Mapping and Assessing Ecosystem Services of Trees Outside Forest

Tuemay Tassew
February, 2017

SUPERVISORS:

Dr. L.L.J.M. Willemen Ir.
L.M. van Leeuwen

Mapping and Assessing Ecosystem Services of Trees Outside Forest

Tuemay Tassew
Enschede, The Netherlands, February, 2017

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.

Specialization: Natural Resources Management

SUPERVISORS:
Dr. L.L.J.M. Willemen
Ir. L.M. van Leeuwen

THESIS ASSESSMENT BOARD:
Dr. Y.A. Hussin (Chairperson, NRS department, ITC, The Netherlands)
Dr. R.J. Zagt (External Examiner, Tropenbos International, The Netherlands)

ABSTRACT

Trees Outside Forest (TOF) are naturally grown or planted trees in croplands which are retained by local beneficiaries except commercial plantation trees such as cacao and teak plantations. TOF are scarce in terms of total coverage and presence compared to trees within forests. TOF play a vital role in the supply of various ecosystem services such as provisioning, regulating and cultural services. However, the role of TOF in the supply of ecosystem service is missing from forest assessments and policies. In rural areas and croplands, there is no sufficient information why TOF are retained by local beneficiaries. The identification of why the beneficiaries retain these trees and what ecosystem services are provided by these trees contribute to a better understanding of TOF distribution and changes. A better understanding of who profits from what trees can help to arrange protection and management of TOF. Information about the location and important ecosystem services and their values supplied by TOF to local and national beneficiaries can lead to better planning for decisions to support species and ecosystem service delivery, identify and inform management strategies for better benefits, identify areas that require special management and provide information to increase awareness to local beneficiaries and government support for evidence-based policy and management decisions. The overall objective of this MSc study was to map TOF in croplands and assess their contribution to the supply of ecosystem services for local and national beneficiaries using participatory research, Google Earth and ArcMap in Ghana as case study area. Participatory research with local beneficiaries was applied to conduct a species inventory of TOF and to identify and value the local ecosystem services provided by TOF species. The national ecosystem service of climate change regulation (the amount of carbon stock) in each TOF were mapped based on field measurements and the TOF species were valued based on the average amount of carbon stock using carbon market price. A satellite image available from Google Earth was used to map croplands, and ArcMap was used to calculate the local and national ecosystem service hotspot areas based on the values assigned to each TOF individuals. The research identified a total of 786 TOF individuals and 50 TOF species in 147 ha of croplands in the study area. *Ficus exasperate, Morinda lucida, Ceiba pentandra, Spathodea campanulata, Mangifera indica, Sterculia tragacantha, Funtumia elastic, Ficus carpensis, Vernonia amygdalina* and *Trilipisium madagascariense* are the top ten most dominant species in terms of species occurrence. Fifteen different local ecosystem services supplied by TOF species were identified and valued of which shade (supplied by 44 TOF species), charcoal (by 2 species), pollination of cacao plants (1 species), timber (32 species), medicine (24 species), soil fertility (15 species) and soil conservation (14 species) were valued the most. The total carbon stored by all 786 TOF in 147 ha of the study area is 759 tons of carbon. The most important TOF species and hotspot locations that require special planning, conservation, and management focus was identified, mapped and assessed. There was a poor correlation between the values of the key species for local and national beneficiaries which might lead to conflict of interest and illegal tree felling. Based on the ecosystem service values for local and national beneficiaries 30% of the top ten TOF species were the same for both beneficiaries. The pattern of the hotspot analysis showed that most of the locations of the key TOF species for local beneficiaries are different from national beneficiaries. The result of this MSc research can contribute to managers and national policy makers of TOF to identify the interest of local and national beneficiaries to resolve conflicts of interest and illegal tree cutting and focus their planning and management on the most important TOF species which are highly valued and multifunctional.

Keywords
Trees Outside Forest (TOF), Ecosystem services, Beneficiaries, Participatory research, Mapping, Carbon stock

ACKNOWLEDGEMENTS

First and above anything, I would like to give my deepest and greatest thanks to my God with his mother Saint Virgin Mary and to all Saints without whom my success is unthinkable.

My heartfelt gratitude goes to my first supervisor Dr. L.L.J.M. Willemen for her close cooperation and follow up as well as for her constructive comments and advice. I would also like to give special thanks for her familiar approach. My next gratitude goes to my second supervisor Ir. L.M. van Leeuwen for her important guidance and input during my research and fieldwork.

My appreciation goes to Dr. George Ashiagbor from KNUST, in Kumasi, Ghana for assigning a field work assistant. My special thanks goes to Bernard Eshun and Agya K. Danquah for their help during field work and data collection. We had a nice time and unforgettable stay.

I would like to be grateful to all NRM mates especially to Muluken Nega for his valuable input in my thesis and his positivity to help others.

