cover types. The following four classes were developed: Forest, Grass, Bare-ground and Buildings. The results and respective area calculations of this classification are displayed in Figure 4. Homogeneous areas of species composition and basal area were interpolated with a semivariogram Kriging method in ArcGIS 10 (Matheron, 1967). These areas were used to inform a spatial assignment of forest stands. A full tutorial of the analysis of the forest stand delineation procedure is detailed in Appendix I.

Forest Inventory Results

The species composition of the forest tells a story of patchy stand composition, which may be expected at the scale of 621 forest hectares. Of the 275 prism inventory points, 33 were located in areas where trees of sufficient diameter were absent. These empty point samples reduced the total basal area and tree density per hectare significantly. However, the empty samples are representative of the area as they were randomly selected. Empty samples were typically located in recently harvested areas or along roads where bare ground was present. The density values of forest and non-forest calculates to 88% forest and is corroborated by a ground cover classification of Spot imagery from 2008 which assigned 90% of the area as forest. Specific interest was given to *E. globulus* and *J. procera* as they were known to be co-dominant species in the forest (Belay, 2005). As the summary statistics of the forest inventory in Table 3 confirm, the two species combined to account for 92.9 % of tree species sampled by the 20 BA factor prism method.

Table 2. Summary statistics of forest inventory

Tree Species	**Sample size** (%)	**Basal area** m^3 Ha^{-1}	**Trees per Hectare** (%)	$\bar{x}$ **DBH** in cm (±SE)	**DBH** Standard Deviation	$\bar{x}$ **Height** in m (±SE)	**Height** Standard Deviation
E. globulus	**446** (58.5)	**7.419**	**583** (63)	**16.57**(0.41)	**7.89**	**14.59**(0.28)	**5.2**
Juniperus procera	**263** (34.4)	**4.375**	**232** (25.1)	**24.94** (0.3)	**15.4**	**9.3** (.19)	**3.03**
Olea europea	**26** (3.4)	**0.432**	**38** (4.1)	**17.34** (1.9)	**9.72**	**10.62** (0.66)	**2.5**
12 mixed afro-montane species *	**28** (3.7)	**0.466**	**72** (7.8)	**12.32** (1.7)	**9.614**	**6.42** (0.66)	**3.3**
Total	**763** (100)	**12.69**	**925** (100)	**19.27** (0.45)	**12.29**	**12.41** (0.21)	**5.66**

*A complete listing of tree species and field data appear in Appendices V and VI.

The variable radius plots provided rapid and accurate estimates of the basal area and trees per hectare across the mixed use forest. Study site wide estimates of 12.69 m^3 ha^{-1} of basal area and a tree density of 925 trees per hectare were generated from the inventory data. *Eucalyptus globulus* dominance was observed across all categories of the forest inventory (Table 3). *Eucalyptus globulus* accounted for above a 50% majority of the 763 trees sampled, total basal area, and trees per hectare.

A mean DBH of 16.6 cm for *E. globulus* as compared to 24.9 for *J. procera* was influenced by a high frequency of younger age classes and coppice stands. As Figure 9 demonstrates the shape of the central tendency of these species varies, which is due to a number of factors. A critical reason for this disparity is the difference in species physiology. *Juniperus procera* is the largest tree of the juniper species (Pohjonen, 1992) and a number of larger "legacy" trees were recorded in this survey. However, a majority of *J.*

procera individuals did not reach their height potential. This may possibly be explained by limited regeneration of the species as well as a cut and coppice technique used in both formal and informal harvesting in the area. Limbs from the *J. procera* are removed allowing the central bole to grow in density but stunting the height of the individual. Further, clear cutting and coppicing of *E. globulus* differs from the informal harvesting methods of *J. procera* where the bole is left intact while branches from the *J. procera* are removed for fuel wood (Legesse, 2010; Kuyah et al., 2013).

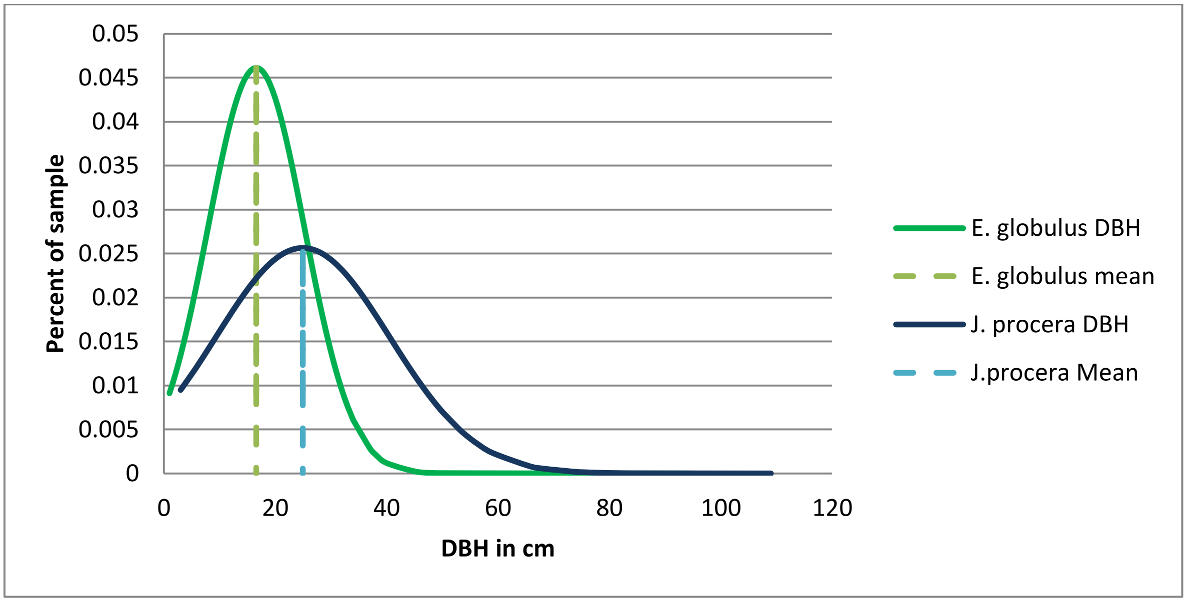


Figure 9. Sample Diameter at Breast Height distribution for *E. globulus* and *J. procera*.

Point cluster results

The point sampling cluster was designed to capture basal area, species composition and inform biomass estimates at multiple spatial scales. The prism points grouped around the plot center explain a medium scale aggregation of sample points around the vegetation plot. The summation of these point cluster samples is explained in equation 2. Cluster values provide details on mid-scale commonalities such as higher density of trees per hectare and basal area (Figure 10).

Eq. 2

$$Cluster\ Basal\ Area = \frac{\sum_{n=1} trees * prism\ factor\ (20)}{Point\ samples\ taken\ (9)}$$

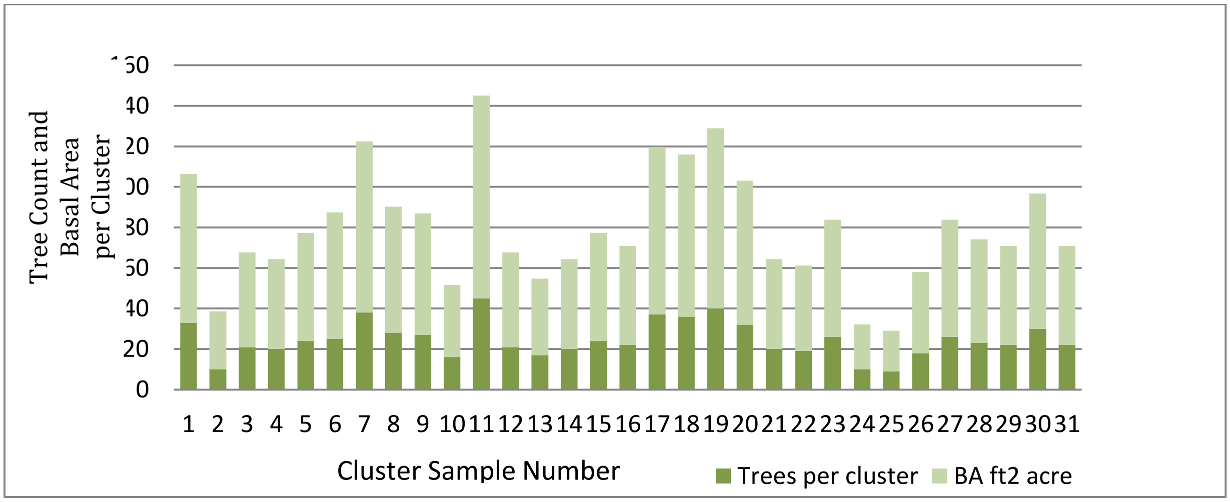


Figure 10. Trees and basal area per cluster sample.

Mean values of 24.5 trees and 12.5 $m^2\ ha^{-1}$ were retrieved for trees and basal area per cluster, respectively. A spatial pattern of homogeneity representative of mean DBH and biomass across the clusters was observed. Isolated measurement s of high basal area and biomass values were also found across the clusters. This may be attributed to the inclusion of infrequent and isolated "legacy" trees such as the maximum values of *J. procera* or *E. globulus* reaching 109 and 94 cm DBH, respectively. These legacy trees are the maximum estimates of biomass and thus C sequestration per tree. The legacy trees are considered outliers due to their position three standard deviations from the mean and qualification under the Mean Absolute Deviation (MAD) (Leys et al., 2013). Further, the trees are outside the confidence intervals of the allometric equations and may provide skewed estimates of biomass. Figure 11 depicts the disparity between the outlying and central tendency data points.

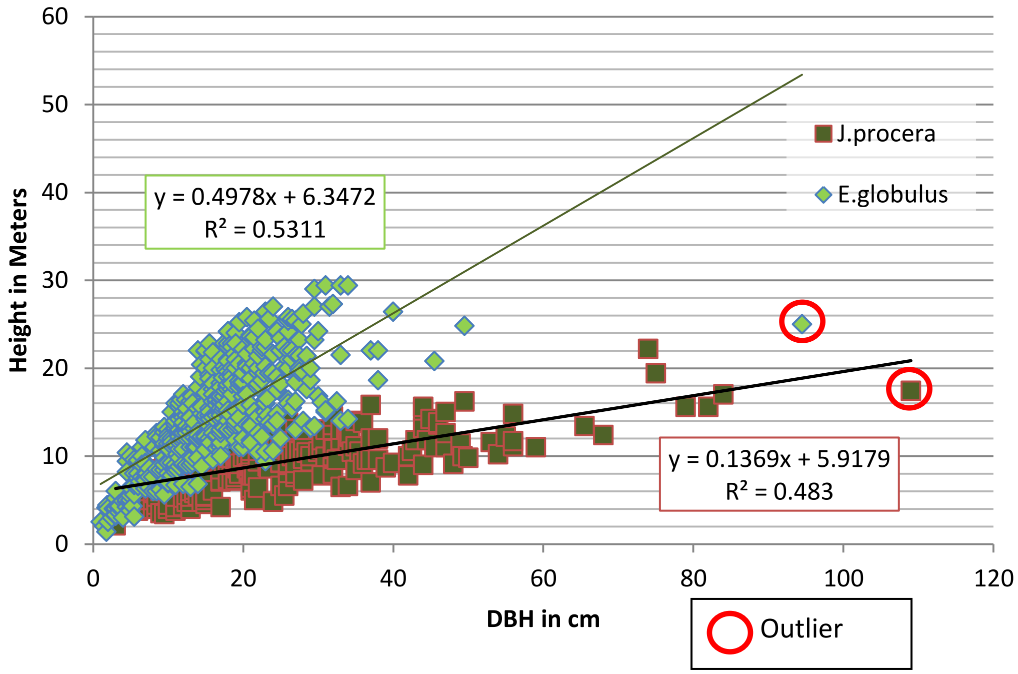


Figure 11. Tree height as a function of diameter at breast height for *E. globulus* and *J. procera*

The total number of trees recorded within a single cluster sample of 9 points had a range between 9 and 45. Both high and low counts of trees per sample cluster can be attributed to coppice stands of *E. globulus* and *J. procera* or both. In the case of low values the coppicing trees were below a diameter threshold to be selected in the 20BA factor prism. However, tree counts higher than 35, as in clusters 7 and 11 (Figure 10) were representative of multiple DBH classes with combinations of coppicing and older age classes.

A third pattern of evenly distributed DBH classes and higher biodiversity was recognized in clusters 17-19 (Figure 10). Higher basal area measurements were evenly distributed across the nine point clusters in this section of forest. These plots correspond with high tree and plant biodiversity as identified in the vegetation inventory. The even distribution of DBH classes in these plots may be due in part to higher levels of seedling regeneration. Higher frequency of species such as *Olinia rochetiana* may also explain this trend due to the species physiology. *Olinia rochetinana* has a smaller diameter bole and produces a more dense concentration of stems relative to *E. globulus* and *J. procera*. Further, tree density values of these plots were one to two hundred trees per hectare higher than the total forest estimate of 925 (e.g. sample no. 7 had a value of 1,203 Trees per Hectare). The 20BA factor prism method, while efficient for basal area and density estimates, is biased for larger DBH trees and unfit for collecting information on trees with a DBH <5cm . As seen in the DBH class distribution in Figure 12 a higher percentage of *E. globulus* are present in the 10-20 cm DBH class. The inverted J-curve distribution is expected for a forest with natural regeneration; however, the distribution does not represent regeneration from coppicing.

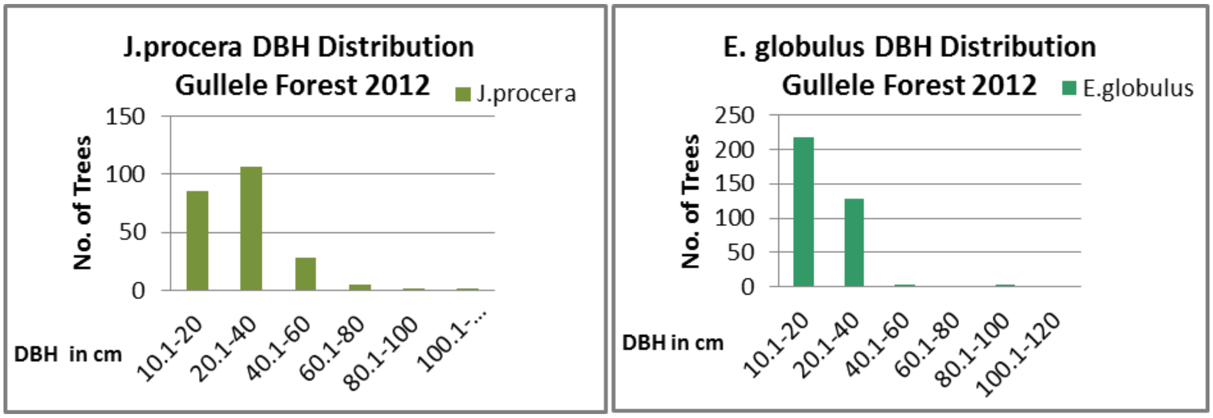


Figure 12. Distribution of DBH classes for *J. procera and E. globulus.*

Results of the forest inventory for species composition are corroborated by previous inventory efforts in the area (Belay, 2005). A discrepancy between the studies does immerge in the collection of rare and smaller diameter species. The disparity is due to random sampling and the bias against smaller DBH trees. This is noticeable in Figure 13 where a disproportionate number of "Mixed Native" rare species were identified in the 0-10 cm DBH class. A 20 factor prism is not fit to collect fine scale species composition data on shrubs and climber species with lower DBH measurements (Ruben et al., 2006). Using a factor 10 prism would include more trees per point and capture tree species known to have smaller boles such as *Rosa abyssinica*.

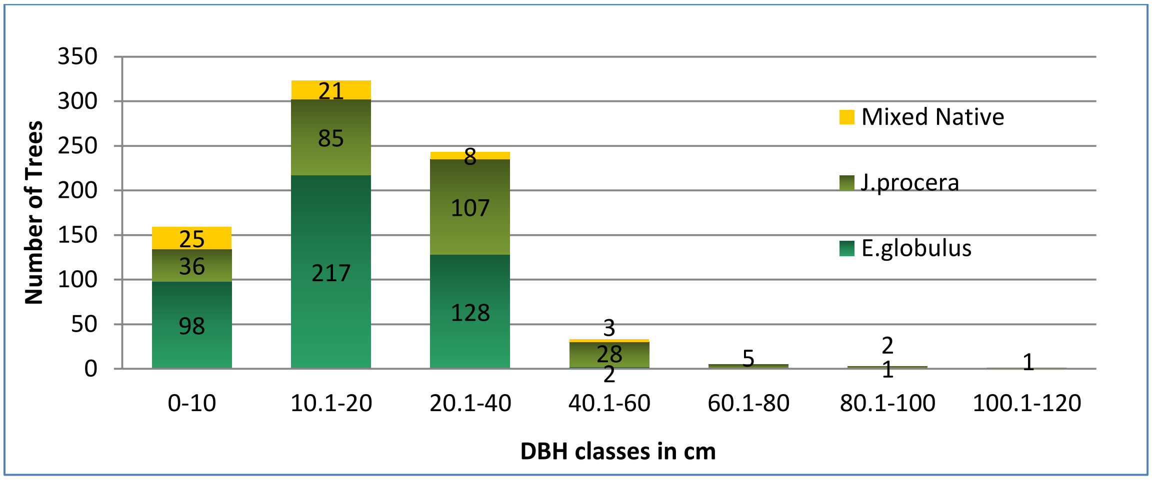


Figure 13. All tree species by diameter at Breast Height class.

The largest discrepancy was seen in the presence of *Rosa abyssinica* in the point samples. While this species was identified in four intensive modified Whittaker samples, the tree was included only once in the prism plots. Neither *R. abyssinica* nor other small DBH species are expected to be significant contributors to C estimates; however, presence of smaller stem diameter species raises the issue of prism factor when considering the best method of forest inventory to answer a research question. Considering the density values and species dominance, the initial baseline data was collected effectively and the research question was addressed using a 20BA factor prism.

The inventory of *E. globulus* revealed significant variance of DBH values both within and across the cluster samples. The variance between and within groups suggests uneven stand structure. Results of a single factor analysis of variance performed on the cluster samples are shown in Table 4. The results in Table 4 demonstrate an F statistic higher than the critical value based on the degrees of freedom and a probability value of 0.05.

Table 3. Single factor ANOVA for mean DBH between cluster sample groups.

Source of Variation	*Sum of Squares*	*Degrees of freedom*	*Mean Squares*	*F stat*	*P-value*	*F critical*
Between Groups	246.93	30	8.231	2.461	8.72E-05	1.506
Within Groups	816.02	244	3.344			
Total	1062.95	274				

Within group variation may also be explained by species composition. As observed in Figures 10 and 12, a variance of 8.5 cm between the means DBH values of *E. globulus* and *J. procera* was observed. This influences the variance within and between values per cluster. Field observations and the land cover classification developed from remotely sensed imagery corroborate a patchwork history of mixed use across the forest landscape. This suggests a pattern of *ad hoc* harvest cycles at unknown intervals relying on cut and coppice strategy. With the forest located adjacent to the urban interface and with known patterns of plantation use in close proximity this forest structure is expected (Pohjonen, 1992; Zewedie et al., 2009). The survey provided data critical to identifying and partitioning patterns of forest composition into forest stands of homogeneous structure.

A crucial management practice required to assist the strategic plan at Gullele Botanic Gardens is the establishment of experimental and management forest stands. As GBG continues to peruse the goals of the institution, the use of stands to organize management treatments is important. Stands arranged by species composition, age and diameter class will provide baseline data to monitor the health, growth and progress of management strategies. Based on the results of the forest inventory, a baseline classification of forest stands was developed. The results and procedure of this classification are explained in the conclusion and Appendix I.

Carbon Stock Estimation

Forest C was estimated as a product of biomass using allometric equations. The equations or models were developed from various sources and applied to the field data retrieved to estimate biomass for *J. procera, E. globulus* and *Olea europea.* Additionally, a generalized equation for native dry tropical tree species was applied for the purpose of comparison. Due to the availability of multiple *E. globulus* equations, the variance between model estimates was analyzed to demonstrate the value of identifying applicable models to answer a research question (Table 5).

Scaling the estimates to the landscape level is dependent on the average DBH and tree density functions as adapted from IPCC (2003) and Kirby et al. (2007). High variance observed in the density estimates of trees per hectare is due to sampling of young coppice boles of *E. globulus* with a DBH less than 3 cm. With these boles included, the density estimate reached 2,133 trees per hectare. To correct for these samples and to comply with exogenous variable requirements of allometric equations, only trees with a DBH greater than 5 cm were considered in the biomass estimates. Excluding saplings with a DBH <5 cm reduced the variance and total trees per hectare to 179,442 and 925, respectively. This accounts for a 98% decrease in total variance and a 57% reduction in estimated trees per hectare. Again the literature directs research to prefer underestimation of biomass and C for conservative and cautionary purposes (Chave et al., 2005).

Table 4. Allometric Equations used to model biomass, C stock and analyze variance

Reference	Location/ Species	Specific Research Question	Equations with D as Diameter in cm and H as Height in meters	Results of Total AGB in Mg C Ha^{-1}
Pohjonen, 1991	Central Ethiopia/ Juniperus procera	Determine volume equations and tables for Juniperus procera	(1) $\ln(v^{*}) = -2.741 + 1.92\, x \ln(\mathrm{D}) + 0.902\, x \ln(\mathrm{H})$ * Volume for trees over 7 cm DBH in decimeters	**(1) Total AGB = 11.418** Addition of specific gravity 0.44, density 535 kg/m^3 and C fraction of 0.5214 eq.(1)→ $(\frac{v}{1000})0.44 \cdot 535 \cdot 0.5214$
Antonio et al., 2007	Costal Portugal/ *E. globulus*	Develop set of complimentary equations to estimate AGB across regional boundaries	AGB = sum of complimentary tree fraction equations based on $\mathrm{AGB} = k_1 D^{a1} H^{b1}$ (2) $\mathrm{ABG} = W_w + W_b + W_l + W_{br}$ ABG= stem + stem bark+ leaves + branches	**(2*)Total AGB = 33.05** (2.1) W_w=23.82 (2.2) W_b=5.66 (2.3) W_l=0.046 (2.4) W_{br}=3.52
Zewdie et al., 2009	Central Ethiopia/ *E. globulus*	Assess the relationship between AGB and diameter and height across chronosequence of coppice age cycles	(3) $\mathrm{AGB} = 0.12(D)^{0.39}(H)^{2.08}$ (4) $\mathrm{AGB} = 0.59+0.3DH^{2}$	**(3*) Total AGB = 37.04** **(4*) Total AGB 48.21**
Perez - Cruzado et al., 2012	Western Spain / *E. globulus*	Estimate biomass, evaluate bias across estimators and ability of crown ratio to improve accuracy	(5) $\mathrm{ABG} = 0.01308 \cdot (D)^{1.87} \cdot (H)^{1.172}$ (6)Total AGB (Mg Ha^{-1}) = $b^{7} * d_g^{b8} * H_0^{b9} * N^{b10}$ With d_g as a relation of the QMD to TPHA and height, H_0 is the mean height, and N is stems ha^{-1}	**(5*) Total AGB = 28.56** **(6*) Total AGB = 33.9**
Chave et al., 2005	Various tropical tree species across nine countries	To test the assumption that a single pan-tropical allometry can be used in AGB estimation.	(7/8)$\mathrm{Ln(ABG)} = a+b+\ln(D)+c(\ln(D))^{2} +d(\ln(D))^{3} +\beta_3 \ln(\rho)$	**(7**) *Olea europea* Total ABG = 1.9** **(8***) Mixed species Total AGB = 2.5**

*Addition of 0.4694 Carbon Fraction (CF)
** Addition of 0.58 CF
***Addition of 0.5 CF

Results of the biomass estimates were tested against the original hypothesis that removal of the largest *E. globulus* trees greater than 35cm DBH would incur a significant loss of biomass and thus C stock of the forest. An analogous logic of this hypothesis follows that removal of the highest value DBH trees would lower the mean value of *E. globulus* and thus reflect a lower estimate of C stored in the forest. The hypothesis was formulated to test both the ability of the allometric equations to estimate larger *E. globulus* trees and the strategy of removing all *E. globulus* regardless of DBH size. A two tail t-test assuming unequal variances was applied to the estimates produced by allometric equations 2, 3, 4 and 5 to assess the difference in biomass estimate for *E. globulus*. Removal of greater than 35cm DBH trees saw the reduction of 7 of the largest trees from the data set of 374 trees and did not account for a significant difference.

Table 5. Summary of t-test results for *E. globulus* trees ≤35cm diameter at breast height.

Reference (equation #)	**AGB** in Mg C Ha^{-1}	**Mean Tree C** kg	**Mean tree C** kg **N=≤35**cm	**Difference in $\bar{x}$ DBH**	**Two tail t-test significance**
Antonio et al., 2007 **(eq.2)**	33.05	56.79	49.36	7.43	0.153
Zewdie et al., 2009 **(eq.3)**	37.04	63.65	61.66	1.99	0.561
Zewdie et al., 2009 **(eq.4)**	48.21	82.84	77.53	5.31	0.336
Perez Cruzado et al., 2012 **(eq.5)**	28.56	49.07	42.61	6.46	0.15

The test found that a significant difference in mean DBH is not likely below a p-value of 0.15 for any of the models based on the reduction of the seven largest E. globulus trees. Given the original hypothesis was made prior to data collection, the removal of 35cm DBH and larger trees was expected to account for a higher frequency of large trees. However, a natural break DBH values occurs above 30cm for *E. globulus* in GBG, suggesting trees larger than 30cm DBH are rare, and therefore trees larger than 35 cm are increasingly scarce across the landscape (Figure 14).

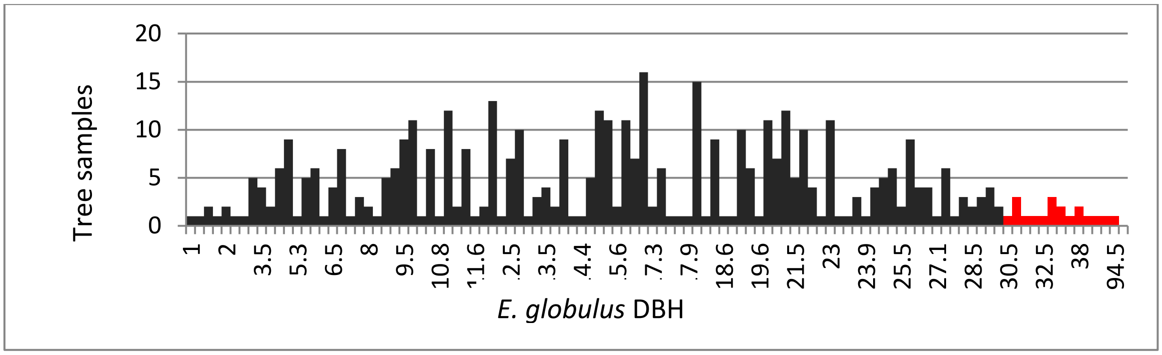


Figure 14. ***E. globulus*** **DBH sample frequency with values above 30 cm in red.**

Secondary Hypothesis

The primary hypothesis was reformulated to assess the removal of trees greater than 30 cm DBH and tested through the same methods. With the adjusted hypothesis, a significant difference was found in models 2 and 5 (Table 7). Corresponding to Antonio et al. (2007) and Perez Cruzado et al., (2012), respectively, models 2 and 5 tested below a 0.05 level of probability to be significantly different (Table 7). This may be due to the reduction of 19 trees out of 393 which accounts for 5% of the total sample size. The loss of the 19 largest trees to the mean and thus forest C estimate may also be caused by overestimation of biomass by equations 3 and 4. Table 7details the results of the reformulated hypothesis.

Table 6. Summary of t-test results for *E. globulus* trees ≤30cm DBH.

Reference (Model #)	**AGB in** Mg C Ha^{-1}	**Mean Tree C** kg	**Mean tree C** kg N≤30 DBH	**Difference in $\bar{x}$ DBH**	**Two tail t-test significance**
Antonio et al., 2007 **(2)**	33.05	56.79	45.52	11.27	0.03
Zewdie et al., 2009 **(3)**	37.04	63.65	59.18	4.46	0.18
Zewdie et al., 2009 **(4)**	48.21	82.84	72.83	10.01	0.058
Perez Cruzado et al., 2012 **(5)**	28.56	49.07	39.24	9.84	0.025

At both extremes of the DBH and height scales, the estimates of tree biomass demonstrate higher variance as compare to estimating an average tree. This is due in part because larger trees are not available or the process to remove and measure larger trees may be too destructive to include in the allometric equation formulation process (Djomo et al., 2010). Error is expected when estimating trees of large DBH values because these trees were not included and, therefore, do not inform the regression used to develop parameters of an allometric equation (Ketterings et al., 2001)

A final curiosity observed in the estimates is that the two equations selected from Zewdie et al. (2009) proved the highest estimates of biomass and were the least likely to reject the null hypothesis of a significant difference. The Zewdie et al. (2009) equations were developed with destructive samples from ten plantations adjacent to GBG in the Entoto hills of Addis Ababa. Allometric estimates should be applied to the same genus species, climate and if possible geographic region to improve accuracy (Zewdie et al., 2009; Kuyah et al., 2013). While the Zewdie equations meet the application criteria they were developed using *E. globulus* plantation trees with an average DBH of 5 centimeters. This average tree DBH contributes to poor estimation of trees larger than 5 cm and errors are expected in the biomass estimates of large diameter trees. This can be seen in Table 8, where despite the removal of outliers, equation 4 retains a variance double the remaining equations. Outliers were identified using both the three sigma standard deviation and MAD methods (Leys et al., 2013)

Table 7. One way ANOVA of carbon equations 2-5 with outliers 3 SD from the mean removed.

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Model (2)	390	20028.94	51.35625	2402.215
Model (3)	390	24403.23	62.57239	2254.333
Model (4)	390	31018.61	79.5349	5215.473
Model (5)	390	17304.26	44.3699	1819.926

ANOVA

Source of Variation	*Sum of Squares*	*Degrees of freedom*	*Mean Square*	*F-stat*	*P-value*	*F critical*
Between Groups	275367.5	3	91789.16	31.40253	1.05E-19	3.794219
Within Groups	4548167	1556	2922.987			
Total	4823535	1559				

A second ANOVA was used to explain the results of the reformulated hypothesis. In this analysis variance within each equation was reduced significantly, suggesting a high likelihood of error in larger tree estimation as shown in Table 9.

Table 8. ANOVA of reformulated hypothesis to identify significant variance despite reduction.

Groups	*Count*	*Sum*	*Average*	*Variance*	*Reduction in Variance*
Model 2	374	17024.56	45.5202	1464.878	937.3367
Model 3	374	22135.66	59.18627	1833.022	421.3105
Model 4	374	27240.27	72.83495	3720.987	1494.486
Model 5	374	14675.68	39.2398	1105.115	714.8111

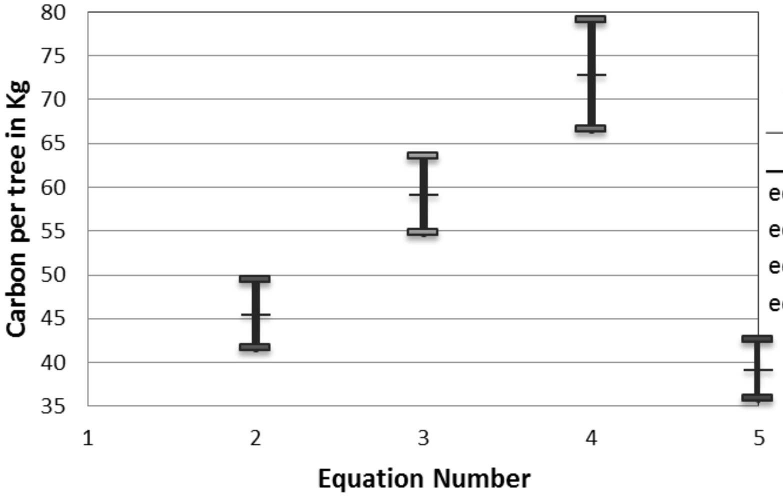
ANOVA

Source of Variation	*Sum of Squares*	*Degrees of Freedom*	*Mean Squares*	*F-stat*	*P-value*	*F critical*
Between Groups	251055.2	3	83685.07	41.20386	1.4E-25	2.611
Within Groups	3030253	1492	2031.001			
Total	3281308	1495				

To better explain the significance identified in the ANOVA test, the Post hoc Tukey's Honestly Significant Difference test was employed. This test is liberal when the sample size is equal, and, therefore has greater chance of committing a type one error (Ott et al., 2010). For this reason a conservative significance level of ρ= 0.01 was chosen to test for a significant difference between groups. With the above ANOVA results, the Tukey's statistic of 10.3 was calculated from the following equation:

Eq. 3 $$HSD = Q\ score * \sqrt{\frac{MS\ within}{n}}\ ;\ 4.4\sqrt{\frac{2031}{374}} = 10.3 \text{ Tukey's statistic}$$

A difference between two means larger than the Tukey's HSD of 10.3 signifies a significant difference as signified in Figure 15 by the confidence intervals. All equations differ significantly with the exception of equations 2 and 5, which are credited with only a 6.28 difference in mean values. The results of the Tukey HSD test point again to the high variation and potential error in the estimates from equations in Zewdie et al. (2009).



