ASSESSMENT OF CARBON SEQUESTRATION BY DRYLAND FOREST AND ECO-CHAR SYSTEM IN TAITA RANCH- VOI, KENYA

JUSTUS EKUWOM EREGAE

MASTER OF SCIENCE

(Environmental Legislation and Management)

JOMOKENYATTA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY

2017

Assessment of Carbon Sequestration by the Dryland Forest and Eco-char System in Taita Ranch- Voi, Kenya

Justus Ekuwom Eregae

A Thesis submitted in partial fulfilment for the Degree of Master of Science in Environmental Legislation and Management in the Jomo Kenyatta University of Agriculture and Technology

2017

DECLARATION

This thesis is my original work and has not been submitted for the award of a degree in any other University.

Signature……………………………… Date ……………………….

Justus Ekuwom Eregae

Supervisors

This thesis has been submitted for examination with our approval as University supervisors

Signature………………. Date ………………

Dr. Margret Wachu Gichuhi, PhD

JKUAT, Kenya

Signature………………. ……… Date…………………….

Dr. Mwangi Githiru, PhD

Wildlife Works, Kenya

DEDICATION

Special dedication goes to my Mother Esther Nangok Ekuwom at a remote village in Lodwar town, Turkana County. She has injected a spirit of believe in myself, that has propelled me to this level and with her blessing and the will of God I was be able to explore beyond the limits. She will not be able to literally read and understand but she will feel the sense and spirit in this script. I Salute you mum.

ACKNOWLEDGEMENTS

My sincere gratitude goes to Wildlife Works-Kenya both for technical and professional support. Gratitude as well goes to my first supervisor Dr. Margret Wachu Gichuhi for quick responses and constructive guidance throughout this study. I would also want to thank Dr. Mwangi Githiru who personally accepted my request to be my supervisor without even knowing who I was. Dr. Mwangi who is the Director of Biodiversity and Social Monitoring at Wildlife Works Kenya invited me to their office at Rukinga in Maungu in Taita Taveta County. He further introduced me to Mr. Rob Korchinsky the Vice president of Wildlife Works Company who gave me a go ahead without any formal request as would have been in many institutions. That acceptance is highly honoured. Dr. Mwangi guided me through the entire process in my research and without him it would have not been possible and his effort his highly appreciated. Last but not least I would like to thank Wildlife Works sampling team led by Mwololo Muasa and eco-char team for their support in data collection, species identification and acting as guides in several wildlife encounters while in the Bush. God bless you all.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

LIST OF NOMENCLATURE AND ABBREVIATIONS

A/R	Afforestation/Reforestation
AD	Avoided Deforestation
AFOLU	Agriculture, Forestry and Other Land Use
AGB	Aboveground Biomass
ARD	Afforestation, Reforestation, and Deforestation
ASALs	Arid and Semi-Arid Lands
CAZRI	Central Arid Zone Research Institute
CBD	Convention on Biological Diversity
CCAP	Centre for Clean Air Policy
CDM	Clean Development Mechanism
CER	Certified Emission Reductions
CfRN	Coalition for Rainforest Nations
CHP	Combine Heat Power
CIFOR	Centre for International Forestry Research
CISDL	Centre for International Sustainable Development Law
CO_2e	Carbon Dioxide Equivalent
COP	Conference of the Parties
CPA	Charcoal Producer Association
CSR	Corporate Social Responsibility
CVC	Charcoal Value Chain
DBH	Diameter at Breast Height
DD	Deforestation and Forest Degradation
DNA	Designated National Authority
ESDA	Energy for Sustainable Development Africa
ESMAP	Energy Sector Management Assistance Program
ETS	Emissions Trading Scheme

FAO	Food and Agriculture Organization (of the United Nations)
FCPF	Forest Carbon Partnership Facility (World Bank's)
FINNIDA	Finnish International Development Agency
FPIC	Free, Prior, and Informed Consent
GEF	Global Environment Facility
GHGs	Green House Gases
GOFC-GOLD	Global Observation of Forest and Land Cover Dynamics
GOK	Government of Kenya
GPG	Good Practice Guide
GPPI	Global Public Policy Institute
HWP	Harvested Wood Products
ICAD	Integrated Conservation and Development
ICDP	Integrated Conservation and Development Project
ICRAF	World Agro forestry Centre
IPCC	Intergovernmental Panel on Climate Change
JI	Joint Implementation
KEFRI	Kenya Forestry Research Institute
KFS	Kenya Forest Service
KWS	Kenya Wildlife Service
LDC	Less Developed Countries
LPG	Liquefied Petroleum Gas
LS	Least Square
LULUCF	Land Use, Land Use Change and Forestry
MAI	Mean Annual Increment
MENR	Ministry of Environment, Water and Natural Resources
MoE	Ministry of Energy
MoP	Ministry of Planning
MRV	Monitoring, Reporting, and Verification
NCCRS	National Climate Change Response Strategy

NGOs	Non-Governmental Organizations
NPV	Net Production Value
NRCO	National REDD+ Coordination Office
PAM	Policies and Measures
PES	Payments for Environmental Services
PRA	Participatory Rural Appraisals
PSDA	Promotion of Private Sector Development in Agriculture
REDD	Reducing Emissions from Deforestation and (Forest) Degradation
REDD+	Reducing Emissions from Deforestation and (Forest) Degradation (Plus)
RIL	Reduced Impact Logging
R-PIN	REDD+ Project Idea Note
R-PP	REDD+ -Readiness Preparation Proposal
TDERM	Tropical Deforestation Emission Reduction Mechanism
TWG	Technical Working Group
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environmental Programmes
UNDP	United Nations Development Programmes
UNFCCC	United Nations Framework Convention on Climate Change
UNFF	United Nations Forum on Forests
VCS	Verified Carbon Standards
VER	Verified Emission Reduction

ABSTRACT

Mapping carbon stock in Kenya is central in establishing the country's potential for carbon emission and emission reduction through forestry. The study aimed to establish the carbon biomass capture and storage by the common tree genus in dryland forest and to assess the sustainability of eco-char production system in Taita Ranch, South Eastern Kenya. Non-destructive approach was used, where key parameters including diameter at breast height (DBH) and Tree height were measured in the field and used to compute carbon biomass estimates. This study fit into an ongoing research experimental set-up, where tenone hectare (ha) blocks have been curved out of a larger area of approximately one thousand and one hundred ha (1100ha) where branch harvesting for eco-charcoal production is done. These blocks were randomly selected and used to study the effects of harvesting at various intensities and frequency on the trees' growth and regeneration. A total of two thousand and sixty (2060) trees belonging to twenty five tree species from 14 genuses were inventoried from the Ten-one ha plots. Genus *Commiphora* dominated the study area with approximately 47% followed by *Lannea* with 19% and *Boswellia* at 13% and *Acacia* and *Boscia* recorded 9% each while the other pooled genus contributed approximately 3%. Species specific Allometric equations generated by Wildlife Works were used to compute tree biomass. Total biomass estimate was approximately 32.8 Mg/ha. Advanced linear regression model was used to perform significance across the study blocks and tree genus. Similarly, t-test was conducted for hypothesis testing. The analysis revealed high significance for mean biomass across the study blocks and tree genus whereby genus *Commiphora* had the highest mean biomass of 24.1Mg ha^{-1} followed by genus *Acacia* by 3.0 $Mgha^{-1}$. Similarly, genus *Acacia* had low density that made it insignificant in carbon sequestration in Taita Ranch. Nonetheless, it has high potential in carbon capture as exhibited by least square mean analysis that indicated genus *Acacia* with highest mean of approximately 0.2 Mg of biomass while an individual in genus *Commiphora* recorded the approximately 0.1 Mg of biomass. Based on these estimates, then *Acacia* species with an average diameter at breast height of 13 cm can potentially release 0.33 Mg of Carbon if the whole tree is harvested for charcoal production, while an individual in genus *Commiphora* would release approximately 0.17 Mg. On the other hand genus *Commiphora* is very light but its abundance makes it to be potentially important. Pruning of trees and branches at 25% and 50% and eco-char production system has no significant impact on the study area biomass and thus the study recommends it to be included in Reducing Emission from Deforestation and Degradation plus programs in dryland forest.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Carbon dioxide (CO_2) is one of the greenhouse gases (GHG) and a primary agent of global warming. It is an important trace gas in Earth's atmosphere currently constituting about 0.04% (400 parts per million) of the atmosphere (Dlugokencky & Pieter, 2015; Vaughan, 2015). Many Greenhouse gases occur naturally in the atmosphere and their presence is important for ensuring that the global climate is warm enough to support life (Broadmeadow & Mathews, 2003). However, an increase in the concentration of GHGs in the atmosphere is responsible for increasing global temperatures (Cheamwongsa, 2010; Pragasan & Karthick, 2013). When humans clear and/or burn trees, most of the carbon quickly gets back to the atmosphere as CO_2. The amount of CO_2 in the atmosphere is increasing by between 1.5 to 2 ppm per year (Oke & Olatiilu, 2011) and has risen to 402 ppm as of 2016 (Dlugokencky, 2016).According to IPCC (2001)report, developing countries will be most vulnerable to climate change impacts, due to their low adaptive capacity and over dependence on ecosystem services. It further suggested that there is need to maintain global temperature below 2°C,and thus global emissions have to be reduced by up to 85% from the year 2000 CO_2 levels latest by the year 2050 and there should be no more increase from 2015(IPCC, 2001).

According to Intergovernmental Partnership on Climate Change 2001 and 2007report, there is dramatic rise of CO_2 concentration that is attributed largely to human activities(IPCC, 2001, 2007). Similarly between 1987- 2007, 10% - 30% carbon emission was attributed to land use change and deforestation. Article 4 of the United Nations Framework Convention on Climate Change (UNFCCC, 2006) requires preventing and minimizing climate change by limiting anthropogenic emissions of greenhouse and protecting and enhancing greenhouse gas sinks and reservoirs.

Atmospheric CO_2 concentration can be decreased not only by reducing fossil fuel burning but also by increasing the terrestrial ecosystems that serve as sinks for CO_2. Through photosynthesis trees are able to reduce CO_2 in the atmosphere, and thus very important in global climate(Kort & Turnock, 1999). Forests are a critical component of the global carbon cycle, apart from carbon stored in rocks and sediments, it stores over 80% of global terrestrial carbon(Dixon *et al.*, 1994).

1.1.1 Carbon sequestration in relation to dryland forest of Taita Ranch

Carbon sequestration is a long-term capture and storage of carbon dioxide or other forms of carbon to either mitigate or defer global warming and avoid dangerous climate change(Kort & Turnock, 1999). Dry land forest as well is part of the terrestrial carbon sinks that store carbon biomass. The process is driven by photosynthesis as shown below;

$$6CO_2 + 6H_2O \xrightarrow{\text{sunlight}} C_6H_{12}O_6 + 6O_2$$ (Whitmarsh & Govindjee, 1999)

The study area is comprised of *Acacia-Commiphora* dryland Forest, where most of the species are drought tolerant, possessing a number of strategies to trap and preserve moisture in a semi-arid environment, including dropping or folding all foliage in dry periods to reduce moisture loss from transpiration, when they photosynthesize through their bark to survive(Korchinsky *et al.*, 2011b).Major species in the study area include; Umbrella thorn acacia -*Acacia tortilis* (Forssk.) Hayne, Egyptian thorn -*Acacia nilotica*(L.) Hurter & Mabb. White swollen-galled acacia- *Acacia bussei* (Harms ex.) sjostedt, White thorn acacia-*Acacia hockii* (De wild.) Seigler & Ebinger, Savanna thorn-*Acacia etbaica* (Schweinf.), River acacia-*Acacia elatior* (Brenan.) Hook-thorn acacia-*Acacia mellifera*(Vahl.)Benth. False-umbrella acacia-*Acacia reficiens* (Wawra.) Kyal. Sudan gum arabic *Acacia senagal* (L.)Wild, Corkwood tree or Myrrh tree (*Commiphora*) that include; Africana myrrh-*Commiphora africana,* (Rich.) Endl.*Commiphora campestris (Engler.), Commiphora edulis (*Klotzch.) Engl.and *Commiphora confusa;* Spiny cluster leaf Terminalia-*Terminalia spinosa* (Engl.), Melia-*Melia volkensii* (Guerke.) Melia, Boscia pax-*Boscia coriacea* (Lam.), Frankincense tree-

Boswellia neglecta (Moore.), Long pod cassia (*Cassia abbreviate* (Oliv.), Odina alata or Lanneaalata-*Lannea alata* (Engl.) Engl, Odina rivae or Lannea rivae-*Lannea rivae (chiov.)* Sacleux,,False marula -*Lannea schweinfurthii* (Engl.) Engl.andLembobo wattle or Lowveld Newtonia-*Newtonia hildebrantii* (Vatke) Torre.Other species include;Tooth brush tree-*Salvadora persica* (L.), African star-chestnut-*Sterculia Africana* (Lour.) Fiori., Lowveld milkberry-*Manilkara mochisia*(Bak.) Dubard,Forest berries or Manilkara sulcata-*Manilkara sulcata* (Engl.) Dubard, Common forest ochna or Red ironwood-*ochna holstii* (Engl.),African olive-*Olea Africana* (Miller),Caterpillar bush or Curled caterpillar-pod-*Ormocarpum kirkii* (Moore)and Knob wood-*Zanthoxylum chalybeum* (Engl.) (Korchinsky *et al.*, 2011b; Najma, 2006).

1.1.2 Eco-charcoal

Eco-charcoal production involves pruning of trees and shrubs branches at between 25-50% and chopping the twigs into smaller size and using portable steel kilns to produce bio char. The system is aimed at providing an alternative and sustainable char production that is likely to replace traditional lump charcoal system that harvest the whole tree without consideration of future benefits. According to author Githiomi *et al.* (2012)there is a widening gap between supply and demand for forest resources that are depleted faster than the rate of replenishment. Forestry planning on the other hand through Ministry of Wildlife and Forestry focuses more on supply of commercial wood product and conservation of protected areas without establishing plans to meet the demand on wood fuel and charcoal (GOK, 2002). Lack of sustainable wood energy production planning has led to scarcity and over-exploitation of natural resources and environmental degradation(Githiomi *et al.*, 2012).The modernization of the wood energy sector is a stepwise process that requires continuous refinement of framework conditions, organizational and procedural aspects, and technological development. For example, improved charcoal kilns are more efficient compared to old model of open air charcoal production system where wood- charcoal conversion efficiency ranges from 20% to 30%(Bio-News, 2015; Nahayo*et al.*, 2013). Unlike the old traditional open system where only about 10% of wood is converted to charcoal thus 90% of the wood goes to waste(Bailis, 2009).

1.2 Statement of the problem

Carbon dioxide is one of the major drivers global warming around the world and dryland forest plays a significant role in its sequestration. The rises in global temperatures have been escalated by the accumulation of greenhouse gases in the atmosphere partially driven by forest degradation and deforestation. Moreover, there is an increased selective harvesting of hard wood species such as genus *Acacia* for charcoal production that has reduced the dryland forest carbon sequestration potential. Additionally, there has not been a plan to thin natural forest that stores a significant amount of carbon. Mature forest in this regard, are not very active in carbon uptake compared to young trees that are very active in carbon uptake since they grow no more. This study therefore aimed to establish the level of carbon capture by different tree genus and potential CO_2 release of hard wood trees that are harvested for charcoal production in dryland forest. It also aimed to establish a sustainable system of charcoal production that takes into account a balance between ecological integrity and human energy demand for posterity.

1.3 Justification of the study

Improved quantification of carbon pools and fluxes in savannah woodland ecosystems underlies the contribution to the net carbon emissions and their potential for carbon sequestration. Secondly, the country has identified forestry as strategy to address climate change in an effort to reduce emissions and enhance carbon sink capacities of forest ecosystems thus make significant contribution towards climate change mitigation(KFS, 2010a). Additionally, there are emerging green economy markets that as country need to fully participate thus establish what potential it has in carbon emission and concentration reduction effort(Eregae *et al.*, 2016). Furthermore, more than 70% of Kenya is arid and semi-arid area dominated by dryland forest(KFS, 2010b) thus would be apparently necessary to establish carbon storage capacity by different plant species in their natural habitat that will be useful in several habitat management especially in selecting species for reforestation programmes.

On the other hand loss of forest cover is particularly severe in the Arid and Semi-arid zones, where the agricultural frontier is expanding and charcoal burning is rampant (Gichu & Chapman, 2014). The study therefore establishes a baseline research on a sustainable system of char production as an alternative system of char production to meet the energy demand. That notwithstanding, pruning of trees and shrub branches is likely to re-activate the dormant mature forest to sequester carbon from the atmosphere. Consequently, the study will establish whether the eco-char production system can be incorporated into REDD+ programs.

1.4 Hypotheses

$Ho_{a:}$ There is no significance difference in carbon storage by the different tree genus in dryland forest in Taita Ranch compared with commensurate savannah woodland

Ho_b: Genus *Acacia* does not make any significant contribution in carbon sequestration spectrum in Taita Ranch.

Ho_c: Eco-char production system does not reduce significantly the total biomass in Taita Ranch

1.5 Objectives

1.5.1 Main Objective

To determine contribution of dryland forest in carbon sequestration spectrum and impact of eco-char production system in carbon stock Taita Ranch, Taita Taveta County, Kenya.

1.5.2 Specific Objectives

1. To determine the level of carbon storage and release in the dryland forest of Taita Ranch.
2. To establish CO_2release potential by genus acacia in dryland forest in Taita Ranch when the same is converted to charcoal.
3. To establish the negative impact of Eco-char production system harvest on dryland forest biomass in Taita Ranch.

1.6 Scope of the study

The study was conducted in Taita Ranch within the larger Taita Ranches 4kms west of MacKinnon shopping centre in Taita-Taveta County. The area lies within the corridor of wildlife that crosses from Tsavo East and Tsavo West National Parks. Data collection was done within 11000 ha site designated for eco-char production courtesy of Wildlife Works Kenya. The area is in its historic condition, thanks to the effort employed by Wildlife Works Kenya that has enhanced its continued protection. That notwithstanding, there are some alteration in forest cover driven by factors such as elephant (*Loxodonta africana)* destruction of trees as they feed; selective harvesting of hardwood species such Acacia for charcoal business and overstocking of livestock that are likely to reduce forest biomass, as they prevent regeneration. These disturbances are of great concern as they remove major carbon sinks that plays a significant role in carbon sequestration.

1.7 Study Limitation

1.7.1 Low diversity index

Diversity index range from 0.01 to 0.15 which is very low and there is likelihood that it doesn’t give a clear statement of savannah woodland. Species such as genus *Acacia* like other species were very low and out of the 2060 individual trees within the study area only 9% of the total tree population. This could be due to selective harvest of acacia species for charcoal production which is evident by the species stumps within the study area. In some sub-plots there were as low as two acacia species with as many stumps as 20 within a sub-plot. Many of the acacia trees surviving were either young or coppiced.

1.7.2 Lack of local harmonized regression model

Many studies have suggested establishment of a harmonized local regression model for biomass estimation. Apart from the Wildlife Works model that the study used to make estimation, there are no other harmonized local models for biomass estimation. There is high variance on conventional regression models developed by Brown and Chave (Brown, 2002; Chave *et al.*, 2005; Chave J. *et al.*, 2014), nonetheless the study applied Wildlife Works model that is used in the study area for carbon project.

1.8 Conceptual framework

This section demonstrate a simple model related to carbon assimilation by plants, carbon cycle in terrestrial biome and impacts of deforestation, fossil fuel burning and increase CO_2 concentration levels in the atmosphere (Figure 1.1:).The diagram shows how forest play a significant role in the global carbon through dynamic exchange of CO_2 with the atmosphere. Forest measurable parameters such as diameter at breast height (1.3m), tree height and canopy diameter are assimilated in the cycle. The size of these measurable parameters represents the amount of carbon stored and how the complex organic carbon compound plants is disintegrated and released back into the atmosphere in form of CO_2. Independent parameters measurements are then used to compute carbon biomass (independent variable). Ultimately Carbon biomass are converted using relative atomic ratios to estimates of CO_2per tree genus in the study area.

