Sokoine University of Agriculture

MSc. Dissertation

Deadwood Carbon Stock and Stand Structure Characteristics in Different Vegetation Types in Tanzania

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DEADWOOD CARBON STOCK AND STAND STRUCTURE CHARACTERISTICS IN DIFFERENT VEGETATION TYPES IN TANZANIA

This dissertation is submitted in fulfilment of the requirements for the Master Degree of Science in Ecosystem Science and Management to Sokoine University of Agriculture, Morogoro

by

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EXTENDED ABSTRACT

Deadwood is an important element playing an essential role in the maintenance of biodiversity, soil fertility and carbon sequestration. The amount of carbon stored in standing dead trees and other fallen woody debris alive or dead forms an important component of the carbon pools. Previous studies have estimated total carbon stocks for different land cover classes but they did not segregate deadwood in estimating carbon and none had considered levels of uncertainty estimates and the state of the woody decay. Also, there are limited information on stand structure of deadwood and how it is related to deadwood biomass. This study aimed to quantify deadwood carbon stocks in different vegetation types, the relationship between deadwood species structural diversity and deadwood carbon stock along different environmental variables. The study used dataset from National Forestry Resources Monitoring and Assessment of Tanzania (NAFORMA). The study revealed that solid deadwoods had higher carbon stocks and emission factor than rotten deadwoods whereby the estimated deadwood carbon stock ranges from 0.11 to 1.01 tC ha^{-1}, contributing 0.79% of the total carbon from different vegetation types. Compared to other vegetation types, forests and woodlands had higher deadwood carbon stocks and emission factor while grasslands had the lowest. Species abundance and soil moisture were positively significant related to deadwood carbon, with the highest effect shown by soil moisture while species richness and soil organic carbon had a negative significant relationship with deadwood carbon. In lowland forest, deadwood carbon stock of *Brachystegia sp.-Pterocarpus angolensis* (BP) community was positively significant influenced by soil moisture while in woodlands, deadwood carbon stock for *Julbernardia globiflora-Pterocarpus angolensis* (JP) community was negatively significant influenced by soil organic carbon and deadwood carbon stock of *Dalbergia melanoxylon-Pteleopsis myrtifolia* (DP) community was positively significant influenced by soil moisture. Understanding how deadwood carbon and stand structure of deadwood interact with environmental conditions contributes to the understanding of forests and woodlands carbon dynamics. Therefore, this study provides valuable insights for policymaking related to climate change mitigation, carbon accounting and effective biodiversity conservation in tropical ecosystems.

IKISIRI KUU

Mbao ozo ni nyenzo muhimu katika kuhifadhi bayoanuwai, rutuba ya udongo na kutunza kaboni. Kiasi cha kaboni kilichohifadhiwa kwenye mbao ozo zilizosimama na vipande vingine vya mbao ozo zilizoanguka hai au zilizokufa, vinatengeneza sehemu muhimu ya hifadhi za kaboni. Tafiti zilizopita zimekadiria jumla ya wastani wa hisa za kaboni kwa aina mbalimbali za uoto, lakini hazikutenganisha mbao ozo wakati wa kutafuta kiwango cha kaboni na pia hazikuzingatia viwango vya makadirio ya kutokuwa na uhakika wa hali ya mbao ozo. Pia, hakuna taarifa za kutosha kuhusu muundo wa mbao ozo na jinsi inavyohusiana na kaboni. Lengo la utafiti huu ni kutathmini kiasi cha kaboni cha mbao ozo katika aina mbalimbali za uoto na kutambua uhusiano uliopo kati ya miundo ya mbao ozo na kiwango cha hisa za kaboni kwa kuzingatia viashiria tofauti tofauti vya mazingira. Matokeo yalionyesha kuwa, mbao ozo zilizokufa zilikuwa na kaboni nyingi kuliko mbao ozo zilizooza. Ambapo kiasi cha kaboni ya mbao ozo imechangia asilimia 0.79 ya jumla ya kaboni kutoka kwenye aina mbalimbali za uoto. Ukilinganisha na aina nyingine za uoto, mifumo ikolojia ya misitu na maeneo ya uwanda wa miti ilikuwa na viwango vya juu vya kaboni wakati maeneo ya uoto wa nyasi yalikuwa na viwango vidogo. Pia, katika mifumo ikolojia ya misitu na maeneo ya uwanda wa miti, wingi wa mimea na unyevu wa udongo vimeonyeshwa kuwa na mahusiano chanya na kaboni ya mbao ozo, wakati kaboni ya udongo ilikuwa na uhusiano hasi na kaboni ya mbao ozo. Aidha, matokeo yalionyesha kuwa ikolojia ya misitu, jumuiya ya *Brachystegia sp.-Pterocarpus angolensis* (BP) imekua na mahusiano chanya na unyevu wa udongo. Katika maeneo ya uwanda wa miti, jumuiya ya *Julbernardia globiflora-Pterocarpus angolensis* (JP) imehusiana hasi na kaboni hai ya udongo wakati jumuiya ya *Dalbergia melanoxylon-Pteleopsis myrtifolia* (DP) iliathiriwa chanya na unyevu wa udongo. Ufahamu wa jinsi miundo ya mbao ozo inavyohusiana na tabia za mazingira huchangia kwenye uelewa wa mienendo ya kaboni ya mifumo ikolojia ya misitu na maeneo ya uwanda wa miti. Utafiti huu utasaidia katika kuandaa miongozo sahihi ya uundaji wa sera zinazohusiana na mabadiliko ya tabianchi, takwimu za kaboni na uhifadhi bora wa bioanuwai katika mifumo ikolojia ya kitropiki.

DECLARATION

I, **SARAFINA N. MASANJA**, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

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Sarafina N. Masanja Date
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The above is confirmed by;

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Dr. Deo D. Shirima Date
(Supervisor)

________________________ ____________________

Prof. Eliakimu M. Zahabu Date
(Supervisor)

LIST OF MANUSCRIPTS

Manuscript 1: Estimating emissions and uncertainty of deadwood carbon pool in tropical dry forests and woodlands

Manuscript 2: Relationship between species diversity, community composition and deadwood carbon stock along different environmental variables.

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I would like to express my gratitude to my supervisors, Dr. Deo D. Shirima and Prof. Eliakimu M. Zahabu, for their enthusiastic support and guidance throughout the research project. They taught me the research methodology and helped me to present my work clearly. I am honored to have worked under their guidance and thank them for their friendship, empathy, and sense of humor. I appreciate their constructive feedback and comments and have learned a great deal from them.

I would also like to extend thanks to the Tanzania Forest Service for granting permission to utilize deadwood NAFORMA data in this study.

My deepest gratitude goes to Kaka Gasper Mkenda and my other friends, for their prayers, encouragement, moral support, and sacrifices for educating and preparing me for my future. You have always special place in my heart. Thank you all so much.

DEDICATION

I would like to dedicate this work to my mother (Lucia), my father (Ndali) and my siblings (Sharon and Brighton). I am proud to call you all my family, and even happier being your daughter. Thank you all for your prayers, love and wisdom.

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LIST OF ABBRIVIATIONS, ACRONYMS AND SYMBOLS

REDD+	–	Reducing Emissions from Deforestation and Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks
EF	–	Emission Factor
IPCC	–	Intergovernmental Panel on Climate Change
NAFORMA	–	National Forestry Resources Monitoring and Assessment
NFI	–	National Forest Inventory
SIVI	–	Species Importance Value Index
VIF	–	Variance Inflation Factor
IV	–	Indicator Value

CHAPTER 1

1.0 GENERAL INTRODUCTION

1.1 Background Information

Terrestrial ecosystems especially forests play a major role in the carbon cycle and constitute a significant part of the world's carbon stocks (Pfeifer et al., 2015). Forests accumulate and store large amounts of carbon and a substantial fraction of this stock is contained in deadwood (Tláskal et al., 2021). Deadwood stores about 8% of the global forest carbon stock and 8.5% of atmospheric carbon (Pan et al., 2011).

Various approaches have been used to quantify the amount and dynamics of forest deadwood i.e., deadwood structure and decay stages (Bauhus et al., 2018; Garbarino et al., 2015; Russell et al., 2015). Monitoring terrestrial carbon storage in different land cover types is crucial due to growing concerns of tropical deforestation and how it contributes to rising atmospheric concentrations of greenhouse gases (Glenday, 2008).

Tanzania is one among rich countries in East Africa in terms of natural resources and biodiversity comprising of different vegetation types (Newmark and Newmark, 2002). In terms of land cover, woodlands occupy 44.7 million ha or 93.0% of the total forest area or 50.6% of mainland Tanzania while forests (forests here collectively refer to lowland forests, montane forests, mangroves and plantations) occupy 3.5%, bushland and grassland 16.6% and cultivated land 25.2% (MNRT 2015).

Among the five carbon pools which are, above ground biomass, below ground biomass, deadwood, soil and litter, the amount of carbon stored in deadwood is recognized by the Intergovernmental Panel on Climate Change (IPCC) that needed to be quantified and monitored for carbon accounting (Takahashi et al., 2010). Accurate accounting of these pools is essential for mitigation, such as through REDD+, Reducing Emissions from Deforestation and Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks (Pfeifer et al., 2015).

Deadwood plays a broad range of important ecosystem processes and key functions in forests and woodlands (Garbarino et al., 2015). They provide resources and habitats for a wide range of plant, fungi, insects and animal species (Brockerhoff et al., 2017), facilitate plant regeneration (Dittrich et al., 2014) and store nutrients and carbon (Godoy et al., 2012). In forest and woodland ecosystem, key elements of deadwood are standing and downed deadwood (Marzano et al., 2013).

Decomposition of deadwood plays a distinguishing role in determining the distribution of carbon pools and fluxes in different forested ecosystems and also contribute to carbon emissions from forests (Joshi and Singh, 2020). The extent of this contribution is determined by the fluctuation in dead wood decomposition rate owing to various factors such as forest type and age (Pregitzer and Euskirchen, 2004), topography affecting tree mortality (Clark et al., 2002), climate (Mazziotta et al., 2014), micro-organisms such as fungi and bacteria (Tláskal et al., 2021), land use history and management of an area (Eaton and Lawrence, 2006) and the forest's tree species composition (Kahl and Bauhus, 2014).

Emission factor refers to the carbon density, as it is the amount of carbon emitted from the forest per unit area (Ravindranath and Ostwald, 2008). To estimate carbon stock changes and greenhouse gas emissions, emission or removal factors (EF) resulting from land cover classifications like forests are needed (Pearson et al., 2014), to account for emissions or removals of carbon dioxide (Verchot et al., 2012) from and to forests and woodlands.

Deadwoods serves as a significant source of carbon and long-lived carbon pool (Joshi and Singh, 2020). The dynamics of climate, natural and human disturbance in woodlands and forests play significant roles in carbon stocks and sequestration. Understanding deadwood carbon and associated factors of changes will be central to predictions of changes and address climate change mitigation efforts (Garbarino et al., 2015). Since, plant species differ in their ability to capture, store and release carbon, the collective functional characteristics of plant communities (functional diversity) can also be a major driver of carbon accumulation in these ecosystems (Conti and Díaz, 2013). Therefore, this study will quantify deadwood carbon stocks and factors influencing deadwood carbon stock across different vegetation types of Tanzania mainland.

1.2 Problem Statement and Study Justification

Although there has been a global initiative to quantify dead wood biomass (Russell et al., 2015), but there are still perceptions that deadwood is less significant resources in the ecosystems especially in the tropical countries (Merganičová et al., 2012). These resources were regarded as wasteful in the environment hence they were not considered during forest management strategies (Merganičová et al., 2012, Pfeifer et al., 2015). Nevertheless, studies by (URT, 2017, Mauya et al., 2019) have estimated total carbon stocks for different land cover classes, but they did not segregate deadwood in estimating carbon and none had considered levels of uncertainty estimates and the state of the woody decay. Also, the coverage of these studies did not foresee the influence of the stand structure on deadwood biomass.

Thus, findings of this study will enhance better understanding of deadwood carbon pool and how stand structure components influence deadwood biomass, which is essential in developing management plans and designing protection and management practices supporting biodiversity. Also, the quantification of emission factor and uncertainty will be crucial to policies related to meeting national and international obligations on mitigate climate change (Zhao et al., 2012).

1.3 Objectives

1.3.1 Main objective

To assess deadwood carbon stocks and stand structure characteristics in different vegetation types in Tanzania.

1.3.2 Specific objectives

1. To quantify deadwood carbon stocks, emission factor and uncertainties in different vegetation types
2. To quantify environmental factors influencing variation in deadwood carbon stock across different vegetation types
3. To examine the relationship between species diversity, community composition and deadwood carbon stock along different environmental factors

1.4 Limitations of the Study

After accomplishing reliable estimates of deadwood carbon stock and its association with stand structure characteristics, several limitations remain. Here, suggestions for follow-up research.

- Future research should consider factors like disturbances, particularly fire, to further comprehend deadwood carbon dynamics in different vegetation types.

1.5 Dissertation Structure

This dissertation is divided into five chapters and is structured as a series of publishable manuscripts. The first chapter provides an introduction to the study, including background information, the problem statement, study objectives, and limitations. Chapter two presents manuscript one which shows deadwood carbon stock distribution, emission factor and uncertainty estimates across different vegetation types at the national level. Chapter three presents manuscript two which highlights the relationship between species diversity, community composition and deadwood carbon stock along different environmental variables. Chapter four is a general discussion of the study's findings, and Chapter five provides a summary of the key contributions and recommendations for future research.

CHAPTER 2

MANUSCRIPT ONE

2.0 Estimating Emissions and Uncertainty of Deadwood Carbon Pool in Tropical Dry Forests and Woodlands[1]

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Abstract

Deadwood carbon is a significant component of forest ecosystems and global carbon cycle. Accounting for deadwood carbon pools requires an accurate assessment of emission factors which can be challenging due to high variability in decay status and species in the tropical vegetation. Understanding the magnitude of this uncertainty can help to quantify the importance of deadwood in different ecosystems and improve the accuracy of carbon stock estimations. This study was carried out to quantify contribution of deadwood on aboveground and belowground estimated carbon stock, its emission factor, and associated uncertainties of different vegetation types in mainland Tanzania using deadwood dataset from the Tanzania National Forestry Resources Monitoring and Assessment (NAFORMA). Results showed that, the estimated deadwood carbon stock ranges from 0.11 to 1.01 t C ha-1 whereby solid deadwoods had higher carbon stocks than rotten deadwoods ($t(7) = -4.22$, $p = 0.0039$) at 95% CI, accounting for 0.79% of the total estimated aboveground and belowground carbon stocks. The carbon uncertainty values range from 0.0008% to 0.28% with the highest uncertainty value from rotten deadwoods in cultivated land

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[1] The material contained in this chapter has been submitted to **Carbon Balance and Management**.

and the lowest value from rotten deadwoods in woodlands. Deadwood emission factors range from 0.58 to 3.7 t CO2eq ha-1 and solid deadwoods had highest emission factor than rotten deadwoods (t (7) = -4.17, p = 0.0041) at 95% CI. The emission factors uncertainty values range from 0.003% to 1.04% with the highest and lowest uncertainty values from rotten deadwoods in cultivated land and woodland respectively. Thus, the state of woody decay has influence on carbon stock estimates in deadwood carbon pool especially in such high dynamic tropical forest and woodland ecosystems. These findings provide valuable insights into the contribution of deadwood on aboveground and belowground estimated carbon stock by showing its carbon stock distribution, emission factor and uncertainty estimates across different vegetation types at the national level, which is crucial to policies related in meeting national and international obligations on climate change mitigation, such as contribution of land use sector on national carbon accounting, REDD+ incentive based mechanisms and sustainable management of natural ecosystems.

Keywords:
Decay status, Deadwood carbon stock, Emission factor, Uncertainty

2.1 Introduction

Worldwide, deadwood carbon is a substantial component of the global carbon cycle, as it contributes significantly to the carbon stock in forest ecosystems (Oswalt et al., 2008). Deadwood carbon stock varies widely across different ecosystems depending on different factors such as climate (Weggler et al., 2012), vegetation type (Paletto et al., 2012) and disturbance history such as fire or wind throw (Bauhus et al., 2018b). Temperate and boreal forests tend to have higher deadwood carbon stocks than tropical forests, due to the low temperatures and longer duration of wood decomposition (Mazziotta et al., 2014).

The amount of carbon stored in standing dead trees and other fallen woody debris alive or dead forms an important component of the carbon pools (C. Woodall and Williams, 2005, Bauhus et al., 2018, Marzano et al., 2013) depending on decomposition rates (Tavankar et al., 2022), geographic region (Oettel et al., 2020), forest stand structure and composition (Oswalt et al., 2008, Vashum and Jayakumar 2012), and forest management practices (Thorn et al., 2020). Moreover, standing and downed deadwood are essential in providing resources and habitats for a wide range of plants, fungi and animal species (Brockerhoff et al., 2017), facilitate plant regeneration (Dittrich et al., 2014) and store nutrients (Godoy et al., 2012).

In tropical rainforests, deadwood is an important component of the forest ecosystem (Öder et al., 2021), however large accumulations of deadwood can increase the risk of wildfire or interfere with forest management activities such as logging (Pearson et al., 2014). Tanzania mainland has a diverse range of vegetation types (MNRT, 2015), each with unique characteristics and different levels of deadwood (McElhinny et al., 2005). Miombo woodlands, one of the largest ecosystems in Tanzania is under high anthropogenic pressure such as agriculture expansion, charcoal making, frequent burning, extensive herbivores and livestock grazing (Jonsson et al., 2005) which interfere with deadwood accumulation.