I am highly indebted to provide thanks to Netherland Fellowship Programmes (NFP) for covering all my study expenses.

Most importantly, my deepest gratitude is to my parents especially to my mother, Birhane Chekole and my father, Tassew Belew for their all lovely contribution to my sweet success. Those families and friends who supported me morally are also highly credited.

Tuemay Tassew
Enschede, The Netherlands
February 2010

TABLE OF CONTENTS

List of Figures

List of Tables

List of Appendices

List of Equations

List of Acronyms

AGB	**Above Ground Biomass**
DBH	**Diameter at Breast Height**
FAO	**Food and Agricultural Organization of the United Nations**
GIS	**Geographic Information System**
MA	**Millennium Ecosystem Assessment**
REDD	**Reducing Emissions from Deforestation and Forest Degradation**
SDGs	**Sustainable Development Goals**
TEEB	**The Economics of Ecosystem and Biodiversity**
TOF	**Trees Outside Forest**
UNDP	**United Nations Development programme**
UNFCCC	**United Nations Framework Convention on Climate Change**

1. Introduction

1.1 Background

Trees outside forest (TOF) are defined in different ways. Meneguzzo, Liknes, & Nelson (2013) defined TOF as separate and minor groups of trees and/or individual scattered trees that are out of forest locations including trees in farmlands, grazing areas, rural areas, residential and urban surroundings, road sides and around waterbodies. According to Gibbons et al., (2008) and Herrera-Fernandez, (2003) TOF are scattered trees which are found in agricultural lands and fruit trees. The Food and Agriculture Organization of the United Nations defines TOF as "trees on land not defined as forest and other wooded land" (FAO, 1998). In this MSc thesis TOF are defined as naturally grown or planted trees in croplands which are retained by local beneficiaries except commercial plantation trees such as oil palm, cacao and teak plantations.

TOF are important land use characteristics in many agricultural landscapes of the world (Meneguzzo, Liknes, & Nelson,2013). Even though these trees are scarce in terms of total coverage and presence, TOF offer diverse ecological, social, economic and environmental benefits (Meneguzzo, Liknes, & Nelson, 2013). TOF play an important role in the supply of various ecosystem services including conserving soil and regulating water, providing wildlife habitat, providing production services such as food and wood, aesthetics values and regulating climate change through carbon sequestration (Guo et al., 2014). Ecosystem services are the advantages people gain from ecosystems, or sometimes called ecosystem service providers (Kremen, 2005). In this MSc research TOF are considered as an ecosystem service provider and the ecosystem services are grouped into local ecosystem services and national ecosystem services. The local ecosystem services are services provided directly or indirectly by TOF mostly limited to local extent demand and benefits of the local beneficiaries which can be identified by themselves, and whereas the national ecosystem services (carbon stock) are services that have a wider national level demand and benefits and cannot be easily recognized by local beneficiaries.

The concept of ecosystem services is becoming an important tool in planning and management of natural resources (Hauck et al., 2013). It is perceived as a promising method for understanding the relations between ecosystems and human well-beings (Hermann, Schleifer, & Wrbka, 2011). Understanding the spatial levels at which the ecosystem services are provided is important to value the services to different stakeholders (Hein, van Koppen, de Groot, & van Ierland, 2006). The first large global assessment of ecosystem services the-Millennium Ecosystem Assessment (MA), (2005) which has later replaced by The Economics of Ecosystem and Biodiversity (TEEB) describes four categories of ecosystem services. The categories include; 1) Provisioning services which include products such as fresh water, food, and medicine. 2) Regulating services such as climate change regulation. 3) Cultural services (non-material) advantages like social, spiritual and aesthetic benefits and 4) Supporting services (universal and immediate benefits) such as nutrient retention, soil formation and provision of oxygen.

Despite the ecosystem services TOF supply, various studies have given much more attention to the contribution of forests for ecosystem services than TOF. This is because forests supply a large amount of ecosystem services such as climate regulation through carbon storage. Scattered trees in farmlands and in many rural areas are missing from forest statistics, natural resource assessments, policies, and legislations (Guo et al., 2014). A report from Food and Agricultural Organization also states that TOF have been let off from the assessment of forests and forest resources. Understanding of the situation and dynamics of TOF are a bottleneck for the evaluation of trees and their services (FAO, 2013). As a result, there is little information and evidence why and for what specific purpose (ecosystem service) these trees are kept as TOF. A report from FAO (2013) suggests that countries must conduct an assessment of TOFs. The report offers agencies accountable for the management and analysis of forests such as Forest Commissions, ministries and experts with tools, methodologies and case studies to improve assessment and monitoring of TOF.