Pairwise difference of estimates
Tukey's HSD statistic = **10.3**

	eq.2	eq.3	eq.4	eq.5
eq.2	0.00			
eq.3	13.67	0.00		
eq.4	27.31	13.65	0.00	
eq.5	6.28	19.95	33.60	0.00

Figure 15. Confidence intervals and Tukey's statistic results comparison.

Management implications for forest stands

Establishment of forest stands is a dynamic process. Forest stands were delineated within the Gullele Botanic Gardens using a combination of spatial analyst tools in ArcGIS 10. Methods of forest stand delineation structured by Kriging interpolation (Matheron, 1967) and zonal statistics (Bell, 1981), are included in a procedure in Appendix I to provide clear instructions on utilizing and editing this data. Spatial data produced and analyzed in this report will be made available to the Gullele Botanic Gardens in a Geo-database format. Figure 16 provides an example of the forest stand boundaries developed with the Kriging process and demonstrates the mean basal area values by stand.

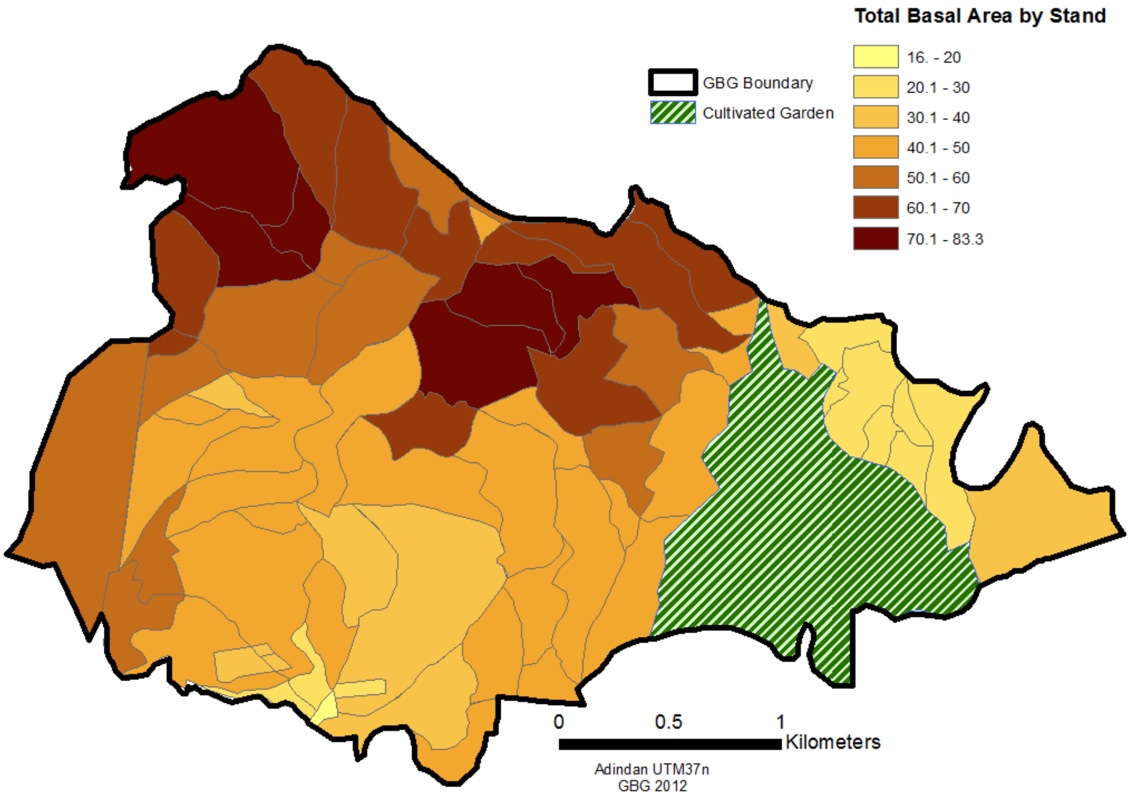


Figure 16. Map of forest stands with interpolated mean basal area by stand

The complete set of stand attribute variation maps as well as C and inventory visualization results are accessible in Appendix II.

The mountainous topography of the conservation area equates to multiple slope and aspect values present in a single forest stand. Stands with obvious majorities were classified with a “dominate” aspect. Stands without a clear majority are symbolized in gray and classified as “South (All directions included)” in Figure 17 because the average slope across the boundary corresponds with a 179° azimuth. Typically these polygons were large and therefore included a larger range of elevation, slope and aspect values. The mean values for the larger polygons must therefore be viewed with skepticism when planting sensitive species.

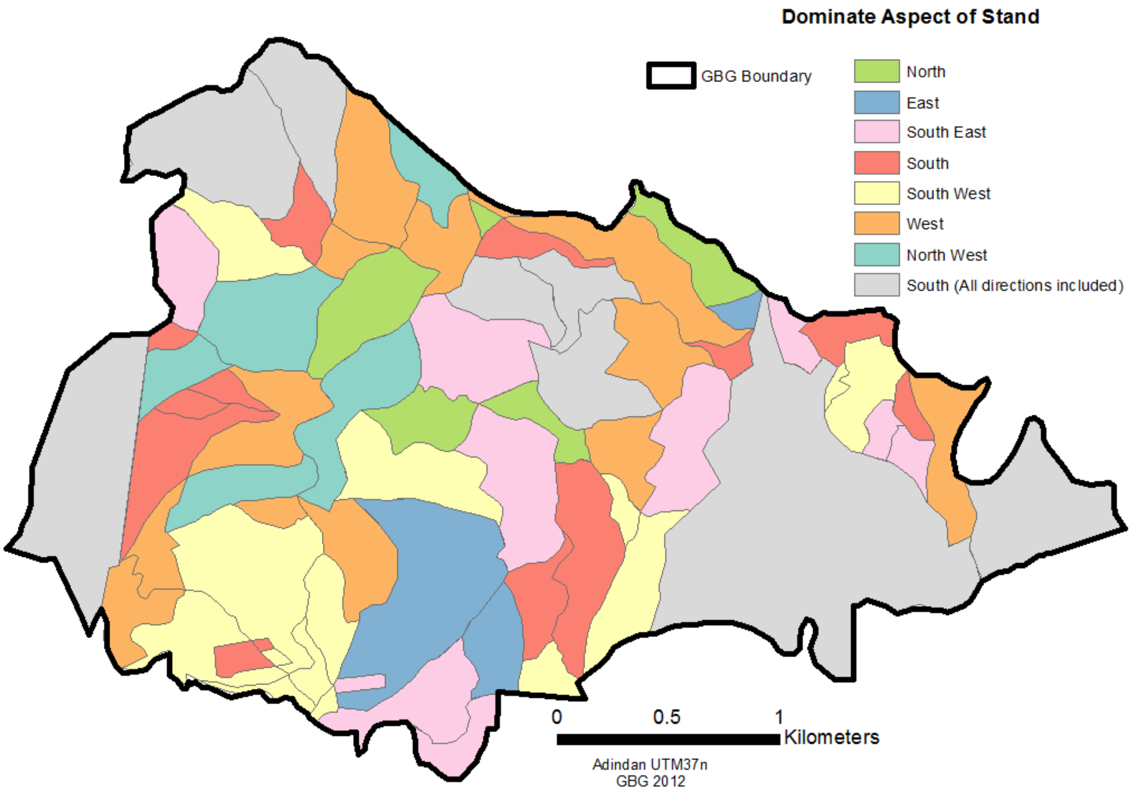


Figure 17. Dominate aspect of forest stands in Gullele Botanic Garden.

Discussion

The analysis of multiple allometric equations designed to estimate biomass of *E. globulus* underscores high levels of variance across estimates and speaks to the value of testing multiple models to fit a targeted research question. As the implementation phase of forest cover type change at GBG moves forward, a monitoring effort to identify the total removal of *E. globulus* biomass may provide the management team with a goal of replacement biomass in the form of native tree species. This goal will help to restore the forest to previous levels of C storage, as well as provide ecosystem services such as higher sub surface-water retention and wildlife biodiversity, which may exceed those previously supported in the *E. globulus* dominate forest. This baseline analysis of C stock estimates C currently stored is between a range of 44 and 64 Mg C per ha^{-1}. This per hectare estimate translates to a total forest C stock between 27,572 and 39,744 Mg, respectively. As the ANOVA and Tukey's statistic demonstrate the upper limit of these estimates, and therefore variance, are significantly different from more conservative estimates of *E. globulus* biomass which in turn drive the total into the territory of overestimation. An error of underestimation is preferred in both the research and management side of a project due to legal implications related to misleading high estimates of biomass and C (Chave et al., 2005). For this purpose a conservative estimate below 44 Mg C ha^{-1} is recommended.

The following caveats and assumptions should be considered with the results of the C stock estimation portion of this report: (1) Supervised Classification with ArcGIS is limited by resolution and user defined classes. Overestimation of higher represented training classes introduces bias into the image classification results. However, results of the forest classification were corroborated with forested area estimates provided by the prism point locations. A total of 88% of the sample points were identified as forested area versus 90% total area forest predicted by the supervised classification.

To restore the forest to a level of C stock assumes replacement of current forested area with native forest cover which is likely to overestimate survival rates of native species. Resource poor soil and competition for resources with *E. globulus* will complicate the restoration strategy, and future estimates of required forest replacement must consider the survival rate. The management policy will include a resolute seedling maintenance strategy to establish native seedlings in reforested areas. A continued planting effort will be required to compete with coppicing stumps of *E. globulus* and adverse conditions throughout the conservation area.

Harvested areas and the cultivated garden account for 21% of the total conservation area. These areas are either recovering coppicing stands or in the case of the cultivated garden under construction to complete the botanic garden infrastructure. In both cases these areas are expected to provide positive contributions to the total C stock. Continued monitoring beyond this baseline study is necessary to track and support the C stock of the GBG forest.

Vegetation Inventory Results

In total, 139 species were identified in 28 modified Whittaker plots which account for 2800 m^2 of total sample area. The area sampled makes up less than 0.05% of the total conservation area. Generalist species such as *Alchemilla pedata* and *Geranium* species were identified in most plots and contributed to a value of 37 species found in more than 25% of plots (Table 10). Conversely, specialized species were uncommon throughout the landscape. As identified by Hanski and Gyllenberg (1997), the Species Area (SA) and

Distribution Abundance (DA) curves show two sides of the same story when a pattern of local abundance and narrow distribution is identified (Figure 18).

Table 9. Species inventory summary statistics

$\bar{x}$ species frequency (SE)	Standard Deviation	Max plot Frequency	Present in ≥ 25% of plots	Present in ≤ 3 plots	Present in only 1 plot
4.92 (±0.37)	4.4	24	37	66	35

The species area or the analogues species accumulation curve shows a pronounced leveling off trend after 25 plots. The final remaining three plots surveyed did not recover new species. The curves in Figure 18 show matching trends for the total plot area of 100 meters, and the subplot areas of twenty five and one meter plots.

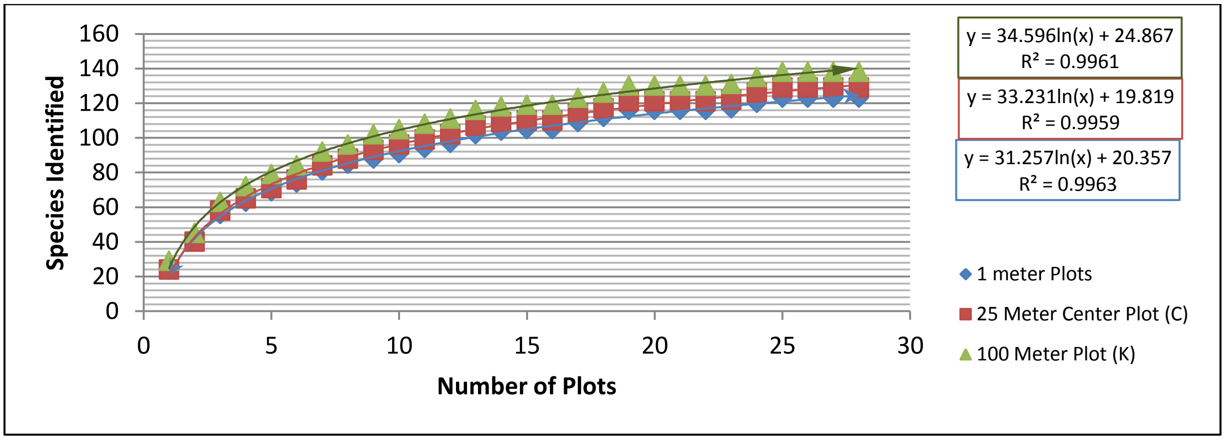


Figure 18. Species Area Curve of modified Whittaker samples subdivided by nested sub plots

These curves demonstrate the diminishing returns gained by intensive sampling over large plot areas. The order in which the plots were sampled and the species distribution pattern contributed to the fact that new species are first identified in the one meter sub plots. Additional species located in the center 25^2 meter plot and in the full 100^2 meter plot are then collected and contribute to the total species count. Species identified in either the center plot or the total plots are characteristic of uneven distribution throughout the plot. These species were often tree or shrub species not present in the one meter plots.

The leveling off result is characteristic of a uniform vegetation pattern across communities and the landscape. In a tropical rainforest, a pattern in line with the habitat heterogeneity hypothesis will demonstrate markedly different results (Preston, 1960). Areas of high diversity may demonstrate a more liner relationship when represented in a species area curve (Hanski and Gyllenberg, 1997). This particular species inventory demonstrates a consistent pattern across the landscape with infrequent and localized areas of variation. The sampling intensity sufficiently captures the species composition (Figure 19); however, species rarity and total number of species are expected to continue to vary and increase respectively with higher sampling intensity.

Species Rarity

A primarily homogenous pattern of species composition with localized rarity of plant species was observed across the modified Whittaker sample plots. A total of 37 species were recovered in 25% or more of the plots and conversely 35 species appeared in only one plot. *Alchemilla pedata* was the most common species as it was found in all but four plots. *Agrocharis melanantha* and *Geranium abaicum* were the second and third most common being found in 79 and 64% of plots respectively. It is beyond the strength of this study to discuss the rarity and fine scale variability of species present in only one plot. A higher sampling intensity would identify additional species, but the sharp decline in species frequency suggests species not captured would be rare and unevenly distributed throughout the forest.

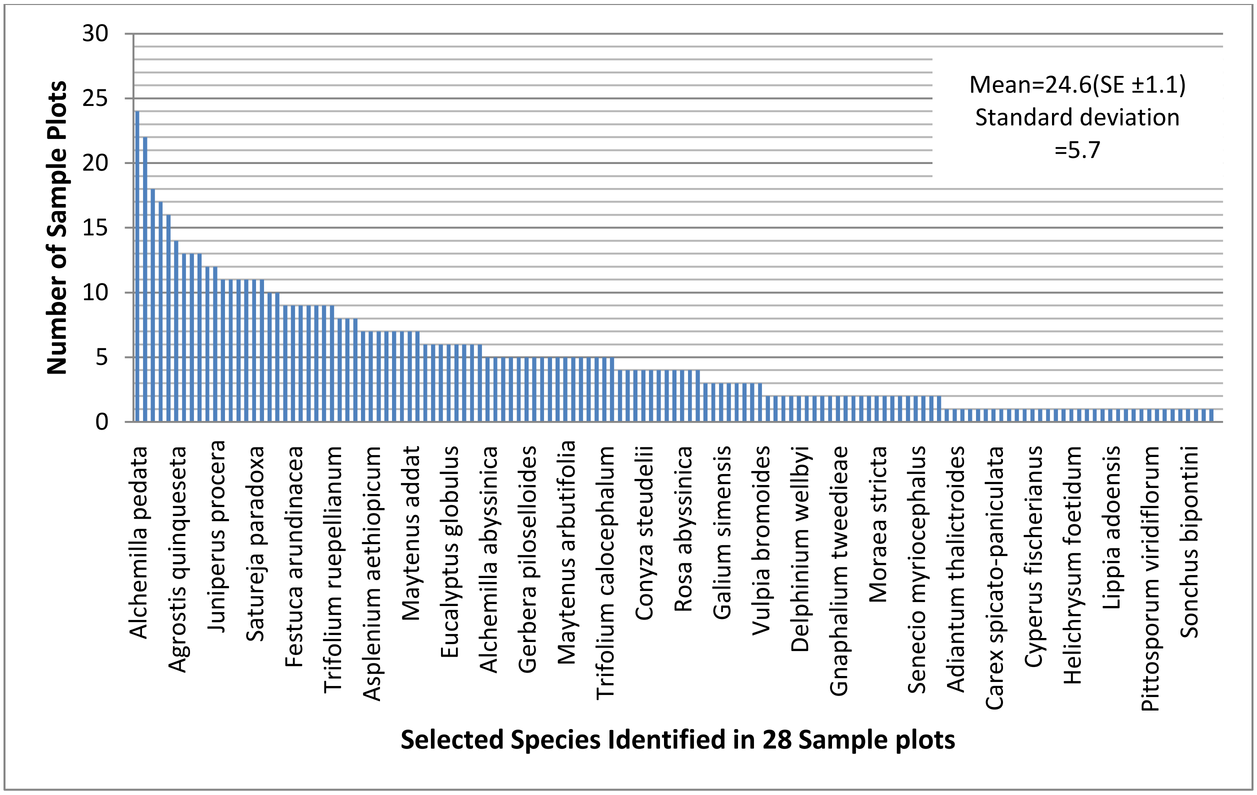


Figure 19. Frequency of species in sample plots.

On average 24.6 species were identified per sample plot with a standard error of 1.1, which ultimately speaks to the uniformity of plots given the sample size (Figure 20). Plots with high species counts such as 3 and 19 represent areas where specialized and generalist species were present. Conversely, plots with few species such as 22 included barren areas located in recently harvested *E. globulus* plantation forests.

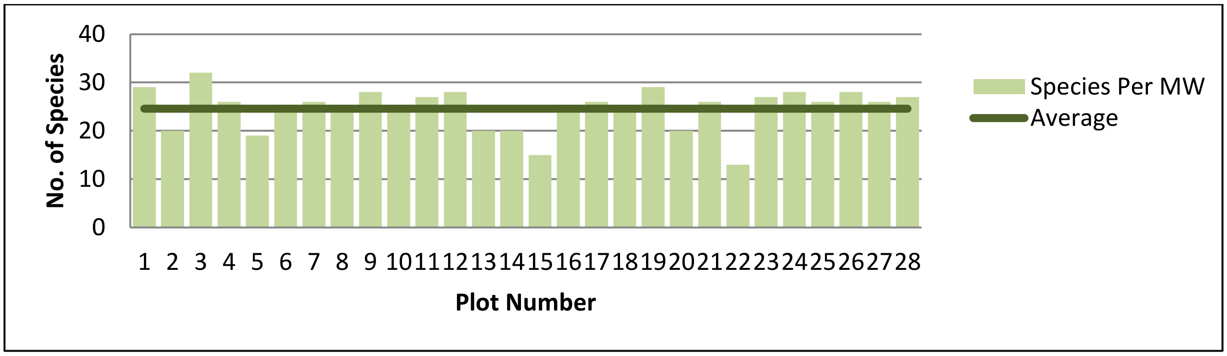


Figure 20. Total number of species recovered per plot.

A majority, comprised of 78 species, of species retrieved are classified as herbs. Shrubs and trees combined to account for more than a quarter of species identified (Figure 21). The remaining species, fall into the following order of percent from high to low: grass, trees, ferns, fungi and succulents.

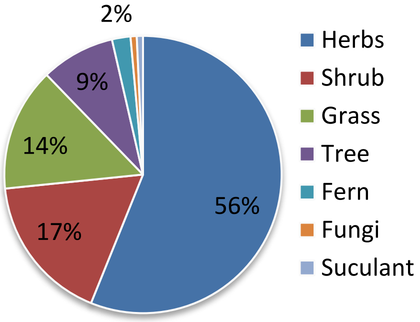


Figure 21. Percentage of species recovered by category.

Plot Uniqueness

Plot uniqueness was calculated for all sample plots based on the following formula:

Eq.4

$$Plot\ Uniqueness = 1 - \frac{\sum Species\ proportional\ frequencies\ of\ total\ plots}{Plot\ species\ richness}$$

This calculation reflects the combined rarity of species present in a given plot on a scale from 0 being common to 1 being completely unique. Plots with high richness comprised of rare species will have a higher uniqueness value. Inversely, a plot comprised of common species, regardless of total richness, will score lower on the uniqueness range. Plot uniqueness results fit within a limited range from 0.6 to 0.76 for the most unique. The map in Figure 22 displays the limited range of plot uniqueness with the highest values in large red points. The minimum value of aggregate proportional species frequency at the plot level is attributed to plot 13 which contributes to the maximum value of uniqueness.

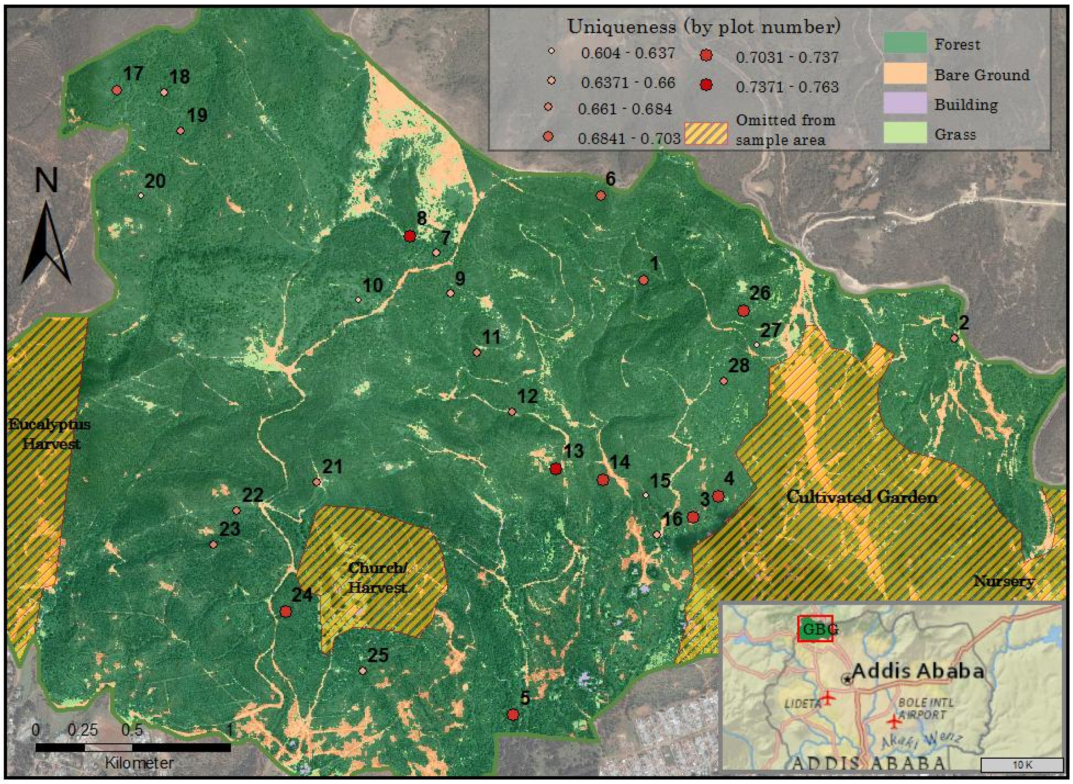


Figure 22. Map of uniqueness by modified Whittaker plot number and summary statistics of uniqueness.

Plot 13 is not overtly more rich or rare than other plots; however, a narrative of this plot is revealed by the uniqueness calculation. *Alchemilla pedata* was absent in plot 13. Although other common species such as *E. globulus* and *J. procera* were recovered, the absence of the highest proportional frequency strongly influenced the uniqueness calculation for this plot. A similar pattern is seen in plots missing the most common species with plot 6, 14, and 26 revealing relatively higher uniqueness scores of 0.69, 0.73, and 0.72, respectively.

Plot uniqueness was tested against ancillary data for correlation (Table 11). Uniqueness was negatively correlated with elevation and found to be a significant result; however, given the limited range of elevation represented in sample area, additional plots are necessary to classify these results significant and corroborate similar results in the literature (Crk et al., 2009). A second correlation, of plot number and new species, is an echo of the species area curve findings. Further, this is autocorrelated based on the understory species homogeneity of the area.

The correlation values listed in table 11 and the limited sample size do not support species modeling techniques for uniqueness nor locations of niche habitats. The limited range of plot uniqueness points again to uniformity on the landscape.

Table 10. Cross correlation results for vegetation inventory plots.

	New Species	*Elevation*	*Uniqueness*	*Slope Percent*	*Plot#*
New Species	1.00				
Elevation	-0.13	1.00			
Uniqueness	0.30	-0.39*	1.00		
Slope Percent	0.05	0.26	-0.22	1.00	
Plot #	-0.72	0.08	-0.28	-0.01	1.00

*Significant to a level of two tailed .035%

However, the calculation of uniqueness is dependent on the identification of rare species and the sample size of an inventory. The identification of additional rare species would increase with a higher sampling intensity. This would widen the range of uniqueness while improving the likelihood of identifying niche areas of higher diversity leading to elevated uniqueness. Alternatively, a higher sampling intensity would identify plots of low uniqueness and widen the bottom limits of the range.

Conclusion

The forest and vegetation inventories and the corresponding analysis provide a baseline for future research. Continued monitoring of tree and plant species with similar sampling methods is recommended as the conservation project moves beyond the construction and implementation phases. Successful species type change and conservation of native plant species are wholly dependent on accurate monitoring programs capable of identifying and correcting complications. This is perhaps most true in the related externalities of forest harvest and physical stump removal. A management plan designed to monitor erosion and water loss from type change would be of great benefit to future implementation phases.

Prioritization of areas for forest type change and native species restoration should be based around the delineated stands. An example of this prioritization would be to restore species such as *Hagenia abyssinica (Koso),* which exist in high elevation areas with abundant water, in the northern high elevation slopes. The area in green on the northern boundary in Figure 17 represents an area of the highest elevation in the forest as well as an area of north facing aspect. Based on the known range of the species, restoration of Koso seedlings may be prioritized to this stand. Once a base of Koso seedlings are established, favorable adjacent stands capable of supporting the species may be identified and planted. Higher survival rates, and thus lower maintenance and seedling replacement, are the ultimate goal of a restoration project. The organization of forest stands will objectively assist in this goal.

The Gullele forest is heavily impacted by harvest and fuelwood extraction from urban interface, and because of this location, biomass estimates based on allometric equations are expected to be skewed as compared to a natural forest. Further, pressure from fuel and leaf litter collection may limit the success of native species restoration because of the impact this activity has on available soil nutrients. In addition, the seedlings may be disrupted by informal grazing, which range from moderate to heavy across the forested area.

Additional steps are necessary to carry out the mission of scientists at GBG such as the installation of experimental stands and monitoring stations to collect site specific temperature, precipitation and water runoff data. These steps will continue to establish GBG as a center for restoration and conservation research in the horn of Africa. Collection of climatic variables will support efforts by students and professional researchers to evaluate the impact of GBG on the immediate site and surrounding area. A synergistic relationship between research and growth of the GBG program is expected. Continued support and development of conservation and research networks at GBG will result in benefits to multiple spatial scales from local to global as GBG establishes and fills its' niche in global conservation efforts.

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Appendix I: Delineating forest stands with ArcGIS 10

Key tools used: **Project, Feature to Polygon, Erase, Merge, Kriging, Clip**, **Editor, Zonal Statistics, Join,** and **Add Field**

Introduction

This tutorial is intended for use on forest stands with high resolution imagery (<30m cell size) and intended for use in spatial analysis of forest stand structure.

Best use of this tutorial will be accomplished with data that is projected and processed prior to beginning the **Data management** section. However, brief instructions on projections are included as an example. It is recommended all rasters be exported to TIFF formats for best use in ArcGIS.

Data management

In order to edit and analyze spatial data it must be projected. Each layer or data set must be in the same projection and datum. To accomplish this use the projection tool in Arc GIS.

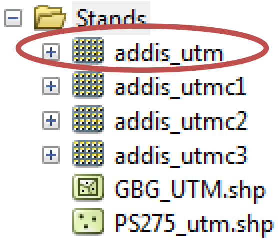
This tool is located under **Data management > Projections and Transformations > Feature >**
For more information on Projections and datums refer to the following online tutorial:
http://ethgis.colostate.edu/WebContent/WS/GISTraining/5_2_Lesson1.html
In this example the following data needs to be projected:

Data NAME:	<Data format>	*metadata*
Addis_Ababa1.tif:	<Remotely sensed imagery Raster>	*SPOT 2008 imagery of northern Addis Ababa Ethiopia1.6m resolution in tif format*
GBG_UTM.shp:	<Polygon Feature>	*Boundary of Gullele Botanic Garden projected in UTM 37N in the Adindan datum*
PS275.shp:	<Point Feature>	*Point samples of prism forest inventory collected in 2012 containing species, tree density, biomass and carbon estimates at each point*
Roads.shp:	<line Feature>	*Line features of main and auxiliary roads digitized from SPOT 2008 imagery.*

Section 1. Dividing an area into polygons with roads data

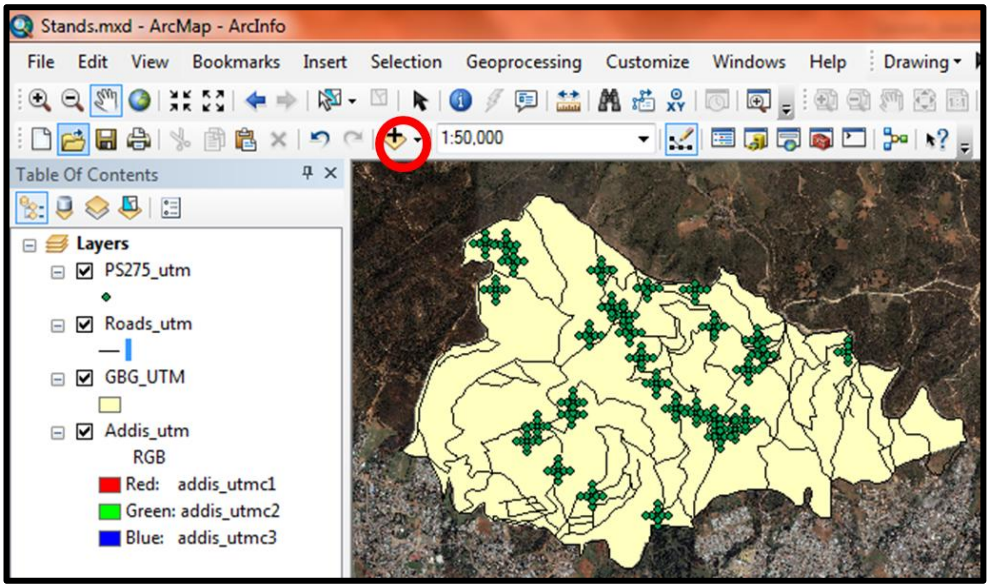
STEP 1: Create a working folder named “Stands” where you will store all inputs and outputs for your analysis.

2: Use the stand folder as the output location for each file you project AND name each file with “_utm” at the end to identify them as projected layers.



Stands
addis_utm
addis_utmc1
addis_utmc2
addis_utmc3
GBG_UTM.shp
PS275_utm.shp

The tiff format will appear as separate the bands in ArcCatalog, but you only need to add the first image without the band number into Arc Map for analysis.



3. Add the projected data using the add data button circled in red above.

Notice that when the roads layer is overlaid on the GBG_utm polygon the layer divides the entire polygon into smaller polygons. To partition and manage stands in the forest it will be practical and efficient to use the roads as natural boundaries for some of the stands.

NOTE: For this analysis the roads must overlap the complete boundary of the area. In this example roads surround GBG which create the boundary polygon. Also the roads must connect across the polygon as seen in the figure above. This is required to divide the forest into smaller polygons. If you do not have a roads layer or the roads do not fit these requirements you may digitize the roads by adding a new layer and editing this layer based on visual evidence of roads from the remotely sensed image.