The amount of carbon dioxide released into the atmosphere from deadwood is a result of activities such as decomposition or combustion of deadwood (Ravindranath and Ostwald, 2008). Determination of the amount of carbon emitted from deadwood require accurate assessment of emission factors at various conditions, which varies depending on several factors, such as tree species, age of the tree at the time of death, climate, as well as the rate of deadwood decomposition (Kindermann et al., 2008), making it a critical parameter in estimating the amount of carbon emitted from deadwood decay. Hence, deadwood emission factors (DEF) are defined as the amount of carbon emitted per unit of deadwood decay, and it is usually expressed in terms of carbon dioxide equivalent (CO2e) emissions.

The estimation of emission factors is accompanied with several sources of uncertainty that can lead to inaccuracies (Griffiths et al., 2021). However, some of the main source of uncertainty during estimating forest deadwood emission factors and carbon stocks are those associated with climate variabilities (Seibold et al., 2021), species types, sampling design, dead wood and debris measurement error (Holdaway et al., 2014) as well as differences in combustion processes when deadwood is burned rather than allowed to decompose due to combustion temperature, oxygen supply and moisture content (Hekkala et al., 2016). By understanding the magnitude of this uncertainty, we can better quantify the importance of deadwood in these ecosystems and improve estimates of carbon storage.

Among the five carbon pools, deadwood carbon pool is often neglected or not estimated by various tropical nations when reporting to meet their reference emission levels due to limited national inventory data and technical capacity in estimating the deadwood emission factors. Previous studies have estimated total carbon stocks for different land cover classes (URT, 2017, Mauya et al., 2019), but they did not segregate deadwood in estimating carbon and none had considered levels of uncertainty estimates and the state of the woody decay. The state of woody decay has influence on the carbon stock estimates especially in such high dynamic tropical forest and woodlands ecosystems. Therefore, this study aims to quantify contribution of deadwood on aboveground and belowground estimated carbon stock, its emission factor, and associated uncertainty in different vegetation types. Specifically, the study aimed at 1) estimating weighted deadwood carbon stock by decay status, 2) determining deadwood emission factor and 3) quantifying associated uncertainty across different vegetation types.

2.2 Materials and Methods

2.2.1 Study area

Tanzania is located between 1° 00' S and 12° 00' S and between 30° 00' E and 41°00' E (Figure 2.1) at an altitude between 358 m a.s.l. and 5,950 m a.s.l. It lies on the east coast of Africa and is bordered by Kenya and Uganda to the north, Rwanda, Burundi, and the Democratic Republic of the Congo to the west, Zambia, Malawi, and Mozambique to the south and the Indian Ocean to the east. Tanzania mainland has a mainly tropical climate but has regional variations due to topography. Temperatures range between 10°C and 20°C during cold and hot seasons respectively. The mean annual rainfall varies from below 500 mm to over 2000 mm per annum, with shot rains from October to December and long rains from March to May. The country's major forest types include deciduous miombo woodlands in the western, central, and southern parts, Acacia-Commiphora woodlands in the north, mangrove forests along the Indian Ocean coast, and closed canopy forests that grow on the ancient mountains of the Eastern Arc.

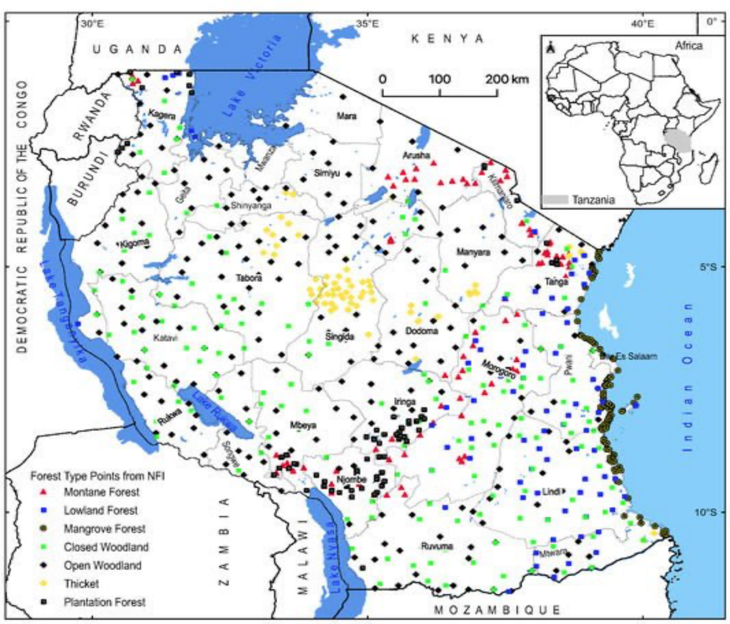

Figure 2.1: Distribution of different vegetation types in Tanzania mainland.

2.2.2 Sampling design

This study is based on the National Forestry Resources Monitoring and Assessment of Tanzania (NAFORMA) sampling design (Tomppo *et al.,* 2014, MNRT, 2015) whereby the country was divided based on predicted growing stock, accessibility and slope. Concentric circular plots of 15 m radius were used as the sampling units and plots were grouped into clusters as a measurement unit. The distribution of deadwood sample plots within the entire Tanzania mainland is presented in Figure 2.3 whereby, the number of plots in a cluster varied from six to ten, depending on the accessibility of the plots. The distance between plots within a cluster was 250m (Figure 2.2) while the distance between clusters varied by stratum, from 10 to 45 km. Measurements were taken for fallen deadwood and large branches which were within the radius of 15m plot. These included deadwood decay status, length and diameter (top and bottom) for deadwood with diameter equal or greater than 10 cm. Deadwood diameters were measured by using tree caliper, lengths were measured by using tape measure. Each deadwood decay status class (either solid or rotten) was detected by using knife test.

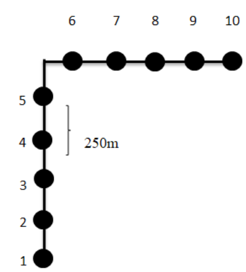

Figure 2.2: NAFORMA cluster design (black solid circles = plot).

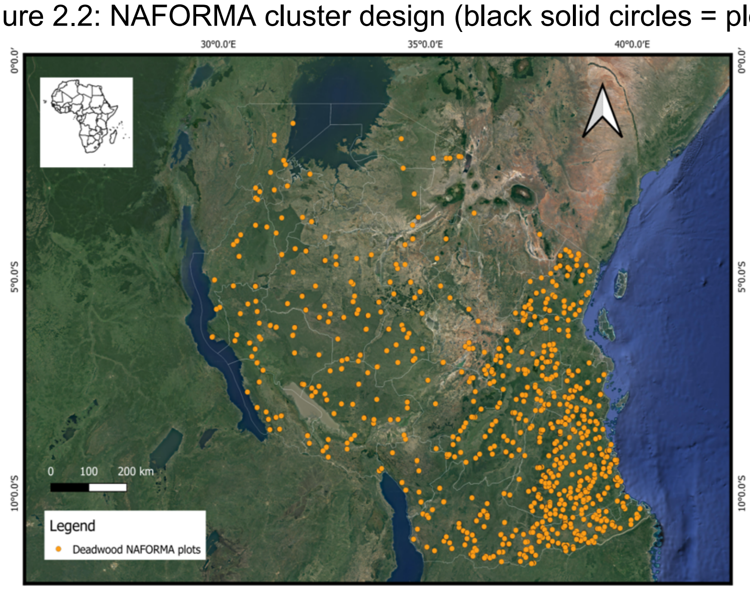

Figure 2.3: Distribution of deadwood sample plots in Tanzania mainland.

2.2.3 Data processing and cleaning

Data were encoded in MS Excel and analyzed by using R software, R v.4.3.0. A total of 21946 data points were imported to R software covering 1798 plots. During data cleaning, out of 21946 entries from the original database, 1207 data points had missing values (NA), 5705 data points had plots which were recorded in more than one vegetation type, 197 data points and 258 data points had deadwood decay status and vegetation types that were not explained in NAFORMA Biophysical Manual respectively (Vesa et al., 2010). Therefore, a total of 7367 data points were omitted (data with missing values, incorrect recorded plots and unexplained deadwood decay status and vegetation types) and hence remaining with 14579 data points that were used in the analysis.

2.2.4 Data analysis

2.2.4.1 Deadwood biomass

Deadwood biomass was estimated by multiplying volume of a given deadwood species with its specific wood density. Species specific wood density values for most of deadwood species in the NAFORMA dataset were sourced from the Global Wood Density database (Chave *et al.,* 2009; Zanne *et al.,* 2009), using the function getWoodDensity() in R. Species wood densities from the NAFORMA ranged between 237 to 1077.2 kg/m^3 and the highest frequency of dense wood was >605 kg/m^3. For those species-specific wood density values that were missing from the database, a default wood density value of 500 kg/m^3 was used. Irrespective of species, default wood density reduction factor of 0.97 were used for solid woods and 0.45 for rotten deadwood (IPCC, 2006). Deadwood volume was calculated by using Smalian formula (Equation 1).

$$V = \pi(d1^2 + d2^2)L/8 \qquad \text{(Equation 1)}$$

The estimated deadwood volume and biomass of individual values were summed up and expressed on per ha basis for each vegetation type sub-class.

2.2.4.2 Weighted deadwood biomass

Deadwood biomass for each vegetation type sub-class was estimated per plot, and then weighted based on their corresponding areas (Equation 2).

$$Yi = \frac{\sum_{i=1}^{n}(X_i \times a_i)}{\sum_{i=1}^{n}(a_i)} \qquad \text{(Equation 2)}$$

Where Y_i is the weighted estimate of deadwood biomass per ha, a_i is the area of vegetation type sub-class i, X_i is deadwood biomass per ha of the vegetation type sub-class and n is the number of vegetation type sub-classes in the primary vegetation type.

2.2.4.3 Deadwood carbon stock and emission factor

Individual weighted deadwood biomass were converted into carbon stocks by multiplying with carbon conversion factor, 0.47 (IPCC, 2006) and later aggregated into carbon stock density i.e. per ha for each primary vegetation type. Then, deadwood emission factor for each primary vegetation type, was computed by following the procedures outlined in (IPCC, 2006). The procedures were based on Tier 2, since we had country-specific information on deadwood with the assumption that, the inventory of carbon stock has been performed once in a time.

$EF = Carbon \times {}^{44}/_{12}$……………………………………………………… (Equation 3)

We used a paired samples t-test to compare deadwood carbon stock and emission factor of solid deadwood and rotten deadwood.

2.2.4.4 Uncertainty

We estimated uncertainty by calculating the simple mean, variance based on the samples, standard deviation and confidence interval. Uncertainty was expressed by a 95% confidence interval constructed using samples obtained from the same sampling design, including the true value.

Variance based on samples was calculated using the following equation:

$S^2 = \frac{\sum(xi-\bar{x})^2}{n-1}$……………………………………………………………….. (Equation 4)

Standard deviation was estimated as the square root of the variance

$S = \sqrt{\frac{\sum(xi-\bar{x})^2}{n-1}}$…………………………………………………………….. (Equation 5)

Uncertainty for each vegetation type was calculated by using equation 10 of (IPCC, 2006). The term "uncertainty" was based on the 95% confidence interval.

$U_{total} = \frac{\sqrt{(U_1 \times X_1)^2 + (U_2 \times X_2)^2 + \cdots + (U_n \times X_n)^2}}{|X_1 + X_2 + \cdots + X_n|}$ ………………………………(Equation 6)

Whereby, U_{total} =Percentage uncertainty of the sum of quantities (half the 95% confidence interval, divided by the total (i.e., the mean) and expressed as a percentage). X_i and U_i =Uncertainty quantity and the associated percentage uncertainties, respectively.

2.3 Results

2.3.1 Deadwood carbon stock

Total deadwood carbon stock across different primary vegetation type ranges from 0.11 to 1.01 t C ha^{-1} (Figure 2.4). Forest had the highest deadwood carbon stock (1.01 ± 0.00057 t C ha^{-1}) compared to other vegetation types, followed by woodland (0.8 ± 0.0004 t C ha^{-1}) while grassland had the lowest deadwood carbon stock (0.16 ± 0.0017 t C ha^{-1}). The paired sample t-test showed that, there was a significant difference in deadwood carbon stock between solid deadwood (mean = 0.462, SD = 0.287) and rotten deadwood (mean = 0.0497, SD = 0.0435); t (7) = -4.22, p = 0.0039). The highest deadwood carbon stocks (0.93 ± 0.00061 t C ha^{-1}) were obtained from solid deadwood found in forest while the lowest deadwood carbon stock (0.004 ± 0.00037 t C ha^{-1}) was obtained from rotten deadwood found in grassland (Table 2.1). Also, the highest (0.28%) and lowest (0.0008%) deadwood carbon uncertainty values were obtained from rotten deadwoods found in cultivated land and woodland respectively (Table 2.1).

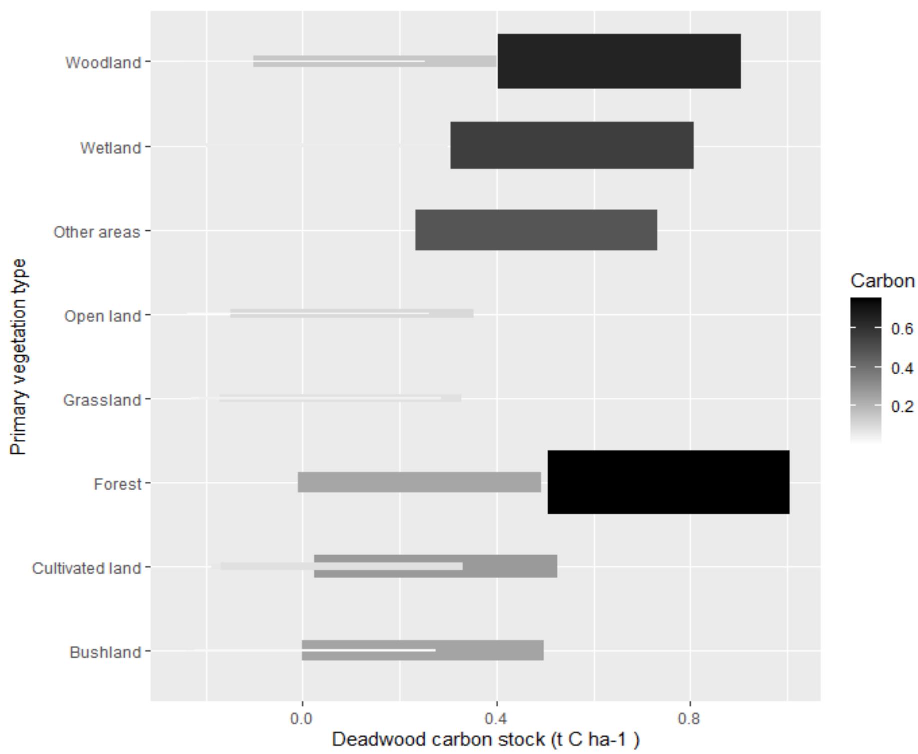

Figure 2.4: A heat map showing deadwood carbon stock distribution across different vegetation types. Deep colour represents higher carbon stock values, slightly deep colour represents median values and lighter colour represents lower values.

Table 2.1: Total deadwood carbon stock and uncertainty estimates for each primary vegetation type.

Primary vegetation type	Decay status	Area (ha)	Weighted biomass (t ha^{-1})	Carbon stock (t C ha^{-1})	Uncertainty (%)
Bushland	Solid	7,608,200	0.790	0.373	0.0130
	Rotten	7,608,200	0.050	0.025	0.0047
Cultivated land	Solid	8,094,200	0.610	0.289	0.0570
	Rotten	8,094,200	0.290	0.138	0.2830
Forest	Solid	3,364,400	1.980	0.930	0.0016
	Rotten	3,364,400	0.160	0.077	0.0015
Grassland	Solid	8,835,900	0.330	0.154	0.0200
	Rotten	8,835,900	0.008	0.004	0.0150
Open land	Solid	234,200	0.230	0.107	0.0840
	Rotten	234,200	0.150	0.007	0.0160
Other areas	Solid	1,892,700	1.170	0.500	0.1260
	Rotten	1,892,700	0.090	0.045	0.1560
Wetland	Solid	1,162,600	1.150	0.544	0.0460
	Rotten	1,162,600	0.120	0.059	0.0280
Woodland	Solid	47,257,200	1.580	0.750	0.0012
	Rotten	47,257,200	0.090	0.043	0.0008

Table 2.2: Contribution of deadwood carbon stock to total estimated carbon stock across each vegetation type.

Primary vegetation type	**[*1] Deadwood carbon stock (t C ha-1)**	**[*2] Deadwood carbon stock (t C ha-1)**	**[*3] Total carbon stock (t C ha-1)**	**Deadwood carbon stock (t C ha-1)**	**Contribution (%)**
Bushland	5.4	0.36	87.4	0.39	0.45
Cultivated land	4.0	0.45	48.9	0.42	0.86
Forest	20.3	2.39	244.5	1.01	0.41
Grassland	0.73	0.17	15.0	0.16	1.07
Open land	1.3	0.11	9.7	0.11	1.13
Other areas	0.5	0.48	7.2	0.59	8.19
Wetlands	2.2	0.64	11.6	0.61	5.26
Woodland	3.5	0.89	91.7	0.80	0.87
Total	**37.93**	**5.49**	**516**	**4.09**	**0.79**

[*1 and 2] Values of deadwood carbon stock from (Mauya *et al.,* 2019; MNRT, 2015) respectively. [*3] Values of total carbon stock from (Mauya *et al.,* 2019).