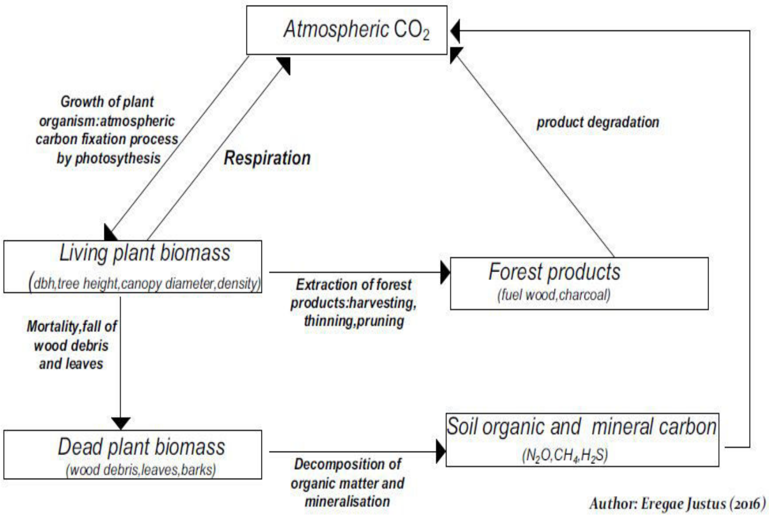

Figure 1.1: Natural terrestrial sequestration diagram

During photosynthesis, atmospheric carbon dioxide in the presence of light is transformed into components necessary for plants to live and grow. As part of this process, the carbon portion present in the atmosphere as carbon dioxide becomes part of the plant: leaves, stem, root, etc. and in the absence of light, plants respire i.e. takes in oxygen and releases carbon dioxide into the atmosphere as a by-product. Plants mortality, fall of wood debris and leaves in the soil undergoes decomposition and mineralization process and as result organic and mineral carbon will be released into the atmosphere through soil. Carbon released into the atmosphere is sequestered back by plants and other sinks and the cycle continues. Nonetheless over-extraction of forest resource in this case dryland forest has interfered with the cycle and has created imbalance in the climate system.

CHAPTER TWO

LITERATURE REVIEW

INTRODUCTION

This highlights two major component that include; theoretical principles and previous work relevant to the study. The section as well, captures literature on programs that connects the study with workable ongoing programs such as the reducing emission from deforestation and forest degradation plus (REDD+) programs and biodiversity conservation initiatives aimed at containing and mitigating climate change and global warming and its possible adaptations.

2.1 Theoretical principles and previous work relevant to the study

This section highlights some of the general definition of terms, theories and literature available in relation to global carbon sequestration, mitigation and adaptation strategies.

2.1.1 Terrestrial sequestration

Terrestrial sequestration means using plants to capture CO_2 from the atmosphere and then storing it as carbon in the stems and roots of the plants as well as in the soil(Johnson & Coburn, 2010) . In photosynthesis, plants take in CO_2 and give off oxygen (O_2) to the atmosphere as a waste gas. The plants retain and use the carbon to live and grow. When the plant withers or dies, part of the carbon from the plant is preserved (stored) in the soil(Crosby *et al.*, 2010).

Terrestrial sequestration is a set of land management practices that maximizes the amount of carbon that remains stored in the soil and plant material for the long term. No-till farming, wetland management, rangeland management, and reforestation are examples of terrestrial sequestration best practices that are already in use(Srivastava *et al.*, 2010). It is important to remember that terrestrial sequestration does not store CO_2 as a gas but stores the carbon portion of the CO_2 (Pacala & Socolow, 2004). If the soil is disturbed and the soil carbon comes in contact with oxygen in the air, the exposed soil carbon can combine with O_2 to form CO_2 gas and re-enter the atmosphere (Pacala & Socolow, 2004; Zummoa & Friedland, 2011).

2.1.2 Global carbon mitigation strategies

The global community efforts to combat and manage climate change established an elaborate United Nation Framework Convention on Climate Change (UNFCCC). The policies were initiated at Rio de Janeiro Brazil in 1992 in a meeting of United Nation on Environmental and Development agenda and the same was ratified by many countries, Kenya included. The key objective of the meeting was to reduce greenhouse gases and to enhance absorption of greenhouse gases. In 1997 Kyoto protocol was formed and adopted by consensus at COP-3 that was held at Kyoto Japan. The protocol compelled developed countries to reduce their greenhouse emission by at least 5% by 2002(UNFCCC, 1998).

One of the limitation of 1997 Kyoto protocol was that in as much more emphasis was established for developed countries there was no clear process for countries that were expected to have developed between five and fifteen years. The 1997 Kyoto report had suggested that the developing countries can as well participate in GHGs reduction effort through voluntary approach and Clean development mechanism(UNFCCC, 1998). Ongoing project in developing countries such as Kenya that have been proven for authenticity for alternative emission reductions are awarded credits that are known as certified emission reduction (CERs) or carbon credits which are in line with Kyoto protocol guideline. This carbon creditor CERs i.e. developed countries can meet their 5% emissions reduction by either offsetting the huge daily emissions or purchase the carbon credit from developing countries(UNFCCC, 1998).

2.1.3 Status, benefits and threats of forest in Kenya

According to FAO report, forest resources in Kenya comprise about 3.5 million ha of land equivalent to 6% of the total land area. Out of this 1.64 million hectares are of closed canopy forest, 610 000 ha of plantation forest, 851 000 ha of rain forest and 211 000 ha of dry zone forest (FAO, 2010b). The most immediate threats to Kenya's forests are linked to the rapidly increasing population numbers, agricultural expansion, unsustainable wood utilization levels, high energy demand, and over-grazing (Walubengo & Kinyanjui, 2010). Forest resources in Kenya just like in any other country are important both for economic, environmental and ecosystem services that they provide. Major forest blocks in Kenya such as Mau forest, Mt. Kenya, Aberdare and others are water catchment that are critical to the survival of Kenya population. Hydro generated power that is about 57% of power consumed in Kenya is Hydro power generate sourced from Mt. Kenya and Aberdare catchment(GTZ, 2007).

Moreover, forest plantation make a substantial contribution to economic development in Kenya that is a source of raw materials for economic development in the wider region(FAO, 2010b). In 2007, the forest sector was estimated to contribute about 1% to GDP (KES 16.4 billion) to the economy, and that more than 10% of households living within 5 kilometres from forest reserves depend on them for subsistence resources (FAO, 2010b).

Kenya recognizes the importance of forests and natural resources and it is entrenched in the Kenyan Constitution(GOK, 2010)that sets a minimum 10% national tree cover target. The country's economic blueprint, Vision 2030(GOK- MoP, 2008), as well focuses on ensuring that 10% forest cover is achieved by protecting the major water towers in Kenya and enhance the forest i.e. planting more trees. This would have been easily achieved if every Kenyan set a portion of their private land for tree plantation.

Kenya has not developed any reference levels, however it has begun to embark on the process recently (KFS, 2010b). In conjunction with the Forest Carbon Partnership Facility (FCPF), Kenya is planning to develop a historically adjusted Reference Level (RL), in order to quantify historical carbon emissions and develop different development scenarios and future emissions/removals trajectories. Reference levels will be coordinated alongside the development of the national Monitoring, Reporting and

Verification (MRV) system as defined by the REDD+ Preparedness Proposal (R-PP) process(KFS, 2010a). According to Gichu (2012) progress has been made on identifying institutional capacity requirements, reference systems and standards to be used, forest and land use maps and satellite imagery.

2.1.4 Effects of global temperature rise as driven by GHGs and suggested adaptations

A bout 20% to 30% of both plant and animal species are likely to be at a higher risk of extinction if the temperature increases greater than 1.5°C to 2.5°C, and risks will even be more if the temperature continue to rise (IPCC, 2007) and for those species that can adapt, they may dramatically change their ranges(Forrest, 2003). As species migrate and in most cases they migrate individualistically thus likely to create new assemblages of species, which can have adverse impacts on food chain and community dynamics, thus biodiversity management and conservation becomes a challenge. Moreover, other human-induced stressors, such as land conversion and fragmentation, habitat destruction, pollution, and overexploitation, leaves ecosystems and biodiversity more fragile in a changing climate(Hanski, 2005). Thus, non-climate drivers such as biodegradation act synergistically with climate change impacts, and such combination is what is posing a huge challenge to conservation presently(Lovejoy & Hannah, 2005).

Due to institutional and financial barriers to the establishment of adaptive capacity, developing countries consequently are more vulnerable than developed countries. Nonetheless, strengthening adaptive capacity entails reducing natural resource depletion, alleviating poverty, mitigating pressures on resources, improving management of risk, and other facets of sustainable development goals is an obligation in any country(Wijaya, 2013). According toLovejoy and Hannah (2005)mitigation of greenhouse gas emissions, advancement of adaptation measures, especially for biodiversity conservation, has been slow to take form(Leadley *et al.*, 2010).

A few jurisdictions have developed adaptation policies for enhancing biodiversity resiliency in a changing climate(Pereira *et al.*, 2010). However, policies have diverged with regard to the rate of policy advancement with some jurisdictions embracing adaptation policies more readily than others and have begun to converge with regard to the type of measures that the final policy embraces(Parmesan *et al.*, 2011). According to (Newton, 2015) resilience policy is being incorporated in environmental management regulations but it is still contested by various entities and little consensus regarding how it should be measured is building up.

2.1.5 Forest for global carbon sequestration

Forests sequester carbon in the atmosphere and stores it in their different reservoir as biomass(Matthews *et al.*, 2000). Additionally, forest offer double benefit of direct carbon sequestration and stability of natural ecosystem whereby they recycle nutrient as well as influence the global climate through evapo-transpiration that form short hydrological cycles (Chavan & Rasal, 2010). Forest ecosystems play a leading role in global terrestrial carbon cycle owing to their huge carbon pool and high productivity(Schlesinger, 1997). Forest program can cost effectively provide roughly 30% of the total global effort needed in all sectors to meet climate mitigation strategies(Webb *et al.*, 1992).

There is major concern on climate change resulting from enhanced anthropogenic greenhouse gas emission and this has resulted to more effort employed in protecting the existing forest as a carbon stock and establishing new carbon stocks(Mbow *et al.*, 2015). The pledge has received a lot support from environmental NGOs and this has enhanced forest cover to approximately 6% in the Kenyan case. The increase in forest cover means enhanced carbon sequestration capacity in the terrestrial ecosystems thus mitigate global warming (Lal, 2005). Forest is carbon sinks that mitigate the greenhouse gas emissions that drive climate change. For these reasons, projects that promote a forestation and reforestation are an integral part of the international effort to meet the climate change challenge(UNFCCC, 2008).

2.1.6 Acacia significance in carbon flux in savannah woodland

Acacia is the common name for plants of the genus Acacia in the pea family, Fabaceae. This genus consists of approximately 1,100-1,200 species primarily of trees, but also including some shrubs and climbers (Harsh & Schnabel, 2000; Lewis, 2005). Globally, acacia species are located in Asia, Madagascar, the Caribbean and Pacific islands, the Americas, and most prominently in Australia and Africa in arid and semiarid tropical zones(Ross, 1981). *Acacia* is part of savannah vegetation that dominates East African savannah woodland and grassland (Coe & Beentje., 1991;Najma, 2006; Pratt & Gwynne, 1977). There are about 170 species of acacia native to Africa where 18 are wide spread and they grow across a wide range of ecosystems, from arid deserts to montane forest, with growth forms that include small shrubs, lianas and large trees (New, 1984).

Genus *Acacia* like many other members of the legume plant family, have associations with two types of microorganisms i.e. *Rhizobium* and *Mycorrhiza* (Hayward & Wales, 2004; ICRAF, 2009). *Rhizobium* allows many legumes including acacias, to thrive in conditions that other plants cannot tolerate because of the ability to fix nitrogen from atmosphere even from depleted soil. Mycorrhizae on the hand provides an elaborate network of fine threads or 'hyphae' formed after roots and fungi come together through which they are able to absorb phosphorus and other important nutrients (Hayward & Wales, 2004; Primack, 1993). Moreover, *Acacia* have the ability to flourish under adverse conditions thus causing soil stabilization and improvement through nitrogen fixation. Its value is a high quality animal fodder, timber, fuel wood, charcoal, gums and just to mention a few (Bercherm, 1994).

Acacia may grow up to 30 meters tall with a characteristic umbrella shape or they may be more shrub-like with extensive basal branching of the stems. The flowers, usually yellow or white, grow in crowded, globular head or cylindrical spikes. Thorns are also another common feature of acacias, which supposedly provide for protection from herbivores, and, in some species, providing a symbiotic home for colonies of ants (Ross, 1981; Stone *et al.*, 1996). African acacia are extremely valuable over their native range in all their important traits. They are, therefore ideal subjects for rapid genetic improvements through selection and breeding(Newton *et al.*, 2003).

None of *Acacia* species have been assessed as globally threatened(IUCN, 2011). However very few of them have been evaluated by the IUCN Red List process and many occur in woodland habitats that are threatened by anthropogenic influence, particularly charcoal production, burning, livestock damage and agricultural encroachment(New, 1984; Sinclair *et al.*, 2008). Globally, *Acacia's* habitats are mostly unprotected by legislation and have therefore received little attention in previous regional biodiversity assessments. As one of the better studied plant genera in Africa, *Acacia* also has an advantage for data acquisition in that it has been well curate in a number of major herbaria (in particular, the East African Herbarium, the Royal Botanic Gardens, Kew, and the Missouri Botanical Garden), with reliable identification and associated meta-data(Marshall *et al.*, 2012).

Within the savannah woodland ecosystem of East Africa, acacias serve an essential ecological and economic role due to a high protein content (15-20% of dry weight), acacia leaves serve as an essential food source for wildlife, especially during the dry season(Bercherm, 1994).According to Primack (1993) in East Africa, Acacias area classic example of keystone species, essential to the functioning of a community. Acacias not only influence the ecology of the community, but also the economy, with uses in lumber production of a termite resistant wood, feeding of livestock, and a wide variety of native uses(Primack, 1993).

Acacia tortilis is the most widely used tree for charcoal production in Kenya(Mutimba & Barasa, 2005).This is likely to be the case due its abundance in dryland ecosystem and due to high 'quality' charcoal. *Acacia tortilis*, *A. nilotica, A Senegal, A. mellifera, A.*

polyacantha, and A. Xanthophloea are the most widely used with almost 50% harvest of the species for charcoal "business". Other popular species for charcoal harvest as well include *Croton, Olea africana, Manilkara, Mangifera, Eucalyptus, and Euclea* (Mutimba & Barasa, 2005).

2.1.7 Wood fuel and charcoal industry in Kenya and around the globe

Wood fuels are usually the primary source of energy for poor populations. The persistence of global poverty in most of the poor and developing countries has prevented any large-scale switch to alternative fuels. According to the International Energy Agency (IEA) report done by (Fritsche *et al.*, 2009), it predicts that by 2030, over 2.7 billion people will be dependent upon biomass energy, up by 8 percent from 2004 levels. Wood fuels and charcoal are the dominant energy source and the leading forest product for most developing countries. In Kenya for instance, charcoal represent between 60 to 80 percent of total wood product consumption while wood fuels often account for 50 to 90 percent of all energy used(MoE, 2002). Although wood fuels are widely perceived as cheap and primitive sources of energy, commercial wood fuel markets are frequently very large, involve significant levels of finance, and provide an important source of income through the supply chain for the rural poor(Miranda *et al.*, 2012).

A report published the Ministry of Energy(MoE, 2002),states that about 90% of Kenyan rural population use wood fuel as a source of energy and the same meets the largest energy needs of rural household. Charcoal on the other hand, is used by the middle and lower class population in the urban centres (Kituyi, 2008; Theuri, 2002). Wood fuel is an important energy source for some small scale industries such as tea drying and bricks making just to mention a few (Githiomi *et al.*, 2012). The scarcity and uncertainty of wood energy data is due to the fact that wood fuel and charcoal energy are mainly handled at local and informal sector and there is little monetary value that can be incorporated in the state economy compared with other forms of energy such as electricity, kerosene and liquefied petroleum gas (Githiomi *et al.*, 2012; Githiomi & Oduor, 2012).

The charcoal consumption is higher in the rural areas than in urban areas at about 156kg per capita compared to 152kg per capita in urban areas which beats the general perception that the urban areas use more charcoal than rural areas(MENR, 2013; MoE, 2002). Nonetheless, there is a paradigm shift from use of fuel wood to use of charcoal in rural area which therefore confirms the above statement of the rural areas being the larger consumers of charcoal. On the other hand, the urban poor population is likely to use other sources of energy that might have reduced their per capita charcoal consumption. According to the Ministry of energy, charcoal makes a huge contribution in energy sector because unlike fuel wood, charcoal is used even by high and middle income earners. The use of this commodity is estimated at 83%`of total energy(MoE, 2002).

The annual consumption of charcoal in Kenya is estimated at between 1.6 -2.4 million tons (Mutimba & Barasa, 2005). According to Kakuru (2010), the highest amount of charcoal produced goes to East African capital cities i.e. at about 10,50 and 70 percent to Nairobi, Dar-salaam and Kampala respectively(Kakuru, 2010). The other huge producer and consumer of charcoal is Malawi where about 90% of charcoal produced is destined to four of its major urban centres(Kambewa *et al.*, 2007). Commercially, there is a huge potential market for briquettes produced from eco-char system since the urban population is the target population that are likely to be convinced to shift from lump charcoal to briquette char.

It is worth to note that most of the wood fuel and charcoal are sourced majorly from dryland forest and since the available forest are protected by law thus making this vital commodity expensive. To counter the same, some of the suggested strategies include enhancing on-farm tree planting, efficient management of rangelands and woodlands, promotion of more efficient cooking stoves, sustainable charcoal production technology and use of alternative sources of energy other than wood(Githiomi *et al.*, 2012).

As the world moves toward a low carbon economy, renewable sources of energy are becoming increasingly attractive for industrial and domestic applications. Sustainably sourced wood fuels are carbon neutral and can contribute to climate change mitigation by replacing fossil fuels (FAO, 2007) a trend likely to be accelerated by new carbon taxes in industrialized nations. According to Fritsche *et al*., (2009) the generation of electricity and heat in combined heat and power (CHP) plants fuelled with biomass are already expanding rapidly in Organization for Economic Co-operation and Development countries. In Germany for instance, biomass-based CHP grew by 23 percent per year from 2004 to 2008(Fritsche *et al.*, 2009).

High fuel prices are likely to prevent the poor from ascending the so-called *energy ladder* towards cleaner burning fuels(ESMAP, 2012). The theory of the energy ladder is that rising of income permits consumers to move from firewood to charcoal to fossil fuels (such as kerosene and liquefied petroleum gas) and, eventually, to electricity (ESMAP, 2012). This progression is slowed or even reversed in an environment of rising fuel prices. The significance of wood fuels is likely to increase even further due to high fossil fuel prices, persistent poverty, and climate change considerations(FAO, 2007).

According to Miranda et al., (2012), Wood fuel sector in many developing countries operates informally and inefficiently, using outdated technology and delivering little official revenue to the government. The unsustainable harvesting of wood fuels to supply large urban and industrial markets can also contribute to forest degradation and deforestation. Given the low carbon development opportunity presented by wood energy, predictions of significant growth in wood fuel demand make it vital that this industry is overhauled and modernized using new technologies, approaches, and governance mechanisms(Miranda *et al.*, 2012).

Wood fuel and charcoal industry value chains are a huge market, involves considerable investment, and provide a source of income for many urban and rural poor. Charcoal is the most commercialized resource in the study area and the Net Present Value for the charcoal business over a 15-year period was US$ 511 ha^{-1} (Luoga *et al.*, 2000). This is evident along Voi- Mombasa road where piles of charcoal bags strike one's eyes as you go down to or from Mombasa. Charcoals sold in these areas are mostly sourced from Taita ranches and some parts of Kwale County. The charcoal value chain does not take into consideration labour cost, raw material and other contingencies. This confines the mind of the local producers to believe to be making profits. But according to author Luogo *et al.,*(2000) on charcoal production and market cost analysis, was that when the cost of labour, raw materials and opportunity costs were considered, the net production value was negative (US$ −868 per hectare). This therefore indicates that the other wood and forest products are compromised at the expense of profit that in economic context is negative(Luoga *et al.*, 2000).

The charcoal sector has acquired considerable economic importance because of rising population in the urban centres that cannot afford LPGs cooking gas but require energy for cooking, heating their houses among other uses. According to the comprehensive national charcoal survey of Kenya undertaken in 2004 by ESDA, now CAMCO, the total annual charcoal consumption is estimated at 1.6 million ton, generating an estimated annual market value of over KES32 billion (US$427m), almost equal to the KES 35 billion (US$467m) from the tea industry(Mutimba & Barasa, 2005). This figure is likely to have gone up as demographics have gone in the last 10 years by almost 30% so the demand for charcoal has also gone up, but there has never been an increase in forest cover to counter that growth(GOK- MoP, 2009). This therefore provoked the need to utilize technologies that balance the demand of the population and ecosystem.