4. Use the Feature to Polygon tool to divide forest into stands with the roads layer.

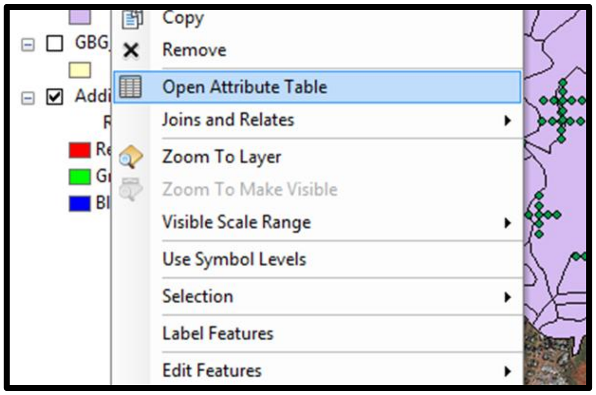
Select the completed roads layer as the input feature.

Set the Environments… extent to “same as GBG_utm” to process the layer inside the boundary only.

Save the file as Roads_poly in your stands output folder and click ok.

The Road_poly layer is a polygon layer with as many polygons as there are road divisions.

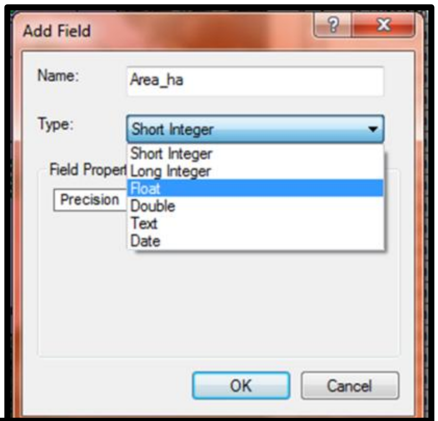
Open the attribute table of the Road_poly layer by right clicking on the layer name and selecting open attribute table:



5. Add a new field to this attribute table.

Click on the file icon in the table Table and select add field.

Name the new field Area_ha and select <u>**float**</u> for the field type:


Add Field

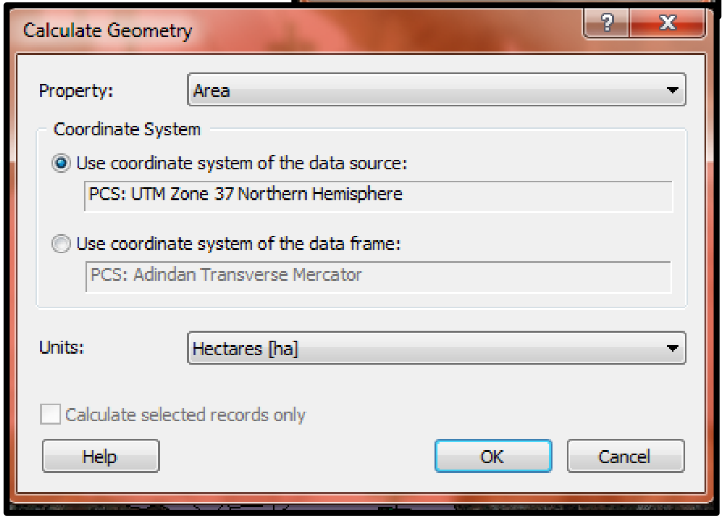
Name: Area_ha

Type: Short Integer

Name the area with an “_ha” to explain the area is in hectares

6. Calculate geometry of the new polygon layer.

Right click on the field name “Area_ha” and select calculate geometry. In the pop up window select Area for property.


Calculate Geometry

Property: Area

Coordinate System

● Use coordinate system of the data source:

PCS: UTM Zone 37 Northern Hemisphere

○ Use coordinate system of the data frame:

PCS: Adindan Transverse Mercator

Units: Hectares [ha]

☐ Calculate selected records only

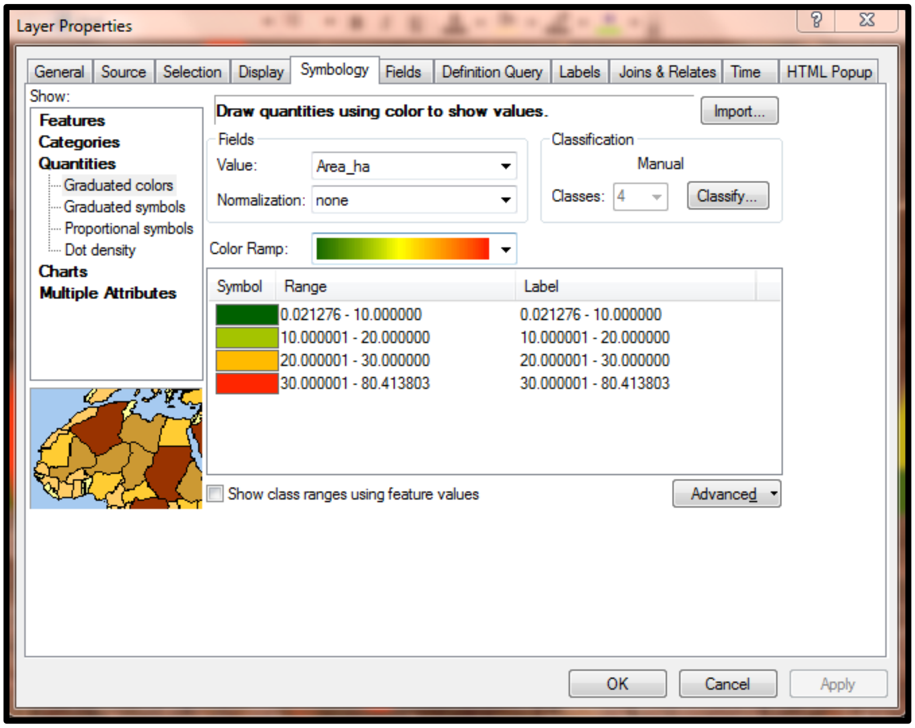
Use the coordinate system of the data source and finally select Hectares [ha] as the unit of calculation. Then click OK.

Now you have a field which lists the area of each polygon created by the roads data.

<SAVE YOUR MAP: > select file save and save your map as Forest_stands.mxd in your “stands” working folder.

In this example the polygons are then symbolized by **Graduated colors** under the symbology tab to highlight the largest polygons in red and smaller in green. (To reach the symbology tab double click on the layer name in the table of contents.)

In this example there are many polygons above the area of 20 hectares and are possibly too large to be managed as one stand for conservation purposes.



Draw quantities using color to show values.

Fields
Value: Area_ha
Normalization: none

Classification
Manual
Classes: 4

Color Ramp:

Symbol	Range	Label
🟩	0.021276 - 10.000000	0.021276 - 10.000000
🟩	10.000001 - 20.000000	10.000001 - 20.000000
🟨	20.000001 - 30.000000	20.000001 - 30.000000
🟥	30.000001 - 80.413803	30.000001 - 80.413803

☐ Show class ranges using feature values

As an example the following arbitrary classification was given based on “manageable sizes”:

Dark Green 0-10ha for manageable
Light Green 10.1-20ha for manageable
Yellow for 20.1-30ha for unmanageable
Red for 30.1-80ha very unmanageable

You may notice many large polygons remain after converting the roads file into the polygon layer. If your files appear to be divided into satisfactory and manageable areas the division component of this analysis is complete.

Section 2. Subdividing polygons by forest and geographic attributes

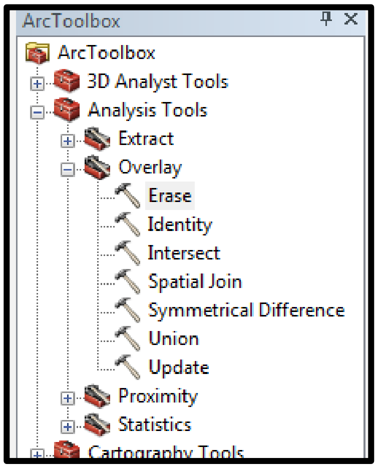
To divide the areas further known areas of recent harvest or alternative land use such as infrastructure, water, grass etc. will be removed.

Step 1. Add layers of harvests or other exclusion polygons.

In this example 5 polygons (3 harvests, 1 church area and 1 cultivated garden) exist in the total area.

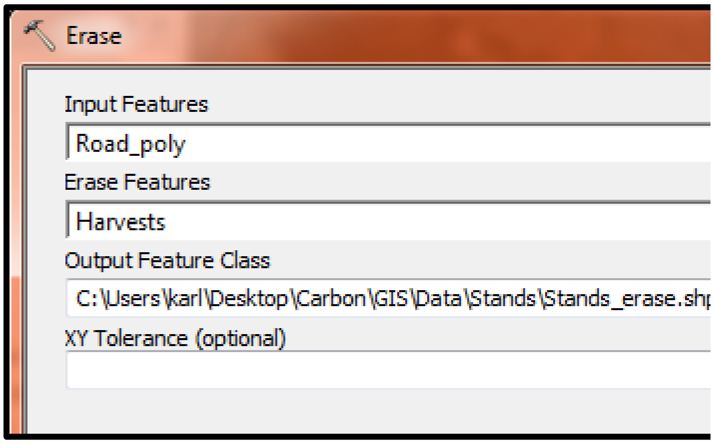
To remove the areas first **Erase** with the exclusion polygons and then **Merge** them together with the stand polygons.

Step 2 Open the analysis toolbox and under the Overlay tools select **Erase.**



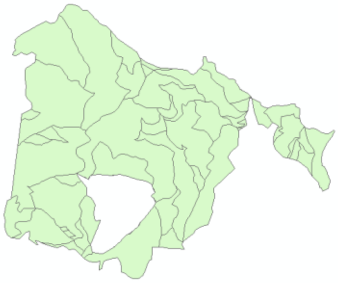
Select the "Roads_poly" and the input and the "Harvests" layer as the Erase Features. This tool will remove the area of the "Harvests" which overlap the "Roads_poly" layer. Be sure to name this new feature a NEW name so you **do not overwrite** the "Roads_poly" data.

Click OK.



Erase

Input Features
Road_poly
Erase Features
Harvests
Output Feature Class
C:\Users\karl\Desktop\Carbon\GIS\Data\Stands\Stands_erase.shp
XY Tolerance (optional)



By itself the example **Erase** output file "Stands_erase" now looks like this:

The area of harvest, church and cultivated garden are removed leaving empty space.

3. Merge the data together to create one polygon file**.**

Add these layers back in by merging the harvest into the place where it erased the stand polygons.

Select merge tool from the geoprocessing menu.

Add the "Stands_erase" and "Harvest" layers as inputs in the merge tool.


Merge

Input Datasets

Harvests
Stands_erase

Output Dataset

C:\Users\karl\Desktop\Carbon\GIS\Data\Stands\Stand_merge.shp

Field Map (optional)

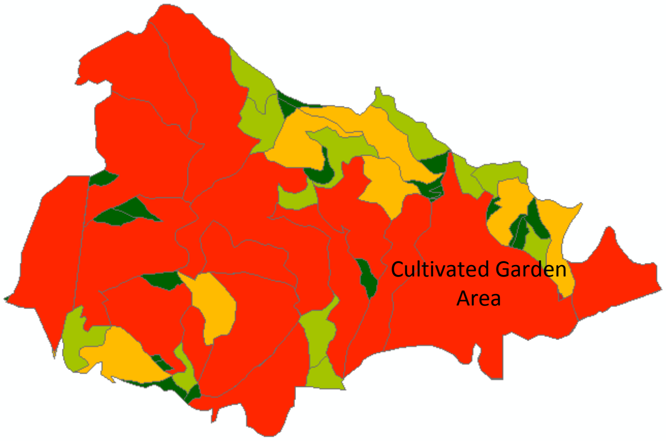
Name the output “Stand_merge” and click OK.

The output will include the attribute information of the values of Area for the “Roads_poly”.

4. Recalculate the geometry

Open the new “Stand_merge” attribute table with a right click on the layer name. To re-calculate the areas simply right click on the name area and select calculate geometry as in **Section I. Step 6**. This will overwrite the old values with a new area calculation.

In this analysis the new output, using the classification from section I, shows the merged layers with polygon areas changing based on the removal of unsuitable stand areas.



Your stand delineation may be complete at this point! If you have satisfactory stands continue through the next section but skip Example 1, 2 and 3 in section III.

<SAVE YOUR MAP: > select file save and save your map as Forest_stands2.mxd

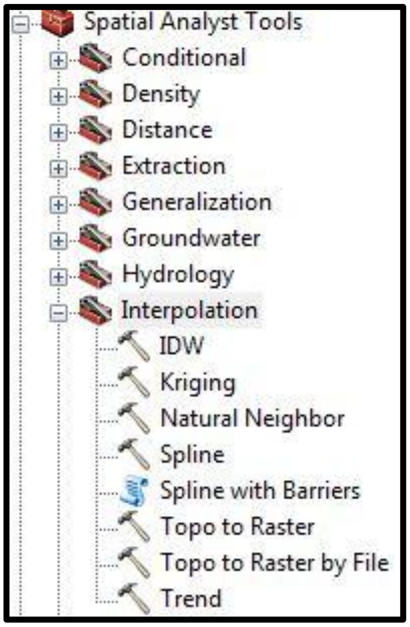
Section 3. Species Basal Area interpolation with Kriging

Forest stands are grouped by areas of similar species composition, age class, tree density per area, or forestry measurements important to a specific management plan.

In this case the stands will be divided based on information collected in forest inventory points. Species basal area, species composition, and access from roads were identified as the three selection criteria for this example. Section I. already accounts for the roads criteria. This section will focus on the other two divisions: species composition and basal area.

The point file "PS275" has many attributes collected on 275 forest inventory samples. The samples were randomly located throughout the forest in clusters of 9 stratified points. To fill in the areas where sample points are not present this example will use **Kriging,** which is one method of spatial **interpolation**.

Interpolation is a method of constructing new data points within the range of a discrete set of known data points. Often this is used to create a raster surface from points of temperature, or to fill in gaps where data has not been collected based on statistical predictions. There are a few methods of interpolation tools included in ArcGIS. However, this example will focus on Kriging because the output will lend itself well to spatial statistics. The interpolation tools are located under spatial analyst toolbox:



Step 1 **Open** the Kriging tool.

Select "PS275_utm" as the point input feature.

For the Z value field select "Nat_BA" as the input. Nat_BA is the basal area value of native tree species other than *Juniperus procera* identified in the samples throughout the forest.

Select the stands folder for your output and name the output "K_native" for Kriging Native.

Leave the **Semivariogram** properties as default. These are the methods which determine the specific method of Kriging. To learn more again try the "show tool help" button.

Select the output cell size for the raster. In this example the cell size will be the same as the input Digital Elevation Model, which is 30m.

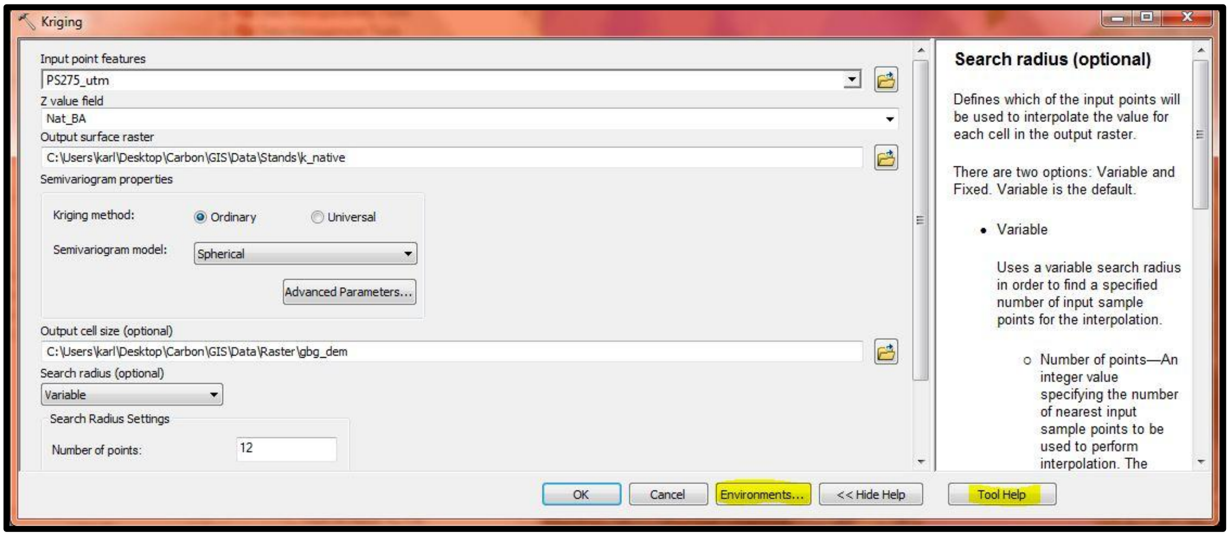
Keep the default of **Variable** search radius.

IMPORTANT: The search radius setting allows you to select the number of points you will use to interpolate each cell in the raster. In this example 12 points are selected for the following reasons:

(1) Each sample cluster is made up of 9 points so values will likely be interpolated based on the cluster value and 3 additional "Nearest Neighbor" samples.
(2) With 275 points based on the scale of 612 hectares of forest using a higher value of 12 is beneficial because this accounts for only 4% of total samples. (A high percentage of the sample will even out the interpolation surface raster while a low value will include more variability.)

(3) Experiment with different values! For this example a choice of 12 points demonstrates plausible results.

ALSO IMPORTANT!!! Set your ENVIRONMENTS Environments… **before you click ok.**



Kriging

Input point features: PS275_utm

Z value field: Nat_BA

Output surface raster: C:\Users\karl\Desktop\Carbon\GIS\Data\Stands\k_native

Semivariogram properties

Kriging method: ● Ordinary ○ Universal

Semivariogram model: Spherical

Output cell size (optional): C:\Users\karl\Desktop\Carbon\GIS\Data\Raster\gbg_dem

Search radius (optional): Variable

Search Radius Settings

Number of points: 12

Search radius (optional)

Defines which of the input points will be used to interpolate the value for each cell in the output raster.

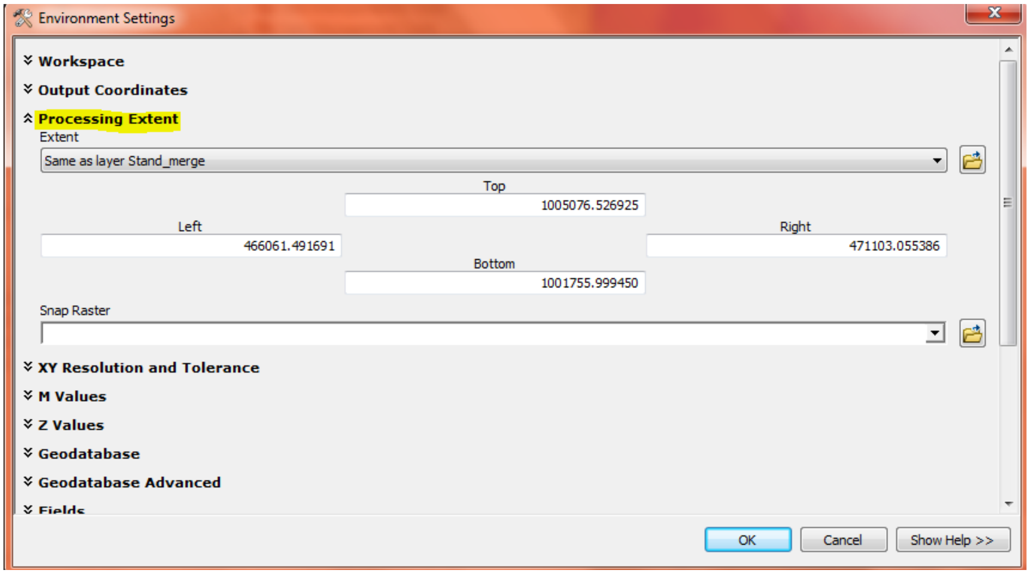
There are two options: Variable and Fixed. Variable is the default.

- Variable

  Uses a variable search radius in order to find a specified number of input sample points for the interpolation.

  - Number of points—An integer value specifying the number of nearest input sample points to be used to perform interpolation. The

If you do not set your environments to an extent larger than the points your raster will only interpolate up to the edge of your points. For this example the extent is set to “same as “Sample_merge”” so the entire stands polygon will have values interpolated for them.



Environment Settings

Processing Extent

Extent: Same as layer Stand_merge

Top: 1005076.526925

Left: 466061.491691

Right: 471103.055386

Bottom: 1001755.999450

Snap Raster:

Click OK to run the tool.

Now you will **REPEAT step 1** two more times but select the other species BA as the input:

2)RUN Kriging with “PS275_utm” as the point input feature. Use all the same inputs as in the first tool (defaults, 12 points)

For the **Z value** field select “Jupr_BA” as the input which is the basal area value of *Juniperus procera*.

Name the output K_JUPR

3) RUN Kriging with “PS275_utm” as the point input feature. Use all the same inputs as in the first tool (defaults, 12 points)

For the **Z value** field select “Eugl_BA” as the input which is the basal area value of *E. globulus*.

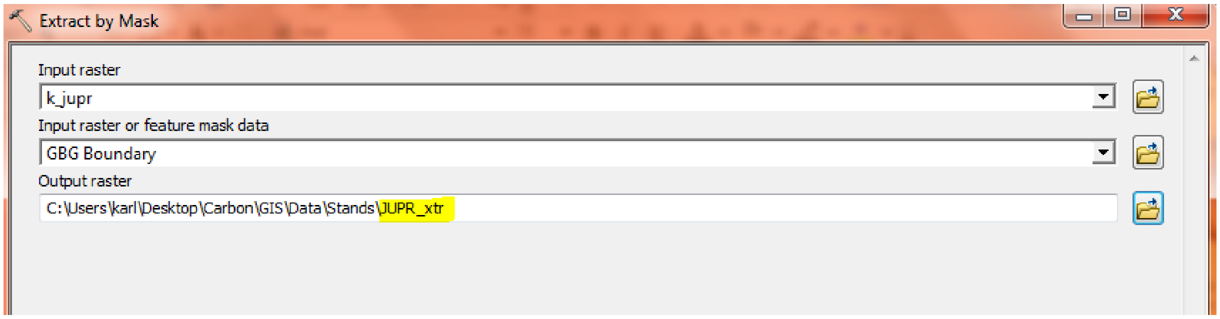
Name the output K_EUGL

The resulting outputs will give you 3 raster layers of the respective interpolated species values.

Notice the various range of these values. In the case of all 3 rasters the maximum value of each range **DOES NOT** match the maximum for that species of BA. Interpolated values are similar to an average but dependent on the distance from that samples used to make the prediction. As is true with most averages the mean is less than the maximum value.

The Kriging surface predicted by the tool may extend beyond the boundary of your study site. You may wish to **Clip** or **Extract** the Kriging raster values to the GBG boundary or to your sample extent.

4) Open the **Extract by mask** tool from Spatial analyst Tools> Extraction and Extract by mask



Input raster: k_jupr

Input raster or feature mask data: GBG Boundary

Output raster: C:\Users\karl\Desktop\Carbon\GIS\Data\Stands\JUPR_xtr

Select the first Kriging raster (in this example k_JUPR) and the boundary for the mask data. Save the output raster in the “Stands” folder as JUPR_xtr to signify this has been extracted.

Click OK

Now REPEAT this tool 2 more times for the k_nativ and k_EUGL rasters

Now the Kriging rasters are masked to the boundary and ready to be classified.

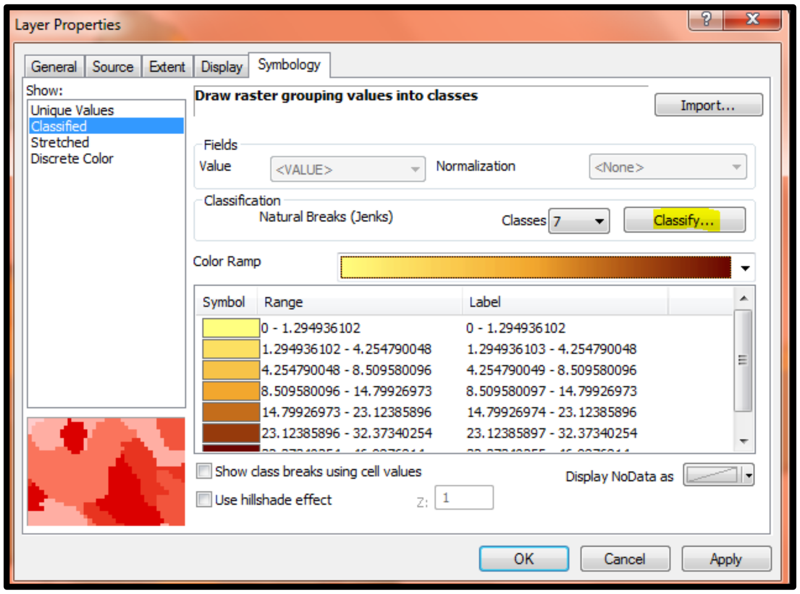
NOTE: *This process is highly dependent on the results of your data and driven by your management goals. In the case of the botanic garden and arboretum in this example there is a bias to identify native sections of the forest and identify areas suitable for cover type change.*

After exploring multiple classification schemes of the Kriging results this example selected the following classification based on % of values in the raster.

For similar classification method follows these steps and repeats the classification **FOR EACH RASTER**:

1) Open the symbology tab under properties
2) Click the classified section on the left side of this window
3) Choose 7 classes
4) Select the classify button
5) Under the classify window choose Manual and then select the percent button.

   Enter the following values (it is easier to start with the maximum values 100, 95 and work down)



Show:
- Unique Values
- Classified
- Stretched
- Discrete Color

Draw raster grouping values into classes

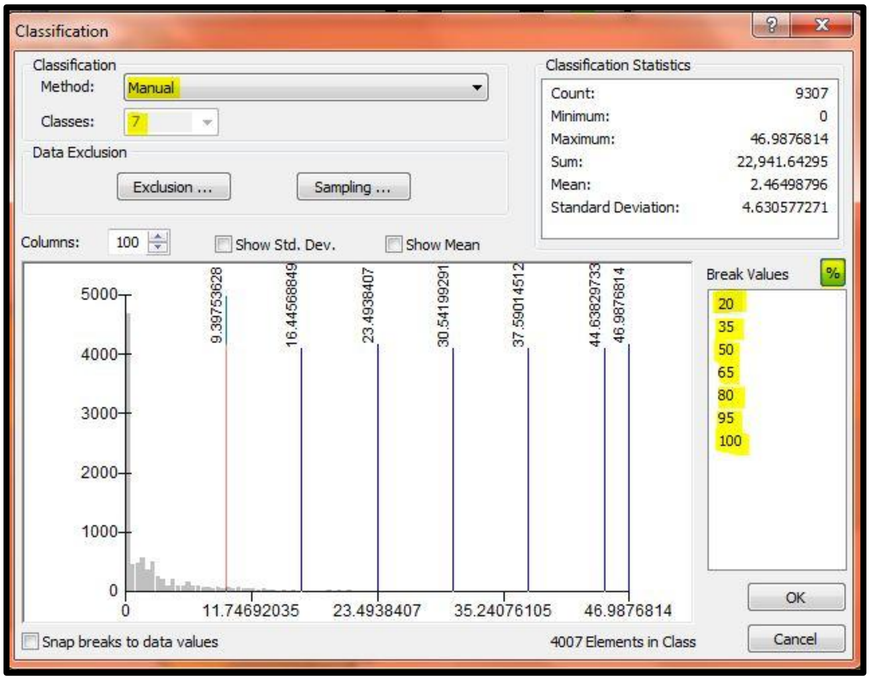
Fields
Value <VALUE>
Normalization <None>

Classification
Natural Breaks (Jenks)
Classes 7

Color Ramp

Symbol	Range	Label
	0 - 1.294936102	0 - 1.294936102
	1.294936102 - 4.254790048	1.294936103 - 4.254790048
	4.254790048 - 8.509580096	4.254790049 - 8.509580096
	8.509580096 - 14.79926973	8.509580097 - 14.79926973
	14.79926973 - 23.12385896	14.79926974 - 23.12385896
	23.12385896 - 32.37340254	23.12385897 - 32.37340254

☐ Show class breaks using cell values
☐ Use hillshade effect Z: 1
Display NoData as



Classification
Method: Manual
Classes: 7
Data Exclusion

Columns: 100 ☐ Show Std. Dev. ☐ Show Mean

Classification Statistics

Count:	9307
Minimum:	0
Maximum:	46.9876814
Sum:	22,941.64295
Mean:	2.46498796
Standard Deviation:	4.630577271

Break Values
20
35
50
65
80
95
100

☐ Snap breaks to data values
4007 Elements in Class

Click Ok.

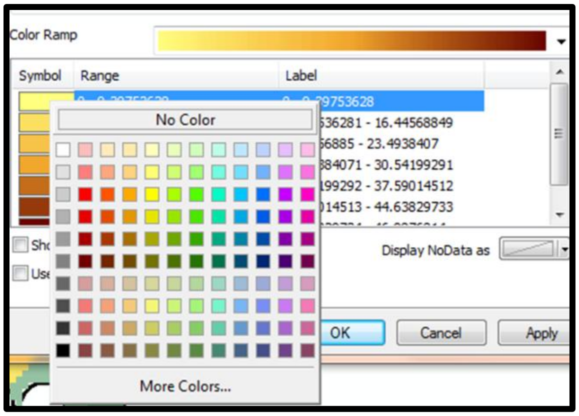
These values were chosen because they will exclude 20% of the low values in the first class, then show equal intervals of 15% for 5 classes with a final 5% class to showcase the highest BA values.

Again, this classification may not be ideal for you study or analysis purpose so be experimental and creative at first with the classification methods but then be consistent across Kriging output rasters.

Select a graduated or directional color ramp- for this example Native species are rare and important to the forest so these values are in light yellow to dark brown and listed at the top of the table of contents-

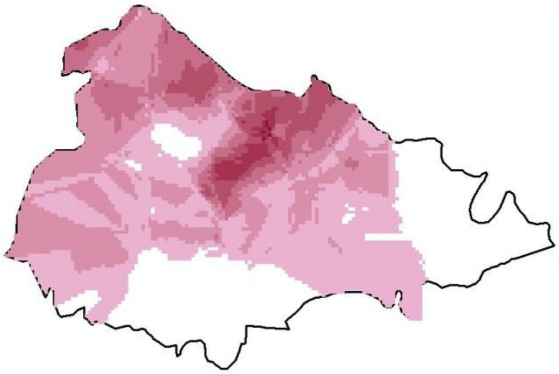
Next change the first class into a clear or null color value.

To do this double click on the first color and choose the first option of “No Color”

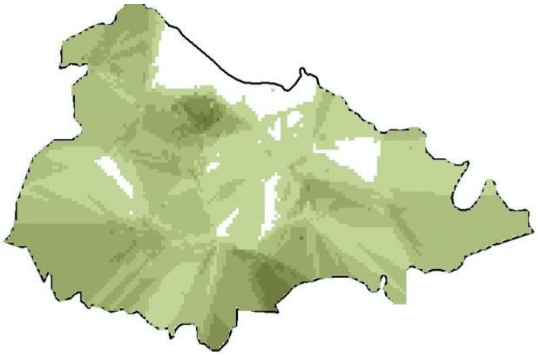


REPEAT this classification process for each raster and choose a <u>unique</u> color ramp for them.