2.3.2 Deadwood emission factor and uncertainty estimates

The estimated deadwood emission factors in primary vegetation types range from 0.58 to 3.7 t CO2eq ha^{-1}. Forests had the highest deadwood emission factor (3.7 ± 0.002 t CO2eq ha^{-1}) while grassland had the lowest deadwood emission factor (0.58 ± 0.006 t CO2eq ha^{-1}). A paired sample t-test showed that, there was a significant difference in deadwood emission factor between solid deadwood (mean = 1.67, SD = 1.05) and rotten deadwood (mean = 0.182, SD = 0.160); t (7) = -4.17, p = 0.0041). The highest deadwood emission factor in forests (3.42 ± 0.002 t CO2eq ha^{-1}) was attributed by the presence of solid deadwood, while the lowest deadwood emission factor in grassland (0.015 ± 0.0014 t CO2eq ha^{-1}) was attributed by the presence of rotten deadwood (Figure 2.5).

Also, cultivated land had the highest emission factor uncertainty value (1.25%), followed by wetland (0.27%), while woodland had the lowest value (0.007%). The highest and lowest emission factor uncertainty value was found in rotten deadwood found in cultivated land (1.04%) and in woodland (0.003%) respectively (Table 2.3).

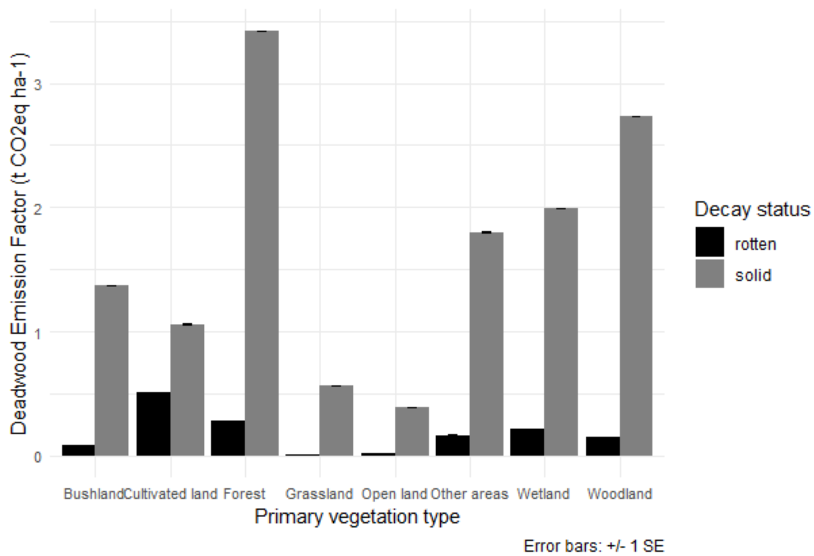

Figure 2.5: A graph showing deadwood emission factors distribution for solid and rotten deadwood across different vegetation types. Rotten deadwood emission factors are represented by black colour, while solid deadwood emission factors are represented by pale black

Table 2.3: Deadwood emission factors and uncertainty estimates for each primary vegetation type.

Primary vegetation type	Decay status	Area (ha)	EF ($tCO_2eq\ ha^{-1}$)	Uncertainty (%)
Bushland	Solid	7,608,200	1.37	0.048
	Rotten	7,608,200	0.09	0.017
Cultivated land	Solid	8,094,200	1.06	0.208
	Rotten	8,094,200	0.51	1.04
Forest	Solid	3,364,400	3.42	0.006
	Rotten	3,364,400	0.28	0.006
Grassland	Solid	8,835,900	0.57	0.072
	Rotten	8,835,900	0.015	0.054
Open land	Solid	234,200	0.39	0.308
	Rotten	234,200	0.026	0.057
Other areas	Solid	1,892,700	1.83	0.463
	Rotten	1,892,700	0.16	0.573
Wetland	Solid	1,162,600	1.99	0.17
	Rotten	1,162,600	0.22	0.103
Woodland	Solid	47,257,200	2.73	0.004
	Rotten	47,257,200	0.16	0.003

2.4 Discussion

The overall objective of this paper was to compute deadwood carbon stocks, emission factor and associated uncertainty while considering the decay status of deadwood in different vegetation types, using Tanzania National Forest Inventory (NFI) dataset referred here as “NAFORMA data”. We found a wide range of deadwood carbon stock values across different vegetation types similar to previous studies (URT, 2017, Mauya *et al.,* 2019), since they also used the dataset which used same sampling design (Tomppo *et al.,* 2014, MNRT, 2015). However, the segregation of deadwood carbon pool as well as the inclusion of levels of woody decay in carbon stock estimation, which was not included in other previous studies, resulted into significant improvement of the uncertainty estimation in carbon stock estimation and provides better understanding on the dynamics of carbon cycling in forest and woodland ecosystems since, deadwood carbon content varies depending on its stage of decay (Harmon *et al.,* 2013, Garbarino *et al.,* 2015).

2.4.1 Deadwood carbon stock

According to (Mauya *et al.,* 2019; URT, 2017) who reported the total amount of carbon stock for different land cover types of Mainland Tanzania from three carbon pools, deadwood being inclusive, this study has segregated deadwood carbon pool to obtain its contribution to the total estimated amount of carbon (aboveground and belowground) across each vegetation type (Table 2.2). We found that, deadwood contribute 0.79% of the total estimated amount of carbon whereby forests and woodlands have higher levels of deadwood carbon stocks, compared to other vegetation types (Figure 2.4). This is due to the inherent characteristics of forests and woodlands, i.e. the accumulation of substantial amounts of woody biomass over time (McElhinny *et al.*, 2005). A notable proportion of the deadwood in these ecosystems is composed of solid deadwood, which takes longer to decompose and maintains its structural integrity for a longer duration, as this contributes to a stable carbon stock compared to rotten deadwood. Along with this, active management practices implemented in these ecosystems, such as sustainable logging (Rozak *et al.,* 2018, Osone *et al.,* 2016) and selective tree harvesting (Pfeifer et al., 2015a) support the accumulation of deadwood which is likely contributed to this observed pattern. However, the estimated carbon stock values are smaller when compared to other studies by Gurmessa *et al.* (2021); Pfeifer *et al.* (2015), this might be attributed to high occurrence of fire incidence in tropical dry forest and woodland (Tarimo *et al.,* 2015). Nevertheless, various studies have demonstrated that, other factors such as tree species composition (Kahl and Bauhus, 2014) and stand age (Pregitzer and Euskirchen, 2004) also play a significant role in influencing deadwood carbon stocks within these ecosystems. Furthermore, the disturbance regimes experienced by these ecosystems, such as natural disasters or human-induced disturbances, can also affect the accumulation and availability of deadwood carbon stock (Joshi and Singh, 2020). Also, results showed that, there was lower deadwood carbon stock in grasslands than other vegetation types which could be attributed to frequent disturbances such as grazing and fire as they limit the amount of deadwood that accumulates in grassland ecosystems. These findings are in line with the other study by Merganičová *et al.* (2012), who revealed that, deadwood carbon stocks in grassland were positively correlated with woody plant cover and negatively correlated with grazing intensity.

2.4.2 Deadwood emission factor and uncertainty

Additionally, the storage of carbon in deadwood can significantly impact carbon flux estimates as deadwood decomposition releases carbon dioxide (CO_2) into the atmosphere (Hoover and Riddle, 2020). Our results showed higher emission factors from solid deadwood in forests and woodlands compared to other vegetation types, which could be attributed to the larger biomass and tree density of solid deadwood, resulting in more deadwoods available for decomposition. Studies by Blanc *et al.* (2009) revealed that, slower decomposition rates in solid deadwood lead to a longer period of carbon release, contributing to higher emission factors. Ecosystems such as grasslands were shown to have lower deadwood emission factors from rotten deadwood, which could be attributed to limited storage time of carbon within rotten deadwood. However, different studies by Gogoi *et al.* (2022) and Tian *et al.* (2011) have discussed that, the carbon sink potential of ecosystems, including the contribution of levels of woody decay, can vary depending on various factors such as climate, vegetation type, and management practices. The extended storage time of carbon within deadwood, contributes to the overall stability and persistence of carbon storage in the ecosystem (Janisch and Harmon, 2002).

Uncertainty estimates play a crucial role in enhancing carbon accounting models and management strategies aimed at addressing climate change. The findings of this study showed higher uncertainty values in carbon and emission factor estimates of rotten deadwood compared to solid deadwood, which are consistent with other studies by Hyvönen *et al.* (2007), Seibold *et al.,* 2016 and Harmon *et al.* (2009), who highlights the variability and challenges associated with accurately estimating carbon content in different stages of decomposition. The inherent variability in decay rates, decomposition patterns, and spatial-temporal dynamics of rotten deadwood contribute to the increased uncertainty in carbon estimation. Russell et al., (2015) further emphasize the difficulties in assessing carbon distribution and accessibility within rotten deadwood could be due to measurement limitations.

2.5 Conclusion

The findings of this study provide valuable insights into the contribution of deadwood in total estimated carbon stock by showing its carbon stock distribution, emission factor and uncertainty estimates across different vegetation types at the national level and highlighting the importance of considering decay status when assessing deadwood carbon stocks and emission factors in different vegetation types. Furthermore, information on uncertainty estimates is critical for improving the accuracy of carbon accounting in different vegetation types and developing effective strategies for reducing bias when estimating greenhouse gas emissions. Nevertheless, the study emphasizes the need for better land management practices that prioritize the conservation and restoration of natural ecosystems, particularly woodland and forest areas, so that to enhance carbon storage potential. Therefore, further research should be conducted to better understand the deadwood carbon emission fluxes and distribution in different vegetation types with their levels of uncertainty. Furthermore, there is a need to promote better understanding and appreciation on the roles of deadwood as carbon source and sinks and their ecological values.

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Conflict of Interest

The authors declare no conflict of interest.

Authors' contributions

All authors have been involved in conceptualizing and designing the study. SNM conducted data analysis, drafted and presented results and discussion, and wrote the manuscript. DDS and EMZ reviewed the analysis, results and the entire manuscript. All authors read and approved the final manuscript for submission.

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CHAPTER 3

MANUSCRIPT TWO

3.0 Relationship Between Species Diversity, Community Composition and Deadwood Carbon Stock along Different Environmental Variables[2]

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Abstract

The amount of carbon stored in forest depends on various factors such as forest structure and environmental variables. Various ecological and environmental studies have been done in Tanzania. However, there is limited information on deadwood carbon and ecosystem structure along different environmental factors in different tropical vegetation. Therefore, this study will be useful to inform forest policy and deadwood management, biodiversity conservation and carbon cycling under climate change in tropical ecosystems like study area. The study hypothesized that, deadwood carbon stock is highly influenced by the ecosystem structure and environmental variables. Multimodal inference approach was used to determine how deadwood carbon related to species diversity and environmental variables i.e. soil (soil organic carbon, texture and moisture) and climate (temperature and precipitation). Results showed that, in forest and woodland vegetation type, species abundance and soil moisture had positive significant relationship with deadwood carbon while species richness and soil organic carbon had negative significant relationship with deadwood carbon. Also, in lowland forest, deadwood carbon stock of *Brachystegia sp.-Pterocarpus angolensis* (BP) community was positively

[2] The material contained in this chapter has been submitted to **Folia Oecologica**.

significant influenced by soil moisture while in woodlands, deadwood carbon stock of *Julbernardia globiflora-Pterocarpus angolensis* (JP) community was negatively significant influenced by soil organic carbon and deadwood carbon stock of *Dalbergia melanoxylon-Pteleopsis myrtifolia* (DP) community was positively significant influenced by soil moisture. Understanding how stand structure of deadwood interact with environmental conditions is a step towards establishing the vital contributions of forest and woodlands to local livelihoods. Although, not included in this study, disturbance especially fire is an important factor that may influence deadwood biomass worth considering in future understanding of the dead wood carbon dynamics in different vegetation types.

Keywords
Deadwood carbon, Species richness, Abundance, Soil moisture, Soil organic carbon

3.1 Introduction

Worldwide, deadwood has emerged as a significant component of terrestrial carbon pools (Moreno-Fernández *et al.,* 2020) and potentially important biodiversity indicators (Humphrey *et al.,* 2005). Deadwood is one among the structural components of forest ecosystems playing a vital role in maintaining ecosystem health and functioning (Brockerhoff *et al.,* 2017). Thus, the study of deadwood carbon stocks and their variability across different ecosystems has gained considerable attention due to its crucial role in understanding global carbon cycling and mitigating climate change (Bauhus *et al.*, 2018).

Diverse ecosystems including tropical rainforests and woodlands exhibit distinct vegetation compositions and disturbance regimes. Forests occupy 31% of the global land area and are among the richest ecosystems in terms of biodiversity and carbon pool (FAO, 2020). However, forests areas and their carbon pool have dramatically decreased due to the increasing rate of deforestation, land use change and agriculture expansion (Curtis *et al.,* 2018). Thus, the diversity of forest structure and composition need to be maintained at landscape and regional scales as a spatial insurance to provide habitats for a large suite of specialist forest species (Brockerhoff *et al.,* 2017).

The amount of carbon stored in forest depends on various factors such as forest structure and environmental variables (Arasa-Gisbert *et al.,* 2018; Gogoi *et al.,* 2022). Environmental factors including climate i.e. temperature and precipitation are major factors that impact forest productivity and species distribution patterns in different forest ecosystems (Toledo *et al.,* 2012). Also, soil variables such as organic carbon content, texture and moisture, have effect in shaping the growth and distribution of plant species, which influence the overall structure and composition of forests (Sharma *et al.,* 2018). Thus, investigating how these environmental gradients interact with deadwood carbon stocks and species attributes, show the underlying mechanisms governing ecosystem dynamics (Austin, 2002).

In East Africa, Tanzania is one among rich countries in terms of natural resources and biodiversity comprising of diverse vegetation types (MNRT, 2015). There are various ecological and environmental studies which have been done in Tanzania, to investigate the relationship between deadwood biomass and composition with canopy (Hezron and Nyahongo, 2021), along elevation and land use gradients (Komposch *et al.,* 2022) and also Lutz *et al.* (2021) compared aboveground woody live biomass and deadwood biomass. However, the investigation of deadwood carbon and ecosystem structure along different environmental gradients in tropical ecosystems was not documented.

Therefore, this study hypothesized that, deadwood carbon stock is influenced by the ecosystem structure and environmental variables. Specifically, the study asked the following questions (1) Does deadwood carbon relate to species richness and diversity across different vegetation types? (2) How environmental factors influence deadwood carbon? (3) Does species community composition determine the relationship between deadwood carbon, richness, and diversity along different environmental gradients? Therefore, this study will be useful to inform forest policy and deadwood management, biodiversity conservation and carbon cycling under climate change.

3.2 Materials and Methods

3.2.1 Study area

Tanzania is located between 1° 00' S and 12° 00' S and between 30° 00' E and 41°00' E (Figure 3.1) at an altitude between 358 m a.s.l. and 5,950 m a.s.l. It lies on the east coast of Africa and is bordered by Kenya and Uganda to the north, Rwanda, Burundi, and the Democratic Republic of the Congo to the west, Zambia, Malawi, and Mozambique to the south and the Indian Ocean to the east. Tanzania mainland has a mainly tropical climate but has regional variations due to topography. Temperatures range between 10°C and 20°C during cold and hot seasons respectively. The mean annual rainfall varies from below 500 mm to over 2000 mm per annum, with shot rains from October to December and long rains from March to May. The country's major forest types include deciduous miombo woodlands in the western, central, and southern parts, *Acacia-Commiphora* woodlands in the north, mangrove forests along the Indian Ocean coast, and closed canopy forests that grow on the ancient mountains of the Eastern Arc.

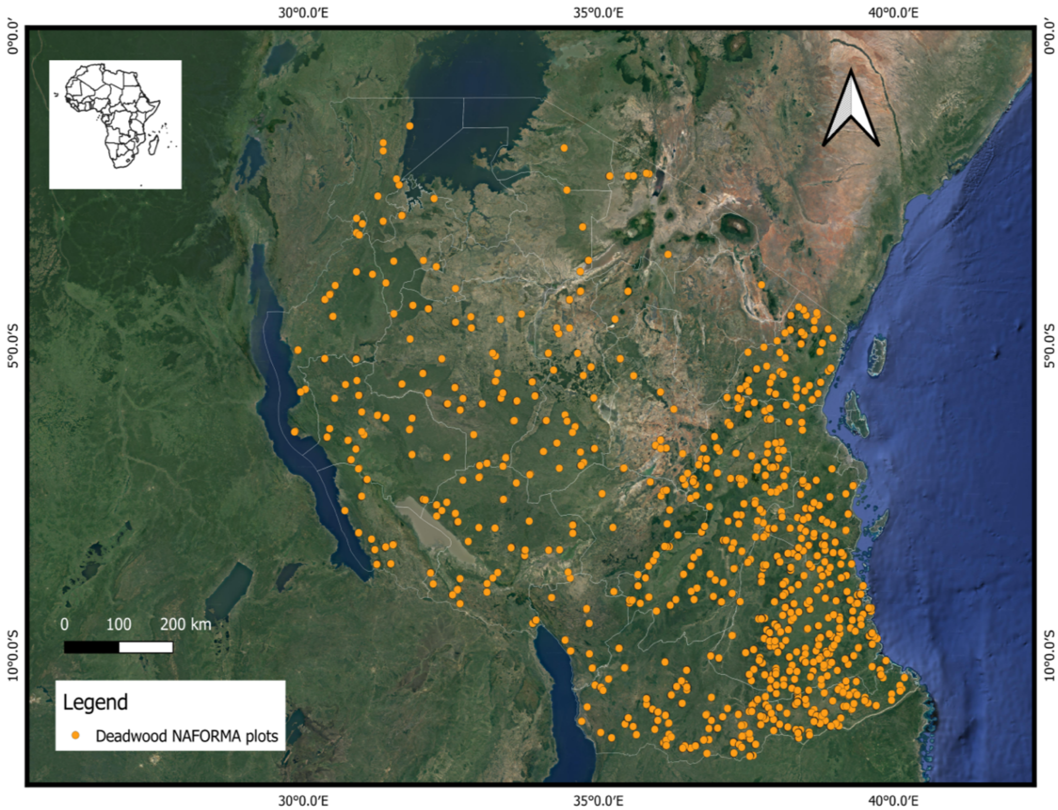

Figure 3.1: Distribution of deadwood sample plots in Tanzania mainland.