The Kasigau Corridor in Taita Taveta County REDD project has now created an economic incentive for the landowners and communities to protect their forest. Wildlife

Works is working with the landowners and local communities to implement forest management plans that exclude the destructive use of forest resources for fuel wood or charcoal, and as a result, the supply of "free" wood for local charcoal use will be greatly reduced(Korchinsky *et al.*, 2011b).

2.1.8 Carbon biomass estimation model

Harvesting of the whole tree for estimation of carbon sequestration would be an accurate method; however, to avoid cutting the trees, carbon sequestration should be estimated using some non-destructive and modelling systems which are accepted by many researchers(Chavan & Rasal, 2010)Carbon projects that include a quantitative evaluation of the accuracy of biomass estimates should be noted by project verifiers so that appraisals of project value or risk may incorporate this information(Robards, 2009).

Biomass regression equations yield the most accurate estimates (IPCC, 2003; Jalkanena *et al.*, 2005) as long as they are derived from a large enough number of trees (GTOS, 2009; Husch *et al.*, 2003). National forest carbon estimates based on inventory data remain very questionable, with more than half of tropical countries relying on 'best guesses' rather than actual measurements (FAO, 2005; Kindermann *et al.*, 2008). Measurements of DBH alone or in combination with tree height can be converted to estimates of forest carbon stocks using allometric relationships. Allometric equations statistically relate these measured forest attributes to destructive harvest measurements, and exist for most forests (Brown, 1997; Chave *et al.*, 2005) grouping all species together and using generalized allometric relationships, stratified by broad forest types or ecological zones, is highly effective for the tropics because DBH alone explains more than 95% of the variation in aboveground tropical forest carbon stocks, even in highly diverse regions (Brown, 2002). Generalized allometric equations also have the major advantage of being based on larger numbers of trees that span a wider range of diameters (Brown, 1997; Chave *et al.*, 2005)

2.1.9 Ramification of REDD+ programs in Kenya

REDD+ is a mechanism agreed to by parties to the UNFCCC to support voluntary efforts of developing-country parties to mitigate climate change by reducing emissions from deforestation and forest degradation, promoting conservation and sustainable management of forests as well as enhancing forest carbon stocks(FAO, 2010b)This is likely to reduce global greenhouse gases that will take short period to realize and cost efficient.

According to Angelsen and others (2009), the global community can achieve their targets of emission reduction by basically negotiating with developing countries both at corporate level, private firms or individual levels that in most cases are ready to sell the carbon credit but lack proper understanding of the trade process and prove for authentication. The process has to be simplified for local farmers to sell their carbon stock other than directly cutting trees for charcoal production or any other unsustainable forest use. This apparently brilliant idea now faces realities on the ground where by the forest ownership is often unclear or contested. The governance is weak, corruption and power struggles at many levels are life. Most countries do not have good data or skills and systems to measure changes in forest carbon (Angelsen *et al.*, 2009).Additionally, the international REDD+ architecture itself is far from clear and will continue to evolve over the next few years.

Furthermore, we are likely to see different REDD+ system emerge. The current global focus is on UNFCCC negotiations. If REDD+ is linked to carbon markets, the main funding source are likely to be the European Union Emission Trading Scheme (ETS) and the US carbon market. Avoided deforestation is currently not included in the ETS and it is uncertain whether it will be included in the near future (Angelsen *et al.*, 2009).In the USA, proposals are on the table to include REDD+ as an offset option. Other national and regional carbon markets and voluntary markets are also likely to emerge or develop further Standards will probably vary between markets which will bring more complications for countries that will want to implement the REDD+. According FAO report, deforestation and forest degradation are responsible for about 70% of global carbon emission(FAO, 2005). Besides reducing carbon emissions, the REDD+ projects could also yield considerable benefits for biodiversity and local communities. REDD+ may be an idea whose time has come, but a range of potential difficulties need to be addressed if REDD+ is to have a major impact on reducing global warming.

According to KFS report, Kenya has no legal framework on REDD+ programs, however several legislative instruments and policies have been reviewed and have captured the component sustainable utilization natural resource for human benefit. National Climate Change Response Strategy (NCCRS) has identified the forestry sector as a strong vehicle for undertaking both mitigation and adaptation efforts and intends to exploit incentives provided within the framework of UNFCCC, especially the REDD mechanism, to implement sustainable forest management approaches(KFS, 2010a). This is a move to the right direction if the NCCRS plan is fully implemented.

The political will must be there for this dream to become a reality otherwise it will be as good as any other good policy formulated and kept in shelves. Nonetheless, according to Gichu (2012), Kenya is very keen in REDD+ programmes and it is currently participating in Forest Carbon Partnership Facility (FCPF) and has developed a National REDD+ strategy and implementation framework in addition to establishing Reference Emission Level and a National Forest Monitoring System(Gichu, 2012).

According to Forest Carbon Partnership Facility (FCPF) report (2012), Kenya is receiving financial and technical support towards developing its Readiness activities and also as an observer member of the UN-REDD+. The Forest Carbon Partnership Facility (FCPF), is an innovative partnership of developed and developing countries, with the World Bank as the Trustee, and the United Nations Forum on REDD+ (UN-REDD) geared to supporting developing countries efforts to formulate, implement policies and strategies to support REDD+ implementation). Kenya’s RPP identifies unsustainable utilization of forest products, especially charcoal production, as a major driver of deforestation and forest degradation in the country(FCPF, 2012). However, any country wishing and eligible to participate in the REDD+ mechanism under the FCPF must first produce a REDD+-Readiness Preparation Proposal (R-PP). Additionally, REDD+ strategy needs to address the charcoal industry with a view to identifying and promoting options that support sustainable production and consumption of charcoal(FAO, 2010a)

The coordination of environmental and climate change policies had full support from the government (MENR, 2013). The then Ministry of Forestry and Wildlife was the one responsible for the coordination of forest conservation and management (KFS, 2010a). The National Climate Change Response Strategy outlines country wide coordination efforts to holistically address climate change challenges(GOK, 2010).

The National REDD+ Management have four tier, bottom-up decision making process and was proposed to consist of a National REDD+ Steering Committee (RSC), the REDD+ Technical Working Group (TWG) and the National REDD+ Coordination Office (NRCO). The NRCO will coordinate with the REDD+ Component Task Forces and the REDD+ Officer of each Local Forest Conservancy(KFS, 2010a). Both the Task forces and the REDD+ officers will report to the NRCO, which will collate results and strategies and forward proposals to the TWG for evaluation. The TWG will then advise the multi-sectorial and inter-ministerial RSC, where final decisions will be taken(KFS, 2010a).

2.1.10 Ramification of conservation biodiversity

According UNEP report (2006), Africa's wealth of biodiversity, accounts for about 25% of global biodiversity, is spread across various habitats from savannah, deserts, wetlands and tropical forests. However, Africa's biodiversity is threatened by factors including climate change, land use change, invasive species, human-wildlife conflicts, pollution and over-exploitation. These threats to biodiversity and ecosystem services have far-reaching socioeconomic and environmental impacts(UNEP, 2006)

The Economics of Ecosystems and Biodiversity (TEEB)is a global initiative focused on making nature's values visible (TEEB, 2010). Its principal objective is to mainstream the values of biodiversity and ecosystem services into decision-making at all levels. It aims to achieve this goal by following a structured approach to valuation that helps decision-makers recognize the wide range of benefits provided by ecosystems and biodiversity, demonstrate their values in economic terms and, where appropriate, capture those values in decision-making(Sukhdev *et al.*, 2008). Extensive research on climate impacts to biodiversity has dramatically improved scientific understandings of the problem, as well as adaptation tools to contend with the challenge, the influence of this knowledge in shaping policy responses has been limited(Kelly Levin, 2007).

2.2 Research gaps and how the study aims to bridge

Carbon mapping have been undertaken outside the region majorly on wet climate forest. However, little has been done to quantify biomass in dry land ecosystem which is about 70% of Kenya land(Eregae *et al.*, 2016). The study will generate sufficient data on dryland forest and contribute to studies already undertaken and on-going research on significance of such ecosystems in climate change spectrum.

There is uncontrolled harvest of *Acacia* species for charcoal production where species such as *A. Tortilis* are widely used tree for charcoal production in Kenya most likely due its abundance and probably a perception to that it produces high 'quality' charcoal (Mutimba & Barasa, 2005). The continued burning of this *acacia* species has not taken into consideration what amount of carbon it releases into the atmosphere. The study will generate and contribute the necessary information to the on-going research on *Acacia* species significance on carbon sequestration.

According to national charcoal survey of Kenya undertaken in 2004 by ESDA, now CAMCO, the total annual charcoal consumption is estimated at 1.6 million ton, (Mutimba & Barasa, 2005).

CHAPTER THREE

MATERIAL AND METHODS

3.0 Study design

The study applied non-destructive approach where it measured trees parameters using a quantitative design approach. This design was preferred because destructive approach was not appropriate in such a fragile ecosystem that was already experiencing limited growth due to prolonged drought coupled with human demand for wood fuel among others. Similarly there are instruments that are used to measure physical parameters such as diameter at breast height, tree height, canopy diameter and distance from one tree to the other without necessarily harvesting the tree or shrub. The quantitative measurement was converted to carbon estimate using regression models. This was done on two major tree carbon pools i.e. stem and root biomass of any tree with DBH≥ 5 cm. The reason for DBH above or equal to five according Wildlife Works Kenya is that trees with diameter below that figure are very light and the biomass in mature forest are insignificant(Freund *et al.*, 2012).The study used IPCC 2006 forest biomass estimation guideline especially on carbon pool determination aboveground biomass and optional below ground biomass.

3.1 Biomass estimation

The study adopted the Wildlife Works model where above ground biomass was calculated by the tree species specific allometric equation as $\mathbf{AGB = \alpha(DBH)^{\beta}}$ **,** where AGB is above-ground weight of the tree in kilogram (kg), DBH is diameter at breast height (1.3m) and $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ are the model coefficients (Korchinsky *et al.*, 2011a; Korchinsky *et al.*, 2011b).Below ground biomass was estimated to be between 20-26% of above ground biomass (Cairns *et al.*, 1997; Santantonio *et al.*, 1997). The study opted to use 25% above ground biomass as below ground as used by Wildlife Works Kenya in the same study area i.e.$\boldsymbol{BGB = AGB \times (25/100)}$. Therefore, to determine the total green weight of the tree, the above-ground weight was multiplied by 125% i.e. ***Total biomass*** $(\boldsymbol{TB}) = \boldsymbol{AGB\ x\ 1.25}$

Dry weight of the tree was based on publication from the University of Nebraska that conducted biomass mapping dryland forest in Egypt with 27.5 % moisture content(Chavan & Rasal, 2010) whereby the dry weight of the tree is calculated by multiplying the total green weight of the tree by 72.5% (Chavan & Rasal, 2010; DeWald *et al.*, 2005). The carbon concentration of different tree parts is rarely measured directly, but it is generally approximated to be 47% of dry weight (IPCC, 2006) Hence in this study, the aboveground carbon stock was calculated by assuming that the carbon content was 47% of the total biomass.

3.1.1 Eco-char sampling design

Eco-charcoal according to Wildlife Works model is the Pruning of trees and shrubs' branches in blocks that were randomly selected at 25% and 50% i.e. one block where pruning was undertaken and one adjacent without pruning being under taken. Four one hectare blocks were set for 25% harvest and the other four for 50% harvest (Plate 3.1). Shrubs involved include; *Grewia bicolar, Grewia vilosa, Grewia molles, Cordia sinesis* whereas trees involved for eco-charcoal production include; all the six acacia species i.e. *Acacia bussei, Acacia etbaica, Acacia hockii, Acacia mellifera Acacia nilotica* and *Acacia tortilis*.

Plate 3.1: Eco-char branch harvesting, chopping and weighing

3.1.2 Eco-char process and briquetting

After pruning, chopping was done to produce small size twigs for easier placement into a kiln. Carbonation of chops was done in ‘special’ drums modified by Wildlife Works Kenya. Carbonation process takes between five to six hours then cooling takes another five to six hours. After cooling of char fines, briquetting process then follows (Plate 3.2). Briquetting involves mixing of char fines with cassava paste (binder) at a ratio of 1:20 that is one kg of the binder paste mixed with 20 kg of char fines.

Compression and compaction was done by manual extruder that was not able to measure the exact pressure applied. Nonetheless, extruder was able to squeeze out air from the mixture thus bind the char together without breaking in the process at about 95% successful briquettes cakes made.

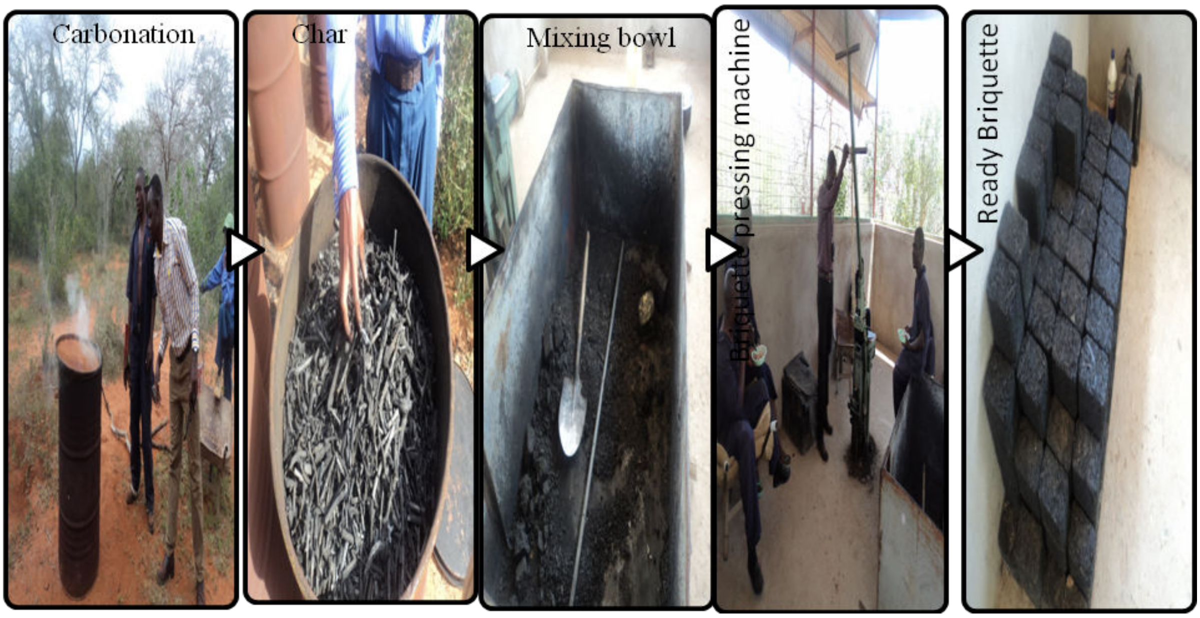

Plate 3.2: Eco-char production process

The best bidder of all times has been proven to be starch and any starch will do but preferably from cassava (HubPages & Hubbers, 2016).Cassava starch was preferred because, it is easily available to the low income societies. Nonetheless, corn starch (maize starch), wheat starch, maize flour, wheat flour and potatoes starch can be used as well.

To use the starch as a bidder it requires that the cassava chips are broken down into fine dust then gelatinize with hot water to form a thick paste that is likely to stick charcoal dust or fines together. Starch binder has to be used unless one use high pressure briquette pressing machine then lignin from biomass can be used as well but in this case manual extruder was used and density of briquette will depend on the person operating the machine. Similarly, gum Arabic or acacia gum, Mashed newsprint/waste paper, molasses, cement, clay and tar can be used as binders (HubPages & Hubbers, 2016).

3.2 Study area and population

The study area is located at eastern edge of Taita Ranch that is 35,612 ha, owned by a collection of indigenous local shareholders under Taita Ranching Company limited. The study area is within Kasigau corridor that connects Tsavo East National Park and Tsavo West National Park in Taita Taveta County and located to the South East of the Taita Hills, approximately 4 kilometres west of Mackinnon Trading Centre, along Voi-Mombasa highway (Fig.3.1). The area qualifies as High Conservation Value based on IUCN guideline (Dodson, 2006). The study area is largely comprised of *Acacia-Commiphora* dryland forest, where the dominant species are drought tolerant. Tree species in the area have a number of strategies for surviving low moisture and surviving in the arid/semi-arid conditions(Korchinsky *et al.*, 2011a). The dominant species include *Vachellia tortilis, Vachellia nilotica, Acacia bussei,Acacia hockii,Commiphora africana, Commiphora campestris and Commiphora confusa*. There are occasional taller hardwood species such as; *Terminalia spinosa,Melia volkensii,Boscia coriacea,Cassia abbreviata, and Newtonia hildebrantii*. The average canopy height was between 5-7 m with the maximum height being approximated to 10m(Korchinsky *et al.*, 2011b).

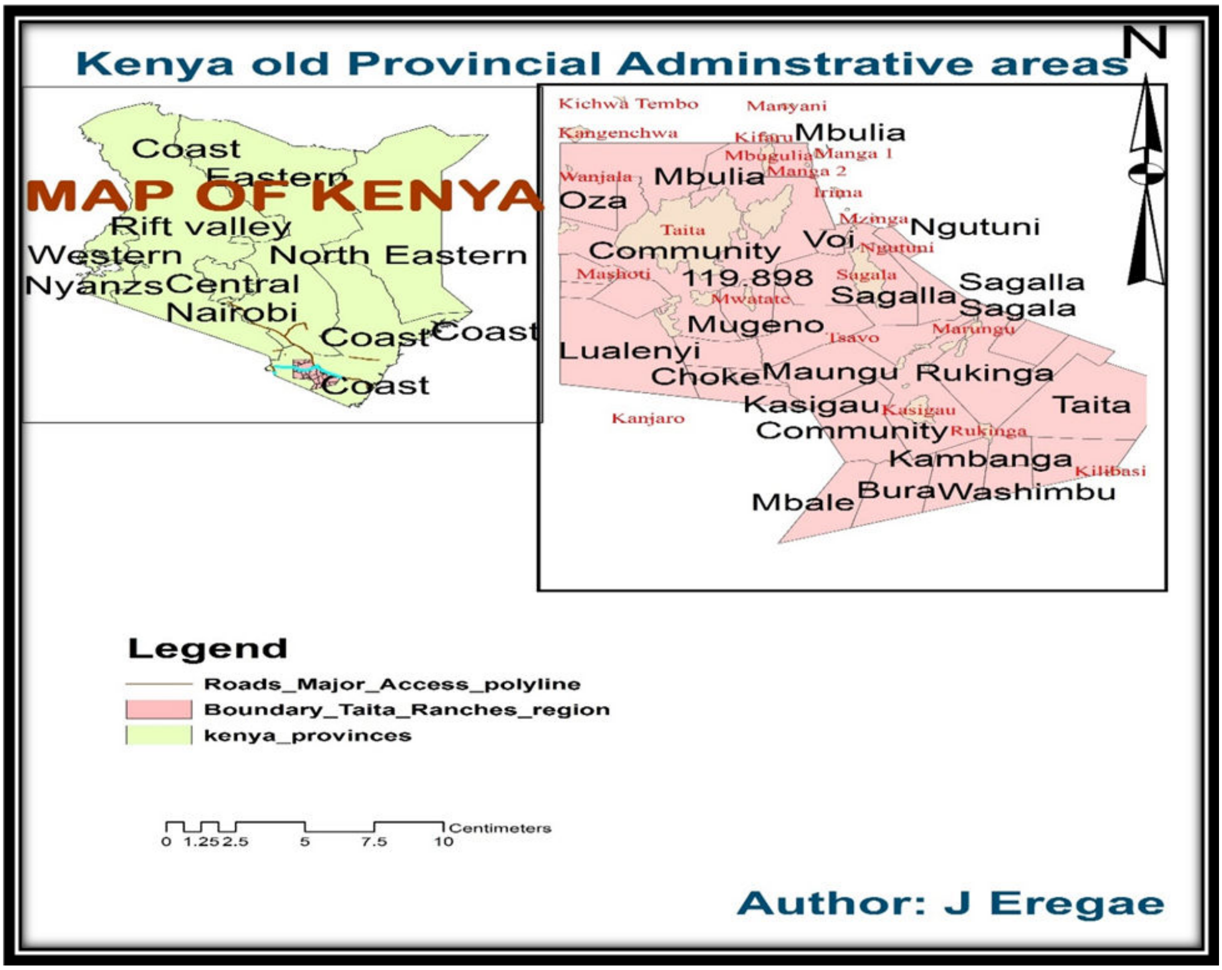

Figure 3.1: Taita Ranches alongside Kenya Map

The climate in this region of Kenya is semi-arid, with average annual rainfall in the 300-450mm range. There are no permanent water sources on the Project Land. Historically, rains occurred seasonally twice a year, in December and April, known as the “grass” rains and the long rains respectively. However, in the past ten years, local climatic conditions appear much more irregular and there have been two periods of extended drought in this time period. The project is located at 3^{o} S, and receives strong sunshine most days of the year. The coolest month is August, the hottest February. The dominant soil type within the project area, is red laterite, which characteristically contains high amounts of iron and aluminium(Korchinsky *et al.*, 2011b).