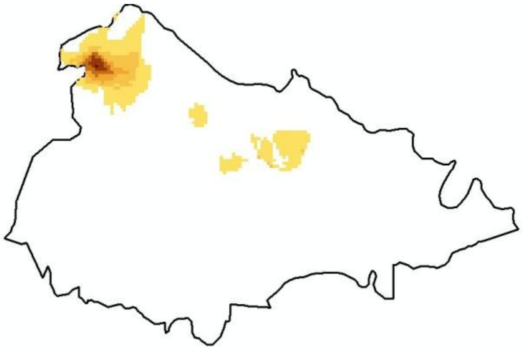
E. globulus results



Juniperus procera results



Native species Kriging results

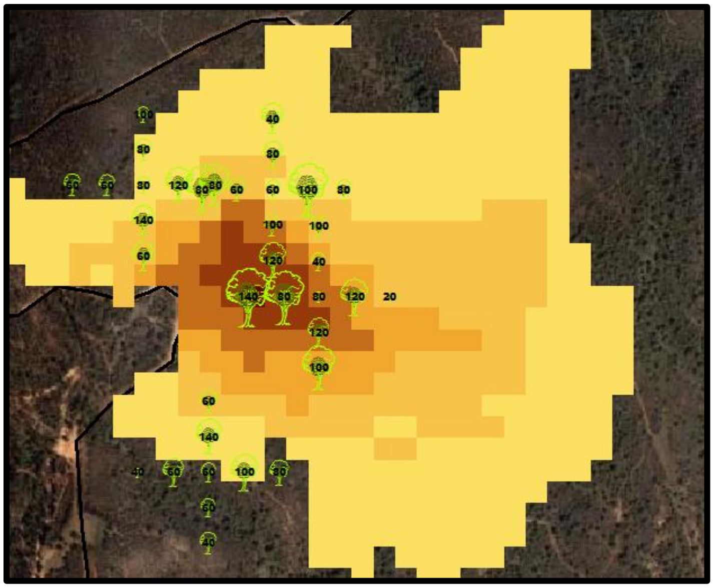


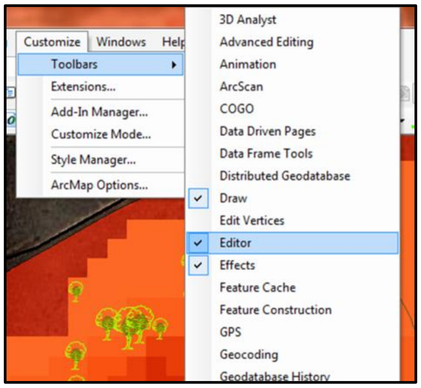
<SAVE YOUR MAP: > select file save and save your map as Forest_stands3.5.mxd

After the classification the procedure becomes subjective. It will require the best judgment of the editor to divide stands based on species boundaries and practical management goals. This process is made easier if high resolution imagery is available to visually confirm forest stands. Three examples of partitioning forest stands are given. Attempting these examples will require strong working knowledge of the forest and practice with ArcGIS editing tools.

Example 1) Forest stands subdivision based on native tree locations

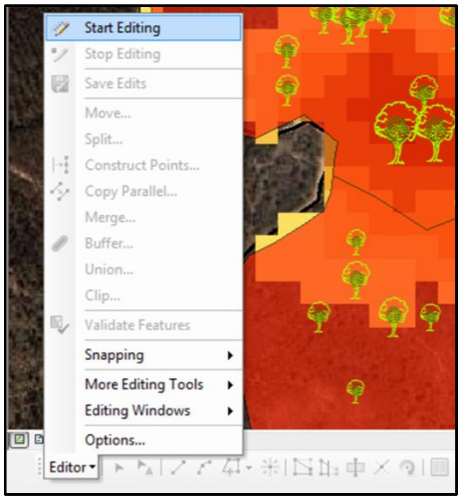
In the north west corner of the forest the samples identified a pocket of high native trees species basal area and diversity. The Kriging tool has interpolated a high likelihood of native tree basal around the sample points. As distance increases away from this area the tool has less confidence that native trees will be present because with increased distance the forest samples did not identify native species. For this reason we can reshape the forest stand polygon around this area by opening an **Editing session**.





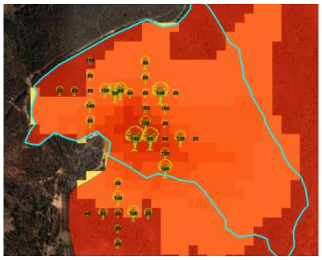
To add the editor toolbar open the "customize" menu and select Toolbars and make sure the editor is checked.

Next on the editor toolbar select "Start Editing" and use the select button to select only the polygon layer you wish to edit.

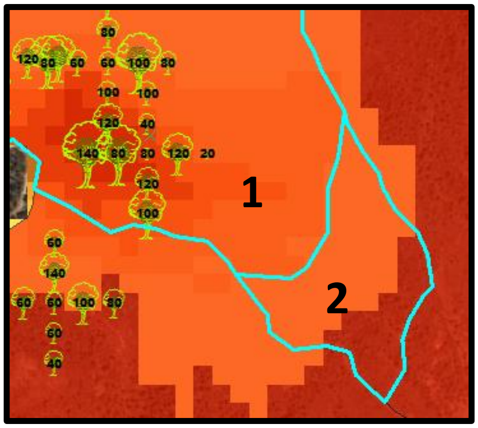


With the select tool click on the polygon you wish to edit, which in this example is "stands_merge". Be sure only one stand is selected. You may need to turn off other layers to select only one polygon at a time.

Now you are ready to edit this stand. Click on the "cut polygon" tool in the editing toolbar.



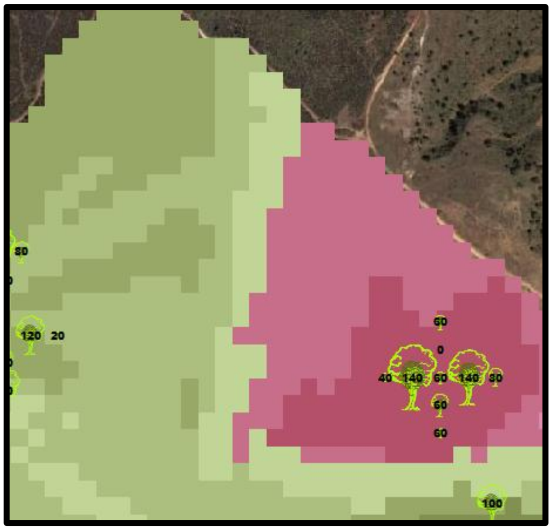
NOTE: Once you cut a polygon you will create a new polygon which does not have a symbol because the area or geometry has not been calculated. Once you make a cut you should recalculate the area of the new polygon to see if it is a manageable size. Start on one edge of the polygon and click to add a new vertex. Add vertices until you reach the other side of the polygon you want to cut. Double click to finish the cut and create a new polygon.



In this case a new smaller polygon (**2**) is created, which shows some native species and some *E. globulus*.

Check to see if this polygon will match visually with the remote sensing image.

Using the split polygon tool the choice here was made to continue the stand delineation close to the road in black but below the area delineated by the Native Species orange in higher concentrations. The northern polygon (**1**) will contain a mixed native stand with homogenous basal area as will the bottom polygon which contains a higher proportion of *E.*



globulus.

Example 2) Dividing stands based on exotic vs. native locations

In this example there is an area of forest with a clear distinction between native Juniper species and exotic *E. globulus* spp. This polygon will be split based on the interpolated boundary between the two species.

REMINDER: this boundary is an output from a GIS tool and should not be considered a final product or a perfect stand. All stands should be ground-truthed for accuracy and additional samples should be taken where blank areas of the map exist.

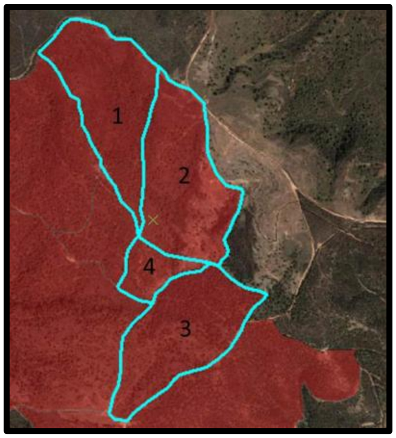
Turn on **ONLY** the *J. procera* Kriging and Kriging rasters to see the boundary in this section.

To check for topological accuracy turn on and off these layers to see if there are visible changes in the forest image. In this case it may be possible to see a change in forest stand structure which corroborates the boundary made by the two Kriging surfaces.

In this image the difference between tree densities is visible and corresponds with the *J. procera* Kriging layer transition. For this exercise the *J. procera* layer will be used as the baseline but the polygon will be split along the visual divide of trees.

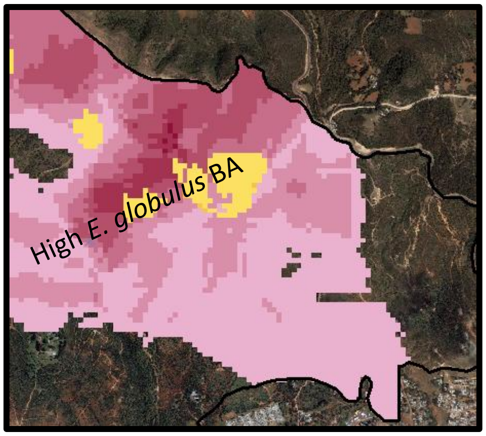
Use the **cut polygon tool** to divide the larger polygon. Because of the size of this polygon three cuts will be made to form 4 stands out of the main polygon.

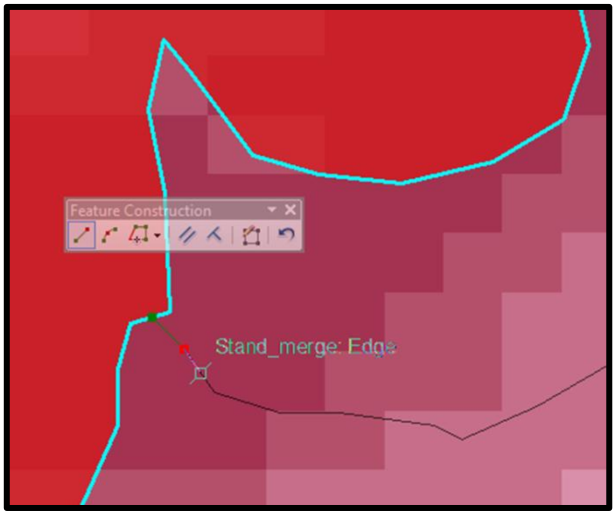
The finished polygons:



Example 3) Reshaping stands based on Basal Area values.
In this example a small polygon will be incorporated into a larger polygon to include similar areas *E. globulus* BA.

This central stand area is dominated by *E. globulus* and therefore the stands should be divided by similar areas of BA or age class. For this example the “reshape feature” tool will be used.

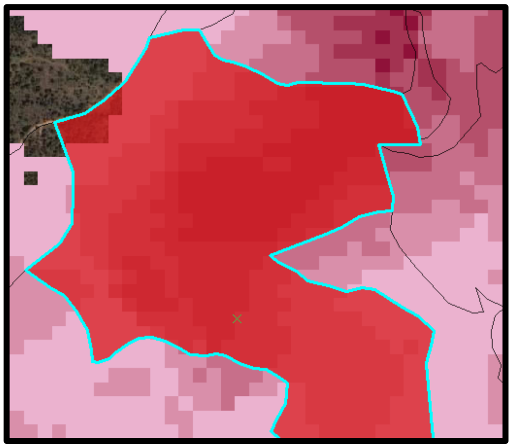




To begin click the **reshape feature tool** and find an intersection of vertices in the polygon that need modification. When using this tool it is easy to mistakenly overlap another polygon boundary.

For this reason you must delete and modify other polygons. Keep the data organized to avoid duplication and overlapping stands.

Continue to add vertices where the new boundary should fit. When you have traced the new area finish the modification with a double click on the boundary of the selected polygon.

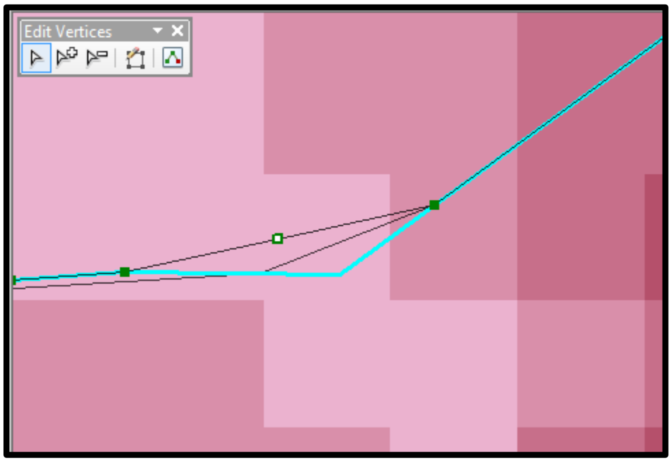


The polygon is now larger and using the **Cut polygon tool** these polygons are divided down to a manageable stand size based on similar BA values.

CARFULLY DELETE EXTRA polygons.

To delete extra polygons first select them and then either open the attribute table and click the delete selected button or simply hit the delete key once the extra polygon is selected.

You will notice this is a slow process and many “slivers” or extra pieces of polygons will exist. To remove these out of the polygon layer use the delete or add vertex tools which are connected to the “Edit vertices” tool.



Simply add or move the vertices to line up on other polygons, or delete extra areas.

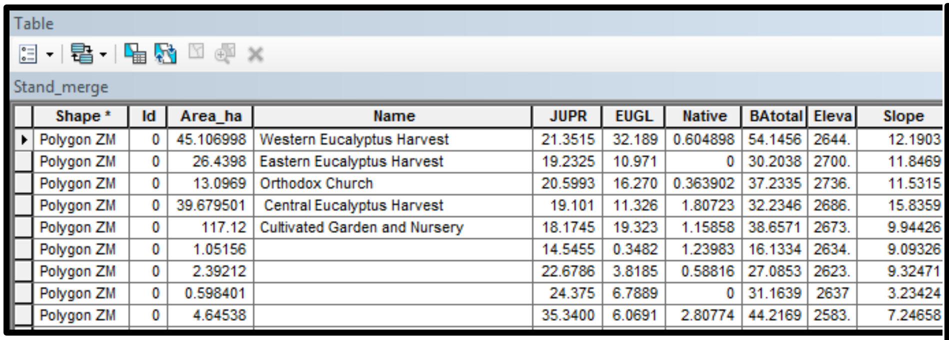
Be sure to remove all of these inaccurate polygons because they will introduce error to any calculations based on stand area.

<SAVE YOUR MAP: > select file save and save your map as Forest_stands4.mxd

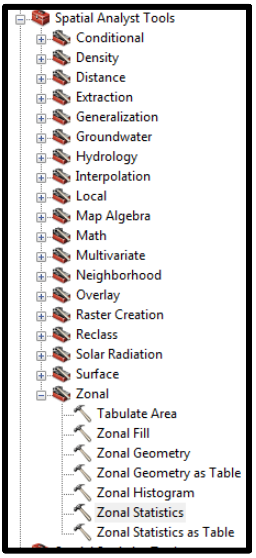
Section 5

The final section of this process will assign attribute data to each of the forest stands. You could fill in the attribute table manually; however, this could take a long time and is prone to errors.

The best method is to use the **Zonal Statistics as Table** tool to calculate and assign a mean value for each polygon. If this tool is run for each of the Kriging rasters, and then twice more for slope, and elevation the following attribute is possible:



Shape *	Id	Area_ha	Name	JUPR	EUGL	Native	BAtotal	Eleva	Slope
Polygon ZM	0	45.106998	Western Eucalyptus Harvest	21.3515	32.189	0.604898	54.1456	2644.	12.1903
Polygon ZM	0	26.4398	Eastern Eucalyptus Harvest	19.2325	10.971	0	30.2038	2700.	11.8469
Polygon ZM	0	13.0969	Orthodox Church	20.5993	16.270	0.363902	37.2335	2736.	11.5315
Polygon ZM	0	39.679501	Central Eucalyptus Harvest	19.101	11.326	1.80723	32.2346	2686.	15.8359
Polygon ZM	0	117.12	Cultivated Garden and Nursery	18.1745	19.323	1.15858	38.6571	2673.	9.94426
Polygon ZM	0	1.05156		14.5455	0.3482	1.23983	16.1334	2634.	9.09326
Polygon ZM	0	2.39212		22.6786	3.8185	0.58816	27.0853	2623.	9.32471
Polygon ZM	0	0.598401		24.375	6.7889	0	31.1639	2637	3.23424
Polygon ZM	0	4.64538		35.3400	6.0691	2.80774	44.2169	2583.	7.24658



To build this attribute table the process of **Joins** to attach tables will be used. Then the joined fields will be used to calculate a new field for each of the attributes created by the zonal statistics tool.

First **Add 6** new fields using float as type to the “stand_merge” attribute table: **JUPR, Native, EUGL, BAtotal, Elevation,** and **Slope**

Then find the **Zonal Statistics <u>as Table</u>** tool under Spatial Analyst tools then Zonal toolboxes.

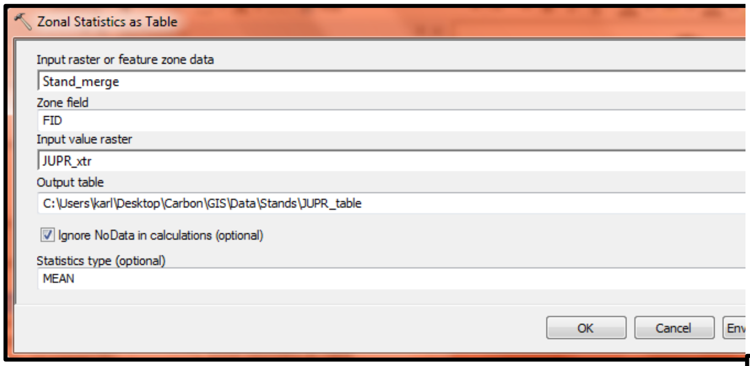
Open the Tool and select the polygon layer as the input “stand_merge”

Then select FID as the zone field.

Choose the raster you wish to calculate the statistics for as the input value raster. In this case JUPR_xtr

Name the table as JUPR_table

Finally select MEAN as the statistic you wish to calculate.



Zonal Statistics as Table

Input raster or feature zone data: Stand_merge

Zone field: FID

Input value raster: JUPR_xtr

Output table: C:\Users\karl\Desktop\Carbon\GIS\Data\Stands\JUPR_table

☑ Ignore NoData in calculations (optional)

Statistics type (optional): MEAN

Click OK

The output of this tool will be a .dbf or table in ArcMap, which can then be attached to our polygon attribute table using the join.

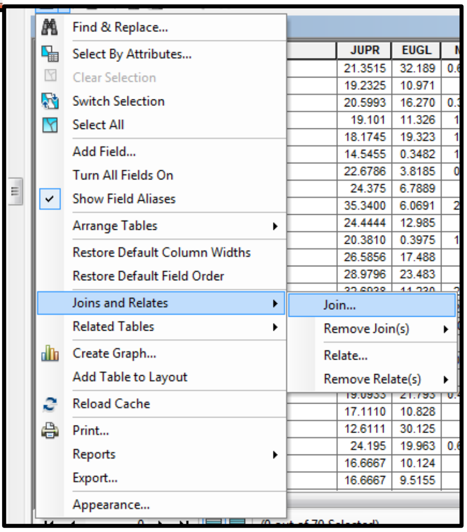
Repeat this process using "Stand_merge" as the input and FID as the zone field for all of the rasters mentioned. The result will be 5 tables total:

JUPR_table, Native_table, EUGL_table, Elevation_table, and **Slope_table**

With these tables you may now join the values to the polygon attribute table.

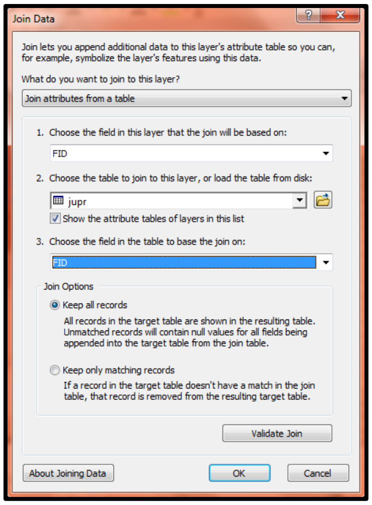
Simply right click on the polygon layer and open the attribute table.

Then select Joins and relates and then **Join**.



JUPR	EUGL
21.3515	32.189
19.2325	10.971
20.5993	16.270
19.101	11.326
18.1745	19.323
14.5455	0.3482
22.6786	3.8185
24.375	6.7889
35.3400	6.0691
24.4444	12.985
20.3810	0.3975
26.5856	17.488
28.9796	23.483
17.1110	10.828
12.6111	30.125
24.195	19.963
16.6667	10.124
16.6667	9.5155

In the join table be sure to include FID as the field you wish to join. Remember FID was used to build the zonal statistics so the FID will now hold the average for each of the polygons with a corresponding FID.



Join Data

Join lets you append additional data to this layer's attribute table so you can, for example, symbolize the layer's features using this data.

What do you want to join to this layer?

Join attributes from a table

1. Choose the field in this layer that the join will be based on: FID
2. Choose the table to join to this layer, or load the table from disk: jupr

☑ Show the attribute tables of layers in this list

3. Choose the field in the table to base the join on: FID

Join Options

● Keep all records

All records in the target table are shown in the resulting table. Unmatched records will contain null values for all fields being appended into the target table from the join table.

○ Keep only matching records

If a record in the target table doesn't have a match in the join table, that record is removed from the resulting target table.

Click OK and repeat this process for each table you need to join

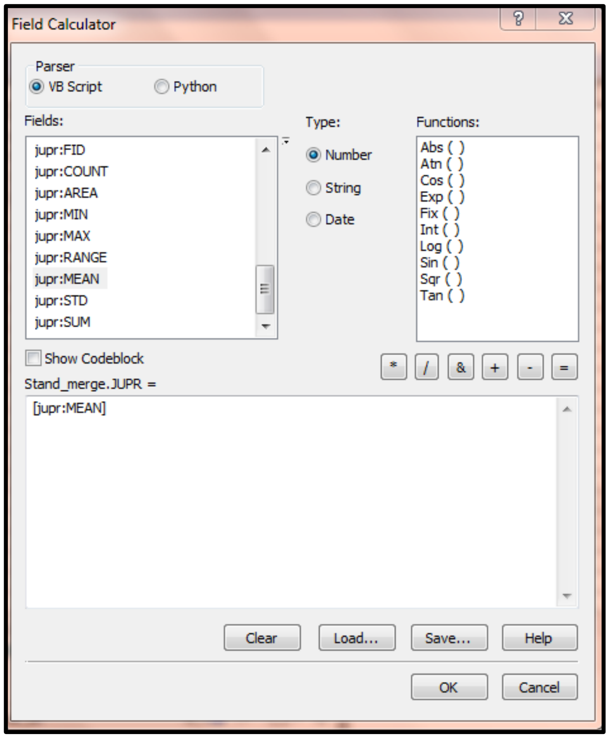
Once all tables are joined symbolyze the layers using graduated colors.

Perminatly join these tables by using the **Join Field** tool or by calculating the field = the join field that matches. In this example the JUPR field we added in the first step of this section would be = to MEAN JUPR_table

For This step right click on the empty field name "JUPR" and select **Field Calculator.**

Then simply double click on jupr_table:MEAN to add it into the diolog box. Notice the box has the heading "Stand_merge.JUPR=" This means anything in the diolog box will be computed and filled in for the field.

<u>Repeat this step 5 times for each table</u>.



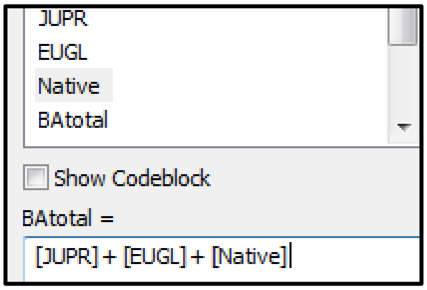
Parser: ● VB Script ○ Python

Type: ● Number ○ String ○ Date

☐ Show Codeblock

Stand_merge.JUPR =

[jupr:MEAN]

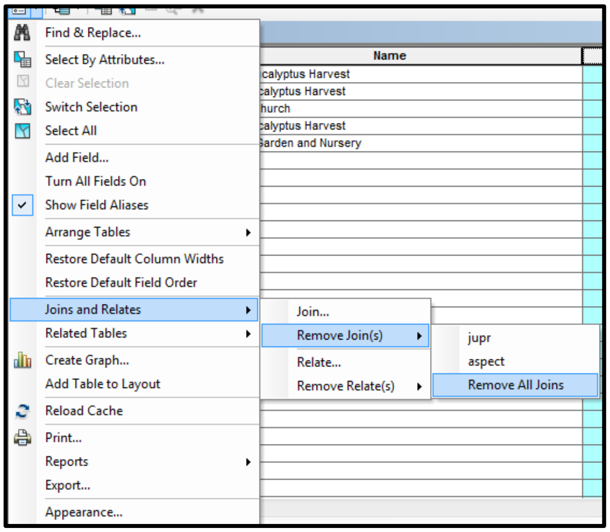


☐ Show Codeblock

BAtotal =

[JUPR] + [EUGL] + [Native]

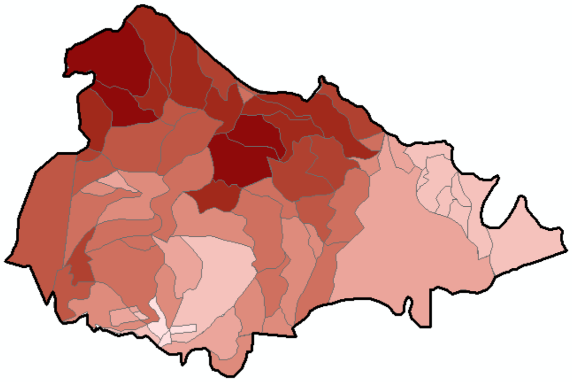
Next Calculate the field "BAtotal" by opening the field calculator and selecting the following fields in this equation:



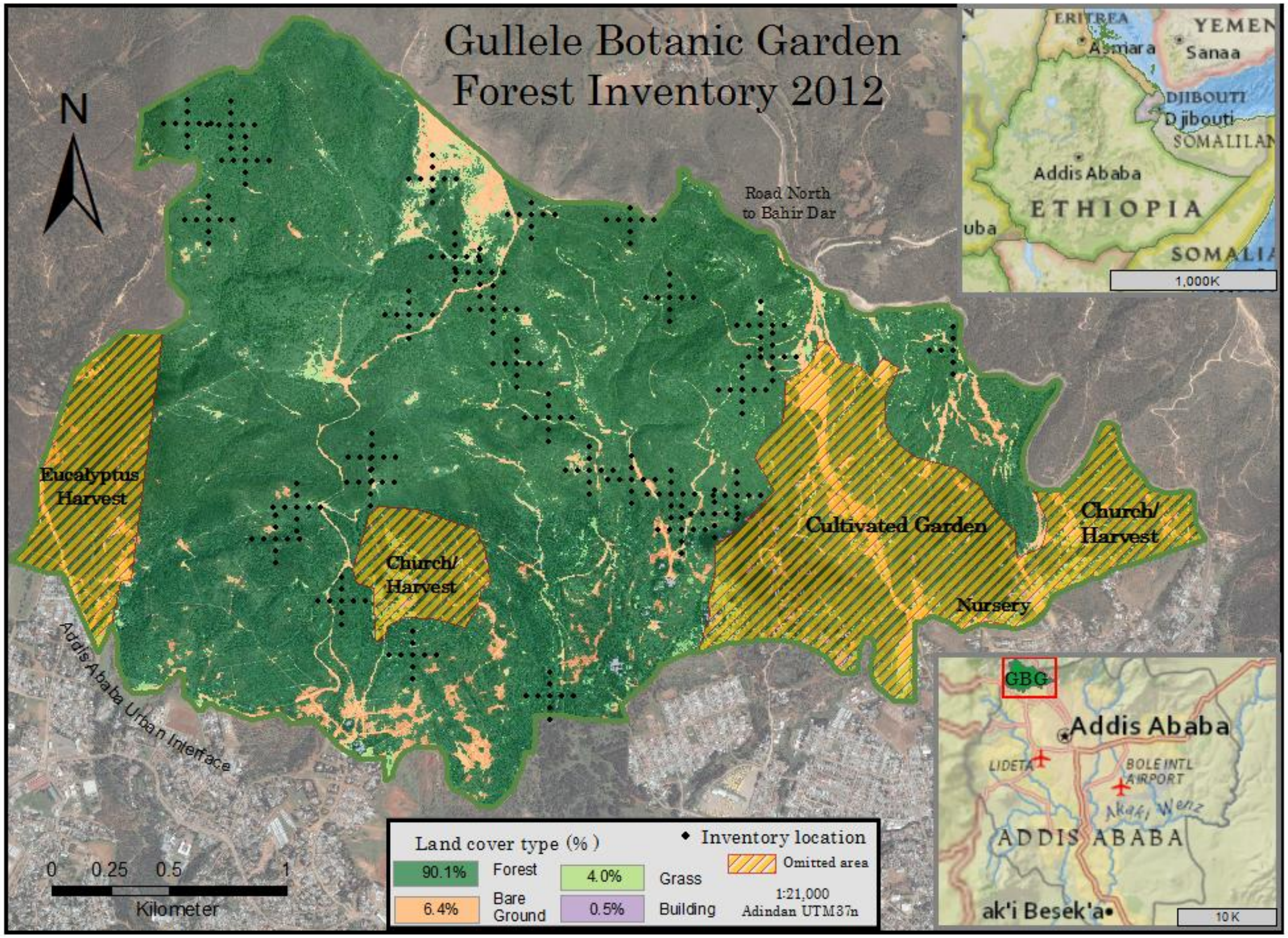
Finally you can remove the joins by right clicking on the polgon name and selecting joins and Remove Joins then **Remove All Joins**.

Now each attribute could be symbolized based on the unique values averaged over each stand

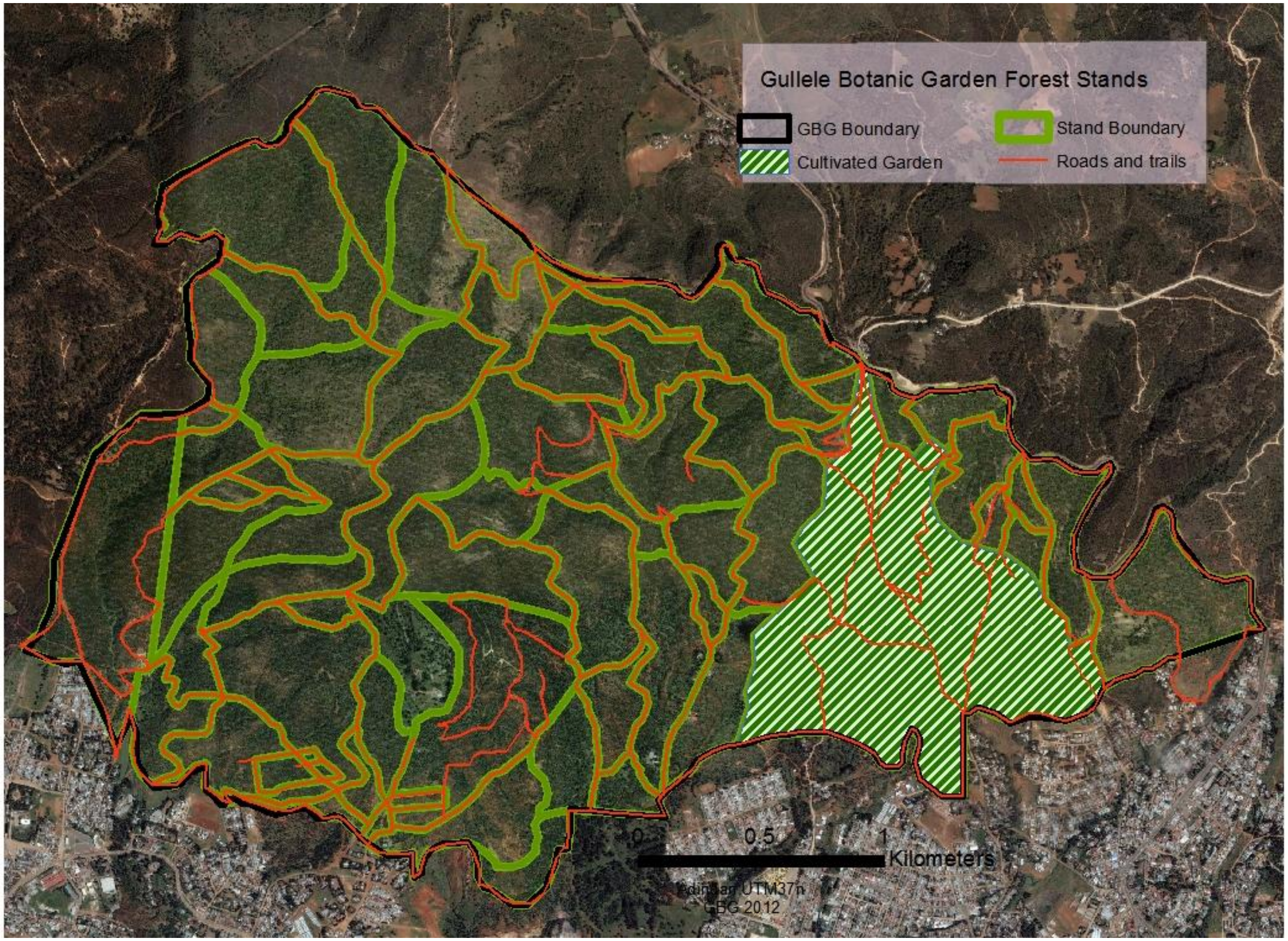
As a last step you can check your work by symbolizing the polygons with graduated colors. This is the final map of the **BAtotal** and an example of all stands with **random colors**.