In recent years, TOF have begun to draw attention with increasing considerations of their potential economic roles and political interest due to their contribution to human wellbeing through ecosystem services. Mapping and assessing the ecosystem services provided by TOF are becoming an important way of understanding the benefits of trees to people. Assessment aims to estimating the value of and contribution from TOF to the beneficiaries. Understanding the value of ecosystem services can help policy makers to take better decisions which can result in better management and use of natural resources (Daily et al., 2009). To recognize the quality, amount, density and spatial distribution of trees and their ecosystem services delivered to the beneficiaries, visualizing the present extent and quantity of TOF through mapping is very important. Mapping is useful for decision and policy makers for better conservation of TOF. The non- homogenous nature of TOF and their distribution needs spatial information for understanding of the relations among TOF, the ecosystem services they provide and their beneficiaries (Hapsari, 2010).

Apart from mapping, knowledge of local beneficiaries on TOF are vital for collecting relevant information about ecosystem services provided by TOF. The local beneficiaries have knowledge and experience about the types of trees and their benefits provided to them especially in the provisioning services such as wood, food, and fruits (Hein et al., 2006, Hapsari, 2010). They provide insight in which services are provided to them because they are regarded as one of the managers, beneficiaries, and stakeholders of the TOF. This can help in developing a better understanding of the relationship between tree based ecosystems and as a source of valuing ecosystem services.

To carry out such assessment the use of satellite imagery and image analysis techniques is crucial to collect data about the cover and density of trees (Bonham, 2013). Satellite images available from Google Earth and using mobile GIS are promising resources to map the quantity and distribution of trees in croplands (Zahidi, 2015). This can help researchers and policy makers to conduct a study on TOF and their ecosystem services for better management and conservation (Sinare & Gordon, 2015).

1.2 Problem Statement

The role of TOF in the supply of ecosystem service is missing from forest assessments and policies. Although some studies exist about the importance of TOF, knowledge is still limited on the role of TOF at local and national levels (Schnell, Kleinn, & Ståhl, 2015a). TOF provide different ecosystem benefits at different spatial levels. Better understanding of who profits from what trees can help to fine-tune protection and management of TOF. In Ghana, trees are owned/managed by the Forest Commission and the right to tree tenure determines who benefits from Reducing Emissions from Deforestation and Forest Degradation (REDD) activities. REDD provide incentives to landowners for improvement in national carbon stock and tree cover including TOF (Corbera, 2012). The national Forest Commission plays a significant role in tree management, land use plan allocation, policy implementation. Due to solid formal systems of tree ownership it can be difficult to obtain certificate of tree ownership (World Agroforestry Centre, 2011). Therefore, landholders typically do not have ownership of trees on their lands. However, they have the right to protect and manage the trees on their lands. Both local and national level institutes play a role in tree conservation and management. When their interests align conflicts regarding trees resources will resolve and trees are at low risk of illegal felling.

Information regarding TOF are required at various geographical scales. At the international scale, treaties such as the United Nations Framework Convention on Climate Change (UNFCCC, 2008) including the Kyoto protocol need information about all tree resources including TOF. Climate change mitigation, life on land and eradicating poverty are some of the 2030 Sustainable Development Goals (SDGs) at international level which require special attention and reporting.

At national levels, REDD in developing countries has emerged as part of the global climate change protection organization to substitute the Kyoto Protocol after 2012 as a new way of reducing CO2 emissions through paying for actions that minimize and prevent forest loss or degradation.. Information about carbon stock provided by TOF are required for REDD. The carbon stock and its value are an important advantage to national Forest Commission of Ghana to benefit from REDD incentives. The Forest Commission of Ghana requires information about the location and essential ecosystem services including carbon stock potential provided by TOF for the design, management, decision making and monitoring of TOF. This information can support policies linked to the protection, management and use of TOF resources and for the valuation of ecosystem services (Schnell, 2015). In Ghana, there is very little information to estimate the carbon stock which can be used as a baseline information for REDD (Hansen, Treue, & Lund, 2009). Therefore, establishing a reliable baseline information for estimation of carbon stock in trees on croplands is a basic requirement for Ghana to benefit from REDD incentives. Carbon storage which reflects the climate change regulation service is considered as a national level ecosystem service. Carbon stock is an ecosystem service obtained from trees (Duarte, Ribeiro, & Paglia, 2016;).

In rural areas and croplands, there is no sufficient information why TOF are retained by local beneficiaries. The identification and prioritization of why the beneficiaries retain these trees and what ecosystem services are provided by these trees might have a significant contribution to a better understanding of TOF at local levels.