According to Wildlife Works Kenya, a total of 53 species of tree were encountered during the extensive plot sampling performed in larger Kasigau Corridor in Taita Taveta County. Most of the study area is in its historic condition, and despite the anthropogenic activities on the project area, such as cattle grazing, selective harvest for charcoal burning and small ecotourism projects, there has been no significant alteration to the forest extent within the project area(Korchinsky *et al.*, 2011b). Nonetheless, the area faces deforestation threat from the neighbouring communities despite providing significant support for the biodiversity, feeding large ungulates such as cape buffalo, common and Gravy's zebra and Eland, and Mega herbivores such as *Loxodonta Africana* which in turn ensures the survival of the large carnivores in the project area (Dodson, 2006)

3.3 Sampling method

This study fit into an ongoing research experimental set-up, where ten 1-ha block have been curved out of a larger area (1100ha) where twig and branch harvesting for eco-charcoal production is done. These blocks were randomly selected and were coded as 40, 48, 49, 58, 59, 68, 69, 79, 80 and 91. As this is a mature forest with mixed distribution of small and large trees, it was therefore necessary to use a uniform plots radius across the study area regardless of varied range of tree DBH. This was also because our method for tree inclusion was independent of DBH, e.g. any tree whose trunk centre fell within our 25m radius was considered in, provided that its DBH was at least 5 cm. Trees less than 5cm in DBH were excluded from our survey, as they are very light, and would yield a conservative outcome for tree biomass. Prior to setting of study sub-plots, a Test Plot for tree counting was performed with a 25 m radius which was set in the area adjacent to the study and named plot 28A and over 20 individual tree of varied species were recorded in test sub-plot. This was within the anticipated range of individual trees per plot, thus the study determined that the Tree Sample Plots for tree counts would be 25 m radius.

Based on the pre-test findings and the structure of the vegetation, systematic stratification was used to identify 25 m x 25 m sub-plots (Plate 3.3). Global Positioning System (GPS) was used to mark four corners and centres of every sub-plot and from the strata established, each study block had 16 sub-plots per block. DBH was measured using diameter tape while distance of tree species from different and the same species and diameter of the canopy was measured using a 50 m regular tape.

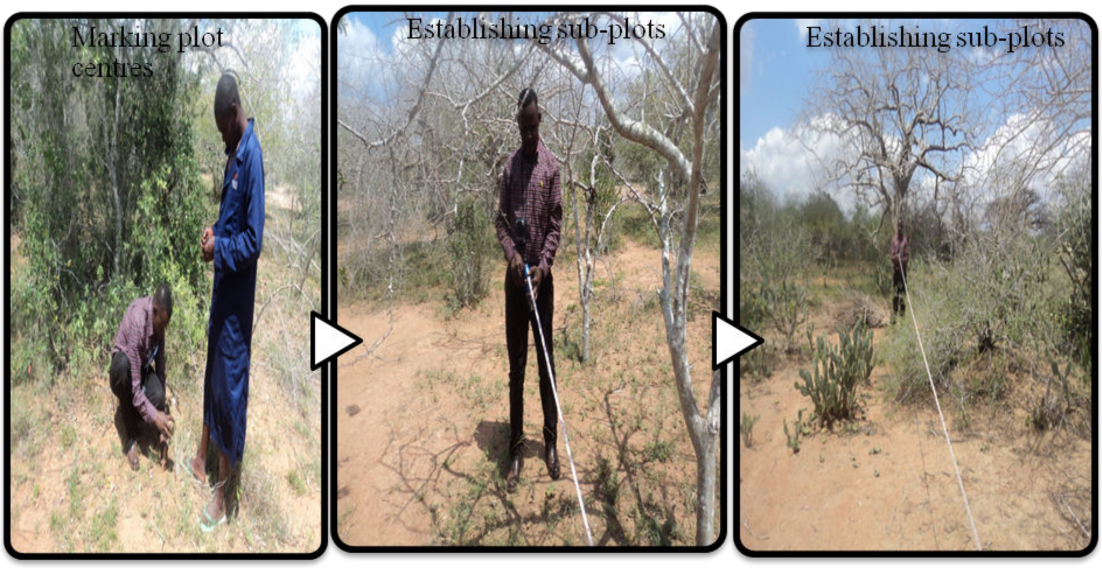

Plate 3.3: Establishing sampling plots

DBH was measured using diameter tape while distance of tree species from different and the same species and diameter of the canopy was measured using a 50 m regular tape. Upper canopy/height of each tree was measured using theodolite. The angle between the tree top and eye view at breast height angle (α) is taken into consideration for tree height measurement and height of the tree is calculated. Considering the angle between tree top and the distance (b) at the point of observer at DBH, the tree height was calculated if α is the angle between eye view and top of the tree, (a) is the height of the tree in feet, (c) is the slope between tree and eye view, (b) is the distance in meters between tree and observer and (h) is height of horizontal plane of theodolite instrument or the height of the observer and (H) is the tree height, formulae: $H = h + b \tan \alpha$(Larjavaara & Muller, 2013). For shrubs, the same 25m radius plot was used, and all shrubs with stem centres within that radius were included in the survey. Shrubs biomass estimates was conducted purposely for eco-charcoal harvest impact assessment as it was included as part of raw material for char production. Shrub biomass was estimated by first determining the class of the respective shrub, taking the measurement of each stem diameter and crown size and the number of stems per a shrub. In the study Shrubs were classified based on stem diameter whereby with stem diameter ≤ 2cm such as genus *Grewia*were categorized as first class and 2cm ≥ 5cm such as species under genus *Combretum*were categorized as 2nd class shrubs while stem diameter > 5cm as 3rd class such as *Cordia monoica*. The study used to biomass estimate done by wildlife works Kenya on various classes of shrubs and based on data the study was able to estimate the shrub biomass for all the blocks designated for pruning.

3.3.1 Carbon pools

The following pools of biomass were included in the study;

Trees:

- Living Trees
- Leaning Living Trees – Elephants routinely push over trees but leave them alive, and they remain alive for many years
- Standing Dead – due to the very dry ecosystem, standing dead trees can survive for many years in a sound condition
- Lying Dead – while there are many lying dead trees in the ecosystem, termites are very active and to provide a conservative estimate of total aboveground biomass from trees. The study excluded this pool, although in some plots the weight of lying dead wood was significant as a result of elephant damage. Nonetheless, in its entirety the biomass for lying dead trees was insignificant.

3.4 Sample size determination

As aforementioned, this study site was curved out of a larger area (1100ha) of ongoing research experimental set-up, where twigs and branches harvesting for eco-charcoal production is done. The study was conducted between March and September 2015 where in the month of August Elephant activities were very high where at some instances had to postpone data collection for a different day. The area surveyed had sparse vegetation cover and between 8 and 20 trees per sub-plot. Since the study target population was majorly on trees especially for biomass mapping, it was then easy to sample all the trees with DBH≥5cm.For the purpose of eco-charcoal biomass, shrubs were sampled with an exemption of small shrubs (stem DBH<1cm) under the first category in all the eco-char sampling blocks. The inclusion of shrub was purposely to estimate shrub carbon biomass in order to make inference on impact of vegetation harvest to the total biomass.

3.5 Research instruments

Below are field instruments and equipment used in the study (Table 3.1). Additionally the data collected was recorded in a specialized data sheet with columns that included study block, sub-plot, sampler, date, tree or shrub species, DBH, tree height , crown diameter, distance to the same species and to different species, wood density and above ground biomass.

Table 3.1: Field equipment and their use

S/NO	ITEM	PURPOSE
01	GPS	Boundary survey, stratification, and locating plots
02	Base Map	Plot Navigation
04	Linear tape	For locating plot boundary and distance measurement between trees
05	Chalk	Marking the trees within the boundaries temporarily before permanent tagging and for ensuring they are measured.
06	Metal Tags for tree	For permanent marking trees
10	Diameter Tape	Measuring the diameter of the tree at breast height
11	Theodolite	Measuring ground slope, top and bottom angle to the tree used to estimate tree height

3.6 Data processing and analysis

Simpson diversity index was used to compute species diversity in the study area (Hill, 1973;Simpson, 1949;Tuomisto, 2010). Tree physical measurement was transformed into biomass estimates using $\mathbf{AGB = \alpha(DBH)}^{\beta}$ model generated by Wildlife Works Kenya. Correlation analysis was carried out to examine relationships between some paired growth parameters i.e. DBH, tree height, canopy diameter, wood density against biomass. Advanced general linear model in Statistica was used to perform regression analysis and One Way ANOVA test to test for significance across tree genus and species within and between study blocks. Ultimately, Least Square mean was used to make inference on the significance of biomass in respect to common trees involved in the study. Significance difference was determined at $P < 0.05$ with 95% confidence level.

3.7 Data validation

All data was examined after collection to detect errors and omissions. Instruments used were calibrated before sample measurements to minimize instrumental errors. Tree physical parameter measurements were carried out in triplicate to minimize random errors. Subsequently, a second sampling team would conduct sampling after first team goes to the next block and make measurements and later we compare the measurements and in case of any variation, the team would jointly go and confirm in field thus make corrections where necessary. Additionally an independent sampling team from Wildlife Works, Kenya conducted random sampling of two blocks within the study area and both results compared for detection of errors and omissions. Excel pivot table was used to evaluate the data range while Q- Test was used to verify the accuracy of the results. Later t-test was used to test for significance thus identifying and correcting systematic errors. Analysis of central tendency was carried out using mean, median and mode, range, standard deviation and variants. Analysis of Variance (ANOVA) was used to calculate the measure of dispersion for all the statistical data obtained. Correlation and regression was used to test for relationship of the obtained data.

NOTE: Some *Acacia* species have been categorized under genus *Vachellia* from 2005 such as Umbrella thorn tree (*Vachellia tortilis),* Egyptian thorn *(Vachellia nilotica)* and many others while others are still classified under genus *Acacia* such as White-galled (*Acacia bussei),* Hook thorn acacia (*A. mellifera), and* Savannah thorn acacia (*A. etbaica)* among others. Nonetheless Acacia is commonly used in a number of literatures and in this report all species under the genus were referred as *Acacia*.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.0 Introduction

This section highlights the study outcome and discusses the result in relation to available literature on carbon sequestration within the region and globally. The data is presented in tables and relevant charts and hypothesis was tested base on the study objectives that include the level of carbon storage and potential of carbon release by most common tree species when the same are harvested for charcoal production. Similarly the section indicates the impact of pruning to total biomass and sustainability of eco-char production system in dryland forest. Furthermore, the section highlights the factors that influence the carbon stock in dryland forest.

4.1 To determine the level of carbon storage and potential release by dryland forest in study area

In total 2060 individual trees were from twenty five (25) tree species, drawn from 14 tree genus that were encountered in the study area. Sixof species recorded were for genus*Acacia,* four species for *Commiphora,* three species for *Lannea* and two species for genus *Manilkara* and the other genus recorded one species each. Genus *Commiphora* recorded the highest number of individual trees followed by *Lannea, Boswellia, Acacia* and *Boscia* respectively. Mean biomass for the tree genus ranged from approximately 34 kg to 210 kg where genus *Commiphora* had the highest mean and *Salvadora* with the lowest mean (Table 4.1). Between 164 and 228 individual trees were encountered in the respective study blocks (1 ha) which therefore approximated to between 10 and 14 individual trees per sub-plot.

Table 4.1: Tree genus, abundance and respective mean biomass

S/No	Tree genus	No. of species	Individual trees per genus	No. of trees /ha	n(n-1)	Biomass Mean	Biomass SE
1	*Acacia*	6	194	20	380	130.2	6.55
2	*Albizia*	1	1	>1	0	163.6	-
3	*Balanite*	1	1	>1	0	66.1	-
4	*Boscia*	1	148	15	210	49.0	6.17
5	*Boswellia*	1	258	26	650	69.2	3.43
6	*Cassia*	1	1	>1	0	153.4	-
7	*Commiphora*	4	957	96	9120	210.1	7.76
8	*Lannea*	3	390	39	1482	38.0	1.15
9	*Manilkara*	2	10	10	90	86.4	12.53
10	*Ormocarpum*	1	2	<1	0	39.5	0.49
11	*Salvadora*	1	10	1	0	33.5	4.96
12	*Sterculia*	1	23	2	2	96.4	17.28
13	*Terminalia*	1	28	3	6	52.1	5.07
14	*Zanthoxylum*	1	1	> 1	0	46.2	
	Grand Total	**25**	**2060**	**217**	**11940**		

Simpson index $\boldsymbol{D} = \frac{\sum n(n-1)}{N(N-1)} = \frac{217}{11940}$

Trees D= 0.02 while shrub included Simpson index is between 0.05 to 0.15 and looking at the study area structure it exhibits low diversity structure. This majorly contributed by anthropogenic activities overgrazing, selective harvest of hardwood species for fuel wood and charcoal production as well prolonged drought, mega herbivores disturbances and among other natural stressors. The dominance of genus *Commiphora* in the study area was majorly attributed to its unattractiveness for uses such as fuel wood, charcoal production and timber unlike genus *Acacia* that was critically affected due to high demand for charcoal production among other uses. The study result indicates that, hardwood species are destroyed due to direct benefits that humans accrue from such tree species. The low abundance thus not necessary means that hard wood species cannot survive in such area but rather due to uncontrolled and selective over harvesting.

4.1.1 Biomass estimation

On regression analysis, the study confirms that DBH explains for about 84% of biomass variation where r^2 =0.8411 (Fig. 4.1). This depicts DBH as a key parameter in biomass estimation better than other measurable parameter. This analysis is agreement with Brown (2002) that indicated that among the other key biomass estimation parameters such as DBH, Tree height and wood density, DBH alone explains more than 95% of the variation in aboveground tropical forest carbon stocks, even in highly diverse regions (Brown, 2002).This is also confirmed by Chave *et al.,* (2005) and Freud *et al.,* 2012 that the most important predictors of above ground biomass of a tree were, in a decreasing order of importance are; the trunk diameter, wood specific gravity, total height, and forest type (dry, moist, or wet).

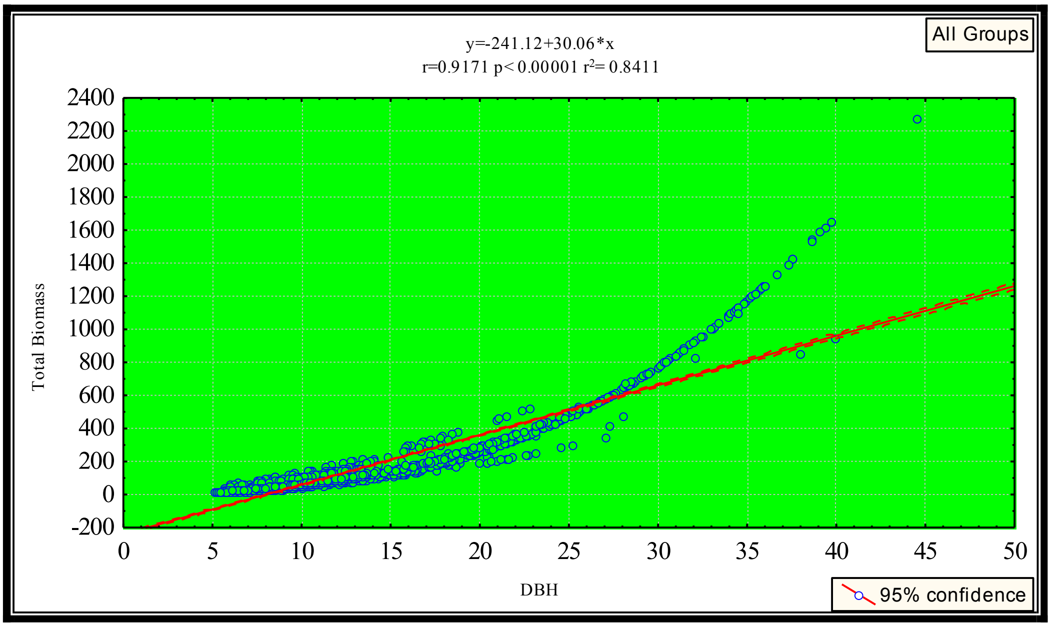

Figure 4.1: Scatter plot for total biomass as a function of DBH

Furthermore, the interaction of DBH and total biomass explicitly confirms that enhanced tree diameter implies increase in total biomass across tree genus (Fig. 4.2). That notwithstanding, the model is appropriate for trees with DBH ≤ 35 cm otherwise it is likely to overestimate the biomass as indicate above. The sentiment is in agreement with the observation made by Wildlife Works Kenya phase II project document and further recommended that the model will not be preferably for tree larger cross-sectional area (Korchinsky *et al.*, 2011b).

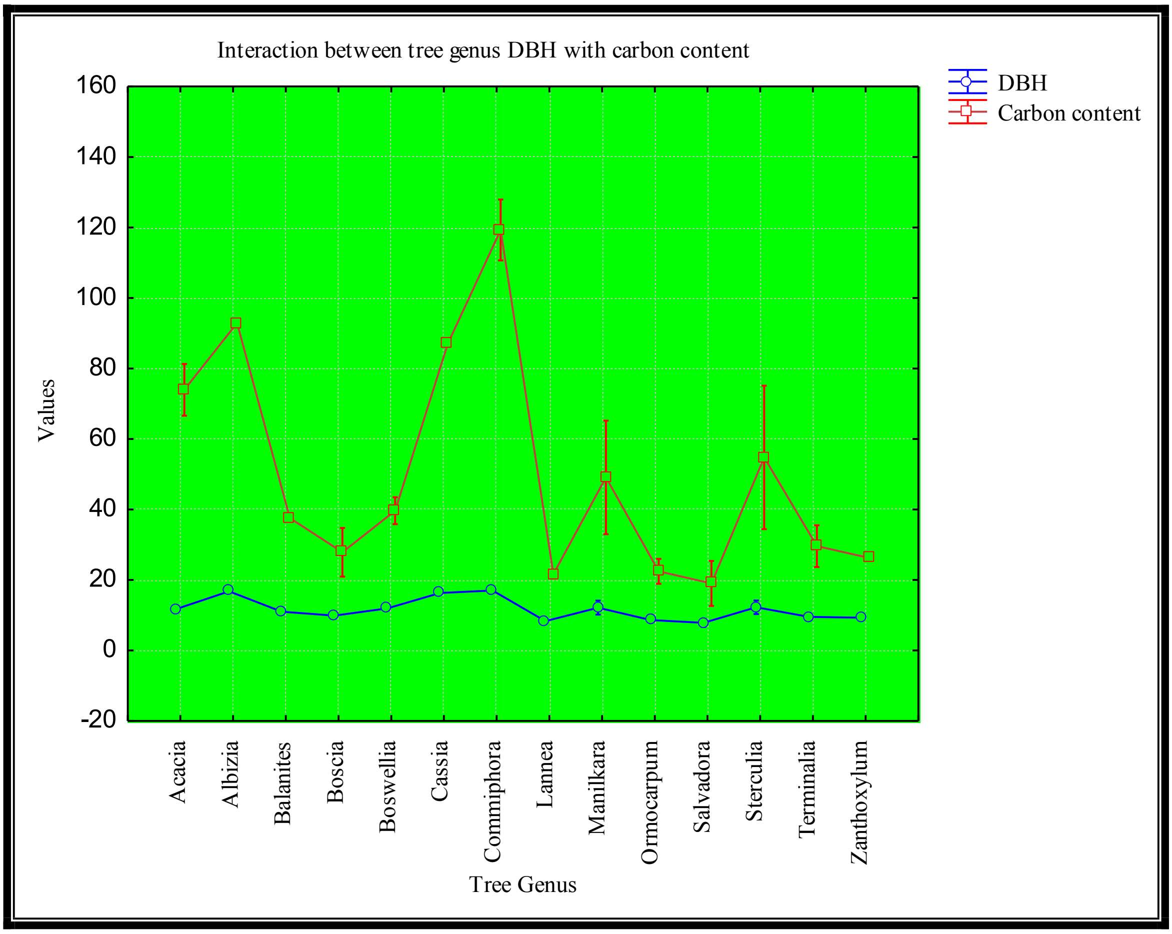

Figure 4.2: Interaction plot of DBH and total biomass against tree genus

On the contrary tree height in this study did not contribute any significant influence in biomass variation where regression analysis in relation to biomass exhibited a low value of r^2= 0.2151 (Fig. 4.3). This then suggest that, the increase in tree height values does not necessary increase biomass in the study area i.e. it is likely to get s a short tree but with high biomass and a tall tree with low biomass given the variance in tree species. Despite, tree height not being influential factor in the study models, it is a very critical factor in biomass estimation. According to Xu *et al.,* (2015),models with height performed better than those without height, indicating tree height (H) as an important parameter in biomass estimation in sub-tropical forest(Xu *et al.*, 2015). The contrast is most likely due to difference in regression model used and in this case the study applied species specific model while Xu and others applied general model. Secondly this could be due to varied wood densities example genus *Commiphora* dominates the study area with very tall trees but low wood density while genus *Acacia* may be very short but with high density compared to most species in the study area as observed by wildlife Works Kenya(Korchinsky *et al.*, 2011b)