3.2.2 Sampling design

This study employed the use of National Forestry Resources Monitoring and Assessment of Tanzania (NAFORMA) sampling design (Tomppo *et al.,* 2014, MNRT, 2015) whereby the country was divided based on predicted growing stock, accessibility and slope. Concentric circular plots of 15 m radius were used as the sampling units and plots were grouped into clusters as a measurement unit. Number of plots in a cluster varied from six to ten, depending on the accessibility of the plots. The distance between plots within a cluster was 250m while the distance between clusters varied by stratum, from 10 to 45 km. Measurements were taken for fallen deadwood and large branches which were within the radius of 15m plot. These included length and diameter (top and bottom) for deadwood with diameter equal or greater than 10 cm. Deadwood diameters were measured by using vernier calliper, lengths were measured by using tape measure. Identification of deadwood species name was done using species checklist.

3.2.3 Data analysis

3.2.3.1 Deadwood carbon

Deadwood biomass was estimated as the product of volume and species specific wood density. Volume was computed using Smalian formula and species specific wood density values were sourced from the Global Wood Density database (Chave *et al.,* 2009; Zanne *et al.,* 2009). Deadwood biomass were converted into carbon stocks by multiplying with carbon conversion factor, 0.47 (IPCC, 2006) and later aggregated into carbon stock density i.e. per ha for each plot.

3.2.3.2 Species community composition and diversity

All recorded deadwood species were sorted to obtain their abundance values and species composition and then, species dominance was determined by estimating species importance value index (SIVI). Species Importance Value Index (SIVI) was computed as the sum of relative density, relative dominance and relative frequency of the species per each plot. Cluster analysis was done to identify similar species communities across each vegetation type. While doing so, the Bray–Curtis's distance matrix was computed using species carbon matrix data and then, hierarchical Ward's minimum variance clustering was performed using Ward's algorithm. Number of clusters was identified based on Silhouette validation technique using function *fviz_nbclust().* Indicator species were identified using package 'labdsv', and then each community was named after the two most dominant species based on high synoptic cover abundance values. Also, alpha diversity metrics including Shannon-Wiener (H'), evenness (J) and richness (S) were calculated for each plot using the 'vegan' package. Shapiro-Wilk tests was used to check if these data were normally distributed and later, Kruskal-Wallis tests was done to examine if there is a statistical difference for each diversity metrics among vegetation types.

3.2.3.3 Acquisition of environmental data

Climatic data (annual mean temperature and annual mean precipitation) were downloaded from WorldClim site (https://www.worldclim.org) with a 30 arc seconds resolution and soil data (soil organic carbon, moisture and texture i.e. sand, silt and clay) were extracted from the Re-gridded Harmonized World Soil Database: ISRIC Data (International Soil Reference and Information Centre) https://data.isric.org. Values for all spatially interpolated climate and soil variables were extracted using QGIS software and sampled using the coordinates of the plot and averaged across plots per vegetation type.

3.2.3.4 Associations between deadwood carbon stock, species diversity and communities along different environmental gradients.
Variance inflation factor (VIF) was used to assess collinearity among environmental predictor variables i.e., climate and soil variables. In cases of high collinearity, VIF greater than 10 was used as an indicator (Chahouki and Zare Chahouki, 2010). Soil texture (sand, silt and clay), Shannon diversity and annual mean temperature, were removed from the model analysis due to high collinearity with other predictor variables.

Multimodal inference approach was used whereby five subset models were fitted focusing on solely using climatic variables (annual mean precipitation), solely using soil variables (soil moisture and soil organic carbon), solely using diversity metrics (abundance, species richness and evenness), combining two variables category; either climate and soil, climate and diversity metrics or soil and diversity metrics and combining all variables together as predictor variables of carbon.

Generalized additive model (gam)-global regression model was used with deadwood carbon as a response variable and species abundance, richness, evenness, annual mean precipitation, soil organic carbon and soil moisture as predictor variables (Zuur et al., 2009). Function *dredge*, implemented in the package 'MuMIn' (Barton, 2009) was used to generate a set of sub-models from the global model using the function *get.models*. Backward-forward stepwise model selection based on the Akaike Information Criterion was done to identify optimal models from the global models. A confidence set at a 95% cumulative weight was defined using the function *get.models* and the best final model was determined by model averaging using the function *model.avg* (Grueber *et al.,* 2011).

3.3 Results

3.3.1 Species composition, richness and diversity

A total of 528 species belonging to 224 genera and 77 families were recorded across all vegetation types. The most dominant families were Fabaceae (equivalent to individuals 3989), Caesalpiniaceae (equivalent to individuals 2717), Combretaceae (equivalent to individuals 1975), Phyllanthaceae (equivalent to individuals 590) and Euphorbiaceae (equivalent to individuals 514). The most common genera were Brachystegia (equivalent to individuals 2237), Combretum (equivalent to individuals 1071), Pterocarpus (equivalent to individuals 759), Julbernardia (equivalent to individuals 752), Terminalia (equivalent to individuals 536) and Acacia (equivalent to individuals 508). The most dominant species, in terms of SIVI were *Brachystegia sp.* (6.66), *Julbernardia globiflora* (4.65), *Pterocarpus angolensis* (4.02), *Brachystegia spiciformis* (3.32) *Dalbergia melanoxylon* (2.63) and *Brachystegia bussei* (2.58),

Table S1. These species contributed to 47.1% of the total weighted deadwood carbon stock (Table S1). In terms of vegetation types, 199 species were only obtained from woodland, 128 species were only obtained from forest and 201 species were shared among the two vegetation types. Higher species evenness was also observed in woodland (0.71) compared to forest (0.66). Also, woodland had higher Shannon-Wiener diversity value (4.47) compared to forest (4.12), Table 3.1. However, there was no statistical difference across these vegetation types in richness, evenness and Shannon diversity.

Table 3.1: Species evenness and Shannon-Wiener diversity index across vegetation types.

Vegetation type	Species evenness (J)	Shannon-Wiener diversity index (H')
Forest	0.66	4.12
Woodland	0.71	4.47

3.3.2 Community composition

Three communities were identified from forests (Figure 3.2A) while four communities were identified from woodlands (Figure 3.2B), and most of the species were shared across communities. Species communities were named based on the two most important species that occurred in the community, using species indicator value (Table S2; Table S3). The identified communities from forests were *Anacardium occidentale-Rhizophora* mucronata (AR), *Brachystegia sp.-Pterocarpus angolensis* (BP) and *Pteleopsis myrtifolia-Milletia sp.* (PM), Figure 3.2A. The highest weighted deadwood carbon stock (0.0088 t C ha^{-1}) was obtained from *Pteleopsis myrtifolia-Milletia sp.* (PM) community while the lowest deadwood carbon stock (0.000016 t C ha^{-1}) was from *Anacardium occidentale-Rhizophora* mucronata (AR) community (Figure 3.3A). From woodlands, the identified communities were *Brachystegia sp.-Diplorhynchus condylocarpon* (BD), *Dalbergia melanoxylon-Pteleopsis myrtifolia* (DP), *Julbernardia globiflora-Pterocarpus angolensis* (JP) and *Brachystegia spiciformis-Parinari excelsa* (BP), Figure 3.2B. The highest weighted deadwood carbon stock (0.01447 t C ha^{-1}) was obtained from *Brachystegia spiciformis-Parinari excelsa* (BP) community while the lowest deadwood carbon stock (0.0000157 t C ha^{-1}) was from *Brachystegia sp.-Diplorhynchus condylocarpon* (BD) community (Figure 3.3B).

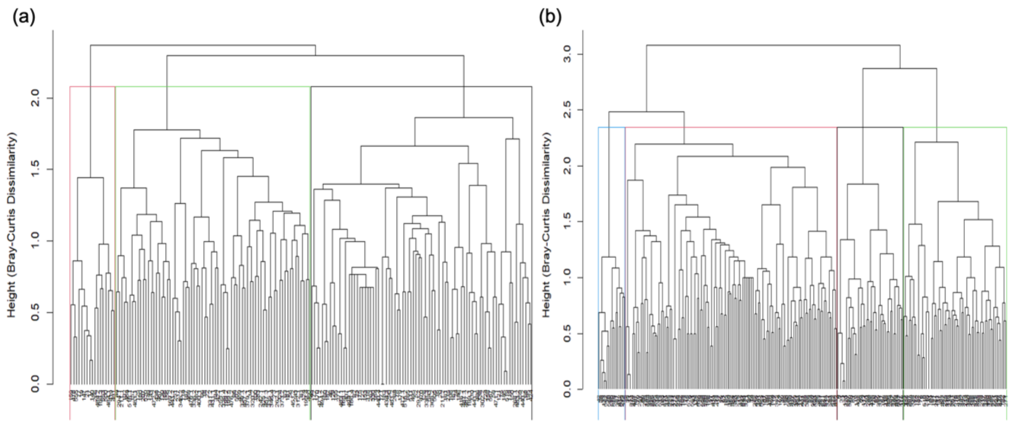

Figure 3.2: Hierarchical dendrograms showing communities as a result of clustering analysis in forest and woodland vegetation type. Figure 3.2A colored rectangles indicate forest communities, *Anacardium occidentale-Rhizophora mucronata* (AR), *Brachystegia sp.-Pterocarpus angolensis* (BP) and *Pteleopsis myrtifolia-Milletia sp*. (PM). Figure 3.2B colored rectangles indicate woodland communities, *Brachystegia sp.-Diplorhynchus condylocarpon* (BD), *Dalbergia melanoxylon-Pteleopsis myrtifolia* (DP), *Julbernardia globiflora-Pterocarpus angolensis* (JP) and *Brachystegia spiciformis-Parinari excelsa* (BP).

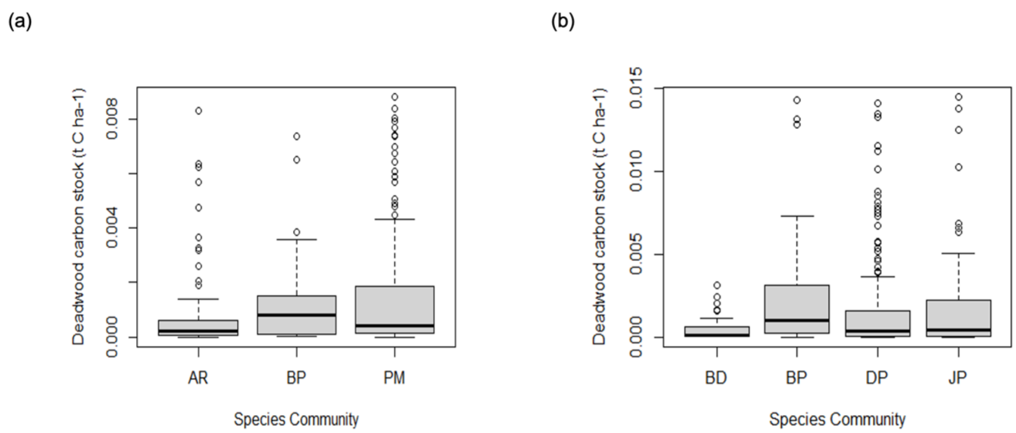

Figure 3.3: Distribution of deadwood carbon stock among the identified species communities; Anacardium occidentale-Rhizophora mucronata (AR), Brachystegia sp.-Pterocarpus angolensis (BP) and Pteleopsis myrtifolia-Milletia sp. (PM) from forests (Figure 3.3A) and Brachystegia sp.-Diplorhynchus condylocarpon (BD), Dalbergia melanoxylon-Pteleopsis myrtifolia (DP), Julbernardia globiflora-Pterocarpus angolensis (JP) and Brachystegia spiciformis-Parinari excelsa (BP) from woodlands (Figure 3.3B). The bottom and the top of each box represent 25th and 75th percentiles, the thick band in the box represents the median, the whiskers show the lowest and the highest values within 1.5 times the inter-quartile range and the dots are values outside the range.

3.3.3 Associations between deadwood carbon stock, species diversity and communities along different environmental gradients

Species abundance and soil moisture were positively significant related to deadwood carbon, with the highest effect shown by soil moisture (Table 3.2; Figure 3.4). However, species richness and soil organic carbon had a negative significant relationship with deadwood carbon (Table 3.2; Figure 3.4). Results also showed that in lowland forest, deadwood carbon stock of *Brachystegia sp.-Pterocarpus angolensis* (BP) community was positively significant influenced by soil moisture (Table 3.3; Figure 3.5A). However, in woodlands, deadwood carbon stock of *Julbernardia globiflora-Pterocarpus angolensis* (JP) community was negatively significant influenced by soil organic carbon (Table 3.3; Figure 3.5B) while deadwood carbon stock of *Dalbergia melanoxylon-Pteleopsis myrtifolia* (DP) community was positively significant influenced by soil moisture (Table 3.3; Figure 3.5C).

Table 3.2: A summary of averaged model estimates using multimodal inference approach

Estimates	Value	Std.Error	z-value	p-value
(Intercept)	-0.00162	0.00602	2.689	0.0072
Abundance	0.000081	0.000017	4.560	<0.05
Richness	-0.00016	0.000105	1.482	≤0.013
Soil moisture	0.000492	0.000143	3.424	≤0.001
Soil organic carbon	-0.00108	0.000433	2.493	≤0.012

Table 3.3: A summary of models showing association between environmental variables and species communities across different vegetation types.

Vegetation type	Parameter	Estimate	Std.Error	t-value	p-value
Forest (soil moisture)	(Intercept)	43.009	0.152	238.4	<0.05
	Community BP	0.701	0.368	-1.906	<0.05
	Community PM	0.031	0.263	-0.119	0.905
Woodland (soil moisture)	(Intercept)	41.987	0.164	256.4	<0.05
	Community BP	0.044	0.272	-0.163	0.871
	Community DP	0.404	0.185	-2.181	≤0.03
	Community JP	0.369	0.211	-1.752	0.08
Woodland (soil organic carbon)	(Intercept)	1.835	0.0701	26.179	<0.05
	Community BP	-0.0073	0.1165	-0.632	0.528
	Community DP	-0.0436	0.0794	-0.549	0.584
	Community JP	-0.175	0.0902	-1.944	<0.05

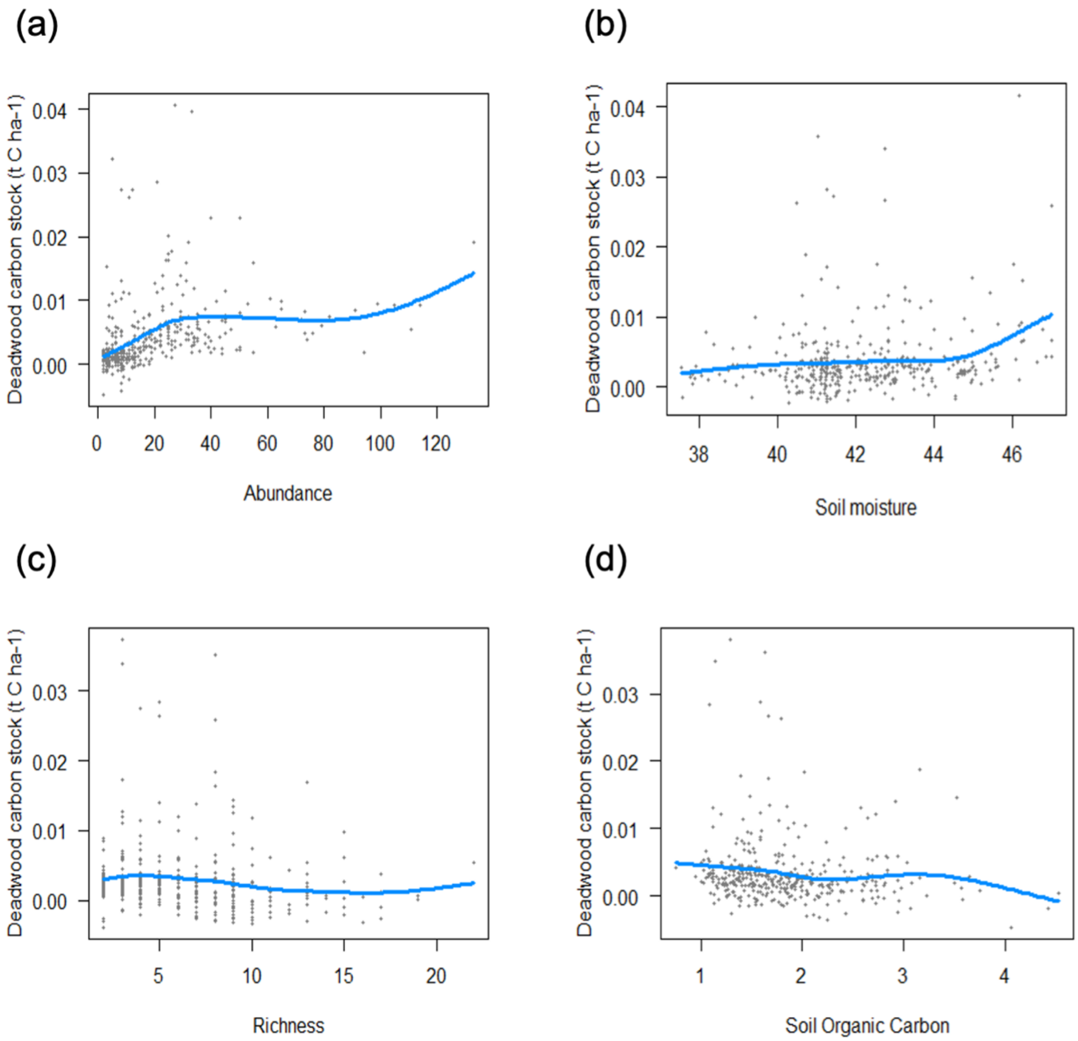

Figure 3.4: Associations between deadwood carbon and species abundance, richness and soil organic carbon and soil moisture. Scatter points are raw data and the lines are predictions from the optimal averaged generalized additive model when other predictors are kept constant.