Quantifying and mapping ecosystem services and their values is not straightforward. Though there are various valuation methods that address ecological, economic and social values (Felipe-Lucia, Comín, & Escalera-Reyes, 2015), there are no standardized methods for valuing ecosystem services (Crossman et al., 2013). Identifying and describing TOF species and their ecosystem services based on local beneficiary's knowledge can reveal the value of the ecosystem services and understand the role of TOF to local livelihood benefits. Process-based methods can be used to quantify and map ecosystem services that are strongly linked to the biophysical processes, such as carbon storage for climate regulation. This MSc research is based on the use of participatory approaches to identify TOF species and local ecosystem services, and process models to quantify and map ecosystem services of TOF for local and national beneficiaries within the croplands of Nkaseim village in Goaso, Ghana.

The conceptual diagram in (Figure 1) shows how TOF, ecosystem services, beneficiaries, and land decision making are related in Ghana. The diagram shows a set of relationships among driving factors inside and outside the study area which are expected to impact on TOF and the ecosystem services they offer.

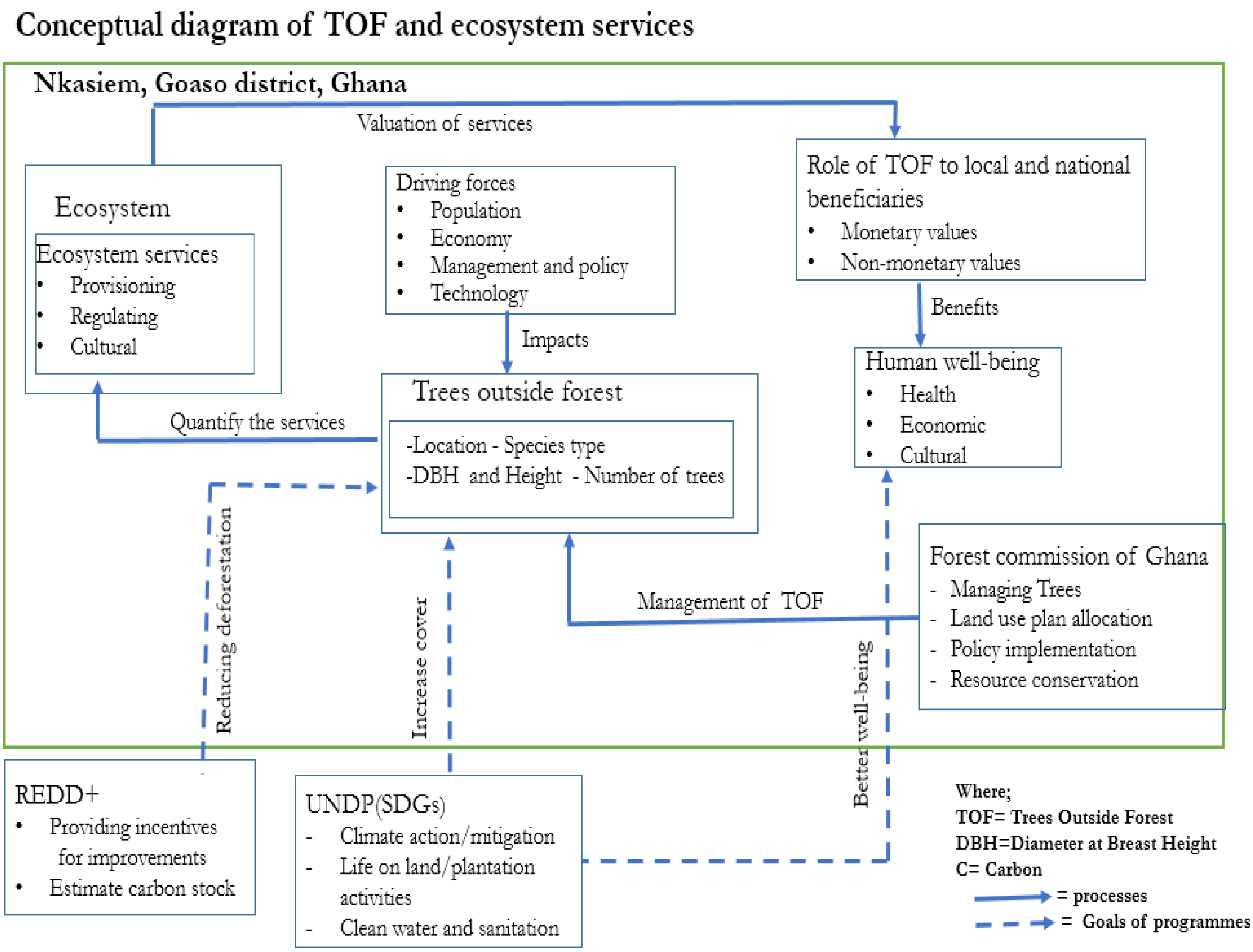

Figure 1 Conceptual diagram of TOF and ecosystem services

1.3 Research Objectives and Questions

The overall objective of the research is to map TOF in croplands and assess their contribution to the supply of ecosystem services to local and national beneficiaries in Goaso, Ghana. This overall objective will be addressed by the following specific objectives and research questions (Table 1).