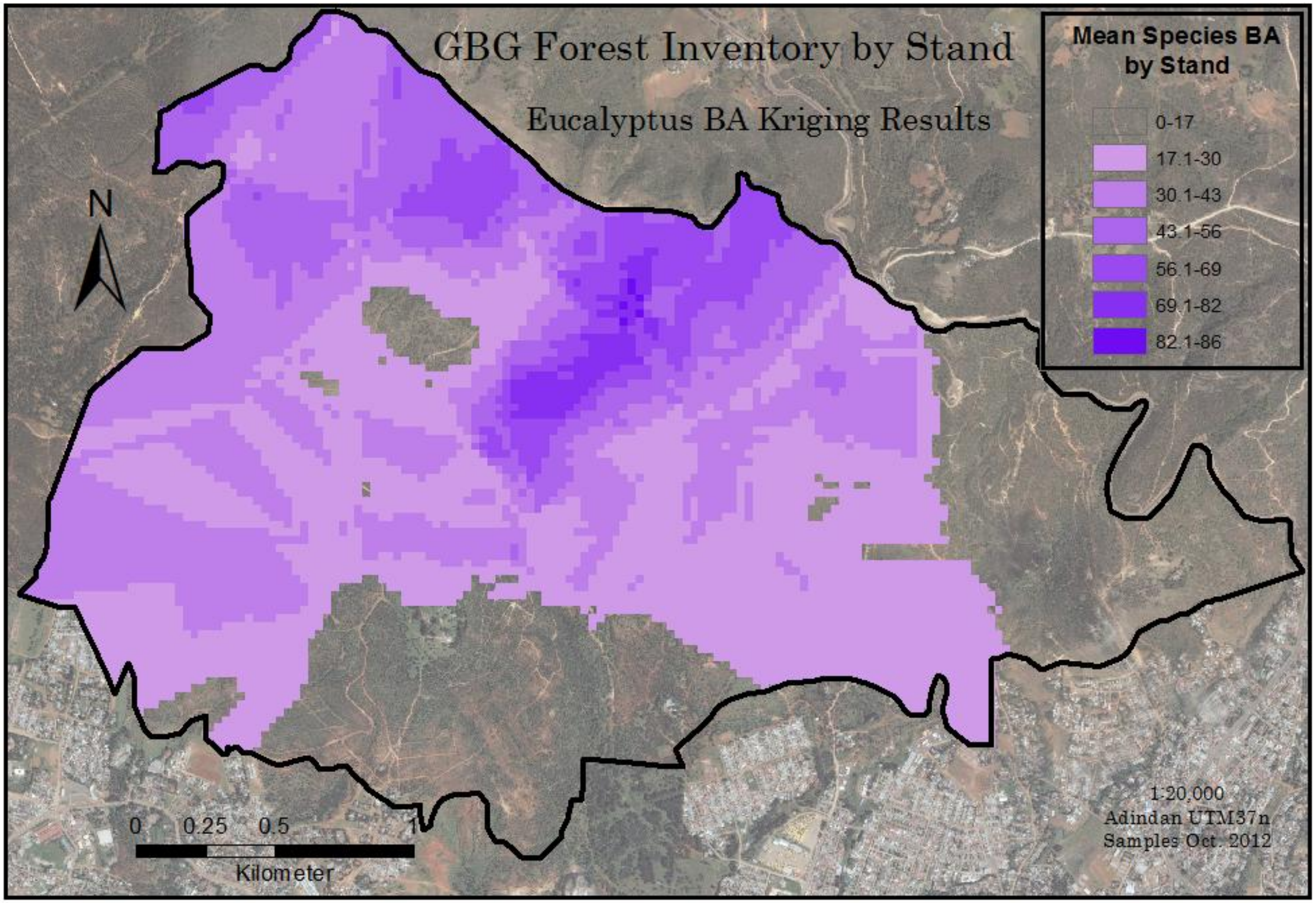
Appendix II: Basemaps and analysis outputs



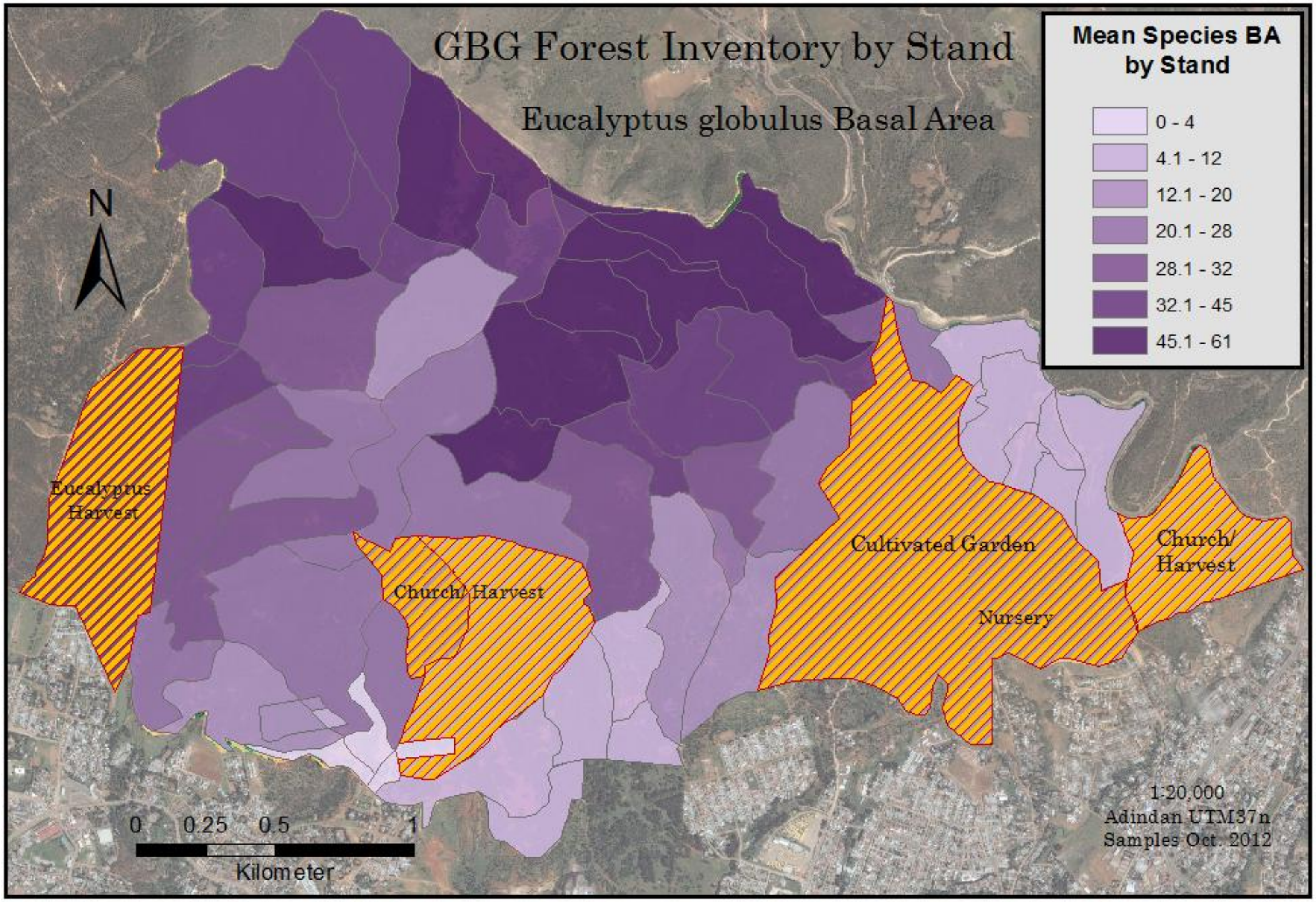
Map 1. Basemap with forest inventory points



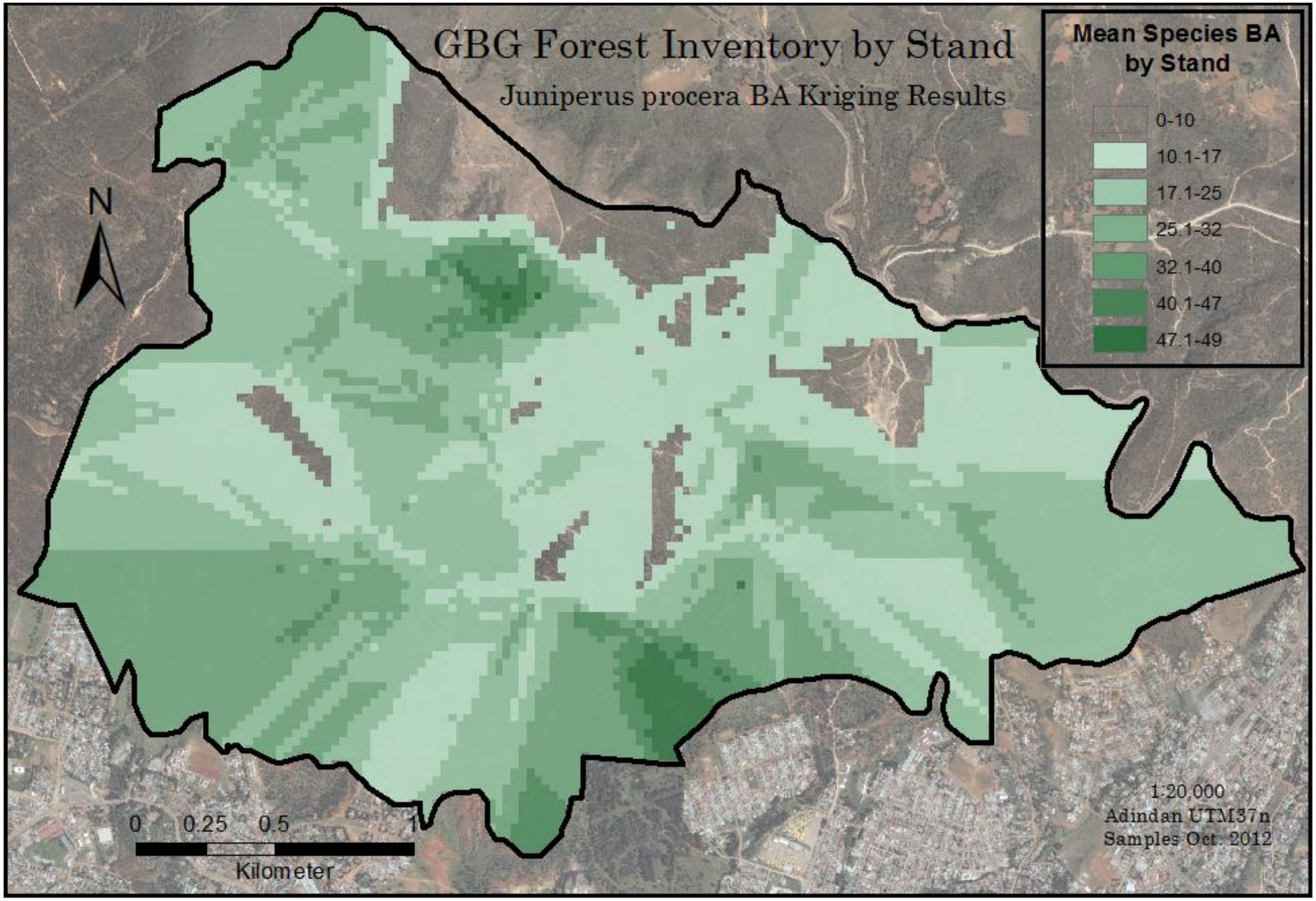
Map 2. Basemap with forest stands and roads



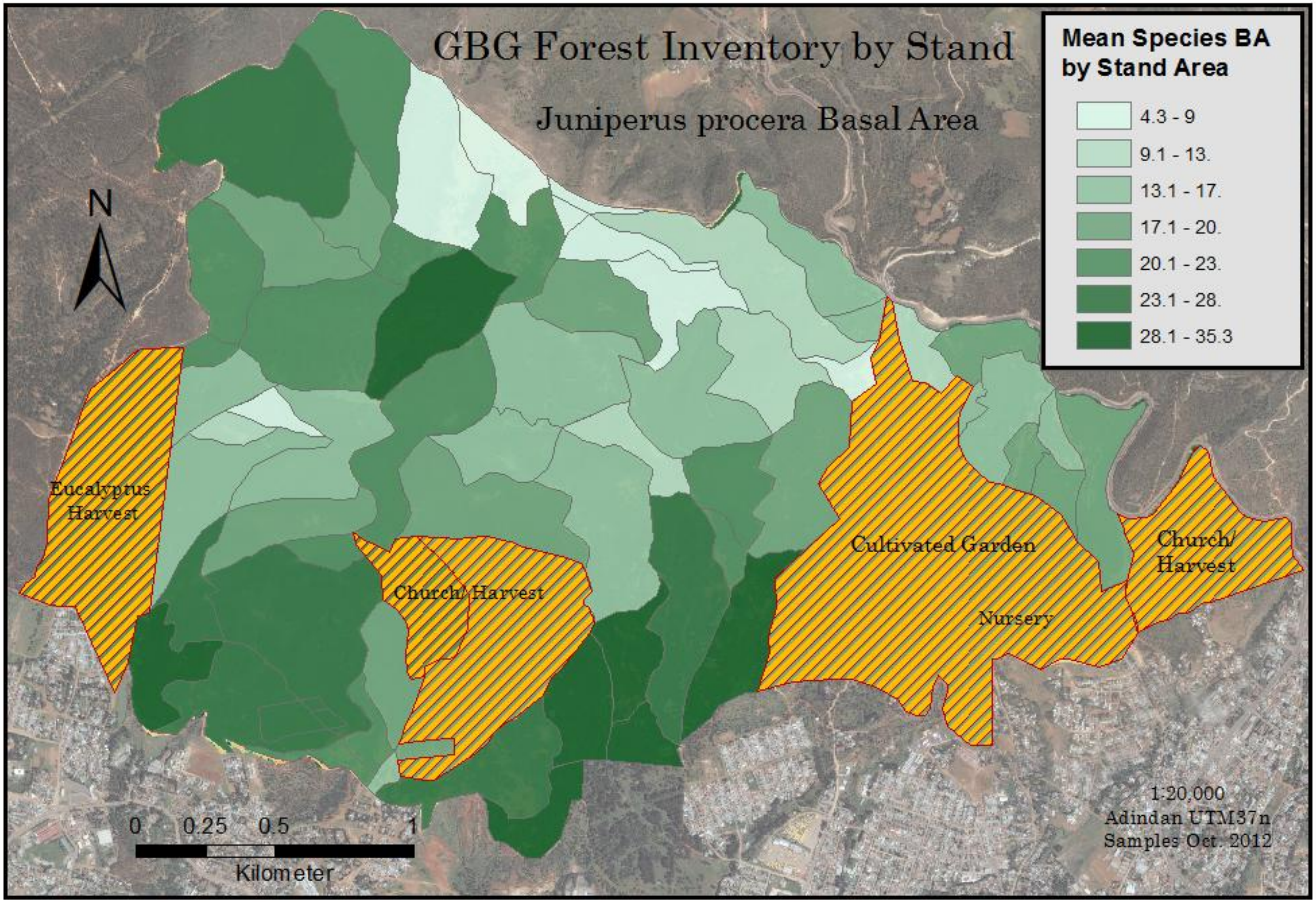
Map 2. ***E. globulus*** **BA Kriging results**



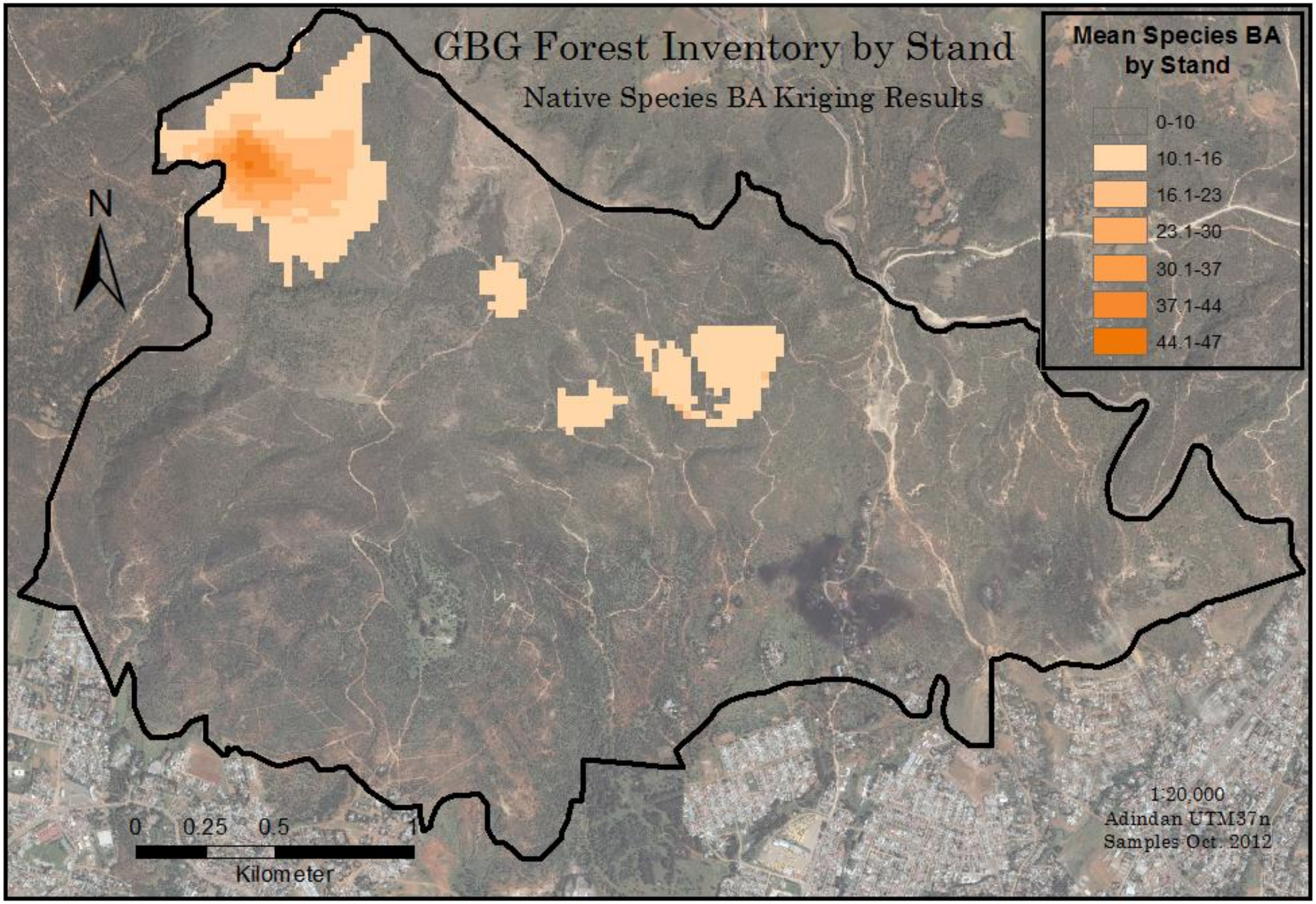
Map 3. ***E. globulus*** **mean BA by stand**



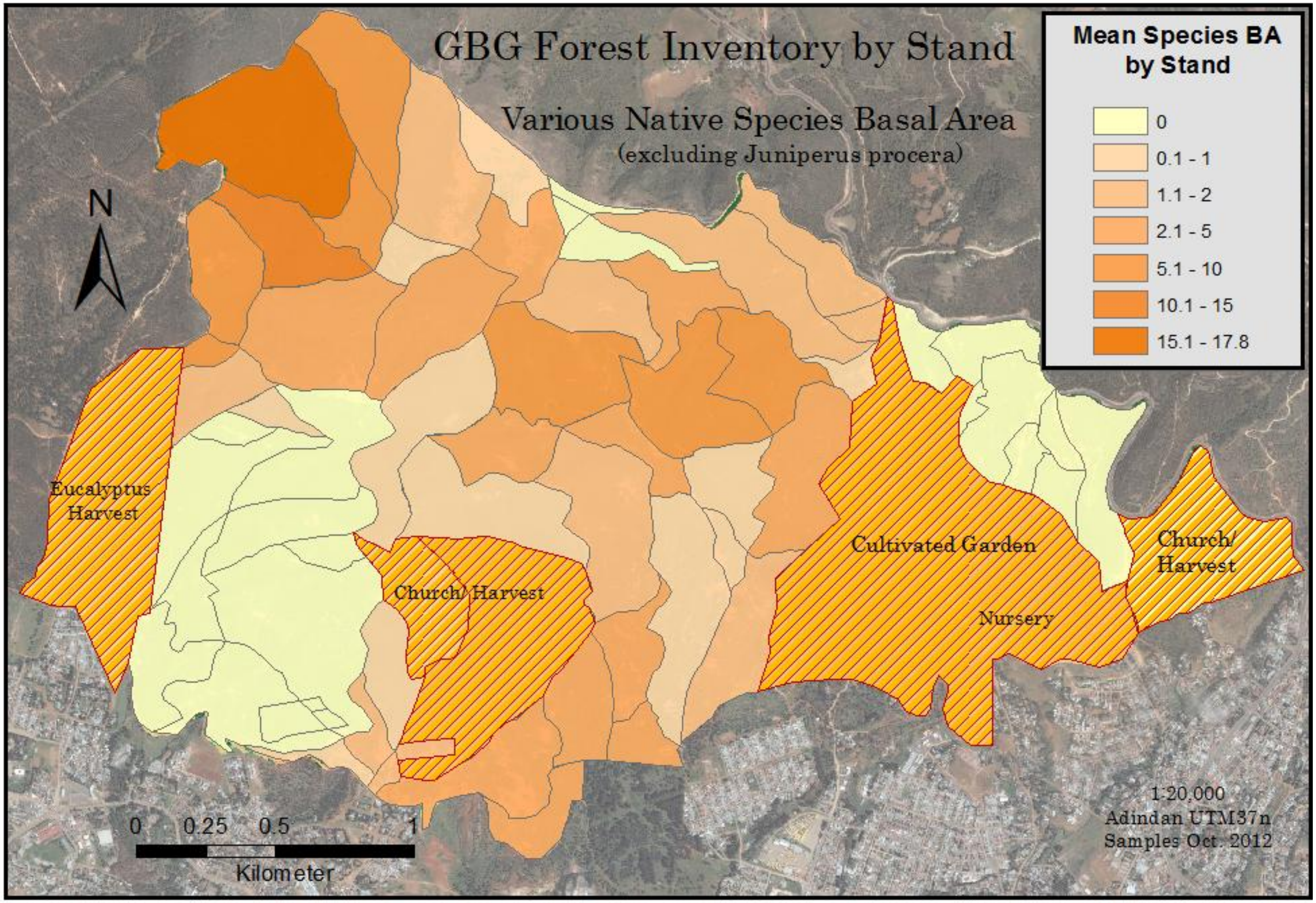
Map 4. ***J. procera*** **BA Kriging Results**



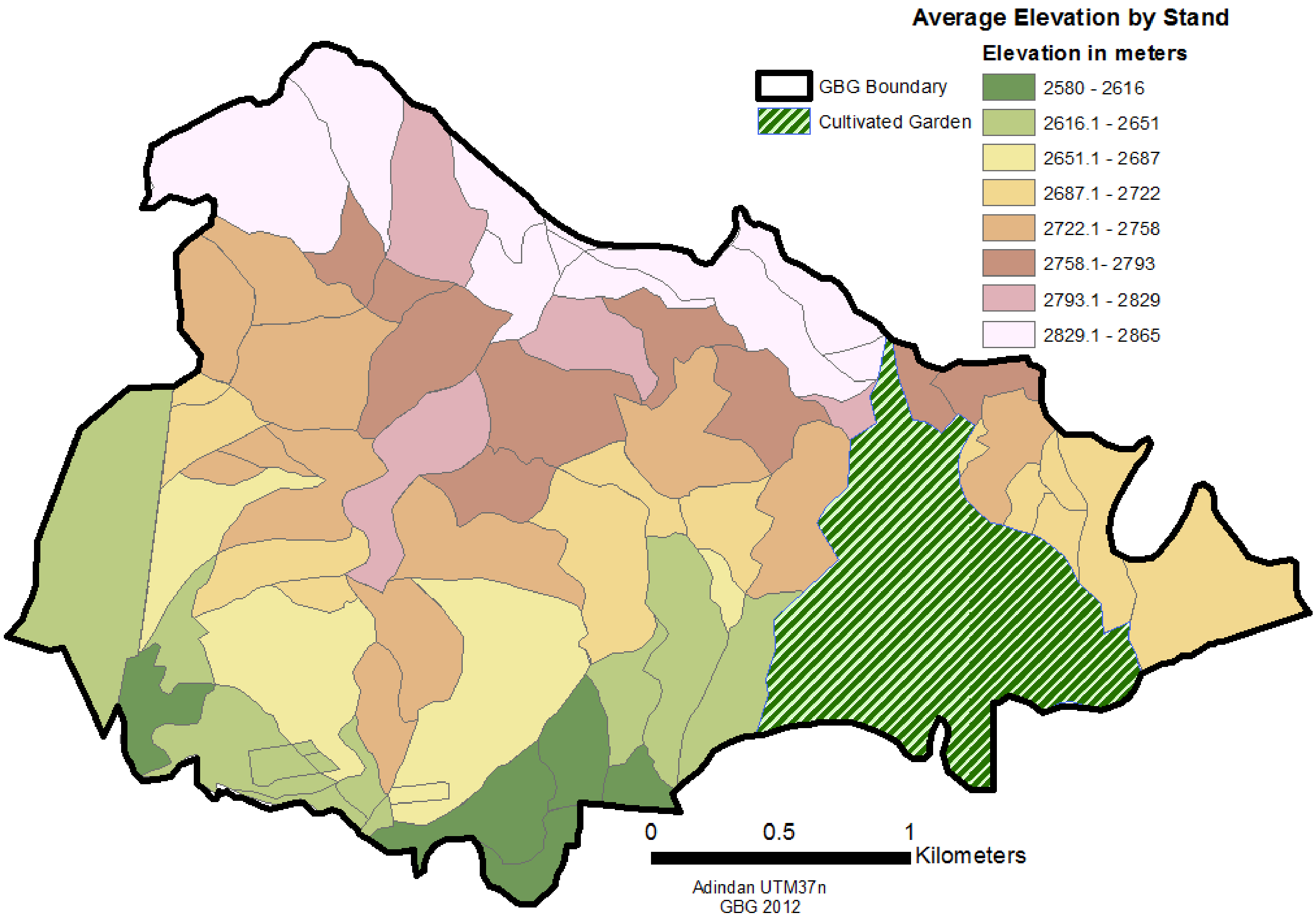
Map 5. ***J. procera*** **mean BA by stand**



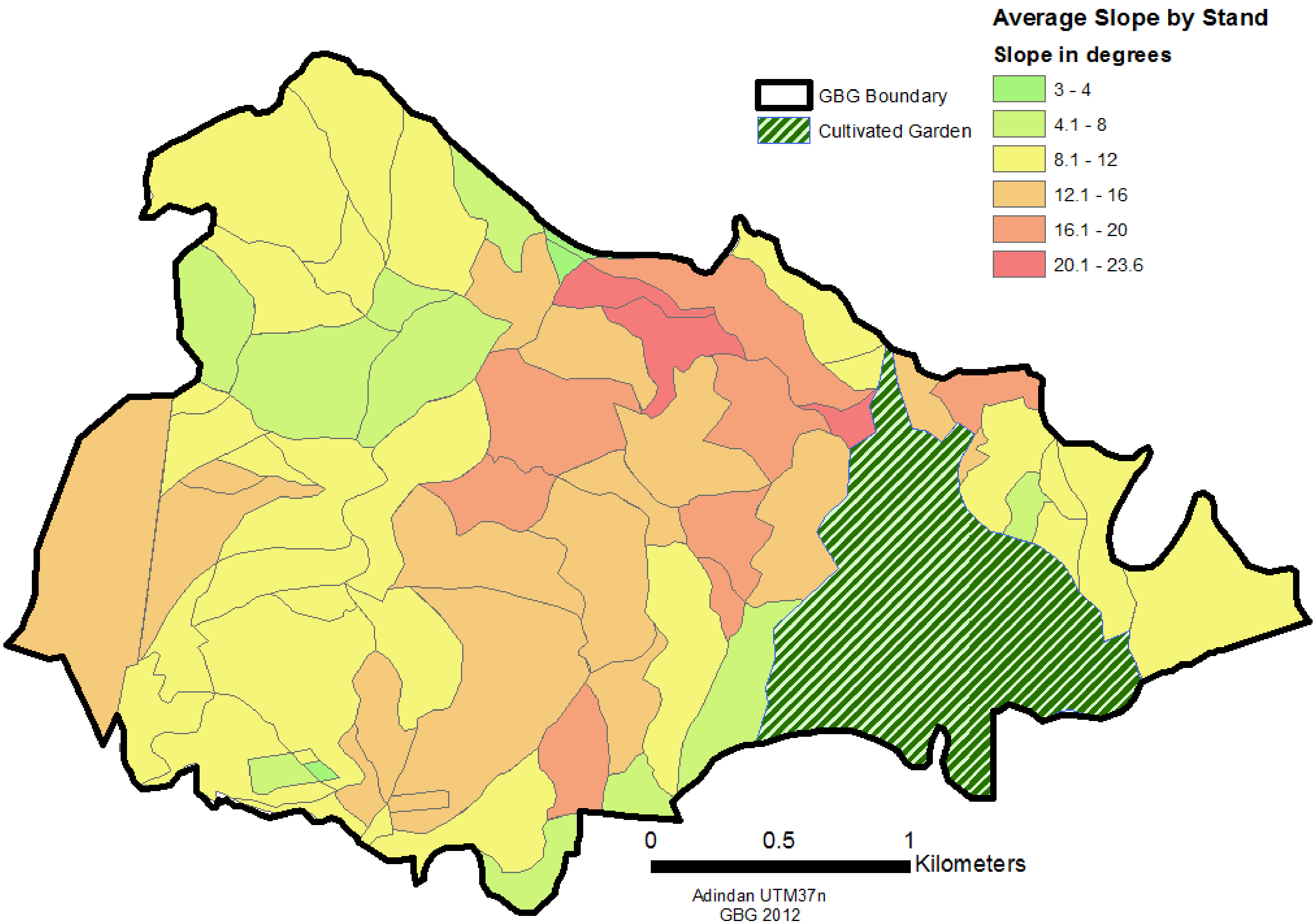
Map 6. Native tree species BA Kriging Results



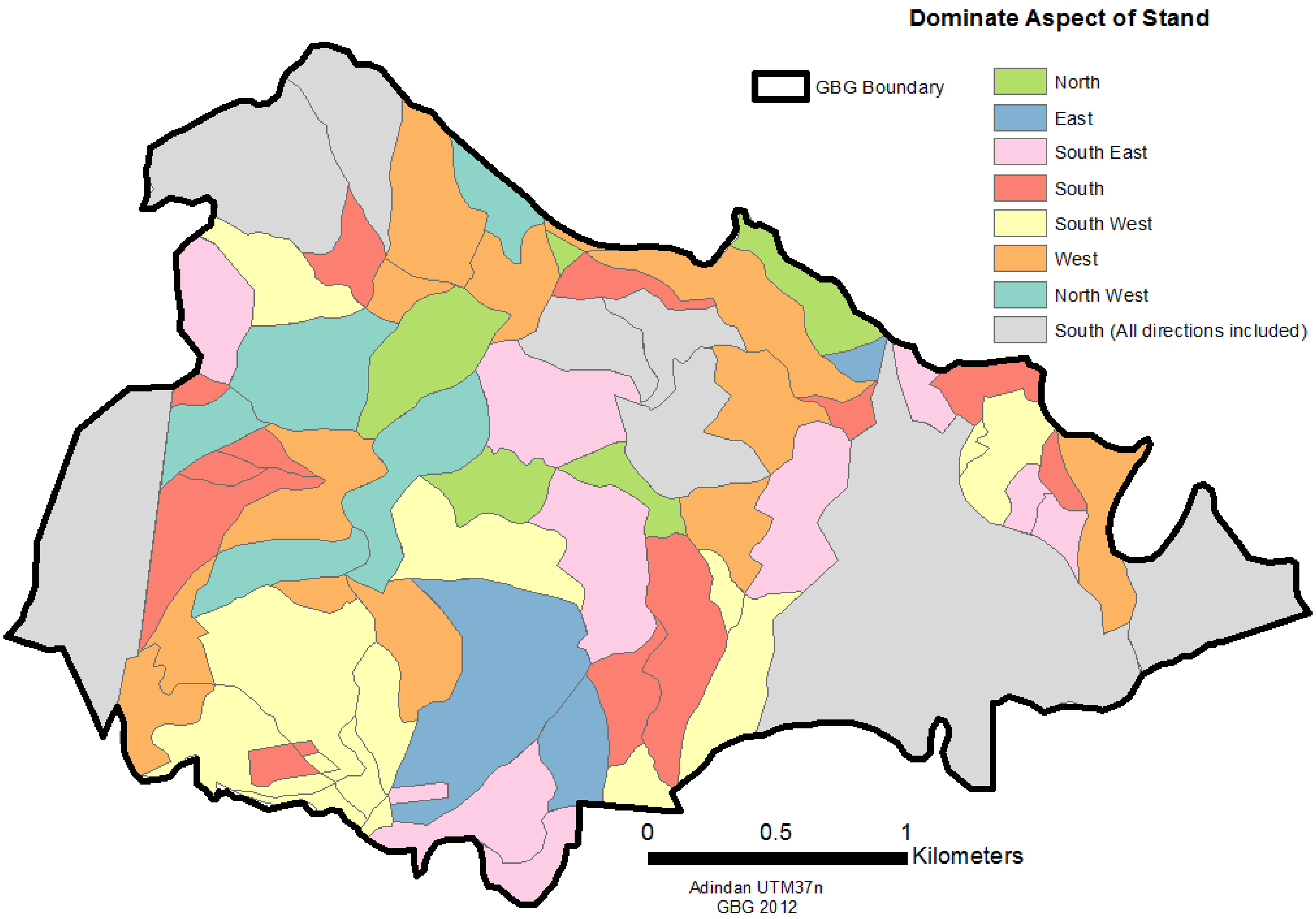
Map 7. Native tree species mean BA by stand