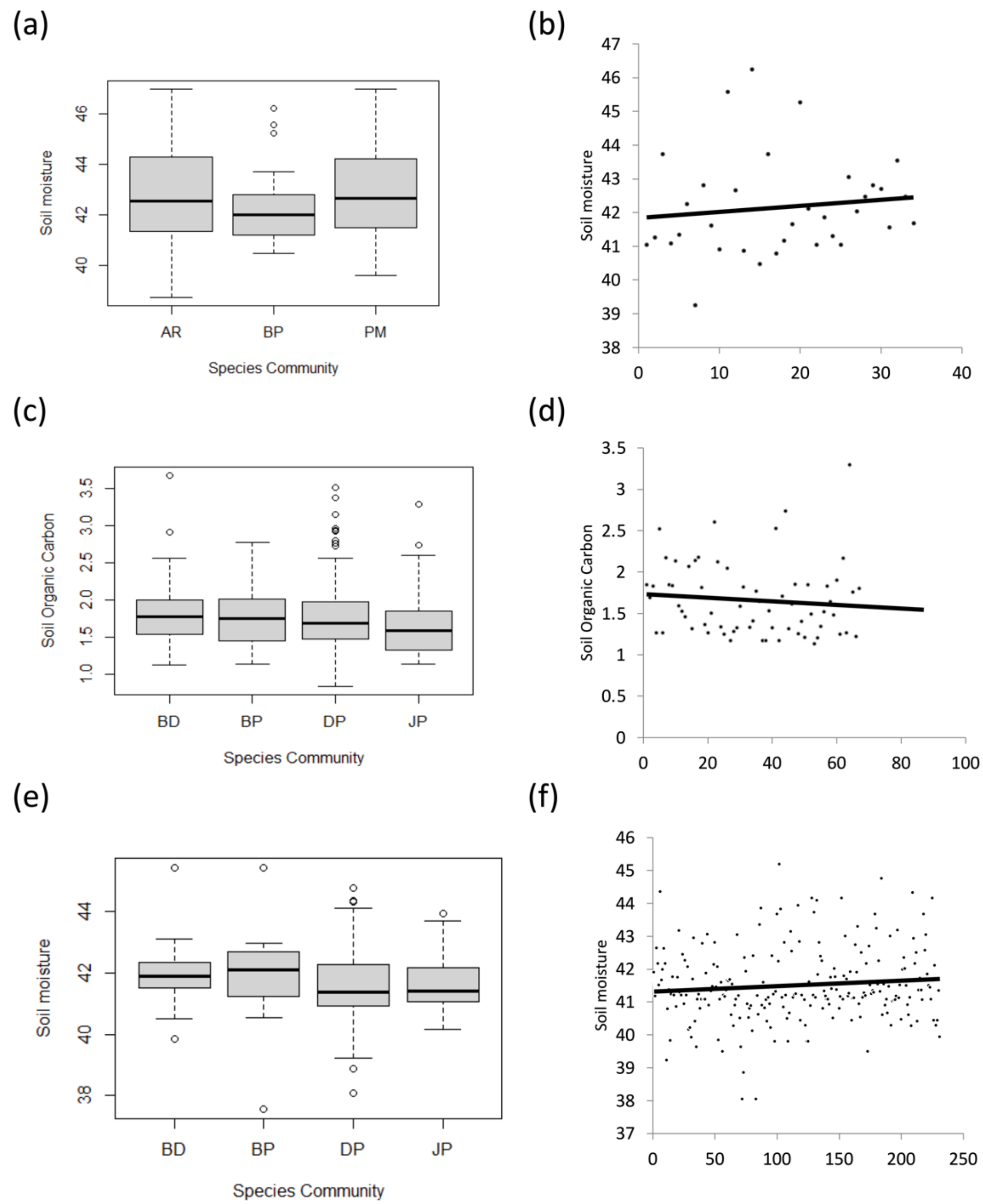

Figure 3.5: Associations between species communities and environmental factors. Scatter points are raw data for significant communities and the lines are predictions from the fitted model. Figure 3.5a and 3.5b represents association between Brachystegia sp.-Pterocarpus angolensis (BP) community and soil moisture; Figure 3.5c and 3.5d represents association between Julbernardia globiflora-Pterocarpus angolensis (JP) community and soil organic carbon; Figure 3.5e and 3.5f represents association between Dalbergia melanoxylon-Pteleopsis myrtifolia (DP) community and soil moisture.

3.4 Discussion

The assemblages of species in ecological communities reflect interactions among organisms as well as between organisms and the abiotic environment. Species composition especially the dominance of species from family Fabaceae and Caesalpiniaceae, are commonly found in woodlands similar to the findings of plant species reported by (Giliba et al., 2011; Mwakalukwa et al., 2014). The higher values of deadwood species richness obtained in this study was attributed to greater employed sampling effort (total study area, number of sample plots, and sizes) as this is in line with other studies documented in dry forests and woodlands (Girmay et al., 2020; Jew et al., 2016). The difference in deadwood species richness obtained from forest and woodland may be attributed to heterogeneity in habitat structure and resource availability as well as environmental and edaphic factors (Mwakalukwa et al., 2014).

The Shannon-Wiener diversity values presented in this study (Table 3.1) are in line with other studies by (Girmay et al., 2020) who reported Shannon-Wiener diversity values ranging from 3.25 to 4.21 but, they are much higher than those of Shirima et al., (2011) who reported the Shannon-Wiener diversity values ranging from 1.05-1.25. High Shannon-Wiener diversity values reported in this study could be attributed to the country-wise coverage of this study as it included a very large sample size. Normally, Shannon-Wiener diversity values range between 1.5 and 4.5 and rarely exceed 5 (Magurran, 2004). A threshold value of 2 has been indicated as minimum value, above which an ecosystem can be regarded as medium to highly diverse. Therefore, the Shannon-Wiener diversity values obtained in this study implies that woodland and forest are highly diverse ecosystems.

The identification of distinct communities provides a deeper understanding of the ecological dynamics and their unique characteristics. The variation in deadwood carbon stock among forest and woodland communities underscores the importance of different species as carbon sinks, with community *Pteleopsis myrtifolia-Milletia sp.* (PM), Figure 3.3A and *Brachystegia spiciformis-Parinari excelsa* (BP), Figure 3.3B standing out as a particularly significant carbon reservoir. The cause of variation in deadwood carbon stock among species communities may be attributed to different micro-climates (Shirima *et al.*, 2011), site-specific environmental conditions and disturbance history (Garbarino *et al.*, 2015; C. W. Woodall *et al.,* 2008).

Many of the ecosystem processes or interactions are related to stand structure rather than species diversity per se (Brockerhoff et al., 2017). With regards to this study, the models showed that species diversity did not have influence on deadwood carbon, but structural diversity such as species abundance and richness have been found to have positive and negative influence on deadwood carbon respectively along environmental factors (Table 3.2; Figure 3.4).The negative relationship between species richness and deadwood carbon could be attributed to small sizes deadwood species encountered in ecosystems. Also, findings highlight that, deadwood carbon had a negative association with soil organic carbon while it was positive for soil moisture. These findings are similar to the study by (Błońska and Lasota, 2017) demonstrating that, accumulation of soil organic carbon and enzyme activity in the soil has influence with deadwood species. Also, (Błońska *et al.,* 2019) discussed that, during deadwood decomposition, carbon is partly emitted to the atmosphere and partly stored as carbon resources in the soil. Therefore, this decreases the amount of deadwood availability which determines the deadwood carbon, with an increase in soil organic matter which is a measure of soil organic carbon. Results are also consistent with the postulate that soil moisture had a positive significant influence on deadwood carbon stock of forest community *Brachystegia sp.-Pterocarpus angolensis* (BP), Figure 3.5A and woodland community *Dalbergia melanoxylon-Pteleopsis myrtifolia* (DP), Figure 3.5B. These findings aligns with the study by (Garbarino et al., 2015) which discussed that, increasing moisture appear to drive not only stand structure but also species composition.

3.5 Conclusion
Understanding patterns of species and community structure within different ecosystems, highlights their ecological significance and potential as indicators for ecosystem health and carbon sequestration capacity. The findings identify distinct communities which provide a deeper understanding of the ecological dynamics and their unique characteristics. Therefore, this study will be useful to inform conservation strategies that prioritize the protection and restoration of high-capacity carbon sequestration ecosystems. Quantification of other factors such as disturbances including fire, on deadwood biomass should be considered towards a clear understanding of the existing carbon dynamics in different vegetation types.

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Conflict of Interest
The authors declare no conflict of interest.

Authors' contributions
All authors have been involved in conceptualizing and designing the study. SNM conducted data analysis, drafted and presented results and discussion, and wrote

the manuscript. DDS and EMZ reviewed the analysis, results and the entire manuscript. All authors read and approved the final manuscript for submission.

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CHAPTER 4

4.0 GENERAL DISCUSSION

The aim of this study was to quantify deadwood carbon stocks in different vegetation types, the relationship between deadwood species structural diversity and deadwood carbon stock along different environmental variables. Results showed that deadwood decay status has influence in deadwood carbon stock estimation. Also, deadwood contributes 0.79% of the total estimated carbon from different vegetation types in Mainland Tanzania. Forests and woodlands exhibited higher levels of deadwood carbon stocks whereby solid deadwoods had higher carbon stocks than rotten deadwoods.

This could be attributed to the accumulation of woody biomass over time and active management practices like sustainable logging and selective tree harvesting. However, it's worth noting that the estimated deadwood carbon stock values in this study were smaller compared to some other studies, possibly due to the prevalence of fire incidents in tropical dry forests and woodlands (Tarimo et al., 2015). The storage of carbon in deadwood has implications for carbon flux estimates, as deadwood decomposition releases carbon dioxide (CO2) into the atmosphere (Hoover and Riddle, 2020).

The findings highlighted that solid deadwood in forests and woodlands had higher emission factors compared to other vegetation types, primarily due to larger biomass and tree density, resulting in more deadwoods available for decomposition. This slower decomposition of solid deadwood contributes to a longer period of carbon release (Blanc et al., 2009). On the other hand, grasslands had lower deadwood emission factors from rotten deadwood due to limited storage time of carbon within it. Also, findings showed higher uncertainty values in carbon and emission factor estimates of rotten deadwood compared to solid deadwood, which are consistent with other studies by Hyvönen et al. (2007), Seibold et al., 2016, and Harmon et al. (2009), highlighting that, the inherent variability in decay rates, decomposition patterns, and spatial-temporal dynamics of rotten deadwood contribute to the increased uncertainty in carbon estimation.
Species diversity and composition were also examined across forest and woodland vegetation type whereby the dominance of species from Fabaceae and Caesalpiniaceae families was similar with previous findings (Giliba et al., 2011; Mwakalukwa et al., 2014) reflecting the typical plant species assemblage in these ecosystems. Additionally, the study reported higher deadwood species richness values, which could be attributed to the extensive sampling effort employed.

The Shannon-Wiener diversity values indicated varying degrees of diversity among ecosystems, with woodlands standing out more highly diverse than forests. Community-level analysis showed that different communities had varying deadwood carbon stocks, suggesting the importance of different species as carbon reservoirs.

In forests and woodlands, species abundance and soil moisture had a positive significant relationship with deadwood carbon while species richness and soil organic carbon had a negative significant relationship with deadwood carbon. This shows that, accumulation of soil organic carbon and enzyme activity in the soil has influence with deadwood tree species (Błońska and Lasota, 2017). Findings also highlighted that, species communities determine the relationship between deadwood carbon, species richness and abundance along soil organic carbon and soil moisture. Therefore, integrating structural components and environmental conditions is vital for comprehensive understanding and effective management of deadwood carbon dynamics in tropical forests and woodland ecosystems.

CHAPTER 5

5.0 KEY CONTRIBUTIONS, CONCLUSION AND RECOMMENDATIONS

5.1 Key Contributions of the Study

The findings will be crucial to policies related in meeting national and international obligations on climate change mitigation, such as contribution of land use sector on national carbon accounting, REDD+ incentive based mechanisms and sustainable management of natural ecosystems.

Moreover, this study sheds light on the importance of deadwood as a carbon pool and in developing management plans and designing protection measures to support biodiversity.

5.2 Conclusion

This study reveals the necessity of accurate assessments considering deadwood decay status and uncertainty estimates, advocating for improved land management to maximize carbon storage potential. On the other hand, the findings highlight the importance of species and community structures as indicators for ecosystem health and carbon sequestration. The relationships between structural components and environmental conditions have consequences on ecosystem properties such as carbon storage and sequestration as well as biodiversity. Thus, integrating these insights is vital for comprehensive understanding and effective management of deadwood carbon dynamics in various vegetation types.

5.3 Recommendations

The findings emphasize the need for more holistic approaches to carbon accounting, considering not only aboveground and belowground carbon but also deadwood components in different ecosystems. Consideration of other factors such as disturbances including fire, on deadwood biomass will be essential towards a clear understanding of the existing deadwood carbon dynamics in different vegetation types.

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APPENDICES

Appendix 1: Checklist of deadwood tree species identified across forest and woodland vegetation type in Mainland Tanzania, showing its family, Species Importance Value Index (SIVI) and corresponding deadwood carbon stock.

Species scientific name	Species code	Family	SIVI	Deadwood C (tC ha^{-1})
Brachystegia sp.	*Brachystsp.*	Caesalpiniaceae	6.66	0.1666
Julbernardia globiflora	*Julbernaglobi*	Fabaceae	4.66	0.1734
Pterocarpus angolensis	*Pterocarangol*	Fabaceae	4.02	0.2662
Brachystegia spiciformis	*Brachystspici*	Caesalpiniaceae	3.33	0.0749
Dalbergia melanoxylon	*Dalbergimelan*	Fabaceae	2.63	0.0612
Brachystegia bussei	*Brachystbusse*	Caesalpiniaceae	2.58	0.1059
Burkea africana	*Burkeaafric*	Caesalpiniaceae	2.21	0.0640
Diplorhynchus condylocarpon	*Diplorhycondy*	Apocynaceae	2.18	0.0176
Combretum zeyheri	*Combretuzeyhe*	Combretaceae	2.02	0.0419
Pteleopsis myrtifolia	*Pteleopsmyrti*	Combretaceae	1.93	0.0385
Pseudolachnostylis maprouneifolia	*Pseudolamapro*	Phyllanthaceae	1.90	0.0359
Combretum molle	*Combretumolle*	Combretaceae	1.69	0.0306
Combretum sp.	*Combretusp.*	Combretaceae	1.65	0.0270
Brachystegia boehmii	*Brachystboehm*	Caesalpiniaceae	1.58	0.0428
Pericopsis angolensis	*Pericopsangol*	Fabaceae	1.41	0.0627
Terminalia sericea	*Terminalseric*	Combretaceae	1.38	0.0257
Anacardium occidentale	*Anacardioccid*	Anacardiaceae	1.31	0.0118
Uapaca kirkiana	*Uapacakirki*	Phyllanthaceae	1.21	0.0325
Terminalia sp.	*Terminalsp.*	Combretaceae	0.97	0.0248
Acacia nigrescens	*Acacianigre*	Fabaceae	0.91	0.0531
Hymenocardia sp.	*Hymenocasp.*	Euphorbiaceae	0.91	0.0032
Acacia sp.	*Acaciasp.*	Fabaceae	0.84	0.0360