Table 1 Specific objectives and research questions

Objectives	Research questions
1. To conduct a spatial inventory of the species and location of TOF	**1 (a). Where are TOF located in the study area?** **1 (b). What are the species in TOF in the study area?**
2. To assess the role of TOF to local livelihood benefits	**2 (a). What are the ecosystem services provided by TOF in the study area?** **2 (b). How ecosystem services of TOF are valued by local beneficiaries in the study area?**
3. To assess the contribution of TOF for carbon stock in national climate change regulation benefits.	**3 (a). How much carbon is stored by TOF in the study area?** **3 (b). What is the value of carbon stock as climate change regulation service of TOF in the study area?**
4. To define the overall role of TOF locations and species in the supply of ecosystem service benefits	**4 (a). Which species and places are ecosystem service hotspots for local and national level beneficiaries?**

2. Literature Review

2.1 Trees Outside Forest (TOF)

In general, TOF are defined as all trees excluded from the definition of forest and other wooded lands. TOF are frequently located on farmlands and built-up areas of rural and urban landscapes. It includes planted and naturally grown trees including trees in agroforestry systems, orchards and small woodlots. TOF can raise in croplands, pastoral areas, along rivers, canals and roadsides, or in towns, gardens and parks (FAO, 2000).

TOF have several varying tree formations of various types, functions and spatial arrangements. As a result, TOF are often noticed differently by different stakeholders (Schnell, Kleinn, & Ståhl, 2015b). Therefore, defining TOF is important to make sure the consistency and comparability of different data sets and to simplify communication. Tree resources ranging from single trees to systematically managed trees in agroforestry practices and trees in agricultural lands, fruit trees and rubber plantations are considered as TOF (Herrera-Fernández, 2003). The Food and Agriculture Organization of the United Nations defines TOF as "trees on land not defined as forest and other wooded land" (FAO, 1998). TOF covers less than 0.5 ha of grouped trees and the height of trees at maturity must reach at least 5 m (FAO, 1998). Based on the official forest definition of FAO, the tree crown cover should be more than 10%, and the area has to be larger than 0.5ha.

In this research context TOF refers to naturally grown or planted trees in croplands or on farms except commercial plantation trees such as oil palm, teak, and cacao plantations.

2.2 Participatory research

Participatory research is the process of generating knowledge in which local stakeholders and researchers are jointly involved in a research process. Participatory research involves the participation of local stakeholders and community members in each stage of a research process including formulation of a research problem and data collection stages (Evans et al., 2006). The local stakeholders have an experiential knowledge of the issue under study. This can fill the knowledge gap scientists and researchers face, by providing new data and analytical insights. Involving local stakeholders in the research process which are directly or indirectly affected by the phenomenon under study can be important to local benefits in the future. It can more likely produce results that are more beneficial to local beneficiaries than the researchers and scientists. This makes participatory research different from conventional research in which the later relatively focuses on the benefit of the researchers or scientists (Ning & Abdollahi, 2005).

Participatory research helps the local beneficiaries and researchers to build their capacity and engage more efficiently in policy formulation and management of tree resources. This enables the research process participants to make better and effective decisions how to apply the research outcome practically and conserve and use the resources in a sustainable way (Ning & Abdollahi, 2005).

Local stakeholder's perceptions are by definition needed for identifying ecosystem services. Ecosystem services can be derived from different ecosystems such as trees, forests and water bodies. Stakeholders perception important for spatial ecosystem service mapping using participatory GIS approach particularly where there is lack of data (Paudyal, Baral, Bhandari, & Keenan, 2015, Bryan, Raymond, Crossman, & Hatton Macdonald, 2010).

2.3 Ecosystem services

Ecosystem services are advantages of an ecosystem to people in which most of the benefits are critical to our survival such as climate regulation, air purification, and crop pollination (Kremen, 2005).The idea of ecosystem services has become a useful concept for integrating into decision-making and ecosystem-related values into decision making. This concept has gained broad attention as one of the main steps to understand and value the importance of ecosystems service providers to beneficiaries (Chan, Satterfield, & Goldstein, 2012). Understanding the value of ecosystem services can help to prioritize the ecosystem service providers based on the services they provide and therefore, for better planning and management of the ecosystems to gain the maximum possible benefit.

Various ecosystems of the world offer an enormous variety of goods and services. The valuable commodities that natural ecosystems provide include; edible plants and animals, medicinal products, and materials for construction or clothing (Pagiola & Bishop, 2004). Ecosystem services are the goods and services delivered by the ecosystem to the society. Ecosystem services offer the basis for the valuation of the ecosystem. The supply of ecosystem services vary over time (Hein, van Koppen, de Groot, & van Ierland, 2006). Figure 2 below shows the various ecosystems often called ecosystem service providers and their ecosystem services.