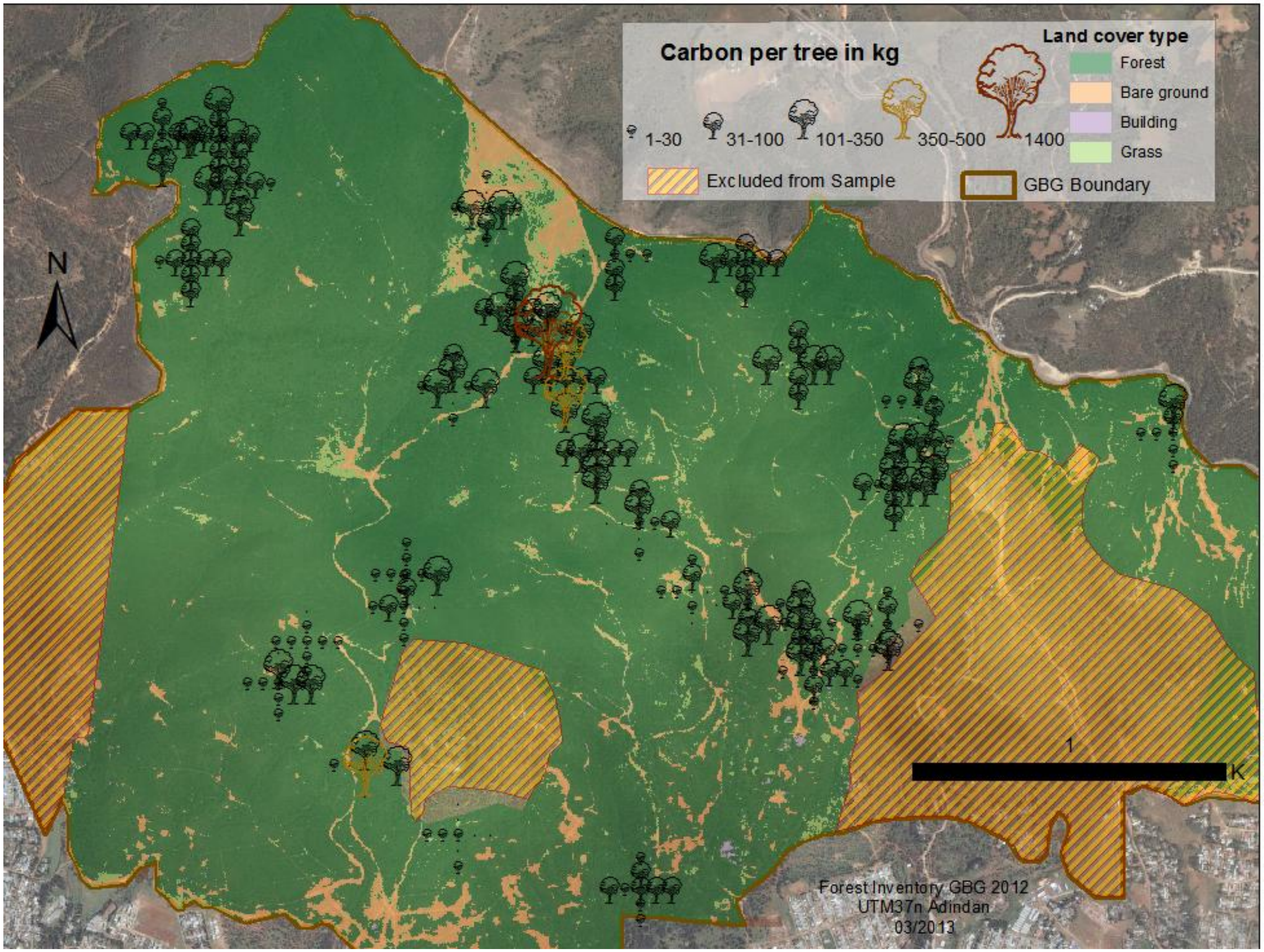
Map 8. Average Elevation by Stand



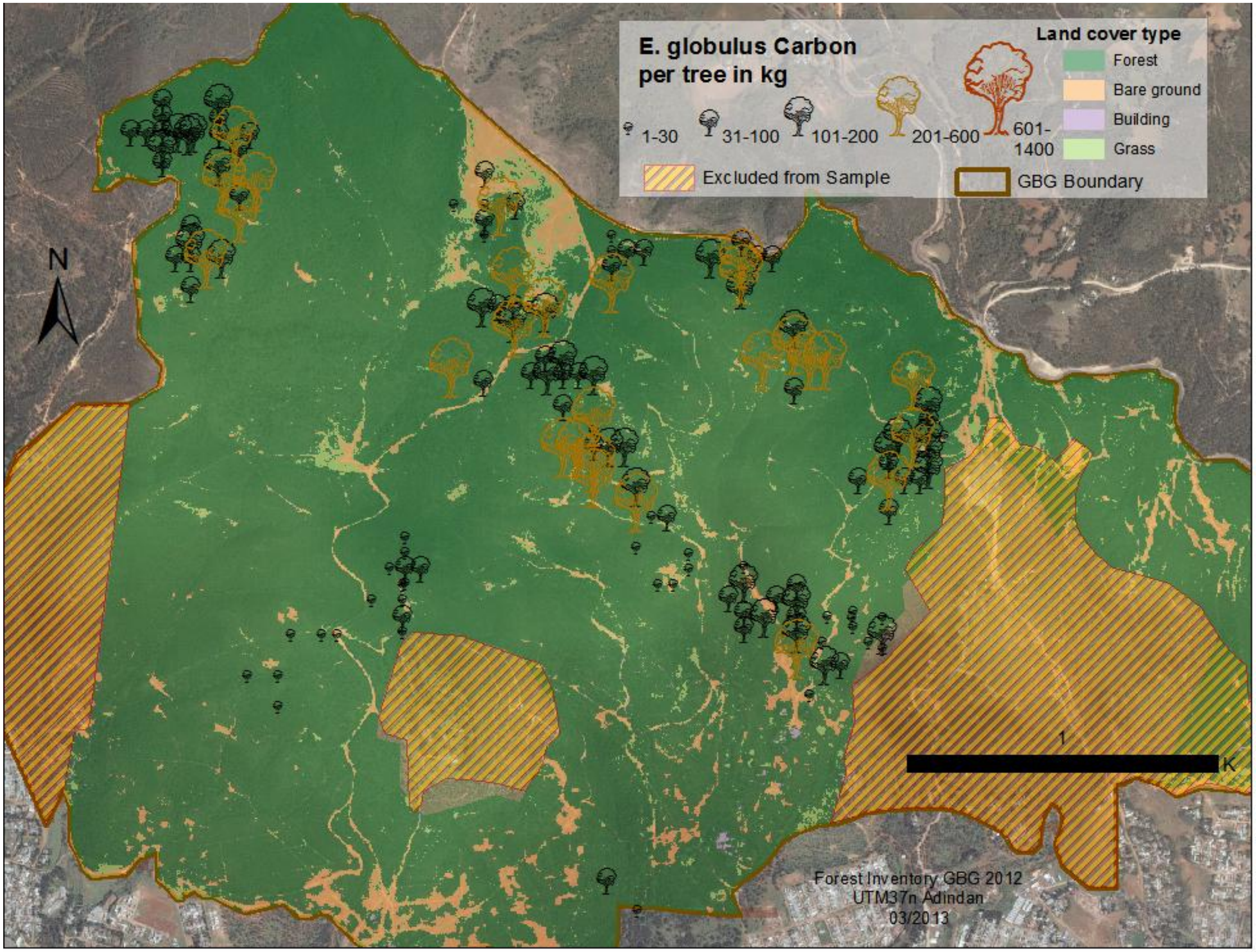
Map 9. Mean slope by stand in degrees



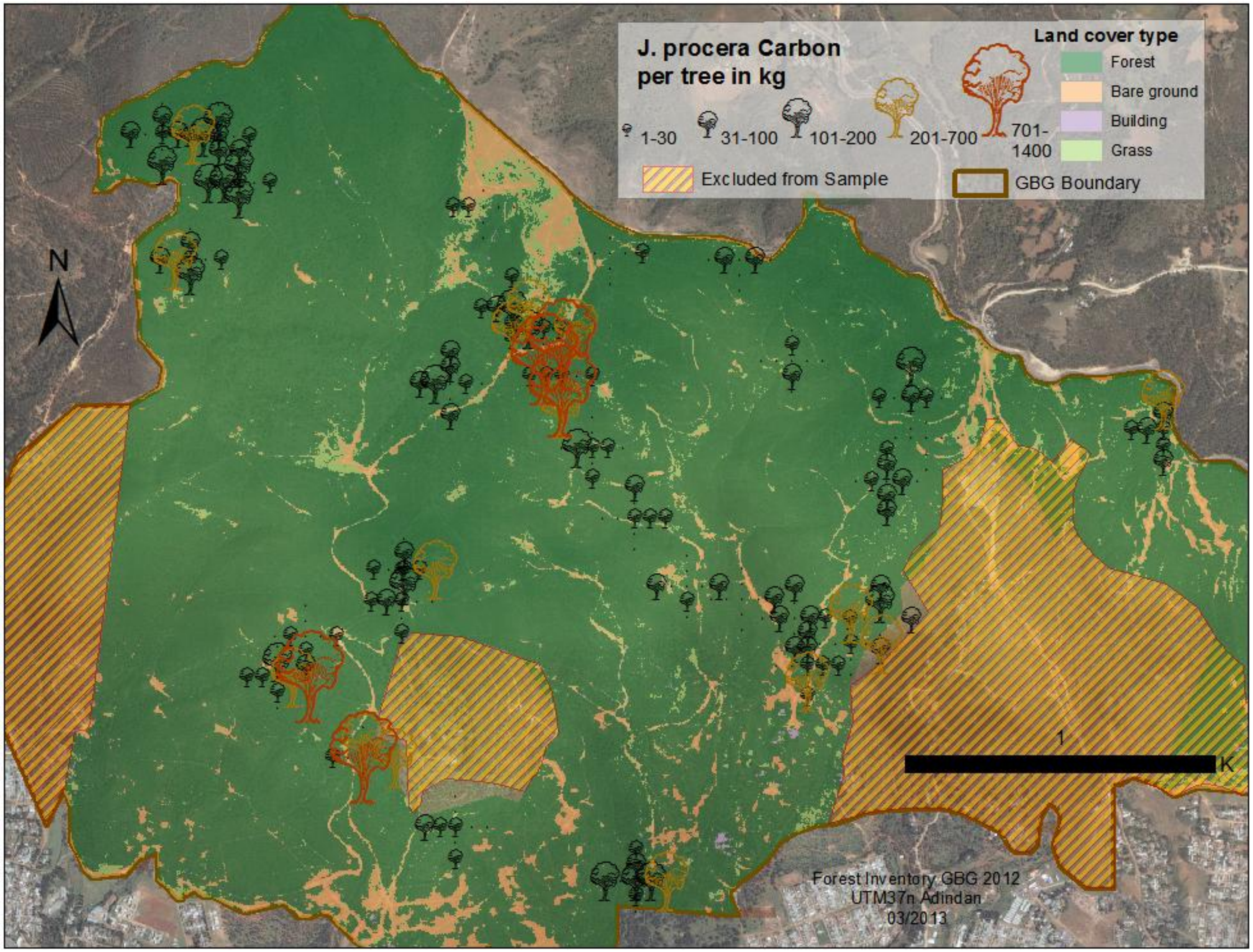
Map 10. Dominate or Mode aspect by stand



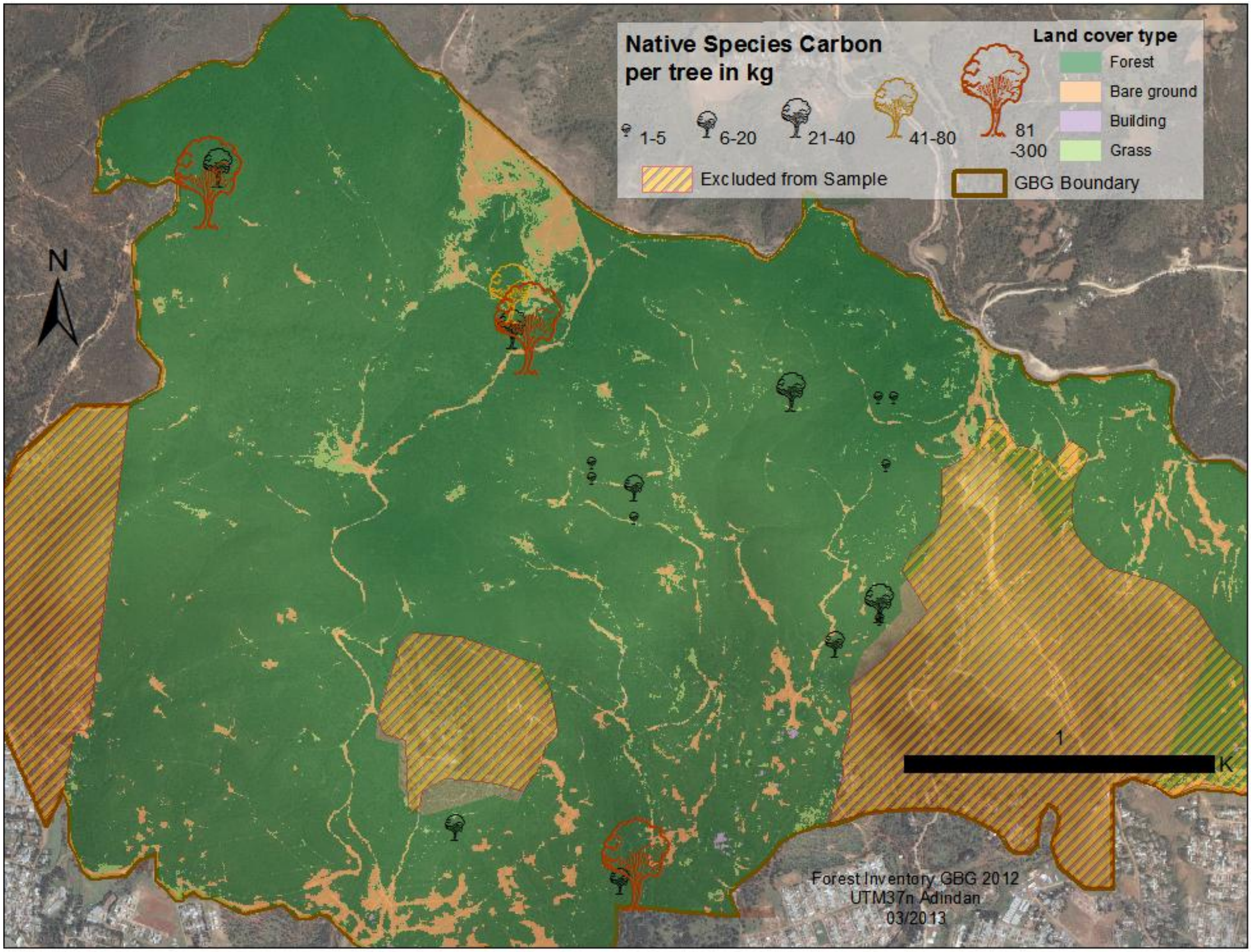
Map 11. Carbon estimate distribution per tree and location of legacy trees in yellow and red



Map 12. ***E. globulus*** **carbon estimate distribution**



Map 13. ***J. procera*** **carbon estimate distribution**



Map 14. Native tree species carbon estimate distribution

Appendix III: Python Code for generating 9 Prism sample points in ArcGIS 10.1

```
######################################
##Name: Create multiple points based on specified distance and cardinal direction
## Purpose: Built to simplify process of adding cluster points of forest inventory plots points to the
center point
## Source Name:
## Version: ArcGIS 10.0
## Author: Carl Reeder
## Required Arguments: Folder to save the shapefile into and the name of the shapefile to create.
## Optional Arguments: None
## Description: This script is a basic transformation of a single x,y coordinate pair into a multipoint
shapefile
##The coordinates supplied are in the Adindan datum horn of Africa and in UTM zone 37N for.
##This script is not setup to be imported directly into an ArcGIS toolbox and requires a Python window.
##  Date April 15, 2012
######################################
import arcpy

# A list of coordinate pairs
pointList =
[[468844.5,1003896],[470041.5,1003672],[469035.5,1002984],[469129.5,1003064],[468341.5,1002219]
,[468676.5,1004223],[468044.5,1004002],
[467941.5,1004067],[468099.5,1003846],[467742.5,1003821],[468200.5,1003617],[468334.5,1003389],
[468507.5,1003169],[468685.5,1003128],
[468851.5,1003067],[468895.5,1002915],[466809.5,1004629],[466992.5,1004622],[467058.5,1004471],
[466902.5,1004223],[467583.5,1003118],
[467273.5,1003009],[467184.5,1002876],[467461.5,1002616],[467759.5,1002391],[469227.5,1003779],
[469280.5,1003647],[469150.5,1003508],
[468259.5,1004243],[467847.5,1004395],[467591.5,1003224]]

# Create an empty Point object

point = arcpy.Point()
# A list to hold the PointGeometry objects
pointGeometryList = []

# For each coordinate pair, populate the Point object and create
#  a new PointGeometry for point1 or point 00 inside the modified whitaker = pointList data above
for pt in pointList:
    point.X = pt[0]
    point.Y = pt[1]
```

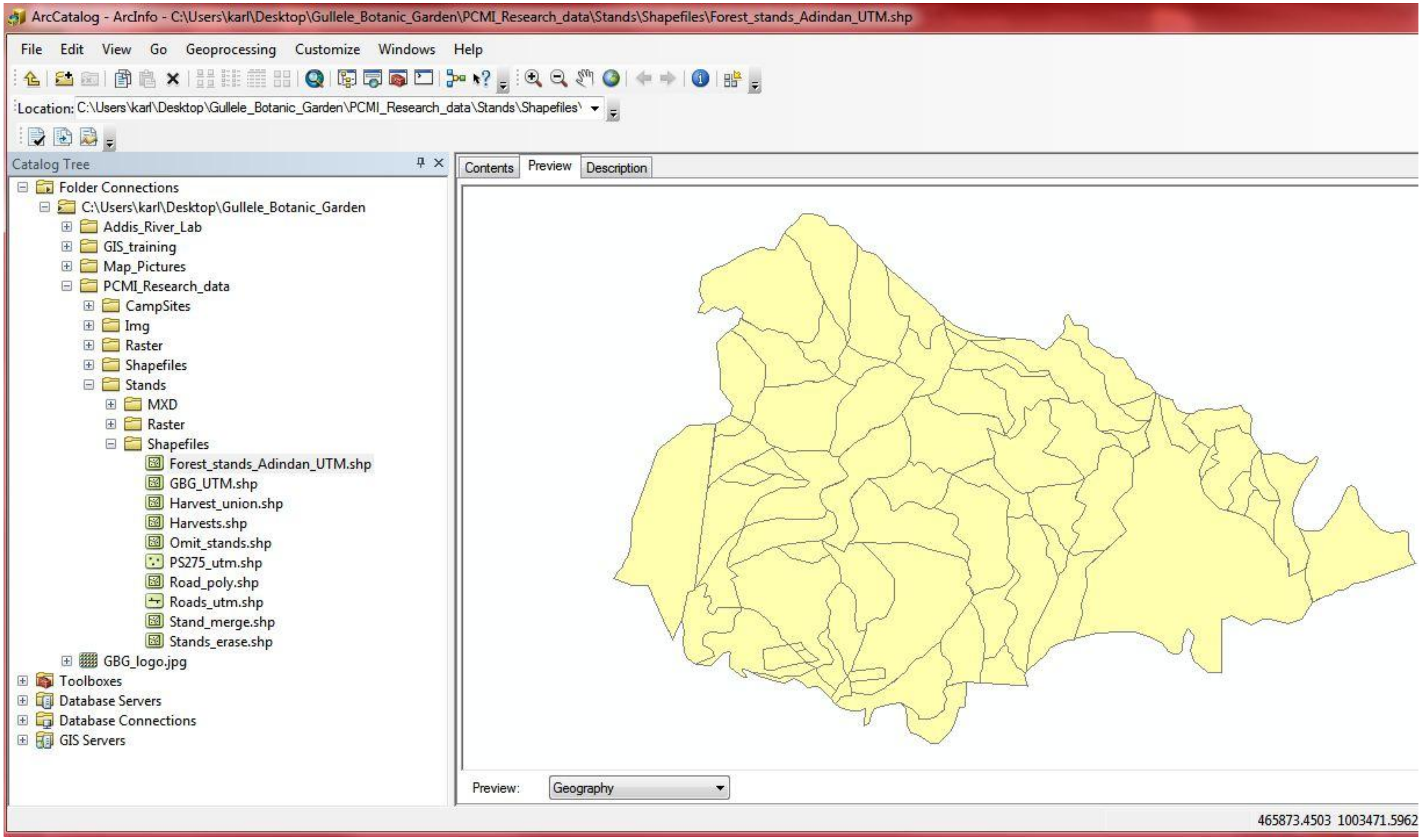
```
    pointGeometry = arcpy.PointGeometry(point)
    pointGeometryList.append(pointGeometry)
##  a new PointGeometry for point2
for pt in pointList:
    point.X = pt[0]+50
    point.Y = pt[1]

    pointGeometry = arcpy.PointGeometry(point)
    pointGeometryList.append(pointGeometry)
### a new PointGeometry for point3
for pt in pointList:
    point.X = pt[0]+100
    point.Y = pt[1]

    pointGeometry = arcpy.PointGeometry(point)
    pointGeometryList.append(pointGeometry)
####  a new PointGeometry for point4
for pt in pointList:
    point.X = pt[0]
    point.Y = pt[1]-100

    pointGeometry = arcpy.PointGeometry(point)
    pointGeometryList.append(pointGeometry)
#####  a new PointGeometry for point5
for pt in pointList:
    point.X = pt[0]
    point.Y = pt[1]-50

    pointGeometry = arcpy.PointGeometry(point)
    pointGeometryList.append(pointGeometry)
######  a new PointGeometry for point6
for pt in pointList:
    point.X = pt[0]-50
    point.Y = pt[1]

    pointGeometry = arcpy.PointGeometry(point)
    pointGeometryList.append(pointGeometry)
#######  a new PointGeometry for point7
for pt in pointList:
    point.X = pt[0]-100
    point.Y = pt[1]
```

```
   pointGeometry = arcpy.PointGeometry(point)
   pointGeometryList.append(pointGeometry)
########  a new PointGeometry for point8
for pt in pointList:
   point.X = pt[0]
   point.Y = pt[1]+100

   pointGeometry = arcpy.PointGeometry(point)
   pointGeometryList.append(pointGeometry)
#########  a new PointGeometry for point9
for pt in pointList:
   point.X = pt[0]
   point.Y = pt[1]+50

   pointGeometry = arcpy.PointGeometry(point)
   pointGeometryList.append(pointGeometry)

# Create a copy of the PointGeometry objects, by using pointGeometryList
#  as input to the CopyFeatures tool.
#
arcpy.CopyFeatures_management(pointGeometryList,
"C:\Users\karl\Desktop\Carbon\GIS\Code\CSE_9pts.shp")
# Local variables:
offset_pts_prj = "CSE_9pts.shp"

# Process: Define Projection
arcpy.DefineProjection_management(offset_pts_prj,
"PROJCS['Adindan_UTM_Zone_37N',GEOGCS['GCS_Adindan',DATUM['D_Adindan',SPHEROID['Clarke_18
80_RGS',6378249.145,293.465]],PRIMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJE
CTION['Transverse_Mercator'],PARAMETER['False_Easting',500000.0],PARAMETER['False_Northing',0.0]
,PARAMETER['Central_Meridian',39.0],PARAMETER['Scale_Factor',0.9996],PARAMETER['Latitude_Of_Ori
gin',0.0],UNIT['Meter',1.0]]")
```

Appendix IV: Geo-database of GBG spatial data

Table 11. GBG Geo-database contents (Yellow indicates Forest Stands output path)

FOLDER NAME	*Sub folder*	*Secondar Subfolder*	Folder Contents
ADDIS_RIVER_LAB			Project Lab exercise and results
	Addis_Data		Lab data: DEM, RS image
GIS_TRAINING			
	GIS_presentations		GBG module for GIS training
	GIS_Training_docs		GIS needs assessment, GPS data collection format
	Worksheets		GPS instructions, GIS tutorials
MAP_PICTURES			GBG pictures from previous projects
	Analysis		Carbon stock and Forest inventory output maps
	Color Variations		GBG pictures from previous projects
	Georef_Images		Georeferenced images of GBG
PCMI_RESEARCH			
	CampSites		Campsite project and results conducted with Ashanafi
	Img		Images of GBG including RS images and georeferenced images
	Maps		Map outputs from various GBG projects
	Raster		Available GBG raster datasets
	Shapefiles		Available GBG shapefiles
	Stands		Forest Stand Tutorial PDF
		MXD	Map documents of analysis compatible with Forest Stand Tutorial
		Raster	Raster layers produced in Forest Stand Tutorial
		Shapefiles	Shapefiles used and produced in Forest Stand Tutorial e.g. "Forest_stands_Adindan_UTM.shp" is the final output file of the stands tutorial


ArcCatalog - ArcInfo - C:\Users\karl\Desktop\Gullele_Botanic_Garden\PCMI_Research_data\Stands\Shapefiles\Forest_stands_Adindan_UTM.shp

Location: C:\Users\karl\Desktop\Gullele_Botanic_Garden\PCMI_Research_data\Stands\Shapefiles\

Preview: Geography

465873.4503 1003471.5962

Figure 23. Database Preview with path to Forest Stand Tutorial output shapefile in yellow

Appendix V: Unprocessed forest inventory data

Date	MW plot #	Point #	Tree point #	Species	DBH (cm)	Height (m)	Comment	SQFT/ tree	TPHA
9/24/2012	0	0	0	NA	0	0	NA		0.00
9/24/2012	1	2	1	EUGL	12.5	14.6	13.3444	0.13	375.49
9/24/2012	1	2	2	EUGL	22	19.5	17.823	0.41	121.22
9/24/2012	1	2	3	EUGL	31	29.4	26.8716	0.81	61.05
9/24/2012	1	2	4	EUGL	24	10.6		0.49	101.86
9/24/2012	1	2	5	EUGL	12	17	15.538	0.12	407.44
9/24/2012	1	2	6	EUGL	19	24	21.936	0.31	162.52
9/24/2012	1	3	1	EUGL	14.5	14.8	13.5272	0.18	279.05
9/24/2012	1	3	2	EUGL	26.5	25.52		0.59	83.55
9/24/2012	1	3	3	EUGL	19	21	19.194	0.31	162.52
9/24/2012	1	3	4	EUGL	21.5	25.4	23.2156	0.39	126.92
9/24/2012	1	3	5	EUGL	27.5	23		0.64	77.58
9/24/2012	1	4	1	EUGL	11.5	12.9		0.11	443.64
9/24/2012	1	4	2	EUGL	17	21		0.24	203.01
9/24/2012	1	4	3	MELA	9	8.		0.07	724.33
9/24/2012	1	4	4	MELA	9	8.		0.07	724.33
9/24/2012	1	4	5	MELA	9	6.398		0.07	724.33
9/24/2012	1	5	1	JUPR	36	9.14		1.10	45.27
9/24/2012	1	5	2	JUPR	28	18.		0.66	74.84
9/24/2012	1	5	3	JUPR	15	4.5		0.19	260.76
9/24/2012	1	6	0	NA		0		0.00	0.00
9/24/2012	1	7	1	EUGL	29.5	23.		0.74	67.42
9/24/2012	1	7	2	EUGL	24	21.5		0.49	101.86
9/24/2012	1	7	3	JUPR	15	5.4		0.19	260.76
9/24/2012	1	7	4	EUGL	17	18.		0.24	203.01
9/24/2012	1	7	5	EUGL	25	23.4		0.53	93.87

9/24/2012	1	7	6	EUGL	15	14		0.19	260.76
9/24/2012	1	8	1	EUGL	16	18.		0.22	229.18
9/24/2012	1	8	2	EUGL	21	23.		0.37	133.04
9/24/2012	1	8	3	EUGL	14	11.2		0.17	299.34
9/24/2012	1	9	1	EUGL	27	13		0.62	80.48
9/24/2012	1	9	2	EUGL	19	13.2		0.31	162.52
9/24/2012	1	9	3	EUGL	15	12.1		0.19	260.76
9/24/2012	1	9	4	EUGL	33	14		0.92	53.88
9/24/2012	1	9	5	JUPR	39	8.7		1.29	38.57
9/24/2012	2	1	1	JUPR	47	15		1.87	26.56
9/24/2012	2	2	1	JUPR	21.5	5		0.39	126.92
9/24/2012	2	2	2	JUPR	35	14		1.04	47.89
9/24/2012	2	2	3	JUPR	32	13		0.87	57.30
9/24/2012	2	3	1	JUPR	29	10		0.71	69.76
9/24/2012	2	4	1	JUPR	30.5	7.8		0.79	63.07
9/24/2012	2	4	2	JUPR	27	7.6		0.62	80.48
9/24/2012	2	5	1	JUPR	37	7		1.16	42.86
9/24/2012	2	6	1	JUPR	26	9		0.57	86.79
9/24/2012	2	7	1	JUPR	29	9.4		0.71	69.76
9/24/2012	2	8	0	NA			ROAD	0.00	0.00
9/24/2012	2	9	0	NA			ROAD	0.00	0.00
9/25/2012	3	1	1	JUPR	10	4.5		0.08	586.71
9/25/2012	3	2	1	EUGL	8.5	6		0.06	812.05
9/25/2012	3	2	2	EUGL	8.5	6		0.06	812.05
9/25/2012	3	2	3	JUPR	6	5		0.03	1629.74
9/25/2012	3	3	1	JUPR	13.5	6.2		0.15	321.92
9/25/2012	3	4	1	EUGL	5	4		0.02	2346.83
9/25/2012	3	4	2	EUGL	5.3	4.3		0.02	2088.67
9/25/2012	3	5	0	NA			ROAD	0.00	0.00