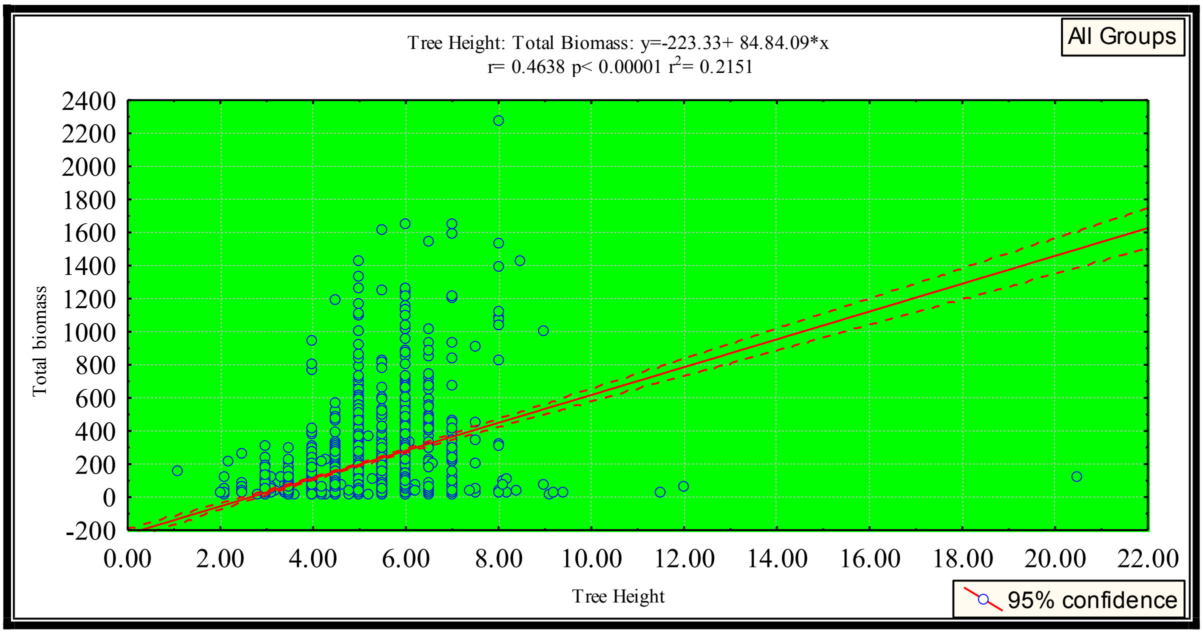

Figure 4.3: Scatter plot for total biomass as a function of tree height

Simple regression analysis indicated that canopy diameter does not contribute significance in biomass estimation with r^2= 317506 (Fig.4.4). This observation was also made by Xu and other (2015) on study conducted at sub-tropical forest in china. The study made an observation that inclusion of crown radius into regression model did not make any improvement to the model used(Xu *et al.*, 2015).

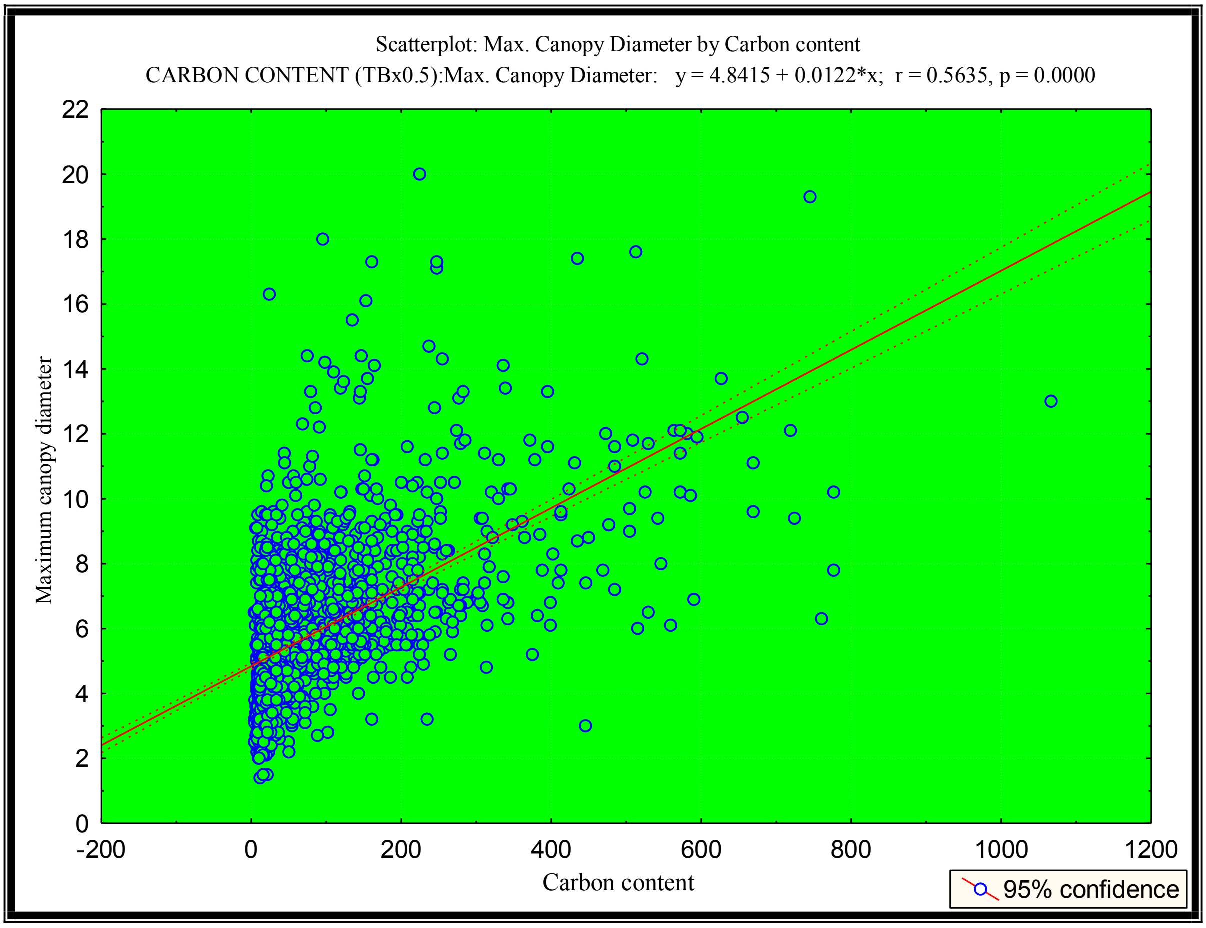

Figure 4.4: Scatter plot for maximum canopy diameter as a function of carbon content

Average DBH across the study area was 13.34 ± 0.30 while that of height (m) was 4.56 ± 0.05. The mean distance of species from the same species was 9.134 ±0.37 and from different species is 5.25± 0.11. Mean carbon content across the study area was 75.5±2.3 (Table 4.2). DBH across species in the study area ranged from 8.7 cm to 44.6 cm. *Commiphora campestris* hadthe highest DBH while *Ormocarpum kirkii* had the lowest DBH. *Boscia coriacea* on the other hand had the largest DBH of up to 40 cm while *Acacia etbaica* had DBH up to 32.1 cm.

Table 4.2: No. of trees and mean of variables among tree genus in the study area

Tree genus	No.	DBH (Cm)	Tree height (M)	Distance from different species (M)	Distance from the same species (M)	Canopy diameter (M)	Carbon content (Kg)
Acacia	191	11.8±0.3	4.8±0.1	5.2±0.2	14.7±0.8	6.4±0.2	74.0±3.7
Albizia	1	16.8	5.5	3.0	30.0	7.3	92.9±0.0
Balanites	1	11.0	5.0	4.8	30.0	2.6	37.6±0.0
Boscia	182	9.9±0.3	4.1±0.1	4.9±0.2	13.1±0.9	4.3±0.1	27.9±3.5
Boswellia	257	11.9±0.2	4.5±0.1	5.0±0.1	9.0±0.5	6.1±0.1	39.6±1.9
Cassia	1	16.3	4.5	3.0	30.0	6.7	87.1±0.0
Commiphora	949	17.0±0.2	4.9±0.0	5.2±0.1	7.4±0.2	6.3±0.1	119.3±4.4
Lannea	386	8.3±0.1	3.8±0.1	5.8±0.1	7.1±0.3	4.5±0.1	21.7±0.6
Manilkara	10	12.2±0.9	4.7±0.5	4.6±1.4	25.5±4.5	5.0±0.5	49.1±7.1
Ormocarpum	2	8.7±0.1	3.0	1.4	30.0	3.3	22.5±0.3
Salvadora	10	7.8±0.5	4.4±0.2	4.7±0.4	19.9±4.0	5.8±0.6	19.0±2.8
Sterculia	23	12.3±0.9	4.2±0.2	5.2±0.7	21.9±2.6	5.1±0.4	54.8±9.8
Terminalia	27	9.5±0.4	4.5±0.2	5.2±0.3	17.8±2.2	5.0±0.3	29.6±2.9
Zanthoxylum	1	9.3±0.0	4.0±0.0	4.9±0.0	30.0±0.0	4.3±0.0	26.2±0.0

4.1.2 Biomass storage and potential release among tree genus within the study area

Total biomass was approximately 32.8 Mg/ha, and from the estimates Genus *Commiphora* had a whopping 74% of the total biomass while Genus *Acacia* despite low number of individual trees had 9% of the total biomass. Genus *Boswellia*, *Lannea* and *Boscia* registered 7%, 5% and 3% respectively while other genus pooled together, registered 2% (Table 4.3). Biomass across the study area varied significantly with LS mean $F_{(9,2030)=}$ 2.3845, p= 0.01105 that is between 25.7 Mg ha^{-1} to 39.6 Mg ha^{-1}. The genus biomass as well, varied from 0.6 Mg ha^{-1} to 24.1 Mg ha^{-1} whereby *Commiphora* recorded the highest mean biomass estimates followed at a distance by genus *Acacia* and other species respectively.

Table 4.3: Sum of total biomass of tree genus across the study blocks

Study Blocks	*Acacia*	*Boscia*	*Boswellia*	*Commiphora*	*Lannea*	Others	Grand Total
40	2.4	1.2	3.1	25.8	0.8	1.3	34.6
48	2.1	1.6	1.3	18.9	1.6	0.2	25.7
49	6.7	1.2	1.9	22.3	1.3	0.6	34.0
58	2.0	0.9	1.7	19.3	2.7	0.7	27.3
59	1.9	0.6	1.9	22.9	2.6	0.3	30.3
68	3.5	0.3	2.1	24.9	2.2	0.5	33.5
69	0.7	1.7	2.5	24.8	2.0	0.2	31.9
79	2.8	1.4	2.1	31.2	1.6	0.5	39.6
80	3.7	0.8	3.3	23.7	2.4	0.9	34.9
91	4.3	1.1	1.7	27.0	0.6	1.2	36.0
Grand Total	**30.1**	**10.8**	**21.7**	**240.9**	**17.8**	**0.6**	**327.7**

The study area biomass is approximately 32.8 Mgha^{-1}whichfalls below global average of dryland biomass that stands at 60 Mg ha^{-1}(Trumper *et al.*, 2008).Given per hectare biomass estimates then the study used carbon atomic ratio in CO_2 of 3.67 to estimate the CO_2e generated per hectare i.e. between 47.2 Mg CO_2e ha^{-1} to 72.7 Mg CO_2e ha^{-1}. According Korchinsky *et al.,* (2011), the average age of the forest in the study was about 35 years which is then likely to release between 1.3-2.1 Mg CO_2e ha^{-1} yr^{-1}. This falls within global average range of carbon release of 0.5-4.1 Mg C ha^{-1}yr^{-1}(FAO, 2001). On the other hand, carbon stored by desert vegetation is considerably lower, with typical quantities being around 2–30 Mg of carbon per ha in total. On comparison with such an ecosystem then the study area had higher biomass than desert biomass estimates(Grace, 2004). Taking cognizance of selective harvest of hardwood species, it is worth to note that study did biomass estimation for tree carbon only and excluded all the other pools such as shrubs, grasses and the lying dead trees where at some blocks had significant number as aforementioned. These are likely reason as to why the carbon levels are lower compared to savannah for instance.

4.1.3 Analysis of mean biomass across tree genus in the study area

Weighted Mean biomass for common tree genus exhibited high significance with $F_{(8, 1938)} = 4.3154$, P= 0.00004. Where by the mean biomass ranged from 40 kg to 254 kg with *Commiphora* recording the highest weighted mean and *salvadora* recording the lowest. *Acacia* had the second highest with a mean of 158 kg followed closely by *Sterculia* and *Manilkara* while other genus registered mean less than 100kgs (Fig. 4.5).

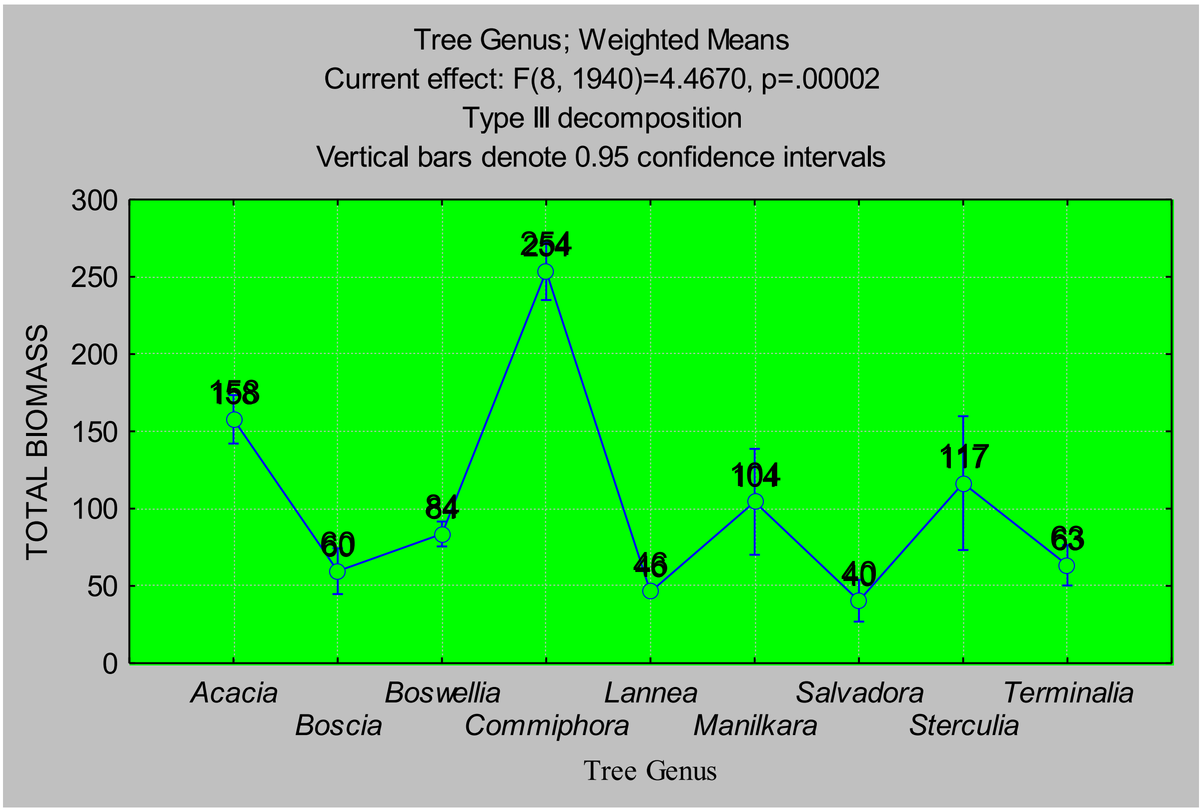

Figure 4.5: Tree genus weighted mean in relation to total biomass

4.1.4 Factors that influence biomass variance as explained by effect size analysis

The difference in biomass was affected by varied attributes generated by different tree genus in the study area. The attributes among others included DBH which varied across tree genus and respective species. Some genus such *Commiphora* had larger stems than others. Variation of tree biomass was not necessarily explained by stem size but rather by genus difference, and the interactions of varied tree parameters that include tree height and to some extend canopy diameter. From effect analysis, the interaction of the DBH and tree genus influences the mean biomass with partial eta squared (the influence of independent variable to dependent variable variance) of 0.119 that is approximately 12% influence on biomass variance. Additionally, the interaction between tree height and DBH and DBH with canopy diameter for instance had partial eta squared approximated at 0.06 i.e. 6% influence (Table 4.4). Nonetheless, independent parameters such as DBH, tree height and canopy diameter plus their interaction had lower influence on biomass variance. Additionally, biomass variance was influenced by difference in tree species where hardwood trees had higher wood density than softwood. This is supported by analysis on effect size where interaction of tree species and DBH explains approximately 31% of variation in genus biomass. The interaction of tree height and DBH explains between 5% and 6% respectively of variation of biomass among tree species. Wood density variance across tree species is most likely to have played a role on biomass difference as depicted by the above figures. The same observation was made a study conducted in Borneo forest in 2010 on environmental correlate on basal area, wood density and tree height(Slik *et al.*, 2010)

Table 4.4: Analysis of major predictor variable on effect size

	DF	F	P	P_{eta}^2	NC	OP (α=0.05)
Intercept	0					
Tree Genus	8	3.1	0.0017	0.012	24.9	0.97
Max. DBH	1	22.4	0.0000	0.011	22.4	1.00
Tree height	1	9.0	0.0027	0.004	9.0	0.85
Max. Canopy Diameter	1	0.2	0.6423	0.000	0.2	0.08
Perp. Canopy Diameter	1	0.2	0.6243	0.000	0.2	0.08
Tree Genus* DBH	8	33.3	0.0000	0.119	266.3	1.00
Tree Genus*Tree height	8	7.9	0.0000	0.031	63.0	1.00
DBH*Tree height	1	127.7	0.0000	0.061	127.7	1.00
Tree Genus*Canopy Diameter	8	1.2	0.2775	0.005	9.8	0.58
DBH*Canopy Diameter	1	19.4	0.00001	0.01	19.4	1.00
Tree height*Canopy Diameter	1	0.6	0.4328	0.000	0.6	0.12
Tree Genus*Canopy Diameter	8	2.0	0.043	0.008	16.0	0.83
DBH*Canopy Diameter	1	120.8	0.0000	0.058	120.8	1.00
Tree height*Canopy Diameter	1	13.7	0.0002	0.007	13.7	0.96
Error	1979					

SS (Sum of Squares) **DF** (degree of freedom) **MS** (mean square) $\mathbf{P_{eta}^2}$ (partial eta squared) **NC** (Non Centrality) **OP** (Observed Power)

4.1.5 Least square analysis

As earlier indicated, Genus *Commiphora* had higher DBH on average, which is a crucial parameter in biomass estimation model. Take DBH factor into perspective it then becomes apparent that the genus had higher weighted mean biomass compared to other genus. The same was confirmed by weighted mean biomass where genus *Commiphora* had the highest compared other tree genus. That notwithstanding, Least Square analysis had genus *Acacia* with the highest mean biomass of 194 kg while genus *Commiphora* had the lowest means of 104 kg (Fig. 4.6). This then depicts that an individual tree of genus *Acacia* has higher density than any other genus encountered in the study area while an individual tree of genus *Commiphora* has lower density. This observation was also made by Korchinsky and other that *Commiphora* species have low density and thus very light despite very huge DBH (Freund *et al.*, 2012)