Ecosystem service	*Ecosystem*									
	Cultivated	*Dryland*	*Forest*	*Urban*	*Inland Water*	*Coastal*	*Marine*	*Polar*	*Mountain*	*Island*
Freshwater			•		•	•		•	•	
Food	•	•	•	•	•	•	•	•	•	•
Timber, fuel, and fiber	•		•			•				
Novel products	•	•	•		•		•			
Biodiversity regulation	•	•	•	•	•	•	•	•	•	•
Nutrient cycling	•	•	•		•	•	•			
Air quality and climate	•	•	•	•	•	•	•	•	•	•
Human health		•	•	•	•	•				
Detoxification		•	•	•	•	•	•			
Natural hazard regulation			•		•	•			•	
Cultural and amenity	•	•	•	•	•	•	•	•	•	•

Figure 2 Main ecosystem types and their ecosystem services (Source: Pagiola & Bishop, (2004))

As it is shown in (Figure 2) above forest provide a wide range of ecosystem services compared to other ecosystems. Ecosystems of TOF provide similar ecosystem services as forests although the supply of ecosystem services differ in terms of quantity and value (Schnell, 2015).

In the literature, ecosystem services are typically classified according to their material or non-material benefits and values. Material benefits of ecosystem services have been considered in connection to provisioning, regulating, and supporting services whereas non-material benefits have been linked with cultural services (Chan et al., 2012). According to (Fisher et al., 2010)(Fisher et al., 2010)(Fisher et al., 2010)(Fisher et al., 2010)(Fisher et al., 2010)(Fisher et al., 2010)(Fisher et al., 2010)(Fisher et al., 2010)(Fisher et al., 2010)(Fisher et al., 2010)(Fisher et al., 2010)TEEB, (2010) , there are twenty-two ecosystem services categorized under four main types of ecosystem services which are supplied by different ecosystems. The four main ecosystem services supplied by various ecosystems include provisioning, regulating, habitat and cultural services. These services are described in (Table 2).

Table 2 Types of ecosystem services in The Economics of Ecosystem and Biodiversity (TEEB) **(Source: TEEB, (2010))**

	Main service-types
	PROVISIONING SERVICES
1	**Food** (e.g. fish, game, fruit)
2	**Water** (e.g. for drinking, irrigation, cooling)
3	**Raw Materials** (e.g. fibre, timber, fuel wood, fodder, fertilizer)
4	**Genetic resources** (e.g. for crop-improvement and medicinal purposes)
5	**Medicinal resources** (e.g. biochemical products, models & test-organisms)
6	**Ornamental resources** (e.g. artisan work, décorative plants, pet animals, fashion)
	REGULATING SERVICES
7	**Air quality regulation** (e.g. capturing (fine)dust, chemicals, etc)
8	**Climate regulation** (incl. C-sequestration, influence of veg. on rainfall, etc.)
9	**Moderation of extreme events** (e.g. storm protection and flood prevention)
10	**Regulation of water flows** (e.g. natural drainage, irrigation and drought prevention)
11	**Waste treatment** (esp. water purification)
12	**Erosion prevention**
13	**Maintenance of soil fertility** (incl. soil formation)
14	**Pollination**
15	**Biological control** (e.g. seed dispersal, pest and disease control)
	HABITAT SERVICES
16	**Maintenance of life cycles of migratory species** (incl. nursery service)
17	**Maintenance of genetic diversity** (esp. gene pool protection)
	CULTURAL SERVICES
18	**Aesthetic information**
19	**Opportunities for recreation & tourism**
20	**Inspiration for culture, art and design**
21	**Spiritual experience**
22	**Information for cognitive development**

2.4 Spatially explicit valuation of ecosystem services

Ecosystem services are quantified based on their importance to a specific use for the beneficiaries. The ecosystem service valuation is conducted after quantifying the ecosystem services. Remote sensing offers spatially explicit data for TOF at considerable costs. However, the attributes that can be collected from remote sensing imagery are limited in number. Field assessments are therefore an essential part of TOF inventories. Scientific and local societies progressively expect numerous values to be integrated within planning for conservation and environmental management. Scientific communities should recognize a more wide-ranging view of the value of nature both in terms of economic and local values (Raymond et al., 2009).

Valuing the economic importance of ecosystem services permits for mapping and comparison among different ecosystem services supplied by various ecosystems. Valuation of ecosystem services is generally carried out based on three kinds of services and four types of values (David.W. Pearce & and Kerry Turner, 1990; Costanza et al., 1997; Millennium Ecosystem Assessment, 2003). Based on different publications Hein et al.,(2006) established a framework for the valuation of ecosystem services. The valuation framework can be used to different ecosystems listed in (Figure 2). The four main steps of ecosystem service valuation framework are described as follows.