9/25/2012	3	6	1	MELA	6.5	4	Measa Lanceolata	0.04	1388.66
9/25/2012	3	6	2	MELA	8	4		0.05	916.73
9/25/2012	3	6	3	MYAD	7.5	3.5	Mytenus Adat	0.05	1043.04
9/25/2012	3	7	1	EUGL	17	11		0.24	203.01
9/25/2012	3	8	1	JUPR	22	6.4		0.41	121.22
9/25/2012	3	8	2	EUGL	11	8.5		0.10	484.88
9/25/2012	3	8	3	JUPR	13	6		0.14	347.16
9/25/2012	3	8	4	JUPR	14	5.5		0.17	299.34
9/25/2012	3	8	5	JUPR	8	5		0.05	916.73
9/25/2012	3	9	1	EUGL	23	9.4		0.45	110.91
9/25/2012	3	9	2	EUGL	5	4.8		0.02	2346.83
9/25/2012	3	9	3	EUGL	5	4.8		0.02	2346.83
9/25/2012	3	9	4	EUGL	4	4.9		0.01	3666.92
9/25/2012	3	9	5	EUGL	4.5	4.8		0.02	2897.32
9/25/2012	4	1	1	EUGL	12	6.8		0.12	407.44
9/25/2012	4	1	2	JUPR	3	2.1		0.01	6518.97
9/25/2012	4	1	3	MELA	8	3.4	Mesa Lanceolata	0.05	916.73
9/25/2012	4	2	0	NA			Coppice	0.00	0.00
9/25/2012	4	3	1	EUGL	4	3		0.01	3666.92
9/25/2012	4	3	2	JUPR	10	4		0.08	586.71
9/25/2012	4	4	1	EUGL	6	7.5		0.03	1629.74
9/25/2012	4	4	2	EUGL	7.2	8		0.04	1131.77
9/25/2012	4	4	3	JUPR	24	4.8		0.49	101.86
9/25/2012	4	5	1	EUGL	17	10.4		0.24	203.01
9/25/2012	4	5	2	EUGL	34	14.2		0.98	50.75
9/25/2012	4	5	3	EUGL	14	6.8		0.17	299.34
9/25/2012	4	6	0	NA			Coppice	0.00	0.00
9/25/2012	4	7	1	JUPR	33	6.5		0.92	53.88
9/25/2012	4	7	2	EUGL	13	5.5		0.14	347.16

9/25/2012	4	8	1	JUPR	15	5.4		0.19	260.76
9/25/2012	4	8	2	EUGL	5	5		0.02	2346.8
9/25/2012	4	8	3	JUPR	13	5.4		0.14	347.16
9/25/2012	4	9	1	JUPR	8.5	4		0.06	812.05
9/25/2012	4	9	2	JUPR	42	7.8		1.49	33.26
9/25/2012	4	9	3	JUPR	8.5	4.5		0.06	812.05
9/25/2012	4	9	4	MELA	20	5		0.34	146.68
9/25/2012	5	1	1	JUPR	14	8.4		0.17	299.34
9/25/2012	5	1	2	JUPR	14	8.8		0.17	299.34
9/25/2012	5	2	1	JUPR	37	12		1.16	42.86
9/25/2012	5	2	2	JUPR	47	12.6		1.87	26.56
9/25/2012	5	2	3	JUPR	55	12.2		2.56	19.40
9/25/2012	5	2	4	JUPR	32	8		0.87	57.30
9/25/2012	5	2	5	JUPR	21	9.2		0.37	133.04
9/25/2012	5	3	1	JUPR	34	6.6		0.98	50.75
9/25/2012	5	3	2	JUPR	17	8.5		0.24	203.01
9/25/2012	5	3	3	JUPR	26	9		0.57	86.79
9/25/2012	5	3	4	JUPR	47	11		1.87	26.56
9/25/2012	5	4	1	EUGL	9.5	9.8		0.08	650.09
9/25/2012	5	5	1	JUPR	59	11	COPPICE	2.94	16.85
9/25/2012	5	6	1	CASP	12	5	Carisa Spinarum	0.12	407.44
9/25/2012	5	7	1	EUGL	13	11		0.14	347.16
9/25/2012	5	7	2	JUPR	9	6		0.07	724.33
9/25/2012	5	7	3	JUPR	8	5.8		0.05	916.73
9/25/2012	5	7	4	JUPR	12.5	5.6		0.13	375.49
9/25/2012	5	7	5	EUGL	17	12.6		0.24	203.01
9/25/2012	5	7	6	EUGL	17	11.5		0.24	203.01
9/25/2012	5	8	1	JUPR	68	12.4		3.91	12.69
9/25/2012	5	9	1	JUPR	11	4.2		0.10	484.88

9/25/2012	5	9	2	ACAB	33.5	5.2	acacia abyssinica	0.95	52.28
10/6/2012	6	1	1	EUGL	22	10.4		0.41	121.22
10/6/2012	6	1	2	EUGL	13	13.2		0.14	347.16
10/6/2012	6	1	3	EUGL	21	13.6		0.37	133.04
10/6/2012	6	1	4	EUGL	23	15		0.45	110.91
10/6/2012	6	1	5	EUGL	26.5	15.5		0.59	83.55
10/6/2012	6	2	1	EUGL	21	11.8		0.37	133.04
10/6/2012	6	2	2	EUGL	22.5	12.2		0.43	115.89
10/6/2012	6	2	3	JUPR	12	5.3		0.12	407.44
10/6/2012	6	3	1	EUGL	15	10.8	ROAD	0.19	260.76
10/6/2012	6	3	2	EUGL	16.5	10.9	ROAD	0.23	215.50
10/6/2012	6	4	1	EUGL	21	19.8		0.37	133.04
10/6/2012	6	4	2	EUGL	13.25	16		0.15	334.19
10/6/2012	6	4	3	EUGL	18.5	20		0.29	171.43
10/6/2012	6	5	1	EUGL	18	21		0.27	181.08
10/6/2012	6	5	2	EUGL	18	22.4		0.27	181.08
10/6/2012	6	5	3	EUGL	16	21.8		0.22	229.18
10/6/2012	6	5	4	EUGL	15	21.9		0.19	260.76
10/6/2012	6	5	5	EUGL	15.5	21		0.20	244.21
10/6/2012	6	6	1	JUPR	21	6.1	Clearing	0.37	133.04
10/6/2012	6	7	1	EUGL	31	15		0.81	61.05
10/6/2012	6	7	2	EUGL	12	15		0.12	407.44
10/6/2012	6	7	3	EUGL	27	18.4	ROAD	0.62	80.48
10/6/2012	6	8	1	EUGL	17	13	ACROSS ROAD!!!!	0.24	203.01
10/6/2012	6	8	2	EUGL	16	13		0.22	229.18
10/6/2012	6	8	3	EUGL	13	14.5		0.14	347.16
10/6/2012	6	9	0	NA			ROAD	0.00	0.00
10/6/2012	7	1	1	JUPR	44.5	19.8		1.67	29.63
10/6/2012	7	1	2	EUGL	94.5	25		7.55	6.57

10/6/2012	7	2	1	JUPR	43	11.8	Coppice	1.56	31.73
10/6/2012	7	3	1	JUPR	9.5	10.5		0.08	650.09
10/6/2012	7	3	2	JUPR	33	13		0.92	53.88
10/6/2012	7	3	3	JUPR	45	14.2		1.71	28.97
10/6/2012	7	4	1	EUGL	28	14		0.66	74.84
10/6/2012	7	4	2	JUPR	17.5	9.1		0.26	191.58
10/6/2012	7	4	3	JUPR	19.5	9.1		0.32	154.30
10/6/2012	7	4	4	JUPR	23	11.4		0.45	110.91
10/6/2012	7	4	5	JUPR	26	13.8		0.57	86.79
10/6/2012	7	4	6	JUPR	36	13.8		1.10	45.27
10/6/2012	7	4	7	JUPR	15.5	10.8		0.20	244.21
10/6/2012	7	5	0	NA			Field	0.00	0.00
10/6/2012	7	6	1	JUPR	17	9.8		0.24	203.01
10/6/2012	7	6	2	MELA	12	9		0.12	407.44
10/6/2012	7	6	3	MELA	9	6		0.07	724.33
10/6/2012	7	6	4	MELA	10	6		0.08	586.71
10/6/2012	7	6	5	MELA	10	14		0.08	586.71
10/6/2012	7	6	6	MELA	13.5	14.2		0.15	321.92
10/6/2012	7	6	7	JUPR	18	9.8		0.27	181.08
10/6/2012	7	6	8	JUPR	17	9.8		0.24	203.01
10/6/2012	7	6	9	JUPR	10.5	6.6		0.09	532.16
10/6/2012	7	7	1	JUPR	21.5	12		0.39	126.92
10/6/2012	7	7	2	JUPR	32	12		0.87	57.30
10/6/2012	7	7	3	JUPR	26	26.4		0.57	86.79
10/6/2012	7	7	4	EUGL	40	26.4		1.35	36.67
10/6/2012	7	7	5	JUPR	24	13.5		0.49	101.86
10/6/2012	7	7	6	MELA	12.5	13.5		0.13	375.49
10/6/2012	7	7	7	JUPR	37	15.8		1.16	42.86
10/6/2012	7	7	8	JUPR	16.5	9.4		0.23	215.50

10/6/2012	7	7	9	JUPR	16.5	9.4		0.23	215.50
10/6/2012	7	8	0	NA			Field	0.00	0.00
10/6/2012	7	9	1	EUGL	18	24.1		0.27	181.08
10/6/2012	7	9	2	EUGL	11.5	15.6		0.11	443.64
10/6/2012	7	9	3	EUGL	8.5	12.6		0.06	812.05
10/6/2012	7	9	4	EUGL	14	22		0.17	299.34
10/6/2012	7	9	5	EUGL	23	22.4		0.45	110.91
10/6/2012	8	1	1	EUGL	20.5	17		0.36	139.61
10/6/2012	8	1	2	JUPR	19	10		0.31	162.52
10/6/2012	8	1	3	JUPR	24	14		0.49	101.86
10/6/2012	8	2	1	JUPR	20	13.6		0.34	146.68
10/6/2012	8	2	2	JUPR	46	13.6		1.79	27.73
10/6/2012	8	2	3	JUPR	19	10.6		0.31	162.52
10/6/2012	8	2	4	EUGL	14.5	12		0.18	279.05
10/6/2012	8	3	1	EUGL	22.5	22		0.43	115.89
10/6/2012	8	3	2	EUGL	27.8	25		0.65	75.92
10/6/2012	8	3	3	EUGL	20	18.2		0.34	146.68
10/6/2012	8	3	4	EUGL	20.5	17		0.36	139.61
10/6/2012	8	4	1	JUPR	24	13.2		0.49	101.86
10/6/2012	8	5	1	EUGL	18	19		0.27	181.08
10/6/2012	8	5	2	EUGL	21	20		0.37	133.04
10/6/2012	8	5	3	EUGL	22	20		0.41	121.22
10/6/2012	8	5	4	JUPR	30.5	11.8		0.79	63.07
10/6/2012	8	6	1	EUGL	22	21.4		0.41	121.22
10/6/2012	8	6	2	JUPR	24.5	11.8		0.51	97.74
10/6/2012	8	7	1	JUPR	32	10		0.87	57.30
10/6/2012	8	7	2	EUGL	21.5	20.5		0.39	126.92
10/6/2012	8	7	3	EUGL	19.5	20.5		0.32	154.30
10/6/2012	8	7	4	EUGL	20.5	20.5		0.36	139.61

10/6/2012	8	8	1	JUPR	18	7.4		0.27	181.08
10/6/2012	8	8	2	EUGL	25	12		0.53	93.87
10/6/2012	8	8	3	EUGL	13.5	11		0.15	321.92
10/6/2012	8	8	4	EUGL	26	24.2		0.57	86.79
10/6/2012	8	8	5	EUGL	23	16.4		0.45	110.91
10/6/2012	8	9	1	MELA	20	10		0.34	146.68
10/6/2012	9	1	1	EUGL	18.5	18.2		0.29	171.43
10/6/2012	9	1	2	JUPR	35.5	10.5		1.07	46.55
10/6/2012	9	2	1	EUGl	5	3.8		0.02	2346.83
10/6/2012	9	2	2	EUGl	24	13.6		0.49	101.86
10/6/2012	9	3	1	EUGL	20	13.2		0.34	146.68
10/6/2012	9	3	2	EUGL	20	13.2		0.34	146.68
10/6/2012	9	3	3	EUGL	17.5	13.2		0.26	191.58
10/6/2012	9	3	4	EUGL	12	11.6		0.12	407.44
10/6/2012	9	3	5	JUPR	13	4		0.14	347.16
10/6/2012	9	3	6	EUGL	13	12.8		0.14	347.16
10/6/2012	9	3	7	EUGL	12.5	12		0.13	375.49
10/6/2012	9	3	8	EUGL	12.5	12.8		0.13	375.49
10/6/2012	9	4	1	JUPR	19.5	8		0.32	154.30
10/6/2012	9	4	2	EUGL	18.6	13		0.29	169.59
10/6/2012	9	4	3	EUGL	16	12.6		0.22	229.18
10/6/2012	9	5	1	JUPR	26.5	10		0.59	83.55
10/6/2012	9	5	2	JUPR	17	4.2		0.24	203.01
10/6/2012	9	6	1	EUGL	30	16.8		0.76	65.19
10/6/2012	9	6	2	EUGL	20.5	13.6		0.36	139.61
10/6/2012	9	6	3	OL RO	23	9.8		0.45	110.91
10/6/2012	9	6	4	JUPR	50	9.8		2.11	23.47
10/6/2012	9	7	1	JUPR	32	8		0.87	57.30
10/6/2012	9	7	2	EUGL	19	15.2		0.31	162.52

10/6/2012	9	7	3	EUGL	24.5	14.8		0.51	97.74
10/6/2012	9	8	1	JUPR	27	8		0.62	80.48
10/6/2012	9	8	2	JUPR	26	8.1		0.57	86.79
10/6/2012	9	8	3	JUPR	35	8.4		1.04	47.89
10/6/2012	9	9	1	EUGL	19	14		0.31	162.52
10/6/2012	9	9	2	EUGL	18	14		0.27	181.08
10/6/2012	9	9	3	EUGL	21	15.8		0.37	133.04
10/6/2012	9	9	4	EUGL	17	17.8		0.24	203.01
10/6/2012	10	1	0	NA			Coppice	0.00	0.00
10/6/2012	10	2	1	JUPR	11.5	6.8		0.11	443.64
10/6/2012	10	3	1	EUGL	29	13.2	Stream	0.71	69.76
10/6/2012	10	4	1	JUPR	6	7		0.03	1629.74
10/6/2012	10	4	2	JUPR	20.5	8.6		0.36	139.61
10/6/2012	10	4	3	JUPR	14	8		0.17	299.34
10/6/2012	10	4	4	JUPR	14	8		0.17	299.34
10/6/2012	10	5	0	NA			Coppice	0.00	0.00
10/6/2012	10	6	1	JUPR	34	13.6		0.98	50.75
10/6/2012	10	7	1	JUPR	14.5	7.8		0.18	279.05
10/6/2012	10	7	2	JUPR	53	11.6		2.37	20.89
10/6/2012	10	8	1	JUPR	18.5	7.2		0.29	171.43
10/6/2012	10	9	1	JUPR	45.4	11		1.74	28.46
10/6/2012	10	9	2	EUGL	23.5	25.6		0.47	106.24
10/6/2012	10	9	3	EUGL	28.5	21.4		0.69	72.23
10/6/2012	10	9	4	EUGL	27	25.4		0.62	80.48
10/6/2012	10	9	5	JUPR	24.5	10.6		0.51	97.74
10/6/2012	10	9	6	JUPR	42.5	10.6		1.53	32.48
10/6/2012	10	9	7	EUGL	31.5	27		0.84	59.13
10/18/2012	11	1	1	EUGL	20.5	20.2		0.36	139.61
10/18/2012	11	1	2	JUPR	23.7	11		0.47	104.45

10/18/2012	11	1	3	ROSE	1.5	2.2		0.00	26075.89
10/18/2012	11	2	1	EUGL	21	15.8		0.37	133.04
10/18/2012	11	2	2	EUGL	20.5	25.8		0.36	139.61
10/18/2012	11	2	3	JUPR	18	9		0.27	181.08
10/18/2012	11	3	1	EUGL	17.5	22.8		0.26	191.58
10/18/2012	11	3	2	EUGL	13	16.2		0.14	347.16
10/18/2012	11	3	3	EUGL	17	16.2		0.24	203.01
10/18/2012	11	3	4	EUGL	15.5	14.2		0.20	244.21
10/18/2012	11	3	5	EUGL	18	16.2		0.27	181.08
10/18/2012	11	3	6	EUGL	3	5.2		0.01	6518.9
10/18/2012	11	4	1	EUGL	18	27.8		0.27	181.08
10/18/2012	11	4	2	MYAD	9	2		0.07	724.33
10/18/2012	11	4	3	EUGL	26.5	22		0.59	83.55
10/18/2012	11	4	4	JUPR	16	10.4		0.22	229.18
10/18/2012	11	4	5	JUPR	34	11.2		0.98	50.75
10/18/2012	11	4	6	EUGL	28	26.2		0.66	74.84
10/18/2012	11	4	7	EUGL	15.5	13.4		0.20	244.21
10/18/2012	11	4	8	EUGL	16.5	16.2		0.23	215.50
10/18/2012	11	4	9	EUGL	2	4		0.00	14667
10/18/2012	11	4	10	EUGL	9.5	11.2		0.08	650.09
10/18/2012	11	4	11	EUGL	34	29.4		0.98	50.75
10/18/2012	11	5	1	EUGL	15.5	14.6		0.20	244.21
10/18/2012	11	5	2	EUGL	32	27.3		0.87	57.30
10/18/2012	11	5	3	EUGL	29.5	27		0.74	67.42
10/18/2012	11	5	4	EUGL	18	20.8		0.27	181.08
10/18/2012	11	5	5	EUGL	24	27		0.49	101.86
10/18/2012	11	5	6	NUCO	8.5	2.5		0.06	812.05
10/18/2012	11	6	1	EUGL	15	20		0.19	260.76
10/18/2012	11	6	2	EUGL	15	22		0.19	260.76

10/18/2012	11	6	3	EUGL	23	26.4		0.45	110.91
10/18/2012	11	6	4	EUGL	19.5	25.2		0.32	154.30
10/18/2012	11	6	5	JUPR	14	9.6		0.17	299.34
10/18/2012	11	7	1	EUGL	18.2	14.8		0.28	177.12
10/18/2012	11	7	2	EUGL	17	14.9		0.24	203.01
10/18/2012	11	7	3	EUGL	10	13		0.08	586.71
10/18/2012	11	7	4	EUGL	11	13		0.10	484.88
10/18/2012	11	7	5	EUGL	25.5	20.2		0.55	90.23
10/18/2012	11	7	6	EUGL	25	22		0.53	93.87
10/18/2012	11	8	1	EUGL	16	20		0.22	229.18
10/18/2012	11	8	2	EUGL	23	23.2		0.45	110.91
10/18/2012	11	8	3	EUGL	21	23.2		0.37	133.04
10/18/2012	11	8	4	EUGL	18	24.2		0.27	181.08
10/18/2012	11	9	1	EUGL	12.5	13.4	Road	0.13	375.49
10/18/2012	12	1	1	MY AD	6	3		0.03	1629.7
10/18/2012	12	1	2	JUPR	7	7		0.04	1197.3
10/18/2012	12	1	3	JUPR	25	9.3		0.53	93.87
10/18/2012	12	2	1	EUGL	15.5	13.4		0.20	244.21
10/18/2012	12	2	2	JUPR	12	10.4		0.12	407.44
10/18/2012	12	3	1	JUPR	14.5	7.5		0.18	279.05
10/18/2012	12	3	2	EUGL	16.5	15.8		0.23	215.50
10/18/2012	12	3	3	EUGL	15.5	15.4		0.20	244.21
10/18/2012	12	4	1	EUGL	12	12		0.12	407.44
10/18/2012	12	4	2	EUGL	10	8		0.08	586.71
10/18/2012	12	4	3	EUGL	6.5	11		0.04	1388.66
10/18/2012	12	4	4	EUGL	6	8		0.03	1629.7
10/18/2012	12	5	0	NA			Road	0.00	0.00
10/18/2012	12	6	0	NA			Erosion	0.00	0.00
10/18/2012	12	7	1	EUGL	4.5	9.4		0.02	2897.3

10/18/2012	12	8	1	EUGL	21.5	22.2		0.39	126.92
10/18/2012	12	8	2	JUPR	20.5	9.2		0.36	139.61
10/18/2012	12	8	3	JUPR	27	9.2		0.62	80.48
10/18/2012	12	8	4	EUGL	15.5	19.2		0.20	244.21
10/18/2012	12	8	5	OLRO	9	9.2	OLENEA Rochata	0.07	724.33
10/18/2012	12	8	6	MYAD	8	5		0.05	916.73
10/18/2012	12	9	1	EUGL	30	24.2		0.76	65.19
10/18/2012	12	9	2	EUGL	24.5	24.2		0.51	97.74
10/18/2012	13	1	1	EUGL	3.5	3.6		0.01	4789.4
10/18/2012	13	2	0	NA			Road	0.00	0.00
10/18/2012	13	3	1	JUPR	12	10.8		0.12	407.44
10/18/2012	13	3	2	JUPR	32	9.7		0.87	57.30
10/18/2012	13	4	0	NA			Clearing	0.00	0.00
10/18/2012	13	5	1	EUGL	3	6		0.01	6518.9
10/18/2012	13	5	2	EUGL	4.5	10.4		0.02	2897.3
10/18/2012	13	5	3	JUPR	20	11.3		0.34	146.68
10/18/2012	13	5	4	JUPR	28.5	10.4		0.69	72.23
10/18/2012	13	6	1	EUGL	7	11.8		0.04	1197.3
10/18/2012	13	6	2	EUGL	9	12.1		0.07	724.33
10/18/2012	13	7	1	JUPR	23	10.8		0.45	110.91
10/18/2012	13	7	2	JUPR	9.5	7.2		0.08	650.09
10/18/2012	13	7	3	EUGl	8.2	11		0.06	872.56
10/18/2012	13	7	4	EUGl	10	12.4		0.08	586.71
10/18/2012	13	7	5	JUPR	13	7.4		0.14	347.16
10/18/2012	13	7	6	EUGl	12	14.4		0.12	407.44
10/18/2012	13	8	1	EUGl	9.5	11.4	Open Soil	0.08	650.09
10/18/2012	13	9	1	EUGL	20	11		0.34	146.68
10/18/2012	14	1	1	EUGL	1	2.5		0.00	58670
10/18/2012	14	1	2	EUGL	2	2.5		0.00	14667.69

10/18/2012	14	1	3	EUGL	2.5	3		0.01	9387
10/18/2012	14	2	1	EUGL	6	9.4		0.03	1629.
10/18/2012	14	3	1	EUGl	17	16.6		0.24	203.01
10/18/2012	14	3	2	JUPR	12.5	10.6		0.13	375.49
10/18/2012	14	3	3	JUPR	17	10.6		0.24	203.01
10/18/2012	14	3	4	JUPR	21	10.6		0.37	133.04
10/18/2012	14	3	5	JUPR	17	10.6		0.24	203.01
10/18/2012	14	4	1	EUGL	21	23.6		0.37	133.04
10/18/2012	14	5	1	JUPR	6	9		0.03	1629.
10/18/2012	14	5	2	EUGL	18.5	17.6		0.29	171.43
10/18/2012	14	5	3	EUGL	18	17.6		0.27	181.08
10/18/2012	14	6	1	EUGL	16	9.6		0.22	229.18
10/18/2012	14	6	2	EUGL	18.5	19.4		0.29	171.43
10/18/2012	14	7	1	EUGl	5	6.4	TRAIL	0.02	2346.8
10/18/2012	14	8	1	EUGL	14	15.4		0.17	299.34
10/18/2012	14	9	1	EUGL	23.3	14.6		0.46	108.07
10/18/2012	14	9	2	EUGL	17.5	15.4		0.26	191.58
10/18/2012	14	9	2	EUGL	24.5	14		0.51	97.74
10/18/2012	15	1	1	EUGL	26	16.4		0.57	86.79
10/18/2012	15	2	1	JUPR	27	10.6		0.62	80.48
10/18/2012	15	2	2	EUGL	4.5	8.2		0.02	2897.3
10/18/2012	15	3	1	JUPR	17.5	12.4		0.26	191.58
10/18/2012	15	3	2	EUGL	10.5	7.8		0.09	532.16
10/18/2012	15	4	1	JUPR	10	10.6		0.08	586.71
10/18/2012	15	4	2	JUPR	12	10.6		0.12	407.44
10/18/2012	15	4	3	JUPR	27	10.6		0.62	80.48
10/18/2012	15	4	4	EUGL	49.5	14.8		2.07	23.94
10/18/2012	15	5	1	EUGL	29	18.6		0.71	69.76
10/18/2012	15	5	2	EUGL	5	5.5		0.02	2346.8

10/18/2012	15	5	3	EUGL	10.5	12		0.09	532.16
10/18/2012	15	6	1	JUPR	22.5	11.6		0.43	115.89
10/18/2012	15	6	2	JUPR	8.5	8		0.06	812.05
10/18/2012	15	7	1	EUGL	27.5	20	Road	0.64	77.58
10/18/2012	15	7	2	EUGL	6.5	10		0.04	1388.6
10/18/2012	15	8	1	EUGL	10.5	11.4		0.09	532.16
10/18/2012	15	8	2	JUPR	8	6		0.05	916.73
10/18/2012	15	8	3	JUPR	28	11.8		0.66	74.84
10/18/2012	15	8	4	EUGL	20	18.4		0.34	146.68
10/18/2012	15	9	1	EUGL	19.5	11		0.32	154.30
10/18/2012	15	9	2	EUGL	23	20.2		0.45	110.91
10/18/2012	15	9	3	EUGL	24.5	19		0.51	97.74
10/18/2012	16	1	1	JUPR	15	5		0.19	260.76
10/18/2012	16	2	1	JUPR	12.5	4.8		0.13	375.49
10/18/2012	16	2	2	EUGl	20	16.8		0.34	146.68
10/18/2012	16	2	3	JUPR	19	7.6		0.31	162.52
10/18/2012	16	2	4	EUGL	20	16.8		0.34	146.68
10/18/2012	16	2	5	EUGL	27	16.2		0.62	80.48
10/18/2012	16	3	1	JUPR	13.5	9		0.15	321.92
10/18/2012	16	3	2	EUGl	19	11.8		0.31	162.52
10/18/2012	16	3	3	EUGl	23	14.2		0.45	110.91
10/18/2012	16	3	4	JUPR	21.5	7.8		0.39	126.92
10/18/2012	16	4	1	JUPR	19	9.2		0.31	162.52
10/18/2012	16	4	2	JUPR	10	4		0.08	586.71
10/18/2012	16	4	3	JUPR	8	4		0.05	916.73
10/18/2012	16	4	4	EUGl	7	9.2		0.04	1197.3
10/18/2012	16	5	1	JUPR	13.5	9.6		0.15	321.92
10/18/2012	16	5	2	JUPR	24	9.8		0.49	101.86
10/18/2012	16	5	3	JUPR	56	11.7		2.65	18.71

10/18/2012	16	6	0	NA			Road	0.00	0.00
10/18/2012	16	7	1	EUGL	5	6.4		0.02	2346.8
10/18/2012	16	7	2	EUGL	6	6.6		0.03	1629.7
10/18/2012	16	8	1	EUGL	4.5	4.2		0.02	2897.3
10/18/2012	16	8	2	JUPR	40	9.2		1.35	36.67
10/18/2012	16	9	1	JUPR	30.5	10.8	Coppice	0.79	63.07
10/19/2012	17	1	1	EUGL	10	11		0.08	586.71
10/19/2012	17	1	2	EUGL	13	12		0.14	347.16
10/19/2012	17	1	3	EUGL	16.5	14.6		0.23	215.50
10/19/2012	17	1	4	JUPR	8.5	4		0.06	812.05
10/19/2012	17	2	1	EUGL	37	22		1.16	42.86
10/19/2012	17	2	2	OLEU	19.5	16		0.32	154.30
10/19/2012	17	2	3	JUPR	24	17		0.49	101.86
10/19/2012	17	2	4	TULA	7	6		0.04	1197.3
10/19/2012	17	2	5	OLRO	10	6		0.08	586.71
10/19/2012	17	3	1	JUPR	34.25	12.2		0.99	50.02
10/19/2012	17	3	2	JUPR	49	11.4		2.03	24.44
10/19/2012	17	3	3	JUPR	56	14.8		2.65	18.71
10/19/2012	17	3	4	EUGL	27.5	21.4		0.64	77.58
10/19/2012	17	4	1	JUPR	25	10.8		0.53	93.87
10/19/2012	17	4	2	JUPR	42	10		1.49	33.26
10/19/2012	17	4	3	JUPR	30	10.5		0.76	65.19
10/19/2012	17	4	4	EUGL	23.5	19.4		0.47	106.24
10/19/2012	17	5	1	EUGL	11	13.6		0.10	484.88
10/19/2012	17	5	2	EUGL	17.5	15.8		0.26	191.58
10/19/2012	17	5	3	EUGL	16	17.6		0.22	229.18
10/19/2012	17	5	4	EUGL	20	19.4		0.34	146.68
10/19/2012	17	5	5	EUGL	16	18.2		0.22	229.18
10/19/2012	17	6	1	EUGL	15	12.4		0.19	260.76

10/19/2012	17	6	2	EUGL	7.5	8.6		0.05	1043.0
10/19/2012	17	6	3	EUGL	21	18.8		0.37	133.04
10/19/2012	17	7	1	EUGL	13	14.4		0.14	347.16
10/19/2012	17	7	2	EUGL	21.5	15		0.39	126.92
10/19/2012	17	7	3	JUPR	32	9.8		0.87	57.30
10/19/2012	17	8	1	EUGL	10	12		0.08	586.71
10/19/2012	17	8	2	EUGL	14	12.8		0.17	299.34
10/19/2012	17	8	3	EUGL	11	13.2		0.10	484.88
10/19/2012	17	8	4	EUGL	11	11.4		0.10	484.88
10/19/2012	17	8	5	EUGL	16	14.4		0.22	229.18
10/19/2012	17	9	1	EUGL	11	11.4		0.10	484.88
10/19/2012	17	9	2	EUGL	16.5	14.6		0.23	215.50
10/19/2012	17	9	3	EUGL	15.5	12		0.20	244.21
10/19/2012	17	9	4	JUPR	38	9.6		1.22	40.63
10/19/2012	18	1	1	JUPR	34	11.6		0.98	50.75
10/19/2012	18	1	2	EUGL	15.5	18.8		0.20	244.21
10/19/2012	18	1	3	EUGL	12	13.6		0.12	407.44
10/19/2012	18	2	1	EUGL	26	20		0.57	86.79
10/19/2012	18	2	2	EUGL	11	14		0.10	484.88
10/19/2012	18	2	3	EUGL	38	22		1.22	40.63
10/19/2012	18	2	4	EUGL	33	21.5		0.92	53.88
10/19/2012	18	2	5	OLRO	19.5	10		0.32	154.30
10/19/2012	18	3	1	JUPR	9.5	6.2		0.08	650.09
10/19/2012	18	3	2	EUGL	21	13.4		0.37	133.04
10/19/2012	18	3	3	EUGL	15.5	15		0.20	244.21
10/19/2012	18	3	4	EUGL	12	12		0.12	407.44
10/19/2012	18	4	1	ACAB	17.5	6.2		0.26	191.58
10/19/2012	18	4	2	EUGL	18.5	22.8		0.29	171.43
10/19/2012	18	4	3	EUGL	19	22.8		0.31	162.52

10/19/2012	18	4	4	EUGL	20	15.8		0.34	146.68
10/19/2012	18	4	5	EUGL	18	13		0.27	181.08
10/19/2012	18	4	6	OLRO	15	7		0.19	260.76
10/19/2012	18	5	1	JUPR	6.8	6		0.04	1268.8
10/19/2012	18	5	2	JUPR	36.5	9.6		1.13	44.04
10/19/2012	18	5	3	OLEU	13	10		0.14	347.16
10/19/2012	18	5	4	OLEU	17	10		0.24	203.01
10/19/2012	18	5	5	OLEU	14	10		0.17	299.34
10/19/2012	18	6	1	JUPR	32	13.5		0.87	57.30
10/19/2012	18	6	2	JUPR	30	13		0.76	65.19
10/19/2012	18	6	3	OLRO	19	18		0.31	162.52
10/19/2012	18	7	1	OLRO	12.5	8		0.13	375.49
10/19/2012	18	7	2	OLRO	43.5	15		1.60	31.01
10/19/2012	18	7	3	JUPR	12.5	9.4		0.13	375.49
10/19/2012	18	7	4	EUGL	38	18.6		1.22	40.63
10/19/2012	18	8	1	EUGL	18	19.6		0.27	181.08
10/19/2012	18	8	2	EUGL	26	25.4		0.57	86.79
10/19/2012	18	9	1	EUGL	14.4	20.4		0.18	282.94
10/19/2012	18	9	2	EUGL	17.5	20.2		0.26	191.58
10/19/2012	18	9	3	JUPR	27	13		0.62	80.48
10/19/2012	18	9	4	JUPR	31	13		0.81	61.05
10/19/2012	19	1	1	JUPR	9.5	9		0.08	650.09
10/19/2012	19	1	2	OLRO	10	8		0.08	586.71
10/19/2012	19	1	3	OLRO	10	8		0.08	586.71
10/19/2012	19	1	4	OLRO	9	6.8		0.07	724.33
10/19/2012	19	2	1	EUGL	18.5	19		0.29	171.43
10/19/2012	19	2	2	EUGL	19.5	18.5		0.32	154.30
10/19/2012	19	2	3	EUGL	18.5	17		0.29	171.43
10/19/2012	19	2	4	EUGL	26	21		0.57	86.79