Albizia sp.	*Albiziasp.*	Fabaceae	0.81	0.0159
Afzelia quanzensis	*Afzeliaquanz*	Caesalpiniaceae	0.80	0.0612
Markhamia obtusifolia	*Markhamiobtus*	Bignoniaceae	0.80	0.0149
Brachystegia longifolia	*Brachystlongi*	Caesalpiniaceae	0.74	0.0190
Spirostachys africana	*Spirostaafric*	Euphorbiaceae	0.73	0.0229
Combretum collinum	*Combretucolli*	Combretaceae	0.73	0.0200
Markhamia sp.	*Markhamisp.*	Bignoniaceae	0.71	0.0181
Pteleopsis sp.	*Pteleopssp.*	Combretaceae	0.64	0.0087
Xeroderris stuhlmannii	*Xeroderrstuhl*	Fabaceae	0.64	0.0196
Brachystegia microphylla	*Brachystmicro*	Caesalpiniaceae	0.59	0.0202
Acacia robusta	*Acaciarobus*	Fabaceae	0.58	0.0145
Diplorhynchus mossambicensis	*Diplorhymossa*	Apocynaceae	0.58	0.0051
Millettia stuhlmannii	*Millettistuhl*	Fabaceae	0.57	0.0205
Commiphora sp.	*Commiphosp.*	Burseraceae	0.56	0.0080
Brachylaena sp.	*Brachylasp.*	Asteraceae	0.53	0.0084
Uapaca sp.	*Uapacasp.*	Phyllanthaceae	0.49	0.0011
Rhizophora mucronata	*Rhizophomucro*	Rhizophoraceae	0.48	0.0004
Millettia bussei	*Millettibusse*	Fabaceae	0.47	0.0146
Ceriops tagal	*Ceriopstagal*	Rhizophoraceae	0.45	0.0007
Millettia sp.	*Millettisp.*	Fabaceae	0.45	0.0055
Syzygium sp.	*Syzygiumsp.*	Myrtaceae	0.45	0.0132
Avicennia marina	*Avicennimarin*	Acanthaceae	0.44	0.0009
Ocotea usambarensis	*Ocoteausamb*	Lauraceae	0.44	0.0707
Markhamia lutea	*Markhamilutea*	Bignoniaceae	0.42	0.0032
Pterocarpus tinctorius	*Pterocartinct*	Fabaceae	0.42	0.0225
Terminalia sambesiaca	*Terminalsambe*	Combretaceae	0.42	0.0356
Commiphora africana	*Commiphoafric*	Burseraceae	0.41	0.0048
Hymenocardia ulmoides	*Hymenocaulmoi*	Euphorbiaceae	0.41	0.0058

Terminalia brownii	*Terminalbrown*	Combretaceae	0.41	0.0155
Annona senegalensis	*Annonaseneg*	Annonaceae	0.40	0.0076
Crossopteryx febrifuga	*Crossoptfebri*	Rubiaceae	0.40	0.0045
Combretum imberbe	*Combretuimber*	Combretaceae	0.38	0.0687
Lonchocarpus sp.	*Lonchocasp.*	Fabaceae	0.38	0.0080
Acacia polyacantha	*Acaciapolya*	Fabaceae	0.37	0.0169
Terminalia mollis	*Terminalmolli*	Combretaceae	0.37	0.0047
Albizia harveyi	*Albiziaharve*	Fabaceae	0.36	0.0028
Grewia sp.	*Grewiasp.*	Malvaceae	0.36	0.0065
Pterocarpus sp.	*Pterocarsp.*	Fabaceae	0.34	0.0164
Scorodophloeus fischeri	*Scorodopfisch*	Fabaceae	0.33	0.0079
Syzygium cordatum	*Syzygiumcorda*	Myrtaceae	0.33	0.0147
Isoberlinia globiflora	*Isoberliglobi*	Fabaceae	0.32	0.0103
Julbernardia magnistipulata	*Julbernamagni*	Fabaceae	0.31	0.0014
Parinari excelsa	*Parinariexcel*	Chrysobalanaceae	0.31	0.0225
Burkea sp.	*Burkeasp.*	Caesalpiniaceae	0.30	0.0082
Combretum melchiorianum	*Combretumelch*	Combretaceae	0.30	0.0031
Julbernardia sp.	*Julbernasp.*	Fabaceae	0.29	0.0128
Sclerocarya birrea	*Sclerocabirre*	Anacardiaceae	0.28	0.0115
Pterocarpus rotundifolius	*Pterocarrotun*	Fabaceae	0.27	0.0020
Pseudolachnostylis sp.	*Pseudolasp.*	Phyllanthaceae	0.26	0.0063
Swartzia madagascariensis	*Swartziamadag*	Fabaceae	0.26	0.0068
Baphia kirkii	*Baphiakirki*	Fabaceae	0.25	0.0099
Parinari sp.	*Parinarisp.*	Chrysobalanaceae	0.24	0.0011
Tamarindus indica	*Tamarindindic*	Fabaceae	0.22	0.0095
Piliostigma thonningii	*Piliostithonn*	Fabaceae	0.21	0.0026
Syzygium guineense	*Syzygiumguine*	Myrtaceae	0.21	0.0032
Combretum adenogonium	*Combretuadeno*	Combretaceae	0.20	0.0008

Commiphora eminii	*Commiphoemini*	Burseraceae	0.20	0.0115
Albizia versicolor	*Albiziaversi*	Fabaceae	0.20	0.0106
Lonchocarpus capassa	*Lonchocacapas*	Fabaceae	0.20	0.0044
Parinari curatellifolia	*Parinaricurat*	Chrysobalanaceae	0.20	0.0056
Pterocarpus chrysothrix	*Pterocarchrys*	Fabaceae	0.20	0.0074
Stereospermum kunthianum	*Stereospkunth*	Bignoniaceae	0.20	0.0073
Albizia gummifera	*Albiziagummi*	Fabaceae	0.19	0.0120
Manilkara mochisia	*Manilkarmochi*	Sapotaceae	0.19	0.0058
Monotes adenophyllus	*Monotesadeno*	Dipterocarpaceae	0.19	0.0037
Millettia dura	*Millettidura*	Fabaceae	0.18	0.0080
Pericopsis sp.	*Pericopssp.*	Fabaceae	0.18	0.0049
Sterculia sp.	*Sterculisp.*	Malvaceae	0.17	0.0020
Brachylaena hutchinsii	*Brachylahutch*	Asteraceae	0.17	0.0077
Diospyros sp.	*Diospyrosp.*	Ebenaceae	0.17	0.0036
Diplorhynchus sp.	*Diplorhysp.*	Apocynaceae	0.17	0.0018
Strychnos innocua	*Strychnoinnoc*	Loganiaceae	0.17	0.0251
Uapaca nitida	*Uapacanitid*	Phyllanthaceae	0.17	0.0038
Xylocarpus granatum	*Xylocarpgrana*	Meliaceae	0.17	0.0003
Dialium holtzii	*Dialiumholtz*	Fabaceae	0.16	0.0018
Grewia bicolor	*Grewiabicol*	Malvaceae	0.16	0.0060
Acacia tortilis	*Acaciatorti*	Fabaceae	0.15	0.0080
Isoberlinia sp.	*Isoberlisp.*	Fabaceae	0.15	0.0047
Dalbergia sp.	*Dalbergisp.*	Fabaceae	0.15	0.0015
Dombeya rotundifolia	*Dombeyarotun*	Malvaceae	0.15	0.0022
Lonchocarpus eriocalyx	*Lonchocaerioc*	Fabaceae	0.15	0.0057
Acacia xanthophloea	*Acaciaxanth*	Fabaceae	0.14	0.0206
Albizia petersiana	*Albiziapeter*	Fabaceae	0.14	0.0012
Cassia abbreviata	*Cassiaabbre*	Fabaceae	0.14	0.0027

Diospyros mespiliformis	*Diospyromespi*	Ebenaceae	0.14	0.0259
Sclerocarya sp.	*Sclerocasp.*	Anacardiaceae	0.14	0.0017
Strychnos sp.	*Strychnosp.*	Loganiaceae	0.14	0.0015
Vitex sp.	*Vitexsp.*	Lamiaceae	0.14	0.0007
Bersama abyssinica	*Bersamaabyss*	Melianthaceae	0.13	0.0049
Ozoroa insignis	*Ozoroainsig*	Anacardiaceae	0.13	0.0028
Vitex doniana	*Vitexdonia*	Lamiaceae	0.13	0.0065
Acacia nilotica	*Acacianilot*	Fabaceae	0.13	0.0028
Bridelia melanthesoides	*Brideliamelan*	Euphorbiaceae	0.13	0.0041
Cassia sp.	*Cassiasp.*	Fabaceae	0.13	0.0007
Erythrophleum africanum	*Erythropafric*	Fabaceae	0.13	0.0024
Millettia lasiantha	*Millettilasia*	Fabaceae	0.13	0.0013
Millettia micans	*Millettimican*	Fabaceae	0.13	0.0030
Stereospermum sp.	*Stereospsp.*	Bignoniaceae	0.13	0.0020
Bridelia sp.	*Brideliasp.*	Euphorbiaceae	0.12	0.0006
Dalbergia nitidula	*Dalberginitid*	Fabaceae	0.12	0.0016
Dombeya sp.	*Dombeyasp.*	Malvaceae	0.12	0.0014
Ochna sp.	*Ochnasp.*	Ochnaceae	0.12	0.0091
Bridelia micrantha	*Brideliamicra*	Euphorbiaceae	0.11	0.0030
Catunaregam spinosa	*Catunarespino*	Rubiaceae	0.11	0.0005
Hyphaene ventricosa	*Hyphaeneventr*	Arecaceae	0.11	0.0083
Margaritaria discoidea	*Margaritdisco*	Euphorbiaceae	0.11	0.0002
Markhamia platycalyx	*Markhamiplaty*	Bignoniaceae	0.11	0.0011
Senna singueana	*Sennasingu*	Fabaceae	0.11	0.0012
Celtis sp.	*Celtissp.*	Cannabaceae	0.10	0.0018
Dichrostachys cinerea	*Dichrostciner*	Fabaceae	0.10	0.0030
Diospyros zambensis	*Diospyrozambe*	Ebenaceae	0.10	0.0003
Lonchocarpus bussei	*Lonchocabusse*	Fabaceae	0.10	0.0023

Securinega virosa	*Securineviros*	Euphorbiaceae	0.10	0.0005
Sterculia quinqueloba	*Sterculiquinq*	Malvaceae	0.10	0.0048
Terminalia spinosa	*Terminalspino*	Combretaceae	0.10	0.0008
Acacia mellifera	*Acaciamelli*	Fabaceae	0.10	0.0048
Combretum fragrans	*Combretufragr*	Combretaceae	0.10	0.0028
Deinbollia borbonica	*Deinbollborbo*	Sapindaceae	0.10	0.0007
Erythrophleum suaveolens	*Erythropsuave*	Fabaceae	0.10	0.0036
Eucalyptus sp.	*Eucalyptsp.*	Myrtaceae	0.10	0.0112
Albizia antunesiana	*Albiziaantun*	Fabaceae	0.09	0.0027
Bridelia cathartica	*Brideliacatha*	Euphorbiaceae	0.09	0.0004
Diospyros consulatae	*Diospyroconsu*	Ebenaceae	0.09	0.0058
Grewia goetzeana	*Grewiagoetz*	Malvaceae	0.09	0.0013
Macaranga kilimandscharica	*Macarangkilim*	Euphorbiaceae	0.09	0.0027
Manilkara sulcata	*Manilkarsulca*	Sapotaceae	0.09	0.0025
Pseudolachnostylis glauca	*Pseudolaglauc*	Phyllanthaceae	0.09	0.0004
Strychnos spinosa	*Strychnospino*	Loganiaceae	0.09	0.0005
Tabernaemontana pachysiphon	*Tabernaepachy*	Apocynaceae	0.09	0.0025
Albizia zimmermannii	*Albiziazimme*	Fabaceae	0.08	0.0061
Boscia salicifolia	*Bosciasalic*	Capparaceae	0.08	0.0022
Combretum coriifolium	*Combretucorii*	Combretaceae	0.08	0.0034
Funtumia africana	*Funtumiaafric*	Apocynaceae	0.08	0.0014
Lannea schimperi	*Lanneaschim*	Anacardiaceae	0.08	0.0008
Markhamia zanzibarica	*Markhamizanzi*	Bignoniaceae	0.08	0.0038
Memecylon sp.	*Memecylosp.*	Melastomataceae	0.08	0.0002
Monotes africana	*Monotesafric*	Dipterocarpaceae	0.08	0.0053
Pittosporum viridiflorum	*Pittospovirid*	Pittosporaceae	0.08	0.0036
Psydrax sp.	*Psydraxsp.*	Rubiaceae	0.08	0.0047
Sideroxylon inerme	*Sideroxyinerm*	Sapotaceae	0.08	0.0026

Tabernaemontana sp.	*Tabernaesp.*	Apocynaceae	0.08	0.0011
Terminalia kilimandscharica	*Terminalkilim*	Combretaceae	0.08	0.0015
Albizia anthelmintica	*Albiziaanthe*	Fabaceae	0.08	0.0012
Baphiopsis sp.	*Baphiopssp.*	Fabaceae	0.08	0.0025
Barringtonia racemosa	*Barringtracem*	Lecythidaceae	0.08	0.0001
Bombax rhodognaphalon	*Bombaxrhodo*	Bombacaceae	0.08	0.0018
Cocos nucifera	*Cocosnucif*	Arecaceae	0.08	0.0068
Combretum hereroense	*Combretuherer*	Combretaceae	0.08	0.0006
Isoberlinia tomentosa	*Isoberlitomen*	Fabaceae	0.08	0.0028
Mangifera indica	*Mangiferindic*	Anacardiaceae	0.08	0.0019
Milicia excelsa	*Miliciaexcel*	Moraceae	0.08	0.0169
Sterculia africana	*Sterculiafric*	Malvaceae	0.08	0.0030
Acacia melanoxylon	*Acaciamelan*	Fabaceae	0.07	0.0018
Diospyros fischeri	*Diospyrofisch*	Ebenaceae	0.07	0.0008
Erythrina abyssinica	*Erythrinabyss*	Fabaceae	0.07	0.0014
Ficus sp.	*Ficussp.*	Moraceae	0.07	0.0023
Millettia usaramensis	*Millettiusara*	Fabaceae	0.07	0.0019
Mimusops kummel	*Mimusopskumme*	Sapotaceae	0.07	0.0025
Newtonia buchananii	*Newtoniabucha*	Fabaceae	0.07	0.0038
Ochna densicoma	*Ochnadensi*	Ochnaceae	0.07	0.0010
Ozoroa sp.	*Ozoroasp.*	Anacardiaceae	0.07	0.0012
Pterocarpus mildbraedii	*Pterocarmildb*	Fabaceae	0.07	0.0007
Securidaca longipedunculata	*Securidalongi*	Fabaceae	0.07	0.0002
Zanthoxylum chalybeum	*Zanthoxychaly*	Rutaceae	0.07	0.0019
Acacia mangium	*Acaciamangi*	Fabaceae	0.06	0.0088
Albizia adianthifolia	*Albiziaadian*	Fabaceae	0.06	0.0004
Antidesma membranaceum	*Antidesmmembr*	Euphorbiaceae	0.06	0.0024
Brachystegia floribunda	*Brachystflori*	Caesalpiniaceae	0.06	0.0025

Bruguiera gymnorhiza	*Bruguiergymno*	Rhizophoraceae	0.06	0.0014
Catunaregam sp.	*Catunaresp.*	Rubiaceae	0.06	0.0002
Combretum schumannii	*Combretuschum*	Combretaceae	0.06	0.0028
Croton pseudopulchellus	*Crotonpseud*	Euphorbiaceae	0.06	0.0000
Euphorbia candelabrum	*Euphorbicande*	Euphorbiaceae	0.06	0.0008
Isoberlinia angolensis	*Isoberliangol*	Fabaceae	0.06	0.0004
Lannea schweinfurthii	*Lanneaschwe*	Anacardiaceae	0.06	0.0005
Maprounea africana	*Maprouneafric*	Euphorbiaceae	0.06	0.0002
Pittosporum sp.	*Pittosposp.*	Pittosporaceae	0.06	0.0022
Vangueria sp.	*Vanguerisp.*	Rubiaceae	0.06	0.0002
Afzelia sp.	*Afzeliasp.*	Caesalpiniaceae	0.06	0.0015
Bauhinia petersiana	*Bauhiniapeter*	Fabaceae	0.06	0.0003
Cassipourea malosana	*Cassipoumalos*	Rhizophoraceae	0.06	0.0013
Combretum binderianum	*Combretubinde*	Combretaceae	0.06	0.0009
Commiphora ugogensis	*Commiphougoge*	Burseraceae	0.06	0.0001
Crossopteryx sp.	*Crossoptsp.*	Rubiaceae	0.06	0.0007
Ficalhoa laurifolia	*Ficalhoalauri*	Theacea	0.06	0.0108
Manilkara sp.	*Manilkarsp.*	Sapotaceae	0.06	0.0019
Ochna holstii	*Ochnaholst*	Ochnaceae	0.06	0.0002
Protea kilimandscharica	*Proteakilim*	Proteaceae	0.06	0.0138
Rinorea sp.	*Rinoreasp.*	Violaceae	0.06	0.0027
Sorindeia madagascariensis	*Sorindeimadag*	Anacardiaceae	0.06	0.0005
Acacia senegal	*Acaciaseneg*	Fabaceae	0.05	0.0018
Brachylaena huillensis	*Brachylahuill*	Asteraceae	0.05	0.0015
Dombeya shupangae	*Dombeyashupa*	Malvaceae	0.05	0.0008
Gyrocarpus americanus	*Gyrocarpameri*	Hernandiaceae	0.05	0.0025
Sonneratia alba	*Sonneratalba*	Lythraceae	0.05	0.0004
Strychnos volkensii	*Strychnovolke*	Loganiaceae	0.05	0.0006