The first step is specifying the boundaries of the ecosystem to be valued (what and where are the ecosystems to be valued. The second step of the valuation framework is to identify/ assess the ecosystem services provided by the ecosystem (ecosystem service provider). The next step is valuing the ecosystem services using different valuation methods such as monetary and non-monetary techniques. The final step of the valuation framework is to compare the various ecosystem services supplied by the ecosystem.

Valuation is a process which helps to understand how important and valuable an ecosystem is to the beneficiaries. Ecosystem service valuation can play a vital role in planning conservation and management of ecosystems(Plummer, 2009). The valuation process provides information about the ecosystem service of TOF in terms of monetary terms such as market prices, costs of plantation and management, and in terms of order and score of the list of ecosystem services. It enables comparisons among the services based on their contribution to the human welfare of the beneficiaries. Misunderstanding of the value TOF might sometimes lead to improper management and use of the trees. This concerns can bring ideas about the need of valuing the ecosystem services supplied by TOF to local and national beneficiaries.

Spatially explicit ecosystem service valuation is conducted by separating the study area into the land cover of interest, in this case, TOF and their supplied ecosystem service types using Geographic Information System (GIS). Conducting a spatial disaggregation using GIS allows beneficiaries and users of TOF to visualize the explicit location of ecologically important areas of the trees which can enhance the likely management applications for valuing ecosystem service (Liu, Costanza, Troy, D'Aagostino, & Mates, 2010). To understand the ecosystem services supplied by TOF stakeholders should able to know their values for a well-defined and particular areas of TOF. The spatially explicit boundary data can be related to TOF cover and valuation data in ArcGIS. Mapping the values of ecosystem services of ecosystems visualizes their specific location and how values vary through space.

2.5 Carbon Estimation

Accurate estimation of carbon in tropical forests is vital for various applications ranging from the commercial utilization of timber to the climate change regulation services. Estimation of above-ground biomass (AGB) with reasonable accuracy is important to establish the enhancement of carbon stored in trees/ forests and to gather accurate information (Basuki, van Laake, Skidmore, & Hussin, 2009).

Mapping carbon stock is useful for better climate change mitigation planning and implementation of policies. This depends on the accessibility of accurate and reliable allometric models to estimate above-ground biomass and carbon (Er, 2014).

Carbon stock is typically derived from above-ground biomass by assuming around 50% of above-ground biomass. The most accurate way for above-ground biomass estimation is by cutting of trees and weighing of their parts. However, this is destructive, costly and labor intensive. Allometric equations are relationships between variables developed on the basis of sparse measurements from destructive - related to more easily collected biophysical properties of trees such as diameter at breast height (DBH) and height. They are applied to estimate parameters which are difficult to measure, such as volume from easily measurable biophysical parameters, like DBH and height (Basuki et al., 2009). Above-ground biomass and carbon stock can be estimated using DBH only, DBH and height, or DBH, height and wood density. However, using more parameters give more accurate estimate than applying only a single parameter. Therefore, using DBH, height, and wood density of trees provide better estimate of above-ground biomass/carbon stock if all the three parameters are available (Chave et al., 2005, van Breugel, Ransijn, Craven, Bongers, & Hall, 2011, Vieilledent et al., 2012).

Based on the United Nations Framework Convention on Climate Change (UNFCCC), countries have to report the state of their forest resources including TOF and emerging mechanisms, such as Reducing Emissions from Deforestation in Developing Countries (REDD) and carbon stock on a regular basis (UNFCCC, 2008).

3. Methods

3.1 Study area

The research was conducted in croplands around Nkasiem village, in the Goaso district which is part of Brong Ahafo region in Ghana, West Africa. It is situated between latitudes of 24° 10' 00" N-24° 50' 00" N and longitudes of 11° 31' 00" E-11° 63' 00" E. The study area covers a total area of 621 hectare and a perimeter of 10.3 km. Of this total study area, 147 hectares of croplands were used to conduct an inventory of TOF. Croplands are areas used for growing and cultivation of various crops. The major crops in the study area include planting, cassava, ginger and cacao and some maize, pepper and rice. In addition to the cultivated crops, there are a number of trees inside and at the boundaries of croplands retained by local beneficiaries. The location and map of the study area within Ghana and Goaso and location of croplands within the study area are shown in (Figure 3).