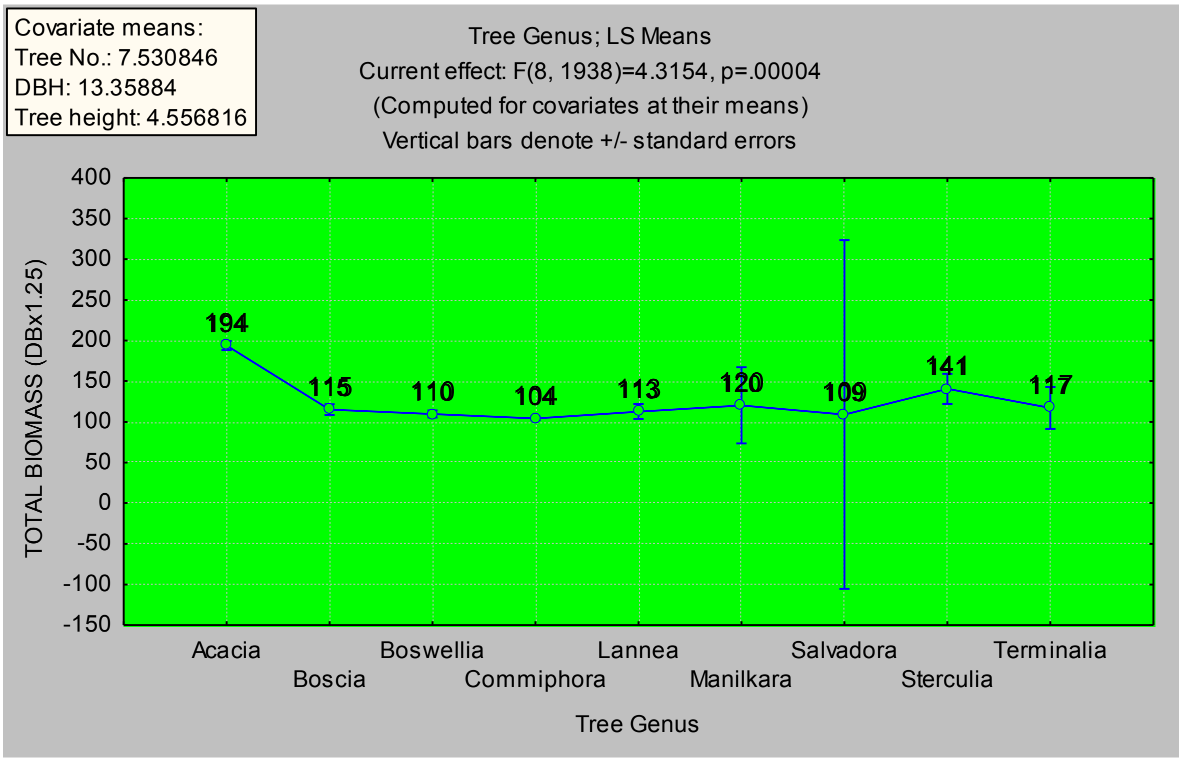

Figure 4.6: Effect size least square means of tree genus in relation to biomass

4.1.6 Factors for low biomass

The spatial pattern of woody biomass described above is subject to frequent and widespread disturbance(Brown, 1997) that reduce biomass, these include: prolonged drought; primarily clearance for agriculture charcoal production (Brouwer & Falcao, 2004; Falcao, 2008) and fire(Williams *et al.*, 2012).Elephant activity as well reduces tree populations significantly which is likely to decreases woody vegetation productivity (Guy, 1989; Ribeiro *et al.*, 2008). Although there was no report on forest fire within the study area, elephant destruction of was evident where huge loads of fuel was observed and just in case a fire occur in such an area then it will definitely consume that ecosystem very easily thus a factor to be taken care of. This observation was also made by wildlife works REDD project phase II report (Freund *et al.*, 2012).

4.1.6.1 Prolonged drought

The study area is frequently subjected to prolonged drought which is the main limiting factor on biomass production and crop yields. The lack of moisture determines the way in which these ecosystems process carbon. According to (Amundson, 2001), plant growth tends to be highly sporadic and plants invest heavily in protecting themselves against water loss and herbivores by making their tissues tough and resistant to decomposition. Lack of water also slows decomposition rates, leading to the accumulation of carbon-rich dead plant material in the soil.

4.1.6.2 Human induced factors

It is evident in the study area that there are human induced disturbances such as selective harvest of hardwood trees. Preference of selective harvest has been to genus *Acacia* as shown by acacia tree stumps remnants found in the study area. The area is overstocked with large numbers of livestock that results to over-grazing. Huge numbers of livestock in dry area destroys tree seedlings, causes soil erosion and introduces invasive alien species. According to Abdi and others (2013), human induced factors such as over cultivation, overgrazing, selective harvesting of hardwood species and other forms of inappropriate land use may result in significant degradation of vegetation, soil leaching and in many cases resulting low diversity index thus imbalanced tree community structure (Abdi *et al.*, 2013).

Similarly, clearing for tropical forests for various reasons also destroy globally important carbon sinks that are currently sequestering CO_2 from the atmosphere which are critical to future climate stabilization. According to Chakravarty *et al.,*(2012) agents of deforestation are those slash and burn farmers, commercial farmers, ranchers, loggers, firewood collectors, infra-structure developers and others who are cutting down the forests (Chakravarty *et al.*, 2012; Korchinsky *et al.*, 2011a). Additionally, Clear cutting and overgrazing have turned large areas of Qinghai province in China into a desert. Overgrazing is causing large areas of grasslands north of Beijing and inside Mongolia and Qinghai province to turn into a desert(Chakravarty *et al.*, 2012). This scenario is apparent in the adjacent ranch that is open access to the public where livestock infestation and uncontrolled harvest of trees, has turned that area to a bare land with no vegetation and this is an example of human driven desertification that is very fast. This same scenario has been reported by Macharia and Ekaya, (2005) in Mashuru area in Kajiado County whereby uncontrolled human activity that include overgrazing, harvest of wood tree for charcoal production that led desertification in mention area (Macharia & Ekaya, 2005).

4.1.6.3 Wildlife disturbance

From the observation made in the study area, some species hardly grows to big trees due to destruction done by African elephants (*L. africana).M. mochisia* for instance is among the species affected by wildlife disturbance and the only few surviving species could only be found under huge shrubs that elephant for some reasons couldn't access. The same was confirmed by(Korchinsky *et al.*, 2011b) who indicated the extent to which African elephants damage the trees in the dryland forest as they feed. The elephant action is believed to open up the canopy to allow more grasses to grow. In addition, Mwambeo and Maitho also indicated that wildlife disturbance causes imbalance in dryland ecosystem especially elephants which have preference for some tree species over others (Mwambeo & Maitho, 2015). Such feeding behaviour is overexploiting some plant species and the end result is the appearance of large open areas devoid of vegetative cover leading to desertification.

4.1.6.4 Fire

Savannah and tropical grasslands are naturally subject to frequent fires, which are an important component in the functioning of these ecosystems. Fire events in savannah can release huge amounts of carbon to the atmosphere estimated at 0.5–4.2 Gt C per year globally(Grace *et al.*, 2006). However, the carbon lost is mostly regained during the subsequent period of plant copping, unless the area is converted to pasture or grazing land for cattle(Grace *et al.*, 2006) and these ecosystems are considered currently to act overall as carbon sinks, taking up an estimated 0.5 Gt C per year(Scurlock & Hall, 1998). As aforementioned earlier, the study area had not reported any fire in the last decade according to Wildlife Works Kenya report of 2011. Otherwise if fire occur in such forest, it is likely to consume a huge area due to availability of huge fuel loads(Freund *et al.*, 2012).

4.1.7 Carbon biomass in the study area in comparison to Commensurate Ecosystem

Savannah and tropical grassland plus the desert and shrub land ecosystems are related to some extent with the study area where desert has low vegetation cover and savannah sparsely populated vegetation cover. According to author Grace and others (2006), the amount of carbon stored by savannah and tropical grassland range from 9 Mg per ha to about 88 Mg per ha while desert and dry shrub land vegetation carbon ranges from as low as 2Mg per ha to 30 Mg per ha (Grace *et al.*, 2006). Soil carbon stocks are high compared to those of the vegetation ~174 Mg and ~ 102 Mg C per ha for savannah and desert ecosystem(Trumper *et al.*, 2009).

On the other hand tropical forest ecosystem has on average ~ 200 Mg C per ha(Chave *et al.*, 2008; Malhi *et al.*, 2006).Globally, terrestrial ecosystems are a vast store of carbon containing more than 2000 Gt C and are acting as a net sink of approximately 1.5 Gt C per year, of which tropical forests account for a large proportion (IPCC, 2007; Luyssaert *et al.*, 2007). Sequestration at these levels would be equivalent to a 40–70 ppm reduction of CO_2e in the atmosphere from anthropogenic emissions by the year 2100 (Canadell &

Raupach, 2008). Nonetheless, tropical forests can vary considerably in their carbon stocks depending on the abundance of the large, densely wooded species that store the most carbon (Baker *et al.*, 2004).

The tree carbon in the study area ranged from 12.5 Mg of C per ha to 20 Mg of C per ha that is approximated using relative atomic ratio of carbon in $CO_2$to between 46 Mg CO_2 per ha and 73 Mg CO_2 per ha. On average according to Grace and other (2006), savannah and desert vegetation have average of 50 Mg of carbon per ha and 16 Mg of carbon per ha respectively while tropical forest vegetation carbon was ~160 Mg per ha. In this regard therefore, the study area carbon was above desert ecosystem carbon average, and was within range but below average of savannah and grassland ecosystem carbon(Grace *et al.*, 2006). As aforementioned, the study did not incorporate shrubs, grass and the leaning trees biomass for carbon mapping since this particular study focus was on standing trees only. Nevertheless, it was necessary for eco-char blocks to sample shrubs purposely to assess impact of pruning to the total biomass and the shrubs estimates was between 2.8Mg C to 4.7Mg C ha^{-1} approximated to 23% of tree biomass.

According to Trumper and others (2009), soil carbon savannah and desert ecosystem is higher than vegetation (Trumper *et al.*, 2009). Nonetheless, the study didn't estimate soil biomass but it is worth to note that soil carbon in the study area is significant as reported by Wildlife Works whereby according to the figures provided by REDD Phase II Project Design Document phase soil carbon is about 2.3 of vegetation carbon(Korchinsky *et al.*, 2011a).Albeit low estimates compared to global savannah average, large surface areas of dryland gives its carbon sequestration a global significance where in particular, total dryland soil organic carbon reserves comprises 27% of global soil organic carbon reserves(MA, 2005).

That notwithstanding, the total forest resources in Kenya comprise about 3 million ha, where 211 000 ha is an area of land under dryland forest which is approximately 7% of the total forest cover in Kenya(World Bank, 2007). Savannah ecosystems are considered currently to act overall as carbon sinks, taking up an estimated 0.5 Gt C per year(Scurlock & Hall, 1998). To put this figures into perspective savannah and desert ecosystem carbon uptake is equivalent to approximately 6% of the total global anthropogenic carbon emissions which is significant as far as carbon emission reduction is concern.

Overall, genus biomass varied significantly with ($t_{calculated} > t_{critical}$) which ranges from 19 Kg to 119 Kg C per tree genus (Table 4.5). Similarly the one hectare block carbon ranged from 25.7 Mg C to 39 Mg C. author Grace and others (2006), found that savannah forest biomass ranges between 9 Mg to 88 Mg C ha^{-1}(Grace *et al.*, 2006). Looking at grace findings, then the study estimates are within savannah biomass range per hectare estimates. A t-test of mean against a constant savannah mean of 48.5 Mg C varied significantly as well with t =-13.5 and despite rejecting the null hypothesis indicates that the study mean biomass is below the savannah average. Nonetheless, the study only did an estimation of tree biomass and it is likely that with inclusion of shrub and grass biomass which is at about 23% of tree biomass then the overall estimate will higher than tree biomass alone.

Table 4.5: Test of mean of key variables against reference constant value across tree genus (One-way paired t-test, n=0.05)

Tree genus	Tested variable	Mean	t-calculated	df	$t_{critical}$ (n=0.05)
All groups	DBH (cm)	13.4± 0.2	88.2	2040	2.78
	Carbon content (Kg)	75.5± 2.3	32.4	2040	2.78
Acacia	DBH (cm)	11.8± 0.3	39.0	190	2.78
	Carbon content (Kg)	74.0± 3.7	19.9	190	2.78
Boscia	DBH (cm)	9.9± 0.3	29.5	181	2.78
	Carbon content (Kg)	27.9± 3.5	7.9	181	2.78
Boswellia	DBH (cm)	11.9± 0.2	54.8	256	2.78
	Carbon content (Kg)	39.6± 1.9	20.4	256	2.78
Commiphora	DBH (cm)	17.0± 0.2	67.8	948	2.78
	Carbon content (Kg)	119.3± 4.4	27.1	948	2.78
Lannea	DBH (cm)	8.3±0.1	79.4	385	2.78
	Carbon content (Kg)	21.7± 0.6	33.3	385	2.78
Manilkara	DBH (cm)	12.2±0.9	13.8	9	2.78
	Carbon content (Kg)	49.1± 7.1	6.9	9	2.78
Ormocarpum	DBH (cm)	8.7± 0.1	172.0	1	2.78
	Carbon content (Kg)	22.5± 0.3	80.7	1	2.78
Salvadora	DBH (cm)	7.8± 0.5	15.1	9	2.78
	Carbon content (Kg)	19.0± 0.5	6.7	9	2.78
Sterculia	DBH (cm)	12.3± 0.9	13.2	22	2.78
	Carbon content (Kg)	54.8± 9.8	5.6	22	2.78
Terminalia	DBH (cm)	9.54±0.4	21.6	26	2.78
	Carbon content (Kg)	29.6±2.9	10.3	26	2.78

4.2 Significance of genus *Acacia* to carbon sequestration spectrum in Taita Ranch

Genus *Acacia* had 194 individual trees, with an average DBH of 12.5cm across the study area. On average *Acacia* species had approximately 158 kg biomass estimate approximated to 290kg of CO_2 potential release per individual over time it had lived (Table 4.6). Overall, genus *Acacia* generated approximately 9% of the total study area biomass estimates (Fig. 4.7)

Table 4.6: Summary of genus Acacia DBH averages, No. of tree, biomass and CO_2e

Tree Genus	Tree species	Ave. DBH (cm)	No. of trees	Total Biomass (Kg)	Biomass/ tree (Kg)	CO_2e	CO_2e /tree/yr.
Acacia	*Acacia bussei*	13	47	10,428	222	17,972	11
Acacia	*Acacia etbaica*	12	17	2883	170	4,969	8
Acacia	*Acacia hockii*	13	11	2098	191	3,616	9
Acacia	*Acacia mellifera*	14.6	2	415	207	715	10
Vachellia	*Vachellia nilotica*	10.9	56	7084	127	12,210	6
Vachellia	*Vachellia tortilis*	11.2	57	7147	125	12,318	6
	G. TOTAL	**12.45**	**190**	**30055**	**158**	**51,800**	8

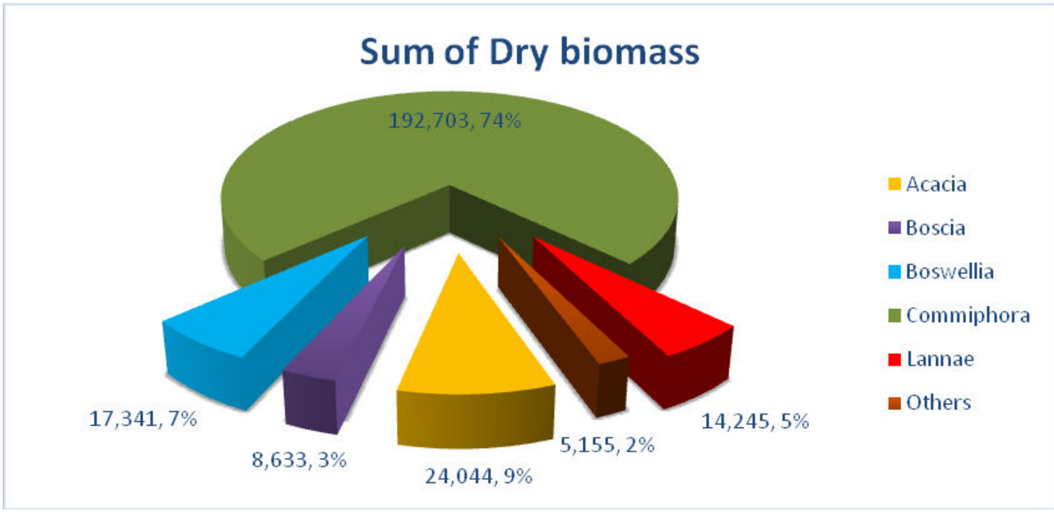

Figure 4.7: Proportion of biomass amongst tree genus in the study area

On average *Acacia* can potentially release 334.4 kg CO_2e and with the report done by wildlife works Kenya on Kasigau corridor that study area forest age is approximately 35yrs (Freund *et al.*, 2012),and with a mean of 13 cm DBH, then genus *Acacia* can release 9.6 kg of CO_2e per year if the same is harvested for charcoal production. Moreover, its preference to other species in dryland forest for charcoal production (Mutimba & Barasa, 2005) and as well as wood fuel makes it even more critical in carbon capture and release than any other tree genus. Genus *Commiphora* are also important in carbon capture and storage due to high tolerance and abundance than any other species but are not of concern in release of CO_2 since they are not harvested for charcoal production.

The study did not assess nutrient moderation by genus *Acacia* but it worth to note that it moderate nutrients in depleted soil possibly due to its association with rhizobia bacteria and mycorrhizae (Bercherm, 1994; Primack, 1993) where the neighbouring plant community may benefit from nitrogen fixing bacteria. Similarly, when parts of the trees die and decay, they fertilize the surrounding soil (Galiana *et al.*, 1998; Springuel & Mekki, 1993). On the poor sandy soils of arid areas in sub-Saharan Africa, this cycle can help improve the growth and yield of field crops(Hayward & Wales, 2004).This therefore means that elimination of acacias through selective harvest is likely to eliminate the nutrients components useful for vegetation in dryland forest. In this regard therefore, destruction of acacia will affect plant community that contributes in climate stabilization as plants regulate CO_2 concentration in the atmosphere through photosynthesis(Read *et al.*, 2009).

Acacia are referred as pioneer species since they can survive under harsh conditions and are able to colonize disturbed sites rapidly(Springuel & Mekki, 1993).The *Acacia* species naturally repairs depleted soils and therefore, offer great potential in areas of Africa where increasing population and livestock, together with a series of droughts, have led to deforestation and severe land degradation(Hayward & Wales, 2004).This therefore makes genus acacia key species in any REDD+ project conducted in arid and semi-arid areas for they are able to stabilize the microclimate, provide shade under which grass which is significant carbon sequestration spectrum and other undergrowth can grow and thus able to provide grass to livestock as well stabilize soil and prevent release of soil carbon(Bercherm, 1994; Primack, 1993).

The result indicate that there is no significance different on mean carbon content of genus *Acacia* against the other categories of trees (Table 4.7).This then suggest that Acacia species biomass falls within a range of the study area mean biomass despite low density compared to genus such *Commiphora* that dominated the study site.

Table 4.7: Significance testing for carbon content of genus Acacia verses non-Acacia

acacia vs non-acacia; LS Means Current effect: F(1, 2039)=.04260, p=.83651 Effective hypothesis decomposition						
	Acacia vs non-*acacia*	Carbon content (tbx0.5) - mean	Carbon content (tbx0.5) - Std. Err.	Carbon content (tbx0.5) - 95.00%	Carbon content (tbx0.5) +95.00%	n
1	*Acacia*	73.95752	7.602493	59.04806	88.86698	191
2	non-*Acacia*	75.60560	2.442794	70.81497	80.39623	1850

On the contrary, the overall contribution to per hectare mean biomass for genus *Acacia* was significantly low with ($t_{calculated} > t_{critical}$) (Table 4.8) thus rejecting the null hypothesis. The insignificance to the study area biomass is due to low density where it recorded to as low as eight species per hectare unlike other genus such as *Commiphora* that recorded to as high as 91 individual trees per hectare. The result suggest that, despite potential carbon capture potential by the genus, its low numbers makes it insignificant in carbon sequestration in Taita Ranch. The most likely reason for low numbers is selective harvest for charcoal production, wood fuel, building posts among other uses. This was evident with many *Acacia* stump observed in many plots within the study site.