Acacia drepanolobium	*Acaciadrepa*	Fabaceae	0.04	0.0005
Acalypha fruticosa	*Acalyphafruti*	Euphorbiaceae	0.04	0.0016
Albizia schimperiana	*Albiziaschim*	Fabaceae	0.04	0.0016
Aphloia theiformis	*Aphloiatheif*	Aphloiaceae	0.04	0.0004
Balanites aegyptiaca	*Balaniteaegyp*	Balanitaceae	0.04	0.0007
Brachystegia allenii	*Brachystallen*	Caesalpiniaceae	0.04	0.0004
Chrysophyllum perpulchrum	*Chrysophperpu*	Sapotaceae	0.04	0.0041
Commiphora mollis	*Commiphomolli*	Burseraceae	0.04	0.0007
Dalbergia boehmii	*Dalbergiboehm*	Fabaceae	0.04	0.0021
Euclea divinorum	*Eucleadivin*	Ebenaceae	0.04	0.0003
Haplocoelum inoploeum	*Haplocoeinopl*	Sapindaceae	0.04	0.0007
Harrisonia abyssinica	*Harrisonabyss*	Rutaceae	0.04	0.0006
Hymenaea verrucosa	*Hymenaeaverru*	Fabaceae	0.04	0.0011
Hymenodictyon floribundum	*Hymenodiflori*	Rubiaceae	0.04	0.0001
Lannea sp.	*Lanneasp.*	Anacardiaceae	0.04	0.0008
Macaranga capensis	*Macarangcapen*	Euphorbiaceae	0.04	0.0003
Maytenus sp.	*Maytenussp.*	Celastraceae	0.04	0.0007
Multidentia crassa	*Multidencrass*	Rubiaceae	0.04	0.0004
Ozoroa obovata	*Ozoroaobova*	Anacardiaceae	0.04	0.0002
Uvariodendron sp.	*Uvariodesp.*	Annonaceae	0.04	0.0000
Zanha africana	*Zanhaafric*	Sapindaceae	0.04	0.0008
Albizia amara	*Albiziaamara*	Fabaceae	0.03	0.0010
Antiaris toxicaria	*Antiaristoxic*	Moraceae	0.03	0.0011
Brachystegia tamarindoides	*Brachysttamar*	Caesalpiniaceae	0.03	0.0012
Byrsocarpus boivinianus	*Byrsocarboivi*	Connaraceae	0.03	0.0007
Byrsocarpus orientalis	*Byrsocarorien*	Connaraceae	0.03	0.0004
Cassipourea gummiflua	*Cassipougummi*	Rhizophoraceae	0.03	0.0013
Combretum ternifolium	*Combretuterni*	Combretaceae	0.03	0.0005

Croton dictyophlebodes	*Crotondicty*	Euphorbiaceae	0.03	0.0007
Cussonia arborea	*Cussoniaarbor*	Araliaceae	0.03	0.0003
Diospyros kirkii	*Diospyrokirki*	Ebenaceae	0.03	0.0001
Drypetes gerrardii	*Drypetesgerra*	Euphorbiaceae	0.03	0.0024
Ficus sycomorus	*Ficussycom*	Moraceae	0.03	0.0007
Gardenia sp.	*Gardeniasp.*	Rubiaceae	0.03	0.0052
Hymenocardia acida	*Hymenocaacida*	Euphorbiaceae	0.03	0.0001
Hymenodictyon sp.	*Hymenodisp.*	Rubiaceae	0.03	0.0004
Khaya anthotheca	*Khayaantho*	Meliaceae	0.03	0.0046
Lecaniodiscus fraxinifolius	*Lecaniodfraxi*	Sapindaceae	0.03	0.0003
Maesa lanceolata	*Maesalance*	Primulaceae	0.03	0.0074
Millettia aeriocarpa	*Millettiaerio*	Fabaceae	0.03	0.0005
Millettia oblata	*Millettioblat*	Fabaceae	0.03	0.0003
Mimusops sp.	*Mimusopssp.*	Sapotaceae	0.03	0.0009
Ormocarpum sp.	*Ormocarpsp.*	Fabaceae	0.03	0.0000
Pachystela msolo	*Pachystemsolo*	Sapotaceae	0.03	0.0041
Piliostigma sp.	*Piliostisp.*	Fabaceae	0.03	0.0003
Polyscias fulva	*Polysciafulva*	Araliaceae	0.03	0.0002
Psydrax kaessneri	*Psydraxkaess*	Rubiaceae	0.03	0.0003
Rourea orientalis	*Roureaorien*	Connaraceae	0.03	0.0003
Senna sp.	*Sennasp.*	Fabaceae	0.03	0.0001
Teclea nobilis	*Tecleanobil*	Rutaceae	0.03	0.0001
Vitex strickeri	*Vitexstric*	Lamiaceae	0.03	0.0024
Acacia hockii	*Acaciahocki*	Fabaceae	0.03	0.0002
Acacia seyal	*Acaciaseyal*	Fabaceae	0.03	0.0002
Afrosersalicia cerasifera	*Afrosersceras*	Sapotaceae	0.03	0.0017
Anacardium sp.	*Anacardisp.*	Anacardiaceae	0.03	0.0002
Annona sp.	*Annonasp.*	Annonaceae	0.03	0.0003

Antiaris sp.	*Antiarissp.*	Moraceae	0.03	0.0006
Baphia sp.	*Baphiasp.*	Fabaceae	0.03	0.0003
Borassus aethiopum	*Borassusaethi*	Arecaceae	0.03	0.0002
Bridelia salviifolia	*Brideliasalvi*	Euphorbiaceae	0.03	0.0000
Chrysophyllum zimmermannii	*Chrysophzimme*	Sapotaceae	0.03	0.0004
Combretum grandifolium	*Combretugrand*	Combretaceae	0.03	0.0046
Combretum psidioides	*Combretupsidi*	Combretaceae	0.03	0.0001
Dichapetalum stuhlmannii	*Dichapetstuhl*	Dichapetalaceae	0.03	0.0005
Dombeya kirkii	*Dombeyakirki*	Sterculiaceae	0.03	0.0012
Erythrina sacleuxii	*Erythrinsacle*	Fabaceae	0.03	0.0003
Grewia similis	*Grewiasimil*	Malvaceae	0.03	0.0000
Heritiera littoralis	*Heritierlitto*	Malvaceae	0.03	0.0003
Lannea welwitschii	*Lanneawelwi*	Anacardiaceae	0.03	0.0004
Lecaniodiscus vaughaniae	*Lecaniodvaugh*	Sapindaceae	0.03	0.0034
Lotus sp.	*Lotussp.*	Fabaceae	0.03	0.0004
Manilkara obovata	*Manilkarobova*	Sapotaceae	0.03	0.0010
Millettia alata	*Millettialata*	Fabaceae	0.03	0.0000
Rhodognaphalon sp.	*Rhodognasp.*	Bombacaceae	0.03	0.0008
Sapium sp.	*Sapiumsp.*	Euphorbiaceae	0.03	0.0002
Schrebera trichoclada	*Schrebertrich*	Oleaceae	0.03	0.0005
Suregada zanzibarensis	*Suregadazanzi*	Euphorbiaceae	0.03	0.0001
Tarenna sp.	*Tarennasp.*	Rubiaceae	0.03	0.0002
Vangueria infausta	*Vangueriinfau*	Rubiaceae	0.03	0.0001
Xeroderris sp.	*Xeroderrsp.*	Fabaceae	0.03	0.0002
Acacia tanganyikensis	*Acaciatanga*	Fabaceae	0.02	0.0014
Allophylus sp.	*Allophylsp.*	Sapindaceae	0.02	0.0003
Anisophyllea sp.	*Anisophysp.*	Anisophylleaceae	0.02	0.0005
Anthocleista grandiflora	*Anthoclegrand*	Gentianaceae	0.02	0.0000

Antidesma venosum	*Antidesmvenos*	Euphorbiaceae	0.02	0.0013
Clausena anisata	*Clausenaanisa*	Rutaceae	0.02	0.0001
Cleistanthus sp.	*Cleistansp.*	Euphorbiaceae	0.02	0.0004
Combretum obovatum	*Combretuobova*	Combretaceae	0.02	0.0007
Commiphora boliviana	*Commiphoboliv*	Burseraceae	0.02	0.0000
Commiphora zimmermannii	*Commiphozimme*	Burseraceae	0.02	0.0003
Cordyla sp.	*Cordylasp.*	Fabaceae	0.02	0.0003
Cussonia zimmermannii	*Cussoniazimme*	Araliaceae	0.02	0.0067
Cynometra webberi	*Cynometrwebbe*	Fabaceae	0.02	0.0371
Diospyros usambarensis	*Diospyrousamb*	Ebenaceae	0.02	0.0000
Dobera loranthifolia	*Doberaloran*	Salvadoraceae	0.02	0.0002
Entada abyssinica	*Entadaabyss*	Fabaceae	0.02	0.0003
Erythroxylum emarginatum	*Erythroxemarg*	Erythroxylaceae	0.02	0.0002
Euclea sp.	*Eucleasp.*	Ebenaceae	0.02	0.0006
Flacourtia sp.	*Flacourtsp.*	Salicaceae	0.02	0.0001
Holarrhena febrifuga	*Holarrhefebri*	Apocynaceae	0.02	0.0001
Lannea stuhlmannii	*Lanneastuhl*	Anacardiaceae	0.02	0.0005
Lecaniodiscus mildbraedii	*Lecaniodmildb*	Rhamnaceae	0.02	0.0000
Lettowianthus stellatus	*Lettowiastell*	Annonaceae	0.02	0.0002
Macaranga sp.	*Macarangsp.*	Euphorbiaceae	0.02	0.0001
Maprounea sp.	*Maprounesp.*	Euphorbiaceae	0.02	0.0000
Memecylon brenanii	*Memecylobrena*	Melastomataceae	0.02	0.0002
Millettia sacleuxii	*Millettisacle*	Fabaceae	0.02	0.0001
Monotes sp.	*Monotessp.*	Dipterocarpaceae	0.02	0.0000
Ocotea sp.	*Ocoteasp.*	Lauraceae	0.02	0.0011
Podocarpus falcatus	*Podocarpfalca*	Podocarpaceae	0.02	0.0013
Protea rubrobracteata	*Protearubro*	Proteaceae	0.02	0.0002
Pseudocyclosorus pulcher	*Pseudocypulch*	Thelypteridaceae	0.02	0.0000

Sapindus sp.	*Sapindussp.*	Sapindaceae	0.02	0.0002
Scorodophloeus sp.	*Scorodopsp.*	Fabaceae	0.02	0.0001
Spirostachys sp.	*Spirostasp.*	Euphorbiaceae	0.02	0.0004
Strychnos cocculoides	*Strychnococcu*	Loganiaceae	0.02	0.0001
Strychnos potatorum	*Strychnopotat*	Loganiaceae	0.02	0.0019
Syzygium owariensis	*Syzygiumowari*	Myrtaceae	0.02	0.0000
Syzygium parvulum	*Syzygiumparvu*	Myrtaceae	0.02	0.0001
Tabernaemontana stapfiana	*Tabernaestapf*	Apocynaceae	0.02	0.0019
Tarchonanthus camphoratus	*Tarchonacamph*	Asteraceae	0.02	0.0001
Tarenna nigrescens	*Tarennanigre*	Rubiaceae	0.02	0.0002
Trema orientalis	*Tremaorien*	Cannabaceae	0.02	0.0001
Vismia orientalis	*Vismiaorien*	Hypericaceae	0.02	0.0003
Vitex mombassae	*Vitexmomba*	Verbenaceae	0.02	0.0015
Ximenia caffra	*Ximeniacaffr*	Olacaceae	0.02	0.0002
Xylopia collina	*Xylopiacolli*	Annonaceae	0.02	0.0001
Ziziphus mucronata	*Ziziphusmucro*	Rhamnaceae	0.02	0.0002
Acacia clavigera	*Acaciaclavi*	Fabaceae	0.01	0.0002
Adansonia digitata	*Adansonidigit*	Bombacaceae	0.01	0.0004
Afromosia angolensis	*Afromosiangol*	Fabaceae	0.01	0.0000
Agauria salicifolia	*Agauriasalic*	Ericaceae	0.01	0.0005
Allophylus abyssinicus	*Allophylabyss*	Sapindaceae	0.01	0.0003
Alsodeiopsis usambarensis	*Alsodeiousamb*	Icacinaceae	0.01	0.0001
Antidesma sp.	*Antidesmsp.*	Euphorbiaceae	0.01	0.0000
Araucaria cunnighamii	*Araucaricunni*	Araucariaceae	0.01	0.0000
Bauhinia sp.	*Bauhiniasp.*	Fabaceae	0.01	0.0000
Beilschmiedia kweo	*Beilschmkweo*	Lauraceae	0.01	0.0020
Bersama sp.	*Bersamasp.*	Melianthaceae	0.01	0.0009
Borassus sp.	*Borassussp.*	Arecaceae	0.01	0.0020

Boscia mossambicensis	*Bosciamossa*	Capparaceae	0.01	0.0001
Boscia sp.	*Bosciasp.*	Capparaceae	0.01	0.0000
Bridelia brideliifolia	*Brideliabride*	Euphorbiaceae	0.01	0.0000
Bridelia duvigneaudii	*Brideliaduvig*	Euphorbiaceae	0.01	0.0000
Byrsocarpus sp.	*Byrsocarsp.*	Connaraceae	0.01	0.0001
Carpodiptera africana	*Carpodipafric*	Tiliaceae	0.01	0.0015
Cleistanthus polystachyus	*Cleistanpolys*	Euphorbiaceae	0.01	0.0001
Coffea sp.	*Coffeasp.*	Rubiaceae	0.01	0.0001
Combretum apiculatum	*Combretuapicu*	Combretaceae	0.01	0.0002
Combretum schweinfurthii	*Combretuschwe*	Combretaceae	0.01	0.0001
Corchorus sp.	*Corchorusp.*	Tiliaceae	0.01	0.0008
Cordia africana	*Cordiaafric*	Boraginaceae	0.01	0.0001
Craibia brevicaudata	*Craibiabrevi*	Fabaceae	0.01	0.0002
Craibia brownii	*Craibiabrown*	Fabaceae	0.01	0.0005
Croton sp.	*Crotonsp.*	Euphorbiaceae	0.01	0.0001
Diospyros abyssinica	*Diospyroabyss*	Ebenaceae	0.01	0.0000
Diospyros squarrosa	*Diospyrosquar*	Ebenaceae	0.01	0.0001
Diplorstachysin africana	*Diplorstafric*	Burseraceae	0.01	0.0003
Dombeya cincinnata	*Dombeyacinci*	Malvaceae	0.01	0.0000
Drypetes sp.	*Drypetessp.*	Euphorbiaceae	0.01	0.0001
Elaeis guineensis	*Elaeisguine*	Arecaceae	0.01	0.0015
Eucalyptus cloezina	*Eucalyptcloez*	Myrtaceae	0.01	0.0000
Gnidia sp.	*Gnidiasp.*	Thymelaeaceae	0.01	0.0000
Gomphia sacleuxii	*Gomphiasacle*	Ochnaceae	0.01	0.0001
Grewia forbesii	*Grewiaforbe*	Malvaceae	0.01	0.0000
Grewia tenax	*Grewiatenax*	Malvaceae	0.01	0.0001
Hagenia abyssinica	*Hageniaabyss*	Rosaceae	0.01	0.0017
Holarrhena pubescens	*Holarrhepubes*	Apocynaceae	0.01	0.0000

Holarrhena sp.	*Holarrhesp.*	Apocynaceae	0.01	0.0000
Hymenocardia mollis	*Hymenocamolli*	Euphorbiaceae	0.01	0.0001
Hyphaene coriacea	*Hyphaenecoria*	Arecaceae	0.01	0.0001
Hyphaene sp.	*Hyphaenesp.*	Arecaceae	0.01	0.0003
Kigelia africana	*Kigeliaafric*	Bignoniaceae	0.01	0.0031
Lannea amaniensis	*Lanneaamani*	Anacardiaceae	0.01	0.0001
Lannea humilis	*Lanneahumil*	Anacardiaceae	0.01	0.0004
Margaritaria sp.	*Margaritsp.*	Euphorbiaceae	0.01	0.0013
Markhamia acuminata	*Markhamiacumi*	Bignoniaceae	0.01	0.0002
Mundulea sericea	*Munduleaseric*	Fabaceae	0.01	0.0000
Myrianthus arboreus	*Myriantharbor*	Urticaceae	0.01	0.0001
Pappea capensis	*Pappeacapen*	Sapindaceae	0.01	0.0014
Persea americana	*Perseaameri*	Lauraceae	0.01	0.0006
Pinus patula	*Pinuspatul*	Pinaceae	0.01	0.0000
Podocarpus gracilior	*Podocarpgraci*	Podocarpaceae	0.01	0.0019
Podocarpus sp.	*Podocarpsp.*	Podocarpaceae	0.01	0.0007
Podocarpus usambarensis	*Podocarpusamb*	Podocarpaceae	0.01	0.0002
Rauvolfia caffra	*Rauvolficaffr*	Apocynaceae	0.01	0.0000
Rhamnus prinoides	*Rhamnusprino*	Rhamnaceae	0.01	0.0025
Rhizophora sp.	*Rhizophosp.*	Rhizophoraceae	0.01	0.0000
Rhus natalensis	*Rhusnatal*	Anacardiaceae	0.01	0.0000
Salvadora persica	*Salvadorpersi*	Salvadoraceae	0.01	0.0003
Sterculia appendiculata	*Sterculiappen*	Malvaceae	0.01	0.0017
Tabernaemontana usambarensis	*Tabernaeusamb*	Apocynaceae	0.01	0.0001
Treculia africana	*Treculiaafric*	Moraceae	0.01	0.0002
Treculia sp.	*Treculiasp.*	Moraceae	0.01	0.0028
Vangueriopsis lanciflora	*Vanguerilanci*	Rubiaceae	0.01	0.0000
Vepris stolzii	*Veprisstolz*	Rutaceae	0.01	0.0000