10/19/2012	19	2	5	OLRO	9.5	9		0.08	650.09
10/19/2012	19	3	1	JUPR	22	9.4		0.41	121.22
10/19/2012	19	4	1	EUGL	29.5	13.4		0.74	67.42
10/19/2012	19	4	2	EUGL	15	17.2		0.19	260.76
10/19/2012	19	4	3	EUGL	29	20		0.71	69.76
10/19/2012	19	4	4	EUGL	27.5	20		0.64	77.58
10/19/2012	19	4	5	OLRO	12.5	7		0.13	375.49
10/19/2012	19	4	6	OLRO	8	8		0.05	916.73
10/19/2012	19	5	1	JUPR	44	15.6		1.64	30.31
10/19/2012	19	5	2	EUGL	22.5	18.6		0.43	115.89
10/19/2012	19	5	3	JUPR	7.5	7.5		0.05	1043.0
10/19/2012	19	5	4	JUPR	7.5	8.5		0.05	1043.0
10/19/2012	19	5	5	OLRO	10	7.2		0.08	586.71
10/19/2012	19	6	1	JUPR	49.5	18		2.07	23.94
10/19/2012	19	6	2	OLRO	33	15		0.92	53.88
10/19/2012	19	6	3	EUGL	45.5	20.8		1.75	28.34
10/19/2012	19	6	4	OLRO	15.5	11		0.20	244.21
10/19/2012	19	7	1	OLRO	44.5	15.5		1.67	29.63
10/19/2012	19	7	2	OLRO	20.5	12		0.36	139.61
10/19/2012	19	7	3	OLRO	16.5	12		0.23	215.50
10/19/2012	19	7	4	OLRO	16	12		0.22	229.18
10/19/2012	19	7	5	APDE	47.5	9		1.91	26.00
10/19/2012	19	7	6	OLRO	24.5	14		0.51	97.74
10/19/2012	19	7	7	OLRO	25	14		0.53	93.87
10/19/2012	19	7	8	JUPR	44	13.2		1.64	30.31
10/19/2012	19	8	1	JUPR	21	11.6		0.37	133.04
10/19/2012	19	8	2	EUGL	20	12		0.34	146.68
10/19/2012	19	8	3	EUGL	14	12		0.17	299.34
10/19/2012	19	8	4	JUPR	19	10.2		0.31	162.52

10/19/2012	19	8	5	JUPR	21	10.2		0.37	133.04
10/19/2012	19	9	1	JUPR	38	12		1.22	40.63
10/19/2012	19	9	2	JUPR	28	13		0.66	74.84
10/19/2012	20	1	1	EUGL	15.6	14.2		0.21	241.09
10/19/2012	20	1	2	JUPR	23.3	8.8		0.46	108.07
10/19/2012	20	1	3	EUGL	19	13.6		0.31	162.52
10/19/2012	20	2	1	EUGL	22.8	19.4		0.44	112.86
10/19/2012	20	2	2	EUGL	23.9	19.4		0.48	102.71
10/19/2012	20	2	3	EUGL	14.3	19		0.17	286.91
10/19/2012	20	2	4	EUGL	17.7	19.8		0.26	187.27
10/19/2012	20	2	5	EUGL	12.4	16.4		0.13	381.57
10/19/2012	20	3	1	EUGL	18.9	21.6		0.30	164.25
10/19/2012	20	3	2	EUGL	9.5	12.7		0.08	650.09
10/19/2012	20	3	3	JUPR	23.5	8.6		0.47	106.24
10/19/2012	20	3	4	EUGL	17.6	17.4		0.26	189.41
10/19/2012	20	4	1	EUGL	19.6	18.2		0.32	152.72
10/19/2012	20	4	2	EUGL	18	17.6		0.27	181.08
10/19/2012	20	5	1	OLRO	6	9		0.03	1629.7
10/19/2012	20	5	2	JUPR	33.7	13		0.96	51.66
10/19/2012	20	5	3	JUPR	34.5	10.5		1.01	49.29
10/19/2012	20	6	1	EUGL	17.3	18.9		0.25	196.03
10/19/2012	20	6	2	JUPR	32	14.5		0.87	57.30
10/19/2012	20	6	3	JUPR	44	15.2		1.64	30.31
10/19/2012	20	7	1	JUPR	21.2	7.8		0.38	130.54
10/19/2012	20	7	2	JUPR	20	9.9		0.34	146.68
10/19/2012	20	8	1	EUGL	19	14		0.31	162.52
10/19/2012	20	8	2	EUGL	17.3	15.2		0.25	196.03
10/19/2012	20	8	3	EUGL	18	15.2		0.27	181.08
10/19/2012	20	9	1	EUGL	17.9	18		0.27	183.11

10/19/2012	20	9	2	EUGL	22	18.2		0.41	121.22
10/19/2012	20	9	3	EUGL	1.8	11.4		0.00	18108.
10/19/2012	20	9	4	EUGL	17	16.8		0.24	203.01
10/19/2012	20	9	5	EUGL	13.2	16.8		0.15	336.72
10/19/2012	20	9	6	EUGL	17.5	16.8		0.26	191.58
10/19/2012	20	9	7	JUPR	32.1	10.8		0.87	56.94
10/21/2012	21	1	1	EUGL	8	6		0.05	916.73
10/21/2012	21	1	2	JUPR	16	6.1		0.22	229.18
10/21/2012	21	1	3	JUPR	25.5	5.5		0.55	90.23
10/21/2012	21	2	0	NA			Road	0.00	0.00
10/21/2012	21	3	1	EUGL	5.5	3.1		0.03	1939.5
10/21/2012	21	4	1	JUPR	13	4.8		0.14	347.16
10/21/2012	21	4	2	JUPR	9.5	3.4		0.08	650.09
10/21/2012	21	4	3	JUPR	14.5	4.8		0.18	279.05
10/21/2012	21	4	4	EUGL	7	6.3		0.04	1197.3
10/21/2012	21	4	5	EUGL	7	7.5		0.04	1197.3
10/21/2012	21	5	1	EUGL	13.25	9.2		0.15	334.19
10/21/2012	21	5	2	EUGL	7	6.3		0.04	1197.3
10/21/2012	21	5	3	EUGL	13.25	9.8		0.15	334.19
10/21/2012	21	5	4	EUGL	3.5	4.5		0.01	4789.4
10/21/2012	21	5	5	EUGL	14.5	12.2		0.18	279.05
10/21/2012	21	5	6	EUGL	7	8		0.04	1197.3
10/21/2012	21	6	1	JUPR	44	9		1.64	30.31
10/21/2012	21	7	1	JUPR	13.5	6.2		0.15	321.92
10/21/2012	21	7	2	EUGL	11	16		0.10	484.88
10/21/2012	21	7	3	EUGL	11.5	14.2		0.11	443.64
10/21/2012	21	8	1	JUPR	19	7.3		0.31	162.52
10/21/2012	21	8	2	JUPR	17	7.2		0.24	203.01
10/21/2012	21	9	1	EUGL	3	4		0.01	6518.9

10/21/2012	21	9	2	EUGL	9.5	8.4		0.08	650.09
10/21/2012	22	1	1	EUGL	3	3.3		0.01	6518.9
10/21/2012	22	1	2	EUGL	3	3.2		0.01	6518.9
10/21/2012	22	1	3	EUGL	5.5	6.7		0.03	1939.5
10/21/2012	22	2	1	EUGL	7.5	6.4		0.05	1043.0
10/21/2012	22	2	2	EUGL	9	6.2		0.07	724.33
10/21/2012	22	2	3	EUGL	11	6.7		0.10	484.88
10/21/2012	22	3	1	JUPR	26	6.6		0.57	86.79
10/21/2012	22	3	2	EUGL	14.5	8.8		0.18	279.05
10/21/2012	22	4	1	JUPR	25	9.2		0.53	93.87
10/21/2012	22	4	2	JUPR	21	8.8		0.37	133.04
10/21/2012	22	5	1	EUGL	4.5	5		0.02	2897.3
10/21/2012	22	5	2	JUPR	10	4.5		0.08	586.71
10/21/2012	22	6	1	EUGL	10	9.2		0.08	586.71
10/21/2012	22	6	2	EUGL	6.5	9		0.04	1388.6
10/21/2012	22	6	3	JUPR	9	3.5		0.07	724.33
10/21/2012	22	7	1	EUGL	3.5	4.3		0.01	4789.4
10/21/2012	22	7	2	EUGL	5.5	5.6		0.03	1939.5
10/21/2012	22	8	0	NA			ROCKS!	0.00	0.00
10/21/2012	22	9	1	EUGL	3.5	4.1		0.01	4789.4
10/21/2012	22	9	2	EUGL	2.75	4		0.01	7758.1
10/21/2012	23	1	1	JUPR	6	3.8		0.03	1629.7
10/21/2012	23	1	2	EUGL	10	6.9		0.08	586.71
10/21/2012	23	1	3	EUGL	9.5	7.1		0.08	650.09
10/21/2012	23	2	1	JUPR	35	11.1		1.04	47.89
10/21/2012	23	2	2	JUPR	18.5	9.8		0.29	171.43
10/21/2012	23	2	3	JUPR	74	25.2		4.63	10.71
10/21/2012	23	3	1	JUPR	46	13.8		1.79	27.73
10/21/2012	23	3	2	JUPR	75	19.4		4.76	10.43

10/21/2012	23	3	3	JUPR	65.5	13.4		3.63	13.68
10/21/2012	23	4	1	EUGL	6	9.5		0.03	1629.7
10/21/2012	23	4	2	EUGL	5	10		0.02	2346.8
10/21/2012	23	4	3	EUGL	10.5	11.4		0.09	532.16
10/21/2012	23	4	4	EUGL	12	13.8		0.12	407.44
10/21/2012	23	5	1	EUGL	5.5	8		0.03	1939.5
10/21/2012	23	5	2	JUPR	9.25	6.7		0.07	685.71
10/21/2012	23	5	3	JUPR	14	7		0.17	299.34
10/21/2012	23	6	1	JUPR	1.5	7		0.00	26075
10/21/2012	23	6	2	EUGL	1.9	14.4		0.00	16252.
10/21/2012	23	6	3	EUGL	1.8	14.1		0.00	18108.
10/21/2012	23	6	4	JUPR	2	7.1		0.00	14667
10/21/2012	23	7	1	JUPR	9.5	6.8		0.08	650.09
10/21/2012	23	7	2	JUPR	11.5	6.8		0.11	443.64
10/21/2012	23	7	3	EUGL	6.25	7.1		0.03	1501.9
10/21/2012	23	7	4	EUGL	11.5	8.8		0.11	443.64
10/21/2012	23	8	1	EUGL	5.5	9.6	Coppice Young	0.03	1939.5
10/21/2012	23	9	1	JUPR	49.2	10		2.05	24.24
10/21/2012	24	1	1	JUPR	21	6.4		0.37	133.04
10/21/2012	24	1	2	JUPR	109	17.4		10.04	4.94
10/21/2012	24	2	0	NA			Coppice Young	0.00	0.00
10/21/2012	24	3	1	EUGL	1.5	2		0.00	26075
10/21/2012	24	3	2	JUPR	79	15.6		5.28	9.40
10/21/2012	24	3	3	JUPR	82	15.6		5.68	8.73
10/21/2012	24	4	0	NA			Road	0.00	0.00
10/21/2012	24	5	0	NA			Coppice	0.00	0.00
10/21/2012	24	6	0	NA			Road	0.00	0.00
10/21/2012	24	7	1	JUPR	22	9.4		0.41	121.22
10/21/2012	24	7	2	JUPR	11	3.8		0.10	484.88

10/21/2012	24	8	0	NA			Road Cows	0.00	0.00
10/21/2012	24	9	1	JUPR	37	9.6		1.16	42.86
10/21/2012	24	9	2	JUPR	14.5	7.2		0.18	279.05
10/21/2012	24	9	3	JUPR	84	17		5.97	8.32
10/21/2012	25	1	1	JUPR	15	10.2		0.19	260.76
10/21/2012	25	1	2	MERSINE	10	10.4		0.08	586.71
10/21/2012	25	2	0	NA			Sinkhole	0.00	0.00
10/21/2012	25	3	0	NA			New Clear Cut	0.00	0.00
10/21/2012	25	4	1	JUPR	11	5.4		0.10	484.88
10/21/2012	25	5	1	JUPR	5.5	8.5		0.03	1939.5
10/21/2012	25	6	1	JUPR	8.5	5.4		0.06	812.05
10/21/2012	25	7	1	JUPR	14	8.7		0.17	299.34
10/21/2012	25	7	2	JUPR	13	9.1		0.14	347.16
10/21/2012	25	7	3	JUPR	15.5	10.7		0.20	244.21
10/21/2012	25	7	4	JUPR	15.5	10.6		0.20	244.21
10/21/2012	25	8	0	NA			CLEARCUT	0.00	0.00
10/26/2012	25	9	0	NA			COPPICE	0.00	0.00
10/25/2012	26	1	1	JUPR	23	10.2		0.45	110.91
10/25/2012	26	1	2	JUPR	15	10.2		0.19	260.76
10/25/2012	26	1	3	JUPR	11	10.2		0.10	484.88
10/25/2012	26	1	4	JUPR	12	10		0.12	407.44
10/25/2012	26	2	1	JUPR	13.5	7.6		0.15	321.92
10/25/2012	26	3	0	NA			Clearing	0.00	0.00
10/25/2012	26	4	0	NA			Cliff>20%	0.00	0.00
10/25/2012	26	5	0	NA			Cliff>20%	0.00	0.00
10/25/2012	26	6	1	DOAB	7.5	4.7		0.05	1043.0
10/25/2012	26	7	1	JUPR	12	4.3		0.12	407.44
10/25/2012	26	7	2	OSQU	9	2.5		0.07	724.33
10/25/2012	26	8	1	JUPR	31	9.9		0.81	61.05

10/25/2012	26	8	2	JUPR	28	9.7		0.66	74.84
10/25/2012	26	8	3	JUPR	20.5	9.5		0.36	139.61
10/25/2012	26	8	4	JUPR	21	9.6		0.37	133.04
10/25/2012	26	9	1	EUGL	23.5	13.8		0.47	106.24
10/25/2012	26	9	2	EUGL	30.5	16.1		0.79	63.07
10/25/2012	26	9	3	EUGL	32.5	16.2		0.89	55.55
10/25/2012	26	9	4	EUGL	22	14.5		0.41	121.22
10/25/2012	26	9	5	EUGL	19.5	14.4		0.32	154.30
10/25/2012	26	9	6	EUGL	26	16		0.57	86.79
10/25/2012	27	1	1	EUGL	22	17.8		0.41	121.22
10/25/2012	27	1	2	EUGL	19.5	17.8		0.32	154.30
10/25/2012	27	1	3	EUGL	14	12.4		0.17	299.34
10/25/2012	27	1	4	EUGL	16.5	12.4		0.23	215.50
10/25/2012	27	2	1	EUGL	11	9		0.10	484.88
10/25/2012	27	3	0	NA			Amphitheatre	0.00	0.00
10/25/2012	27	4	1	EUGL	20	22.2		0.34	146.68
10/25/2012	27	4	2	EUGL	25.5	22.4		0.55	90.23
10/25/2012	27	4	3	EUGL	16.5	16.4		0.23	215.50
10/25/2012	27	5	1	EUGL	22	24.5		0.41	121.22
10/25/2012	27	5	2	EUGL	19	20		0.31	162.52
10/25/2012	27	6	1	EUGL	22.5	22.4		0.43	115.89
10/25/2012	27	6	2	EUGL	18.5	22.4		0.29	171.43
10/25/2012	27	6	3	EUGL	26	20		0.57	86.79
10/25/2012	27	6	4	EUGL	15	14.2		0.19	260.76
10/25/2012	27	7	1	EUGL	15.5	22.8		0.20	244.21
10/25/2012	27	7	2	EUGL	26	25.8		0.57	86.79
10/25/2012	27	8	1	EUGL	10	11.4		0.08	586.71
10/25/2012	27	8	2	EUGL	11.5	16		0.11	443.64
10/25/2012	27	8	3	EUGL	11.75	16.4		0.12	424.96

10/25/2012	27	8	4	EUGL	20.5	21.6		0.36	139.61
10/25/2012	27	8	5	EUGL	14.5	15.6		0.18	279.05
10/25/2012	27	9	1	EUGL	12.5	12.6		0.13	375.49
10/25/2012	27	9	2	EUGL	15	14.6		0.19	260.76
10/25/2012	27	9	3	EUGL	12	12.6		0.12	407.44
10/25/2012	27	9	4	EUGL	11.75	12.6		0.12	424.96
10/25/2012	27	9	5	EUGL	10	11.1		0.08	586.71
10/25/2012	28	1	1	EUGL	27.5	19.6		0.64	77.58
10/25/2012	28	1	2	EUGL	27.5	19.6		0.64	77.58
10/25/2012	28	1	3	EUGL	22	18.2		0.41	121.22
10/25/2012	28	2	1	JUPR	27.5	10.5		0.64	77.58
10/25/2012	28	2	2	EUGL	28.5	17.6		0.69	72.23
10/25/2012	28	3	1	EUGL	21.5	23.5	Riparian	0.39	126.92
10/25/2012	28	4	1	EUGL	31	15.2		0.81	61.05
10/25/2012	28	4	2	JUPR	19	9.2		0.31	162.52
10/25/2012	28	4	3	JUPR	26	9.2		0.57	86.79
10/25/2012	28	4	4	EUGL	10.5	9.2		0.09	532.16
10/25/2012	28	5	1	JUPR	18.5	9		0.29	171.43
10/25/2012	28	5	2	JUPR	33	11.8		0.92	53.88
10/25/2012	28	6	1	JUPR	20.75	8	Road	0.36	136.27
10/25/2012	28	7	1	EUGL	9	10.4		0.07	724.33
10/25/2012	28	7	2	EUGL	22	12.6		0.41	121.22
10/25/2012	28	8	1	EUGL	18	18.1		0.27	181.08
10/25/2012	28	8	2	JUPR	10	8		0.08	586.71
10/25/2012	28	8	3	EUGL	9.5	9		0.08	650.09
10/25/2012	28	8	4	EUGL	16	17		0.22	229.18
10/25/2012	28	8	5	EUGL	18.5	18.2		0.29	171.43
10/25/2012	28	9	1	JUPR	28	9.7		0.66	74.84
10/25/2012	28	9	2	EUGL	25	22		0.53	93.87

10/25/2012	28	9	3	MYAD	5.5	2.8		0.03	1939.5
10/16/2012	29	1	1	EUGL	10.5	11.2		0.09	532.16
10/16/2012	29	2	1	EUGL	13.5	13.8		0.15	321.92
10/16/2012	29	2	2	EUGL	8	7.6		0.05	916.73
10/16/2012	29	2	3	EUGL	10.5	11.6		0.09	532.16
10/16/2012	29	2	4	EUGL	9	10.6		0.07	724.33
10/16/2012	29	3	1	JUPR	13.5	5.8		0.15	321.92
10/16/2012	29	3	2	EUGL	11.25	10.2		0.11	463.57
10/16/2012	29	3	3	EUGl	15	10.7		0.19	260.76
10/16/2012	29	3	4	EUGL	15	12.2		0.19	260.76
10/16/2012	29	4	1	EUGL	11	8.2		0.10	484.88
10/16/2012	29	4	2	EUGL	12.5	9		0.13	375.49
10/16/2012	29	4	3	EUGL	26	22		0.57	86.79
10/16/2012	29	4	4	EUGL	13.8	10.7		0.16	308.08
10/16/2012	29	4	5	EUGL	13.5	12.1		0.15	321.92
10/16/2012	29	4	6	EUGL	17	19.8		0.24	203.01
10/16/2012	29	4	7	EUGL	12.5	15.4		0.13	375.49
10/16/2012	29	5	1	EUGL	16	16.2		0.22	229.18
10/16/2012	29	5	2	EUGL	11	14		0.10	484.88
10/16/2012	29	5	3	EUGL	14	17.8		0.17	299.34
10/16/2012	29	5	4	EUGL	8.5	12.2		0.06	812.05
10/16/2012	29	5	5	EUGL	9.5	13.3		0.08	650.09
10/16/2012	29	6	0	NA			HARVEST	0.00	0.00
10/16/2012	29	7	0	NA			HARVEST	0.00	0.00
10/16/2012	29	8	1	EUGL	13.5	13.1		0.15	321.92
10/16/2012	29	9	0	NA			HARVEST	0.00	0.00
10/16/2012	30	1	1	EUGL	8.5	8.5		0.06	812.05
10/16/2012	30	1	1	EUGL	11.5	9.8		0.11	443.64
10/16/2012	30	1	1	EUGL	13	9.9		0.14	347.16

10/16/2012	30	2	1	EUGL	15.6	11.5		0.21	241.09
10/16/2012	30	2	2	EUGL	23	16		0.45	110.91
10/16/2012	30	2	3	EUGL	21	11.5		0.37	133.04
10/16/2012	30	2	4	EUGL	23	10.5		0.45	110.91
10/16/2012	30	2	5	EUGL	28	19.5		0.66	74.84
10/16/2012	30	2	6	EUGL	29.5	29		0.74	67.42
10/16/2012	30	2	7	EUGL	23	16		0.45	110.91
10/16/2012	30	3	1	EUGL	17	15.4		0.24	203.01
10/16/2012	30	3	2	EUGL	10	7		0.08	586.71
10/16/2012	30	3	3	EUGL	10.8	8.5		0.10	503.01
10/16/2012	30	3	4	EUGL	13.8	11		0.16	308.08
10/16/2012	30	4	1	EUGL	12	10.8		0.12	407.44
10/16/2012	30	4	2	EUGL	6.5	7.6		0.04	1388.6
10/16/2012	30	4	3	EUGL	9	8.4		0.07	724.33
10/16/2012	30	5	1	EUGL	25	18.2		0.53	93.87
10/16/2012	30	5	2	EUGL	7.5	7.6		0.05	1043
10/16/2012	30	5	3	EUGL	11.6	11.5		0.11	436.02
10/16/2012	30	6	1	EUGL	33	29.4		0.92	53.88
10/16/2012	30	6	2	EUGL	27.1	21.5		0.62	79.89
10/16/2012	30	6	3	JUPR	19.25	8.6		0.31	158.33
10/16/2012	30	6	4	EUGL	26.5	21		0.59	83.55
10/16/2012	30	6	5	EUGL	23.2	16.5		0.46	109.00
10/16/2012	30	6	6	EUGL	24.5	17.5		0.51	97.74
10/16/2012	30	6	7	EUGL	25	22		0.53	93.87
10/16/2012	30	7	1	JUPR	25	6.6		0.53	93.87
10/16/2012	30	7	2	EUGL	9.5	5.6		0.08	650.09
10/16/2012	30	8	1	EUGL	17	10		0.24	203.01
10/16/2012	30	8	2	EUGL	12	9		0.12	407.44
10/16/2012	30	8	3	EUGL	13	9		0.14	347.16

10/16/2012	30	9	0	NA			Road/Path	0.00	0.00
10/21/2012	31	1	1	JUPR	13	9.5		0.14	347.16
10/21/2012	31	1	2	EUGL	14	9.8		0.17	299.34
10/21/2012	31	1	2	JUPR	15.5	9.8		0.20	244.21
10/21/2012	31	1	3	EUGL	10.5	15		0.09	532.16
10/21/2012	31	1	3	EUGL	11.25	8.4		0.11	463.57
10/21/2012	31	2	1	EUGL	17	14.6		0.24	203.01
10/21/2012	31	2	2	EUGL	7	9.1		0.04	1197.3
10/21/2012	31	2	3	EUGL	6	9.5		0.03	1629.7
10/21/2012	31	2	4	JUPR	22	10.6		0.41	121.22
10/21/2012	31	2	5	EUGL	10	10.8		0.08	586.71
10/21/2012	31	3	1	JUPR	48	9.1		1.95	25.46
10/21/2012	31	3	2	JUPR	56	11.1		2.65	18.71
10/21/2012	31	4	0	NA			ROAD	0.00	0.00
10/21/2012	31	5	1	JUPR	21	9		0.37	133.04
10/21/2012	31	5	2	EUGL	9	10.6		0.07	724.33
10/21/2012	31	5	3	JUPR	54	10.2		2.47	20.12
10/21/2012	31	6	1	EUGL	7	7.2		0.04	1197.3
10/21/2012	31	7	1	JUPR	11	6.6		0.10	484.88
10/21/2012	31	8	1	EUGL	11.5	12.2		0.11	443.64
10/21/2012	31	9	1	EUGL	11.5	10.8		0.11	443.64
10/21/2012	31	9	2	EUGL	10.1	10.8		0.09	575.15
10/21/2012	31	9	3	EUGL	12	9.1		0.12	407.44
10/21/2012	31	9	4	JUPR	32.5	9.6		0.89	55.55

Appendix VI: Unprocessed Vegetation inventory data organized by new species ID

Species	**Modwit #**	**New_speciesID**	**Frequency**	**Native/Exotic**	**Subplot Area**	**Total Sample Area**
Alchemilla pedata	1	1	24	Native	1	100
Sporobulus africanus	1	2	13	Native	1	100
Agrocharis melanantha	1	3	22		1	100
Crepis rueppellii	1	4	16		1	100
Echinops macrochaetus	1	5	1		1	100
Cyanotis barbata	1	6	17		1	100
Gerbera viridifolia	1	7	2		1	100
Centella asiatica	1	8	7	Native	1	100
Satureja punctata	1	9	6		1	100
Satureja pseudosimensis	1	10	11		1	100
Cynodon dactylon	1	11	2		1	100
Digitaria abyssinica	1	12	11		1	100
Hypoestes triflora	1	13	9		2	100
Plectocephalus varians	1	14	3		2	100
Rubia cordifolia	1	15	5		3	100
Agrostis quinqueseta	1	16	14		3	100
Trifolium acaule	1	17	9		3	100
Trifolium calocephalum	1	18	5		3	100
Trifolium ruepellianum	1	19	9		3	100
Oxalis radicosa	1	20	4		3	100
Linum trigynum	1	21	6		3	100
Salvia nilotica	1	22	8		3	100
Maytenus addat	1	23	7	Native	4	100
Helichrysum forsskahlii	1	24	9		4	100
Apodytes dimidiata	1	25	1	Native	29	100
Juniperus procera	1	26	12	Native	29	100

Embelia schimperi	1	27	1		29	100
Ekebergia capensis	1	28	1	Native	29	100
Eucalyptus globulus	1	29	6	Exotic	29	100
Festuca simensis	2	30	2	Native	101	200
Scabiosa columbaria	2	31	13		101	200
Bulbostylis hispidula	2	32	2	Native	101	200
Gerbera piloselloides	2	33	5		101	200
Pennisetum sphacelatum	2	34	5		101	200
Carduus schimperi	2	35	4	Native	102	200
Satureja paradoxa	2	36	11		102	200
Commelina benghalensis	2	37	9	Native	102	200
Senecio ochrocarpus	2	38	9		103	200
Helichrysum schimperi	2	39	5		103	200
Asplenium aethiopicum	2	40	7	Native	103	200
Geranium arabicum	2	41	18		103	200
Sparrmannia ricinocarpa	2	42	2		103	200
Thymus schimperi	2	43	13		103	200
Conyza steudelii	2	44	4		103	200
Asparagus africanus	2	45	6	Native	103	200
Alchemilla abyssinica	3	46	5	Native	201	300
Bidens pilosa	3	47	7	Native	201	300
Festuca arundinacea	3	48	9		201	300
Lippia adoensis	3	49	1		201	300
Eleusine floccifolia	3	50	1		201	300
Rosa abyssinica	3	51	4	Native	201	300
Achyrospermum schimperi	3	52	2		202	300
Delphinium wellbyi	3	53	2		202	300
Rhamnus staddo	3	54	1		202	300
Jasminum abyssinicum	3	55	5	Native	202	300

Bersama abyssinica	3	56	1	Native	204	300
Oxalis obliquifolia	3	57	8		204	300
Clematis simensis	3	58	11	Native	204	300
Maesa lanceolata	3	59	1	Native	203	300
Peucedanum mattirolii	3	60	7		203	300
Adiantum thalictroides	3	61	1		203	300
Nuxia congesta	3	62	4	Native	229	300
Hypericum revolutum	3	63	2		229	300
Crepis foetida	4	64	12		301	400
Helichrysum stenopterum	4	65	4		302	400
Olea europaea L.subsp. Cuspidata	4	66	2	Native	303	400
Galium simensis	4	67	3		303	400
Plantago lanceolata	4	68	11		304	400
Anthospermum herbaceum	4	69	6		304	400
Eragrostis schweinfurthii	4	70	2		304	400
Hyparrhenia hirta	4	71	3		329	400
Argyrolobium ramoseum	4	72	6		329	400
Kalanchoe petitiana	5	73	2		401	500
Sida schimperiana	5	74	4		401	500
Oldenlandia monanthos	5	75	8	Native	401	500
Achyranthes aspera	5	76	4		402	500
Carissa spinarum	5	77	1	Exotic	402	500
Bidens prestinaria	5	78	5	Native	403	500
Acacia abyssinica	5	79	1	Native	500	500
Aira caryophyllea	6	80	7	Native	501	600
Poa annua	6	81	3		501	600
Pennisetum villosum	6	82	1		501	600
Carex spicato-paniculata	6	83	1		502	600
Commelina africana	6	84	4	Native	503	600

Veronica abyssinica	7	85	5	Native	601	700
Trifolium simense	7	86	10		601	700
Conyza Schimperi	7	87	7	Native	601	700
Cineraria abyssinica	7	88	2	Native	601	700
Andropogon abyssinicus	7	89	11	Native	602	700
Sonchus bipontini	7	90	1		603	700
Cyperus fischerianus	7	91	1		603	700
Vernonia leopoldii	7	92	4		629	700
Carex steudneri	8	93	1		701	800
Selaginella abyssinica	8	94	5	Native	701	800
Plantago major	8	95	1		702	800
Festuca abyssinica	8	96	7	Native	702	800
Myrsine africana	9	97	10	Native	802	900
Helichrysum foetidum	9	98	1		802	900
Senecio myriocephalus	9	99	2		804	900
Smilax aspera	9	100	5		829	900
Rubus steudneri	9	101	2		829	900
Pentas schimperiana	9	102	1		900	900
Andropogon amethystinus	10	103	5	Native	901	1000
Deschampsia flexuosa	10	104	5		903	1000
Cynoglossum amplifolium	10	105	1		903	1000
Vernonia amygdalina	11	106	2		1001	1100
Pentas lanceolata	11	107	1		1001	1100
Pimpinella hirtella	11	108	6		1002	1100
Cotula abyssinica	12	109	5		1101	1200
Justicia heterocarpa	12	110	5		1103	1200
Impatiens hochstetteri	12	111	1		1103	1200
Vulpia bromoides	13	112	3		1201	1300
Swertia abyssinica	13	113	2	Native	1202	1300

Argyrolobium rupestre	13	114	1	Native	1203	1300
Gnaphalium tweedieae	13	115	2		1204	1300
Urtica simensis	13	116	1	Native	1204	1300
Torilis arvensis	14	117	6		1301	1400
Crassula schimperi	14	118	1		1301	1400
Cardamine trichocarpa	15	119	1	Native	1402	1500
Cotula anthemoides	17	120	3		1602	1700
Anagallis arvensis	17	121	3	Native	1603	1700
Olinia rochetiana	17	122	2	Native	1604	1700
Gladiolus dalenii	17	123	2		1604	1700
Jasminum stans	18	124	3		1701	1800
Leonotis ocymifolia	18	125	2		1701	1800
Maytenus arbutifolia	18	126	5		1701	1800
Osyris quadripartita	19	127	2		1801	1900
Pittosporum viridiflorum	19	128	1		1801	1900
Lobelia holstii	19	129	5		1802	1900
Hypericum peplidifolium	19	130	4		1802	1900
Inula confertiflora	23	131	1		2204	2300
Trifolium semipilosum	24	132	1		2301	2400
Moraea stricta	24	133	2		2301	2400
Impatiens rothii	24	134	1		2301	2400
Sonchus oleraceus	24	135	1		2329	2400
Solanum anguivi	25	136	1		2401	2500
Plectranthus punctatus	25	137	1		2401	2500
Hypoestes forsskaolii	11	138	2		2800	1100
Linum usitatissimum	25	138	1		2402	2500