Table 4.8: T-test analysis per hectare biomass against Acacia biomass

(One-way paired t-test, n=0.05)

All Groups T-test for Independent Samples where Variables were treated as independent samples								
	Mean - Group 1	Mean - Group 2	t-value	df	p	df	Std dev. Group 1	Std dev. Group 2
Total biomass (Mg/ha) vs. *Acacia* biomass	32.7652	1.1419	22.3696	18	0	12.0764	4.122	1.7303

4.3 Eco-Charcoal as a sustainable charcoal production system and impact on total biomass in the study area

The Eco-char biomass harvested ranged from 1669 kg to 1879 kg Biomass per hectare that approximated to an average of1801 kg ha^{-1}. The blocks exposed to 50% harvest had on average 3160 kg biomass while the blocks exposed to 25% harvest had 2100 kg approximated to 4.6% and 6.6% of the total biomass respectively. Overall, the eco-char biomass was 5.6% of the total study area biomass. The analysis exhibited no significant difference after harvest with $F_{(1, 12)}$= 0.02, P= 0.88969 at 95% confidence interval. Similarly, the analysis on the respective proportion at 25% and 50% harvest exhibited no significance difference as well with $F_{(1,12)}$=0.35. P= 0.3586 (Table 4.9). However, that reduction has some impact on area biomass to some extend and the burning of twigs is likely to release CO_2 and other GHGs to the atmosphere during carbonation process. Nonetheless, the impact is low compared if the whole tree or shrub was to be harvested for charcoal production whereas GHGs released to the atmosphere is likely to be countered by regeneration of harvested plants in the long term.

Table 4.9: Univariate test of significance, effect sizes and powers for total biomass against % of harvest

	DF	F	p	$P_{(eta)}^2$	NC	OP (alpha=0.05)
Intercept	1	101.3	0.000000	0.894097	101.31	1.000000
Biomass (B & A)	1	0.02	0.889694	0.001670	0.0201	0.051960
%Harvest	1	0.36	0.560432	0.029014	0.3586	0.085613
Biomass (B & A)*%Harvest	1	0.02	0.897714	0.001435	0.0172	0.051683
Error	12					

On average 1.8 Mg of biomass per hectare was generated from eco-char harvest and after carbonation, the char fines produced was approximately 30% of the total harvest. Between 300 and 400g of briquette were produced depending on manual force applied during compaction and probably the char tree species mixture composition whereby one briquette would have high density fines than others i.e. the char fine have different species composition with different densities. As aforementioned manual extruder was used in making briquette cakes and thus the pressure applied was not constant. Depending on force applied at a particular compaction and composition of char fine then will determine the weight of a briquette cake produced at particular time.

According to Mutimba & Barasa , (2005) annual per capita charcoal consumption is approximately 150 kg that translates to about 2.4 million tons, which means approximately 16 million Kenyans depends on charcoal as there source of energy as at 2005 (Mutimba & Barasa, 2005). According to Onekon and Kipchir (2016), 15,174 ha of forest cover are depleted every year in Kenya whereby 65% of this is attributed to charcoal consumption(Onekon & Kipchirchir, 2016).Given the fact that Kenya forest covers is only 3.3 million ha whereby 0.2 million ha are of dryland forest (FAO, 2010b) and if no sustainable systems are employed then it will take less than 15 years to clear an equivalent of dryland forest.

Any wood species can be carbonized for char, but the quality of charcoal varies with different species and the method used for carbonation. The study did harvest *A. bussei, A. nilotica, A. mellifera, A. etbaica, A. tortilis and A. hockii, Cordia sinesis, C. monaica, Combretum exaltatum, C. molle, Croton pseudopulchellis, Bourreria teitensis, Grewia species such as G. bicolor, G. mollis, G. similis, G. villosa, Ochna ovata* among the species with high density and calorific value that produced "quality" char. Author Mugo with others (2007) partly agreed with this observation especially on tree species that produced 'quality' charcoal that included; *Casuarina equisetifolia* (Coast oak, beach oak/casuarina), *A. Mearnsii* (black wattle), *A. Polyacantha* (white thorn*),and A. Xanthophloea* (fever tree)and other *Acacia* and *Combretum* species are some of the species that produce high 'quality' charcoal in terms density and calorific value (Mugo & Ong, 2006; Mugo *et al.*, 2007). Most *Acacia* species such as *A. tortilis* are widely used for charcoal production in Kenya(Mutimba & Barasa, 2005). This is attributed to its availability, especially in rangelands, and the production of high quality charcoal. *Acacia tortilis, A. nilotica, A. senegal, A. mellifera, A. polyacantha,* and *A. Xanthophloea* are the most widely used (38%) and preferred (45%). Other popular species include *Croton, Olea, Manilkara, Mangifera, Eucalyptus,* and *Euclea* (Mutimba & Barasa, 2005).

Apart from hard wood species such as *Maerua angolensis, Maerua crassifolia, Maerua decumbens, Maerua kirkii Maerua triphylla Maytenus mossambicensis Maytenus sp, Boscia* species due to long time it takes before it is fully carbonized, all other hard wood species and shrubs that are harvested, chopped and carbonated for eco-char. Similarly, soft wood trees such as genus *Commiphora, Boswellia sp., Lannea sp.,* among other were not harvested for char production since they very light and are converted into ash within a very short before hard wood species are fully carbonized thus were not appropriate with eco-char system of char production. This was evident when we tried to carbonate *Boscia coriacea* with the same temperature and duration it produced charcoal that were not fully carbonized.

Huge percentage of charcoal produced in Kenya are sourced from rangeland whereby production is mostly done using traditional inefficient technologies that waste between 85% and 90% of wood product in carbonation process(Liyama *et al.*, 2014). According to Government of Kenya through state ministry responsible for Energy (2002), the national wood fuel and charcoal usage per capita per year stands at 152kg (MoE, 2002). If this statistics is anything to go by 40% of charcoal coming from the range land that is only 6% of the forest cover in Kenya and with continued, unchecked forest resource exploitation where clearing of forest is done without replacement (MENR, 2013), then we are likely to lose the already limping ecosystem.

Eco-char system has a huge potential in meeting some of the energy demands at low cost. New and innovative models are needed for the large-scale production of wood fuel by rural communities in ways that are more economically attractive and ecologically sustainable and this, in turn, requires a different set of incentives for producers (Miranda *et al.*, 2012). All factors made constant then the approximate biomass of char produced is between 600kg and 700kg therefore the briquette produced per ha can take care of between four and five individuals energy need per year. This technology will mean, more forest destruction as the local population tries to meet the wood fuel demand. Eco-char is efficient technology that utilizes between 30% and 40% of wood for char. Similarly, eco-char system only harvest between 25% and 50% of the branches and therefore the plant remains standing and is able to regenerate.

According to author Read *et al* (2009), the management of such terrestrial forest carbon stocks can deliver a significant component to International climate change abatement strategies (Read *et al.*, 2009).Furthermore, the study observed regeneration after one month of harvest especially shrubs and young trees. Additionally, Pruning of branches is likely to reduce competition as was observed with sprouting grass in most of the blocks where harvesting was done. If the same is done in natural forest then it will spring vibrant healthy ecosystem and thus resilience of biodiversity.

The result indicated that the mean biomass after harvest at both 25% and 50% had no significance difference with (t calculated < t critical) thus the study does not reject the null hypothesis (Table 4.10). This then suggest that any harvest at below 50% does not reduce the total biomass of such ecosystem.

Table 4.10: T-test analysis on impact of harvest on total biomass

(One-way paired t-test t(critical 2.78), n=0.05)

T-test for Independent Samples where Variables were treated as independent samples

	Mean - Group 1	Mean - Group 2	t-value	df	p	Std dev. 1	Std dev.2
Total biomass (kg) vs. Biomass after harvest	39137.38	37003.00	0.895429	14	0.385695	4668.69	4863.849

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSSION

Nature will judge us severely if the population doesn't control their appetite in destroying the environment they need to survive. Despite uncontrolled harvest and extreme dry condition, the study area total biomass of 32.8 Mg ha^{-1} falls within savannah ecosystem biomass range of 9-88 Mg $ha^{-1}$and above the desert average. Similarly genus *Acacia* has low density in the study area despite high potential storage of significant carbon stock. On the other hand, eco-char production system is an example of green economy as it is likely to meet energy demand while taking into consideration ecological integrity and reducing environmental destruction.

5.1.1 Determining the level of carbon storage and release in the dryland forest in Taita Ranch

The study area had an average of 200 individual trees per hectare with 16 Mg of tree carbon per hectare that translates to 0.08 Mg C per a standing tree. On average one tree if harvested for charcoal will release approximately 283 kg CO_2e to the atmosphere. In comparison with savannah forest mean, the study area biomass is very low and it is majorly attributed by low density of hard wood species caused by selective harvest for charcoal and wood fuel.

5.1.2 Establish CO_2 release potential by genus acacia in dryland forest of Taita Ranch

Despite low density in the subject area, genus *Acacia* has high potential of releasing significant amount of carbon about 9 Kg CO_2e per year if they are allowed to be harvested for unsustainable charcoal production. The preference for charcoal production to other genus makes it even more critical in carbon sequestration spectrum. Genus

Commiphora species on the other hand are as well important in carbon sequestration due to high tolerance and dominance compared to other species. Nonetheless, they are not of major concern in release of CO_2 since they are not harvested for charcoal production.

5.1.3 Establishing the impacts of eco-char system harvest on dryland forest biomass in Taita Ranch

The unsustainable system of charcoal production such as lump char may meet the demand wood fuel and charcoal only for a short period of time and if it continues then in a few years to come, there will be no raw material for charcoal production. If the population and country cares about tomorrow then Eco-char system approach is the way to go as it takes into account ecosystem integrity as well as meeting the growing energy demand sustainably. Additionally, it is likely that pruning of trees and shrubs will re-ignite shoots growth within a short period of time and reduce competition in plant structures as well as plant community. If such management strategy is applied across the dryland, then it is likely to spring vibrant healthy ecosystem and thus resilience in biodiversity.

5.2 RECOMMENDATION

1. Pruning and thinning of natural forest should be used as a management tool for reducing competition and re-activating dormant carbon pool.
2. Genus Acacia has high carbon release potential and the study suggest that assessment on its status has to be done since the uncontrolled harvest of its species is likely endanger its survival especially in open access areas.
3. Establish a proper regulatory framework to sustainably manage wood fuel and charcoal industry thus deters negative impacts on dryland forest in Kenya.
4. Eco-char production system can be incorporated in REDD+ programs since it has proved to be sustainable in long run.

5. Further research to be conducted on temperature levels exposed to different tree species chopping during carbonation process and pressure applied when making briquettes from char fines.
6. Further research on nutrient moderation by genus *Acacia* in dryland forest
7. Further study to be conducted on post-harvest re-generation rate of various species and their potential in carbon sequestration.

REFERENCES

Abdi, O., Edinam, K. G.& Luukkanen, O. (2013). Causes and Impacts of Land Degradation and Desertification: Case Study of the Sudan. *International Journal of Agriculture and Forestry, 3*(2), 40-51. doi: 10.5923/j.ijaf.20130302.03

Amundson, R. (2001). The carbon budget in soils. . *Annual Review of Earth and Planetary Sciences . 29*, 535-562.

Angelsen, A., Brockhaus, M., M. Kanninen, M., Sills, E., Sunderlin W.D., & Wertz-Kanounnikoff, S. (eds) (2009). Realising REDD+. In A. Angelson (Ed.), *Realising REDD+ National strategy and policy options*. . Bogor, Indonesia.

Bailis, R. (2009). Modelling climate change mitigation from alternative methods of charcoal production in Kenya. *Biomass and Bioenergy,*(33), 1491-1502.

Baker, T.R., Phillips, O. L., Malhi, Y., Almeida, S., Arroyo, L., Di Fiore, A…,& Vásquez Martínez, R. (2004). Variation in wood density determines spatial patterns in Amazonian forest biomass. *Global Change Biology*(10), 545-562.

World Bank. (2007). Strategic Environmental Assessment of the Forests Act 2005. Nairobi: World Bank.

Bercherm, J. (1994). Acacia spp. in Aspect of traditional and potential Utilization of the Indigenous Vegetation of Northern East Africa 147-159.

Bio-News (Producer). (2015). Charcoal production methods. *Biomass News*. Retrieved from http://ukrfuel.com/news-charcoal-production-methods-24.htm

Broadmeadow, M. S. J.,& Mathews, R. W. (2003). *Forests, Carbon and Climate Change: the UK Contribution*. 231 Corstorphine; Road Edinburgh; EH12 7AT: Forestry commission Retrieved from http://www.forestry.gov.uk/.

Brouwer, R.& Falcao, M. P. (2004). Wood fuel consumption in Maputo, Mozambique. *Biomass Bioener, 27*(3), 233-245.

Brown, S. (1997). Estimating biomass and biomass change of tropical forests *A primer. FAO Forest Resources Assessment Publication 134*, 55.

Brown, S. (2002). Measuring carbon in forests: current status and future challenges. *Environmental Pollution* (116), 363-372.

Cairns, M. A., Brown, S., Helmer, E. H.& Baumgardner., G. A. (1997). Root biomass allocation in the world's upland forests. *Oecologia 111:1-11., 111*, 1-11.

Canadell, J. G.& Raupach, M. R. (2008). Managing forests for climate change mitigation. *Science* (320), 1456-1457.

Chakravarty, S. K., Ghosh, C. P., Suresh, A. N. D., & Shukla, G. (2012). Deforestation: Causes, Effects and Control Strategies; sustainable-forest-management/deforestation-causes-effects-and-control-strategies D. D. C. A. Okia (Ed.) *Global Perspectives on Sustainable Forest Management,* (pp. 300pgs). Retrieved from http://www.intechopen.com/books/globalperspectives

Chavan, B. L.,& Rasal, G. B. (2010). Sequestered Standing Carbon Stock in Selective Tree Species Grown in University Campus at Aurangabad, Maharashtra, India. *International Journal of Engineering Science and Technology*(2), 3003-3007.

Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D…, & Yamakura, T. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia, 145*(1), 87-89.

Chave, J., Olivier, J., Bongers, F., Chatelet, P., Forget, P. M., van der Meer, P…, & Charles-Dominique, P. (2008). Aboveground biomass and productivity in a rain forest of eastern South America. *Journal of Tropical Ecology* (24), 355-366.

Chave J., Maxime, R. M., Alberto B., Emmanuel C., Mathews C., Welington B. C…,& Vieilledent, G. (2014). Improved Allometric Models to Estimate the Above ground Biomass of Tropical trees. *Global change biology* (20), 3177-3190.

Cheamwongsa, P. (2010). *The Potential of Carbon dioxide Content on Above ground biomass in Eucalyptus Camaldulensis Dehnhn.* Master of Science (Appropriate Technology for Resources and Environmental Development), Mahidol Bangkok, Thailand.

Coe, M., & Beentje, H. (1991). A field guide to the Acacias of Kenya.

Crosby, M. K., Alice, F., Christopher, F., Charles, H., Elizabeth, H., Emily, M.,& Rosalind, V. (2010). Carbon Sequestration and its Relationship to Forest Management and Biomass Harvesting in Vermont *Environmental Studies Senior Seminar Winter*. Middlebury College: Middlebury College Environmental Studies.

DeWald, S., Josiah, S., & Erdkamp B. (2005). Heating With Wood: Producing, Harvesting and Processing Firewood. Retrieved from www.ianrpubs.unl.edu/ website: www.ianrpubs.unl.edu/

Dixon, R. K., Brown, S., Houghton, R. A., Solomon, A. M., Trexler, M. C., & Wisniewski, J. (1994). Carbon pools and flux of global forest ecosystems. *Science*(263), 185-190.

Dlugokencky, E. (2016). Annual Mean Carbon Dioxide Data *ESRL (Earth System Research Laboratory) National Oceanic & Atmospheric Administration.*

Dlugokencky, E., & Pieter, T. (2015). global greenhouse Gas Reference Network *ESRL (Earth System Research Laboratory)- Global Monitoring Division.* US: National Oceanic & Atmospheric Administration. .

Dodson, R. (2006). Mt. Kasigau Area Biodiversity Survey Report, 2006, details on this HCV area. *High Conservation Value Survey*. Rukinga Ranch Wildlife Works Kenya.

Eregae, J., Gichuhi, M. W., &Mwangi G. (2016). Quantification of carbon stock with common tree genus in Taita Ranch S E Kenya. *Jomokenyatta University of Agriculture and Technology II*(17).

ESMAP. (2012). Commercial Woodfuel Production. *Knowledge Series 012/12*.

Falcao, M. P. (2008). *Charcoal production and use in Mozambique, Malawi, Tanzania, and Zambia:*. Maputo, Mozambique.

FAO. (2001). Global Forest Resources Assessment 2000 *Main Report*. Rome: FAO.

FAO. (2005). Global Forest Resources Assessment 2005,Progress towards sustainable forest management. In S. Fennica (Ed.), (Vol. 147). Rome.

FAO. (2007). Forests and Energy. . Rome: Food and Agricultural Organization.

FAO. (2010a). Criteria and Indicators for Sustainable Forest Management. . Rome: Food and Agricultural Organization of the United Nations

FAO. (2010b). Global Forest Resources Assessment Country Report Kenya. *Global Forest Resources Assessment* Rome: Food and Agricultural Organization of the United Nations

FCPF. (2012). REDD Readiness Progress Fact Sheet Kenya. *REDD Readiness Progress Fact Sheet Kenya*. . Nairobi, Kenya: FOREST CARBON PARTNERSHIP FACILITY.

Forrest, J. (2003). EarthTrends Featured Topic: Protecting Ecosystems on a Changing Planet. Washington D.C.: World Resources Institute.

Freund, J., Korchinsky, M., & Dodson, R. (2012). Project Implementation Report (PIR) For Verification Using the Climate, Community and Biodiversity (CCB *The*

Kasigau Corridor REDD Project Phase II – The Community Ranches (2nd Edition ed.). Rukinga- Kenya: Wildlife Works Kenya.

Fritsche, U. R., Hennenberg K., Hünecke K., Thrän D., Witt J., Hennig C., & N., Rensberg. (2009). IEA Bioenergy Task 40: Country Report Germany. In IEA (Ed.), *IEA Bioenergy Program*. Paris.

Galiana, A., Gnahoua, G., Chaumont, J., Lesueur, D., prin, Y. , & Mallet, B. (1998). Improvement of nitrogen fixation in Acacia mangium through inoculation with Rhizobium. *Agro-Forestry System*(40), 297 – 307.

Githiomi, J. K., Kung'u, J. B., &Mugendi, D. N. (2012). Analysis of woodfuel supply and demand balance in Kiambu, Thika and Maragwa districts in central Kenya. *Journal of Horticulture and Forestry 4*(6), 103-110. doi: 10.5897/JHF12.003

Githiomi, J. K., & Oduor, N. (2012). Strategies for Sustainable Wood fuel Production in Kenya. *International Journal of Applied Science and Technology 2* (No. 10).

GOK. (2002). *Maragwa District Development Plan 2002-2008: Effective Management for Sustainable Economic Growth and Poverty Reduction.* Nairobi- Kenya: Government Printers.

GOK. (2010). *Kenya Constitution 2010*. Nairobi: Government printers.

Grace, J. (2004). Understanding and managing the global carbon cycle. *Journal of Ecology 92*, 189-202.

Grace, J., San José, J., Meir, P., Miranda, H. S., & Montes, R. A. (2006). Productivity and carbon fluxes of tropical savannas. *Journal of Biogeography, 33*, 33, 387-400.

GTOS. (2009). Assessment of the status of the development of the standards for the terrestrial essential climate variables. . *NRL, FAO-Rome*, 18.

GTZ. (2007). *Eastern Africa Resource Base.* Regional and Country Specific Energy Resource Database: GTZ-Energy Resource.

Guy, R. (1989). The influence of elephants and fire on a Brachystegia. *Tropical Ecology 5*(2), 215–226.

Hanski, I. (2005). The shrinking world: Ecological consequences of habitat loss. . *International Ecology Institute*.

Harsh, J. & Schnabel, A. (2000). *Population Genetic Structure of Acacia Brevispica from East Africa*. Department of Biology. Indiana University. Indiana University.

Hayward, B.,& Wales, Z. (2004). *Acacia tree; A sustainable Resource for Africa*. UK: Rowes The Printer Penzance.