Vernonia subuligera	*Vernoniasubul*	Asteraceae	0.01	0.0002
Vitex fischeri	*Vitexfisch*	Lamiaceae	0.01	0.0000
Vitex keniensis	*Vitexkenie*	Lamiaceae	0.01	0.0009
Ximenia americana	*Ximeniaameri*	Olacaceae	0.01	0.0002
Ximenia sp.	*Ximeniasp.*	Olacaceae	0.01	0.0029
Acacia abbreviata	*Acaciaabbre*	Fabaceae	0.01	0.0018
Acacia gerrardii	*Acaciagerra*	Mimosaceae	0.01	0.0000
Acacia sieberiana	*Acaciasiebe*	Fabaceae	0.01	0.0000
Aeschynomene sp.	*Aeschynosp.*	Fabaceae	0.01	0.0000
Anisophyllea boehmii	*Anisophyboehm*	Anisophylleaceae	0.01	0.0001
Baphiopsis stuhlmannii	*Baphiopsstuhl*	Fabaceae	0.01	0.0001
Barringtonia sp.	*Barringtsp.*	Lecythidaceae	0.01	0.0001
Bauhinia thonningii	*Bauhiniathonn*	Caesalpiniaceae	0.01	0.0000
Boscia angustifolia	*Bosciaangus*	Capparaceae	0.01	0.0002
Breonadia salicina	*Breonadisalic*	Rubiaceae	0.01	0.0003
Caloncoba sp.	*Caloncobsp.*	Flacourtiaceae	0.01	0.0001
Caloncoba welwitschii	*Caloncobwelwi*	Flacourtiaceae	0.01	0.0001
Calycosiphonia spathicalyx	*Calycosispath*	Rubiaceae	0.01	0.0001
Cassipourea mollis	*Cassipoumolli*	Rhizophoraceae	0.01	0.0005
Celtis gomphophylla	*Celtisgomph*	Cannabaceae	0.01	0.0000
Coffea zanguebarica	*Coffeazangu*	Rubiaceae	0.01	0.0000
Commiphora fischeri	*Commiphofisch*	Burseraceae	0.01	0.0000
Commiphora mossambicensis	*Commiphomossa*	Burseraceae	0.01	0.0000
Commiphora pilosa	*Commiphopilos*	Burseraceae	0.01	0.0000
Commiphora trothae	*Commiphotroth*	Burseraceae	0.01	0.0000
Cordyla africana	*Cordylaafric*	Fabaceae	0.01	0.0000
Cordyla densiflora	*Cordyladensi*	Fabaceae	0.01	0.0002
Croton longipedicellata	*Crotonlongi*	Euphorbiaceae	0.01	0.0000

Cussonia sp.	*Cussoniasp.*	Araliaceae	0.01	0.0000
Dalbergia stuhlmannii	*Dalbergistuhl*	Fabaceae	0.01	0.0000
Delonix elata	*Delonixelata*	Fabaceae	0.01	0.0002
Dichapetalum sp.	*Dichapetsp.*	Dichapetalaceae	0.01	0.0001
Dichrostachys sp.	*Dichrostsp.*	Fabaceae	0.01	0.0001
Diospyros bussei	*Diospyrobusse*	Ebenaceae	0.01	0.0003
Diospyros rouleiriana	*Diospyroroule*	Ebenaceae	0.01	0.0000
Droogmansia sp.	*Droogmansp.*	Fabaceae	0.01	0.0000
Ehretia sp.	*Ehretiasp.*	Boraginaceae	0.01	0.0000
Erythrophleum sp.	*Erythropsp.*	Fabaceae	0.01	0.0002
Euclea schimperi	*Eucleaschim*	Ebenaceae	0.01	0.0004
Euphorbia bilocularis	*Euphorbibiloc*	Euphorbiaceae	0.01	0.0001
Faurea saligna	*Faureasalig*	Proteaceae	0.01	0.0003
Faurea sp.	*Faureasp.*	Proteaceae	0.01	0.0000
Faurea speciosa	*Faureaspeci*	Proteaceae	0.01	0.0000
Ficus stuhlmannii	*Ficusstuhl*	Moraceae	0.01	0.0002
Flueggea virosa	*Flueggeaviros*	Euphorbiaceae	0.01	0.0000
Garcinia livingstonei	*Garcinialivin*	Clusiaceae	0.01	0.0000
Garcinia sp.	*Garciniasp.*	Clusiaceae	0.01	0.0000
Gardenia ternifolia	*Gardeniaterni*	Rubiaceae	0.01	0.0000
Grewia mollis	*Grewiamolli*	Malvaceae	0.01	0.0001
Hallea rubrostipulata	*Hallearubro*	Rubiaceae	0.01	0.0000
Halleria lucida	*Hallerialucid*	Stilbaceae	0.01	0.0007
Haplocoelum sp.	*Haplocoesp.*	Sapindaceae	0.01	0.0000
Heeria reticulata	*Heeriaretic*	Anacardiaceae	0.01	0.0001
Landolphia sp.	*Landolphsp.*	Apocynaceae	0.01	0.0000
Lannea tomentosa	*Lanneatomen*	Anacardiaceae	0.01	0.0000
Lawsonia sp.	*Lawsoniasp.*	Lythraceae	0.01	0.0000

Leptonychia usambarensis	*Leptonycusamb*	Malvaceae	0.01	0.0002
Magnistipula butayei	*Magnistibutay*	Chrysobalanaceae	0.01	0.0002
Maytenus lancifolia	*Maytenuslanci*	Celastraceae	0.01	0.0033
Maytenus senegalensis	*Maytenusseneg*	Celastraceae	0.01	0.0002
Melica uhimilis	*Melicauhimi*	Poaceae	0.01	0.0000
Mimusops fruticosa	*Mimusopsfruti*	Sapotaceae	0.01	0.0002
Multidentia sp.	*Multidensp.*	Rubiaceae	0.01	0.0001
Myrianthus holstii	*Myrianthholst*	Urticaceae	0.01	0.0000
Myrica salicifolia	*Myricasalic*	Myricacea	0.01	0.0000
Ochna eveta	*Ochnaeveta*	Ochnaceae	0.01	0.0000
Ochna longipes	*Ochnalongi*	Ochnaceae	0.01	0.0000
Olax dissitiflora	*Olaxdissi*	Olacaceae	0.01	0.0000
Oncoba spinosa	*Oncobaspino*	Salicaceae	0.01	0.0001
Ormocarpum kirkii	*Ormocarpkirki*	Fabaceae	0.01	0.0000
Ozoroa reticulata	*Ozoroaretic*	Anacardiaceae	0.01	0.0002
Paivaeusa dactylophylla	*Paivaeusdacty*	Euphorbiaceae	0.01	0.0000
Pappea sp.	*Pappeasp.*	Sapindaceae	0.01	0.0000
Pavetta sp.	*Pavettasp.*	Rubiaceae	0.01	0.0000
Phoenix reclinata	*Phoenixrecli*	Arecaceae	0.01	0.0000
Psorospermum febrifugum	*Psorospefebri*	Hypericaceae	0.01	0.0001
Psychotria sp.	*Psychotrsp.*	Rubiaceae	0.01	0.0000
Randia malleifera	*Randiamalle*	Rubiaceae	0.01	0.0008
Randia sp.	*Randiasp.*	Rubiaceae	0.01	0.0006
Rinorea holtzii	*Rinoreaholtz*	Violaceae	0.01	0.0001
Rytigynia schumannii	*Rytigynischum*	Rubiaceae	0.01	0.0001
Rytigynia sp.	*Rytigynisp.*	Rubiaceae	0.01	0.0000
Schrebera alata	*Schreberalata*	Oleaceae	0.01	0.0000
Schrebera koiloneura	*Schreberkoilo*	Oleaceae	0.01	0.0000

Schrebera rioloneura	*Schreberriolo*	Oleaceae	0.01	0.0000
Securinega sp.	*Securinesp.*	Euphorbiaceae	0.01	0.0001
Shirakiopsis sp.	*Shirakiosp.*	Euphorbiaceae	0.01	0.0000
Strychnos aculeata	*Strychnoacule*	Loganiaceae	0.01	0.0001
Strychnos pungens	*Strychnopunge*	Loganiaceae	0.01	0.0001
Suregada sp.	*Suregadasp.*	Euphorbiaceae	0.01	0.0000
Swartzia sp.	*Swartziasp.*	Fabaceae	0.01	0.0001
Syzygium malaccensis	*Syzygiummalac*	Myrtaceae	0.01	0.0001
Tarenna graveolens	*Tarennagrave*	Rubiaceae	0.01	0.0001
Teclea sp.	*Tecleasp.*	Rutaceae	0.01	0.0000
Terminalia aemula	*Terminalaemul*	Combretaceae	0.01	0.0001
Trichilia emetica	*Trichiliemeti*	Meliaceae	0.01	0.0001
Trimeria sp.	*Trimeriasp.*	Salicaceae	0.01	0.0005
Turraea sp.	*Turraeasp.*	Meliaceae	0.01	0.0001
Uapaca guineensis	*Uapacaguine*	Phyllanthaceae	0.01	0.0000
Uapaca usambarensis	*Uapacausamb*	Phyllanthaceae	0.01	0.0000
Vangueria acutiloba	*Vangueriacuti*	Rubiaceae	0.01	0.0000
Vangueria madagascariensis	*Vanguerimadag*	Rubiaceae	0.01	0.0000
Vangueria tomentosa	*Vangueritomen*	Rubiaceae	0.01	0.0000
Vepris sp.	*Veprissp.*	Rutaceae	0.01	0.0000
Vitex ferruginea	*Vitexferru*	Lamiaceae	0.01	0.0000
Voacanga africana	*Voacangaafric*	Apocynaceae	0.01	0.0003
Warburgia elongata	*Warburgielong*	Canellaceae	0.01	0.0000
Warburgia sp.	*Warburgisp.*	Canellaceae	0.01	0.0000
Warburgia stuhlmannii	*Warburgistuhl*	Canellaceae	0.01	0.0000
Xeromphis obovata	*Xeromphiobova*	Rubiaceae	0.01	0.0000
Xylopia parviflora	*Xylopiaparvi*	Annonaceae	0.01	0.0000
Zanthoxylum sp.	*Zanthoxysp.*	Rutaceae	0.01	0.0001

Zenkerella sp.	*Zenkerelsp.*	Fabaceae	0.01	0.0000
Ziziphus sp.	*Ziziphussp.*	Rhamnaceae	0.01	0.0015

Appendix 2: Results for indicator species analysis with species listed in bold had the highest indicator values (IV) and were used to name forest communities.

Species scientific name	Species code	Community	IV	P Value
Anacardium occidentale	***Anacardioccid***	**1**	**0.2759**	**0.014**
Rhizophora mucronata	***Rhizophomucro***	**1**	**0.2454**	**0.011**
Xylopia collina	*Xylocarpgrana*	1	0.2454	0.011
Sclerocarya birrea	*Sclerocabirre*	1	0.2366	0.015
Avicennia marina	*Avicennimarin*	1	0.2195	0.021
Ceriops tagal	*Ceriopstagal*	1	0.2195	0.019
Cocos nucifera	*Cocosnucif*	1	0.2195	0.013
Bersama abyssinica	*Bersamaabyss*	1	0.1901	0.032
Ficus sp.	*Ficussp.*	1	0.1901	0.036
Syzygium cordatum	*Syzygiumcorda*	1	0.1901	0.045
Brachystegia spiciformis	***Brachystspici***	**2**	**0.9945**	**0.001**
Pterocarpus angolensis	***Pterocarangol***	**2**	**0.5175**	**0.003**
Brachystegia longifolia	*Brachystlongi*	2	0.4851	0.001
Pseudolachnostylis maprouneifolia	*Pseudolamapro*	2	0.4233	0.005
Brachystegia boehmii	*Brachystboehm*	2	0.3440	0.050
Brachystegia sp.	*Brachystsp.*	2	0.3351	0.046
Diplorhynchus mossambicensis	*Diplorhymossa*	2	0.3334	0.021
Pterocarpus tinctorius	*Pterocartinct*	2	0.2925	0.042
Pteleopsis myrtifolia	***Pteleopsmyrti***	**3**	**0.3849**	**0.021**
Millettia sp.	***Millettisp.***	**3**	**0.3428**	**0.046**
Spirostachys africana	*Spirostaafric*	3	0.3310	0.028
Grewia sp.	*Grewiasp.*	3	0.3097	0.020
Parinari excelsa	*Parinariexcel*	3	0.3097	0.033
Scorodophloeus fischeri	*Scorodopfisch*	3	0.3097	0.025
Pteleopsis sp.	*Pteleopssp.*	3	0.3056	0.055
Acacia nigrescens	*Acacianigre*	3	0.3034	0.047
Pericopsis angolensis	*Pericopsangol*	3	0.3024	0.044
Hymenocardia ulmoides	*Hymenocaulmoi*	3	0.2927	0.043
Ocotea usambarensis	*Ocoteausamb*	3	0.2617	0.047

Appendix 3: Results for indicator species analysis with species listed in bold had the highest indicator values (IV) and were used to name woodland communities.

Species scientific name	Species code	Community	IV	P Value
Brachystegia sp.	***Brachystsp.***	**1**	**0.9217**	**0.001**
Diplorhynchus condylocarpon	***Diplorhycondy***	**1**	**0.4290**	**0.001**
Syzygium sp.	*Syzygiumsp.*	1	0.3781	0.001
Parinari sp.	*Parinarisp.*	1	0.3616	0.001
Julbernardia sp.	*Julbernasp.*	1	0.3325	0.002
Uapaca kirkiana	*Uapacakirki*	1	0.3229	0.003
Pericopsis sp.	*Pericopssp.*	1	0.3215	0.001
Combretum sp.	*Combretusp.*	1	0.3137	0.029
Terminalia sp.	*Terminalsp.*	1	0.3135	0.015
Pseudolachnostylis maprouneifolia	*Pseudolamapro*	1	0.3051	0.012
Burkea sp.	*Burkeasp.*	1	0.3044	0.001
Dalbergia sp.	*Dalbergisp.*	1	0.2942	0.004
Uapaca sp.	*Uapacasp.*	1	0.2814	0.002
Pterocarpus sp.	*Pterocarsp.*	1	0.2785	0.002
Pteleopsis sp.	*Pteleopssp.*	1	0.2670	0.014
Vitex sp.	*Vitexsp.*	1	0.2624	0.004
Diospyros sp.	*Diospyrosp.*	1	0.2507	0.011
Strychnos sp.	*Strychnosp.*	1	0.2506	0.011
Diplorhynchus sp.	*Diplorhysp.*	1	0.2413	0.014
Ochna sp.	*Ochnasp.*	1	0.2411	0.002
Monotes africana	*Monotesafric*	1	0.2339	0.008
Piliostigma sp.	*Piliostisp.*	1	0.2004	0.024
Syzygium guineense	*Syzygiumguine*	1	0.1991	0.054
Pseudolachnostylis sp.	*Pseudolasp.*	1	0.1990	0.037
Ficus sp.	*Ficussp.*	1	0.1937	0.026
Deinbollia borbonica	*Deinbollborbo*	1	0.1936	0.026
Dalbergia melanoxylon	***Dalbergimelan***	**2**	**0.4234**	**0.009**
Pteleopsis myrtifolia	***Pteleopsmyrti***	**2**	**0.2809**	**0.047**
Combretum molle	*Combretumolle*	2	0.2721	0.023
Albizia sp.	*Albiziasp.*	2	0.2696	0.025
Acacia nigrescens	*Acacianigre*	2	0.2577	0.041
Julbernardia globiflora	***Julbernaglobi***	**3**	**0.6150**	**0.001**
Pterocarpus angolensis	***Pterocarangol***	**3**	**0.5130**	**0.001**
Combretum zeyheri	*Combretuzeyhe*	3	0.3551	0.037
Pericopsis angolensis	*Pericopsangol*	3	0.3546	0.017
Terminalia sericea	*Terminalseric*	3	0.3355	0.014
Burkea africana	*Burkeaafric*	3	0.3339	0.023

Species scientific name	Species code	Community	IV	P Value
Isoberlinia globiflora	*Isoberliglobi*	3	0.2491	0.012
Brachystegia spiciformis	***Brachystspici***	**4**	**0.9350**	**0.001**
Parinari excelsa	***Parinariexcel***	**4**	**0.2691**	**0.001**
Brachystegia boehmii	*Brachystboehm*	4	0.2627	0.013
Bridelia micrantha	*Brideliamicra*	4	0.2000	0.016

Kuhusu Tasnifu Hii

Mbao ozo ni nyenzo muhimu katika kuhifadhi bayoanuwai na kutunza kaboni. Tafiti zilizopita zilikadiria kiwango cha kaboni ya aina mbalimbali za uoto bila kutenganisha mbao ozo. Hivyo, lengo la utafiti huu lilikuwa ni kutathmini kiasi cha kaboni cha mbao ozo na kutambua uhusiano uliopo kati ya miundo ya mbao ozo na kaboni kwa kuzingatia viambata mbalimbali vya mazingira. Matokeo yameonyesha, mbao ozo zilizokufa zilikuwa na kaboni nyingi kuliko mbao zilizokufa kwa kuoza. Kiwango hiko cha kaboni kimechangia 0.79% ya jumla ya kaboni ya uoto mbalimbali. Pia, katika mifumo ikolojia ya misitu na maeneo ya uwanda wa miti, kaboni ya mbao ozo ilihusiana chanya na wingi wa mimea na unyevu wa udongo wakati ilihusiana hasi na kaboni ya udongo. Utafiti huu utasaidia katika kuandaa miongozo sahihi ya uundaji wa sera zinazohusiana na mabadiliko ya tabianchi, takwimu za kaboni na uhifadhi bora wa bioanuwai katika mifumo ikolojia ya kitropiki.