Hill, M. O. (1973). Diversity and Evenness: A Unifying Notation and Its Consequences. *Ecology 54*(2).

HubPages, & Hubbers. (2016). How to Make Fuel Briquettes – Charcoal Dust – Carbonization and Pyrolysis of Biomass. *Renewable and Alternative energy*. Retrieved from

Husch, B., Beers, T. W., &Kershaw, J. A. (Jnr.) . (2003). Forest measurement, 4th edition. *Wiley, Hoboken*, p443.

ICRAF. (2009). Unique Acacia Tree's Promise To Revive African Soils., *Science Daily*. Retrieved from www.sciencedaily.com/releases/2009/08/090824182535.htm

IPCC. (2001). Climate Change 2001:Impacts, Adaptation, and Vulnerability *Contribution of Working Group II to the 3rd Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge and New York.

IPCC. (2003). Intergovernmental Panel on Climate Change. Good Practice Guidance for Land Use, Land-Use Change and Forestry.

IPCC. (2006). Default biomass conversion and expansion factors. . In I. G. f. N. G. G. Inventories (Ed.), *Agriculture, Forestry and Other Land Use, Intergovernmental Panel on Climate Change.* (Vol. 4). Japan: IPCC.

IPCC. (2007). Climate Change 2007:Synthesis Report. . In R. K. Pachauri & A. Reisinger (Eds.), *Contribution of Working Groups I, II and III to the Fourth Assessment Report of the IntergovernmentalPanel on Climate Change.* IPCC: Geneva, Switzerland.

IUCN. (2011). IUCN Red List of Threatened Species. .

Jalkanena, A., Mäkipääb, R., Ståhlc, G., Lehtonenb, A., &Petersson, H. (2005). Estimation of the biomass stock of trees in Sweden: comparison of biomass equations and age-dependent biomass expansion factors. *62*(8), 845-851. Retrieved from doi:10.1051/forest:2005075

Johnson, I. & Coburn, R. (2010). *Trees for carbon sequestration*. State of New South Wales: Primefact 981 Retrieved from www.dpi.nsw.gov.au/primefacts.

Kakuru, W. (2010). A study of Timber, Charcoal and Fuel Wood value chains in the districts of Mubende, Kyenjojo and Kyegegwa in Western Uganda. . *CARE international.*

Kambewa, P., Mataya, B., Sichinga, K.,& Johnson, T. (2007). Charcoal: the reality – A study of charcoal consumption, trade and production in Malawi. Small and Medium Forestry Enterprise Series. *International Institute for Environment and Development, London, UK.*(No. 21).

Kelly, L. (2007). *Protecting Biodiversity in a Changing Climate: The State of Adaptation Policies Dedicated to Enhancing the Resiliency of Biota*. Paper presented at the Proceedings of the 2007 George Wright Society Conference Yale School of Forestry and Environmental Studies, 75 St. Alphonsus Street,Apartment 1606, Boston, MA 02120.

KFS. (2010a). *National REDD Readiness Preparation Proposal (R-PP)* Paper presented at the National REDD Readiness Preparation Proposal (R-PP)-Validation Workshop,. , Kenya School of Monetary Studies.

KFS. (2010b). *Revised REDD Readiness Preparation Proposal. Kenya. Submitted to the Forest Carbon Partnership Facility. October 2012.* . Nairobi: government Printers.

Kindermann, G. E., McCallum, I., Fritz, S., &Obersteiner, M. (2008). A Global Forest Growing Stock, Biomass and Carbon Map Based on FAO Statistics. *Silva Fennica 4, 42*(3), 387–396.

Kituyi, E. (2008). *Policy Proposal for Sustainable Consumption and Production of Energy in Kenya:* . Nairobi- Kenya: A Memorandum to the National Environment Policy Committee.

Korchinsky, M., Freud, J., &Jessie, P. (2011a). The Kasigau Corridor REDD Project Phase I In M. Korchinsky (Ed.), *Rukinga Sanctuary Project Document (PD*. Rukinga- Kenya: Wildlife Works.

Korchinsky, Jeremy Freund, Lara Cowan, & Rob Dodson. (2011b). Wildlife Works Carbon CCB PDD - Phase II *The Kasigau Corridor REDD Project Community Ranches* (pp. 11). Rukinga- Kenya: Wildlife Works Kenya.

Kort, J., & Turnock, B. (1999). Carbon reservoir and biomass in Canadian prairie shelterbelts, Agroforestry Systems. (44), 175-186.

Lal, R. (2005). Forest soils and carbon sequestration. *Forest Ecology and Management,*(220), pp 242-258.

Larjavaara, M., & Muller, H. C. (2013). Measuring tree height: a quantitative comparison of two common field methods in a moist tropical forest. *Methods in Ecology and Evolution* (4), 793-801.

Leadley, P. W., Pereira H. M., Alkemade R., Fernandez-Manjarrés J. F., Proença V., Scharlemann J.P. W., &Walpole M. (2010). *Projections of 21st century change in biodiversity and associated ecosystem services.* Paper presented at the Secretariat of the Convention on Biological Diversity, Montreal Canada.

Lewis, G. (2005). 'Tribe Acacieae: Legumes of the world. *Research gate*, 187-192.

Liyama, M., Neufeldt, H., Dobie, P., Njenga, M., Ndegwa, G., & Ramni, J. (2014). The potential of agroforestry in the provision of sustainable woodfuel in sub-Saharan Africa. *Elsevier Limited, 6*, 138-147.

Lovejoy, T. E.,& Hannah, L. J. (2005). Climate Change and Biodiversity. . *New Haven,Convention: Yale University Press.*

Luoga, E. J., Witkowski, E. T. R., & Balkwill, K. (2000). Economics of charcoal production in miombo woodlands of eastern Tanzania: some hidden costs associated with commercialization of the resources. *Ecological Economics, 35*(2), 243-257.

Luyssaert, S., Inglima, I., Jung, M., Richardson, A. D., Reichsteins, M., Papale, D…, & Janssens, I. A. (2007). CO_2 balance of boreal, temperate, and tropical forests derived from a global database. . *Global Change Biology* (13), 2509-2537.

MA. (2005). Millenium Ecosystem assessment.Ecosystem and Human well being: . *Desertification synthesis*.

Macharia, P. N., & Ekaya, W. N. (2005). The Impact of Rangeland Condition and Trend to the Grazing Resources of a Semi-arid Environment in Kenya. *Journal of Hum. Ecology 17*(2), 143-147.

Malhi, Y., Wood, D., Baker, T. R., Wright, J., Phillips, O. L., Cochrane, T…, & Vinceti, B. . (2006). The regional variation of aboveground live biomass in old-growth Amazonian forests. . *Global Change Biology* (12), 1107-1138.

Marshall, D. J., Philip J. P., Roy, E. G., Kindeketa, W., Kang'ethe, S., & Marchant, R. (2012). The genus Acacia (Fabaceae) in East Africa:distribution, diversity and the protected area network. *Plant Ecology and Evolution 145*(3), 289-301.

Matthews, S. P., Payne, R., Rohweder, M., &Murray, S. (2000). Forest ecosystem carbon storage sequestration and carbon sequestration in Soil. *Global Climatic Change Digest, 12*(2).

Mbow, C., Smith, P., Skole, D., Duguma, L., &Mercedes, B. (2015). Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in Africa. *Science Direct*(6), 8–14.

MENR. (2013). Analysis of the Charcoal Value Chain in Kenya (KFS, Trans.). In N. R. coordinator (Ed.), *Final report on charcoal value chain*. Nairobi.

Miranda, R. C., Steve, S., &Eliane, C. (2012). Best forestry practices for sustainable production of commercial woodfuels. In M. Owen. (Ed.), *Knowledge Series 012/12*. NW | Washington DC 20433 | USA: World bank ESMAP- Energy Sector Management Assistance Program.

MoE. (2002). Study on Kenya's Energy Demand, Supply and Policy Strategy for Households, Small Scale Industries and Service Establishments. . In K. C. Ltd. (Ed.), *Final Report for the Ministry of Energy*. Nairobi- Kenya: Ministry of Energy.

GOK-MoP. (2008). *Kenya Vision 2030*. Nairobi: Government Printers.

GOK- MoP. (2009). *Kenyan Census Report*. Nairobi: Government Printers.

Mugo, F., & Ong, C. (2006). Lessons of eastern Africa's unsustainable charcoal trade. *ICRAF Working Paper no. 20. World Agroforestry Center, Nairobi, Kenya*.

Mugo, F., Nungo, R., Odongo, F., Chavangi, N.,& Abaru, M. (2007). An assessment of the energy saving potential and heat loss pattern in fireless cooking for selected commonly foods in Kenya. . *CARPA Working Paper series,* (No.2).

Mutimba, S., & Barasa, M. (2005). National charcoal survey: Summary report. Exploring the potential for a sustainable charcoal industry in Kenya *Energy for Sustainable Development Africa (ESDA)*. Nairobi, Kenya ESDA.

Mwambeo, H. M., & Maitho, T. (2015). Factors Influencing Elephants to Destroy Forest; Acase of Ngare Ndare Forets in Meru County. *Ethiopian Journal of Environmental Studies & Management, 8*(4), 398-407.

Nahayo, A., Ekise, I., & Mukarugwiza, A. (2013). Comparative Study on Charcoal Yield Produced by Traditional and Improved Kilns: A Case Study of Nyaruguru and Nyamagabe Districts in Southern Province of Rwanda. *Energy and Environment Research, 3*(1). doi: 10.5539/eer.v3n1p40

Najma, D. (2006). Field Guide to Acacias of East Africa

New, T. R. (1984). A biology of Acacias.

Newton, A. C. (2015). Biodiversity Risks of Adopting Resilience as a Policy Goal. *Society for Conservation Biology*, 1-8. doi: 10.1111/conl.12227

Newton, A. C., Barnes R. D, & Timberlake J. (2003). Acacia handbook *Acacia handbook CBC Publishing,*

Oke, D., & Olatiilu, A. (2011). Carbon Storage in Agroecosystems: A Case Study of the Cocoa Based Agroforestry in Ogbese Forest Reserve, Ekiti State, Nigeria *Journal of Environmental Protection*(2), 1069-1075.

Onekon, W. A., & Kipchirchir, K. O. (2016). Assessing the effect of charcoal production and use on transition to green economy in Kenya *Tropical and Subtropical Agroecosystems,*(19), 327-335.

Pacala, S. W., & Socolow, R. H. (2004). Stabilization wedges-solving the climate problem for the next 50 years with current technologies: . *Science, 305*, p. 968-972.

Parmesan, C., Duarte, C. M., Poloczanska, E., Richardson, A. J., &Singer, M. C. (2011). Overstretching attribu2tion. *Nature Climate Change*.

Pereira, H. M., Leadley, P. W., Proença, V., Alkemade, R., Scharlemann, J. P, Fernandez-Manjarrés, J. F…, &Walpole, M. (2010). Scenarios for global biodiversity in the 21st century. *Science, 330*(6010), 1496-1501.

Pragasan, A., & Karthick, A. (2013). Carbon Stock Sequestered by tree plantations in University campus at Coimbatore, India. *International Journal of Environmental Science, 3*(5).

Pratt, D. J., & Gwynne, M. D. (1977). Rangeland management and ecology in East Africa. London, Hodder & Stoughton. *London, Hodder & Stoughton.*

Primack, R. B. (1993). Essentials of Conservation Biology *Sinauer Associates: Massachusetts.*

Read, D. J., Freer-Smith, P. H., Morison, J. I. L., Hanley, N., West, C. C., & (eds.), Snowdon, P. (2009). Combating climate change – a role for UK forests. An assessment of the potential of the UK's trees and woodlands to mitigate and adapt to climate change. In T. S. Office (Ed.), *The Synthesis Report*. Edinburgh: National Assessment of UK Forestry and Climate Change Steering Group

Ribeiro, N. S., Shugart, H. H., &Washington-Allen, R. (2008). The effects of fire and elephants on species composition and structure of the Niassa Reserve, northern Mozambique. *Forest Ecology and Management, 255* (5-6), 1626–1636.

Robards, T. A. (2009). Empirical Forest Growth Model Evaluations and Development of Climate-Sensitive Hybrid Models. University of California, . *University of California, Berkeley, Berkeley*, 234.

Ross, J. H. (1981). An analysis of the African Acacia species: their distribution, possible origins and relationships. *Bothalia, 13*(3 & 4), 389-413.

Santantonio, D., Hermann R. K., & Overton, W.S. (1997). Root biomass studies in forest ecosystems. *Pedobiologia 17*, 1-31.

Schlesinger, W. H. (1997). An Analysis of Global Change. In A. Press (Ed.), *Biogeochemistry*. San Diego: Academic Press.

Scurlock, J. M.,& Hall, D. O. (1998). The global carbon sink: a grassland perspective. . *Global Change Biology* .(4), 229-233.

Simpson, H. E. (1949). Measurement of Diversity. *Nature 163*(688). doi: doi:10.1038/163688a0

Sinclair, A. R. E., Hopcraft, J.G.C., Olff, H., Mduma S., Galvin K. A., & Sharam, G. J. (2008). Historical and future changes to the Serengeti ecosystem. . *Human Impacts on Ecosystem Dynamics*, 7-46.

Slik, J. W. F., Shin-Ichiro, A., Brearley, F. Q., Cannon, C. H., Forshed, O., Kitayama, K…, &Johan van, V. (2010). Environmental correlates of tree biomass, basal area, wood specific gravity and stem density gradients in Borneo's tropical forests. *Global Ecology and Biogeography,*(19), 50–60.

Springuel, I. V., & Mekki, A. M. (1993). Economic Value of Desert Plants. 1. Acacia Trees in Wadi Allaqi Conservation Area. *Allaqi Project Working Paper* (20).

Srivastava, S. C., McIlvried, H., Vikara, D., Carr, T., Wielopolski, L., & Katherine, G. (2010). Best Practice Terrestrial Sequestration of Carbon Dioxide. In Rattan Lal (Ed.), *Terrestrial Sequestration of Carbon Dioxide*. Albany: U.S Department of Energyy.

Stone, G., Willmer, P., &Nee, S. (1996). Daily Partioning of Pollinators in an African Acacia Community. *Proceedngs of Royal Society of London, B*(263), 1389-1393.

Sukhdev, P., Bishop, J., Brink, P. T., Gundimeda, H., Karousakis, K., Kumar, P…, &Heidi, W. (2008). TEEB (2008) An Interim Report. European Communities. *TEEB*.

TEEB. (2010). The Economics of Ecosystem and Bioversity: Mainstreaming the Economics of Nature: a Synthesis of the approach, Conclussion and Recommendation *Economics of Ecosystem and Biodiversity*. Nairobi- Kenya: UNEP.

Theuri, K. (2002). Woodfuel Policy and Legislation in Kenya; a paper presented during the Regional Workshop on Woodfuel Policy and Legislation held in ICRAF. P. 6.

Trumper, K., Bertzky, M., Dickson, B., van der Heijden, G., Jenkins, M., &Manning, P. J. (2009). The Natural Fix? The role of ecosystems in climate mitigation. . In UNEP (Ed.), *Rapid response assessment. United Nations Environment Programme*. Cambridge, UK: UNEP WCMC.

Trumper, K., Ravilious, C., &Barney, D. (2008). Carbon in Drylands: Desertification, Climate Change and Carbon Finance. In U.-W. f. UNEP (Ed.), *Technical Note Discussion*. Turkey: UNEP.

Tuomisto, H. (2010). A diversity of beta diversities: straightening up a concept gone awry. Part 2. Quantifying beta diversity and related phenomena. *Ecography*.

UNEP. (2006). Africa Evironment Outlook 2. Nairobi- Kenya: United Nation Environmental programs

UNFCCC. (1998). Kyoto Protocol to the United Nations Framework Convention on Climate Change *Convention on Climate Change*. Kyoto.

UNFCCC. (2006). United Nations Framework Convention on Climate Change (UNFCC), 2015, from http://unfcc.int/resource/docs/convkp/conveng.pdf

UNFCCC. (2008). Report of the Conference of the Parties on its thirteenth session, held in Bali from 3 to 15 December 2007 *Conference of Parties*. Bali: UNFCCC.

Vaughan, A. (2015). Global carbon dioxide levels break 400ppm milestone, *The Guardian.*

Walubengo, D., & Kinyanjui, M. (2010). Investing in Locally Controlled Forestry. . *Kenya Background Paper.*

Webb, E. K., Pearman, G. I., &Leuning, R. (1992). Correction of flux measurements for density effects due to heat and water vapour transfer. *Quarterly Journal of the Royal Meteorological Society,*(106), pp 85-106.

Whitmarsh, J. & Govindjee. (1999). The Basic Photosynthetic Process. In Singhal G. S., Renger G., Sopory S. K., Irrgang K. D. & Govindjee (Eds.), Concepts in Photobiology: Photosynthesis and Photomorphogenesis. (pp. p. 13). Boston: Kluwer Academic Publishers.

Wijaya, A. S. (2013). *Climate Change, Global Warming and Global Inequity in Developed and Developing Countries (Analytical Perspective, Issue, Problem and Solution).* Paper presented at the InternationalConferencesonGeological,Geographical,AerospaceandEarthSciences, Townsville, Queensland, Australia.

Williams, M., Hill, T. C., Ryan, C. M., &Karthick, A. (2012). Using biomass distributions to determine probability and intensity of tropical forest disturbance. *Plant Ecology & Diversity, 6*(1), 87-99.

Xu, Y., Zhang, J., Franklin, S. B., Liang, J., Ding, P., Luo, Y…, & Jiang., M. (2015). Improving allometry models to estimate the above- and belowground biomass of subtropical forest, China. *Ecosphere, 6*(12), 289. doi: http://dx.doi.org/10.1890/ES15-00198.1

Zummoa, L. M., & Friedland, A. J. (2011). Soil carbon release along a gradient of physical disturbance in a harvested northern hardwood forest. *Forest Ecology and Management,*, *261*(6), 1016-1026. doi: http://dx.doi.org/10.1016/j.foreco.2010.12.022

APPENDICES

APPENDIX I: Table for summary of AGB, total biomass, total CO_2 and CO_2/tree/yr.

Tree species	Tree No.	Above ground Biomass(Kg)	Total Biomass (Kg)	Total CO_2(Kg)	CO_2 per tree (Kg)	CO_2 /tree/yr. (Kg)
Acacia bussei	47	8,342	10,428	19,135	407	11.6
Acacia etbaica	17	2,307	2,883	5,291	311	8.9
Acacia hockii	11	1,678	2,098	3,850	350	10.0
Acacia mellifera	2	332	415	761	381	10.9
Acacia nilotica	56	5,667	7,084	13000	232	6.6
Acacia tortilis	57	5,718	7,147	13,115	230	6.6
Albizia anthelmintica	1	158	198	363	363	10.4
Balanites aegyptiaca	1	64	80	147	147	4.2
Boscia coriacea	180	8,633	10,791	19,801	110	3.1
Boswellia neglecta	251	17,341	21,677	39,777	159	4.5
Cassia abbreviata	1	148	185	340	340	9.7
Commiphora africana	50	5,543	6,929	12,714	254	7.3
Commiphora campestris	400	139,438	174,297	319,835	800	22.8

Commiphora confusa	485	47,710	59,638	109,436	226	6.4
Commiphora edulis	1	12	15	28	28	0.8
Lannea alata	352	12,109	15,137	27,776	79	2.3
Lannea rivae	14	619	774	1,420	101	2.9
Lannea schweinfurthii	18	1,516	1,896	3,478	193	5.5
Manilkara mochisia	7	486	607	1,114	159	4.5
Manilkara sulcata	3	350	437	802	268	7.6
Ormocarpum kirkii	2	76	96	175	88	2.5
Salvadora persica	10	324	405	743	74	2.1
Sterculia africana	23	2,144	2,680	4,918	214	6.1
Terminalia spinosa	26	1,360	1,701	3,121	120	3.4
Zanthoxylum chalybeum	1	45	56	102	102	2.9
Grand Total	2016	262,121	327,652	601,241	298	8.5

APPENDIX II: Table for standard stem weight for dominant shrubs in Taita Ranches

Shrub species	Size class (S/M/L)	Crown diameter range	Crown height range	Average stem diameter	Standard weight (Kg)
Cordia sinesis	S				3
	M				15
	L				33
Grewia Sp.	S	<1m	<1m		1.5
	M	>1<2m	>1m<2m		4.3
	L	>2m	>2m		9
Acacia ruficiens	S			5	23
	M			9	43
	L			12	131

Source: Wildlife Works Kenya (2015