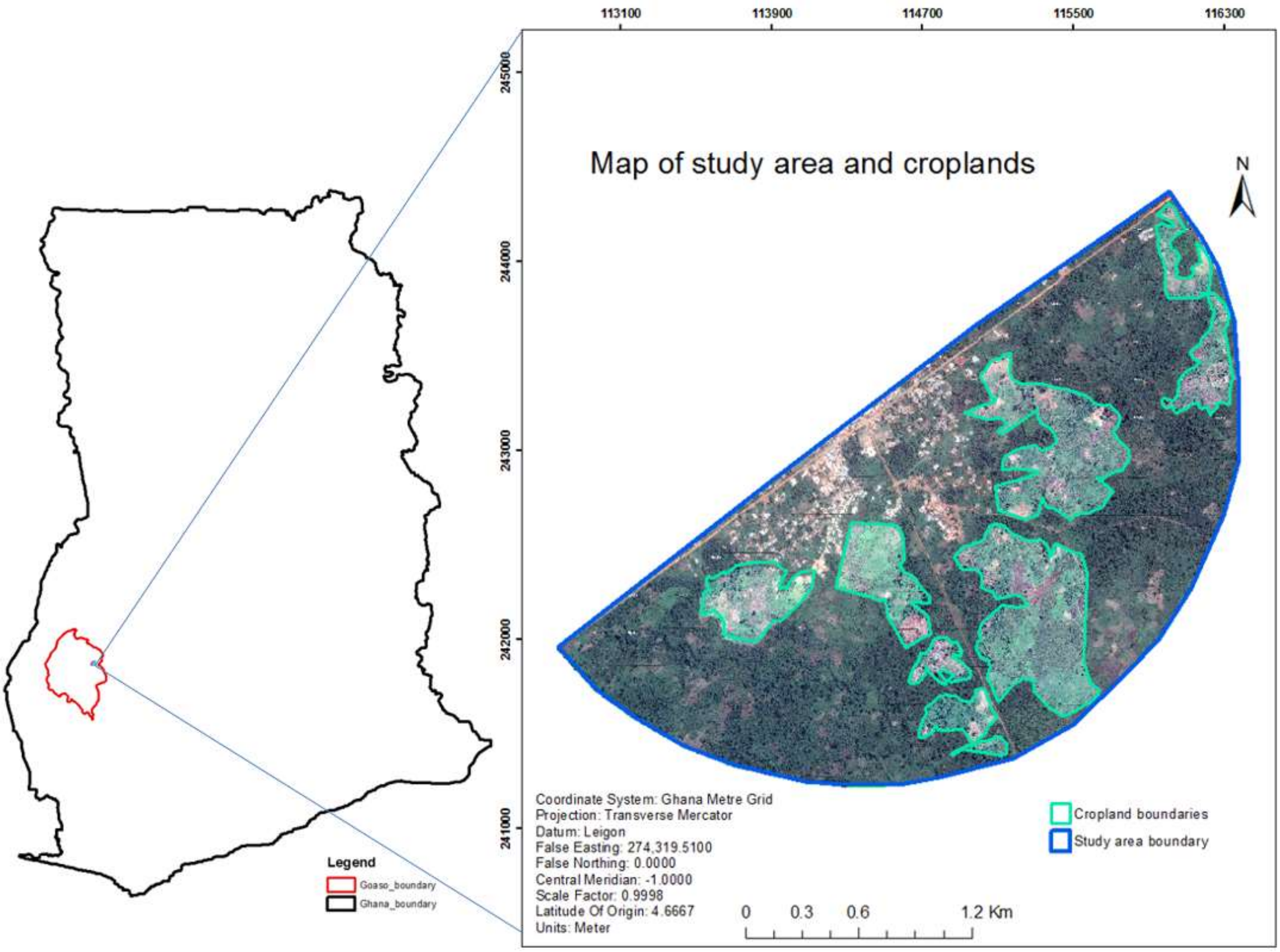

Figure 3 The location of the study area within Ghana and Goaso, and location of croplands within the study area

3.2 Spatial TOF Inventory

3.2.1 Mapping TOF

The locations of croplands within the study area were identified visually from satellite images of Google Earth. The visual image analysis was done based on tree cover to identify croplands. Croplands of the study area were mapped using Google Earth imagery of date 4/2/2015 from the satellite imagery provider of CNES/ Astrium 2016 and with a resolution of 2.6 x 2.6 m. The image available from Google Earth was downloaded and saved as rectified images using Elshyal Smart software (downloaded from http://elshayal-smart.en.lo4d.com/) to get higher resolution and georeferenced image. The rectified georeferenced image was uploaded to a smart-phone and tablet using Locus map free software for offline navigation within the study area (Locus Map - knowledge base, 2016). Printed and laminated maps were used to navigate to the study area.

The boundaries of croplands where TOF inventory was carryout were digitized manually on Google Earth based on visual image interpretation of land cover. The croplands where the TOF inventory was conducted were masked based on the digitized boundary of croplands. Based on field observations and TOF inventory the manually digitized boundaries of croplands were improved in ArcMap 10.4.1 to develop the final map of croplands.

Each TOF within the croplands were recorded using Garmin-60 GPS. The GPS points were overlaid on the masked cropland images in ArcGIS to map TOF locations. TOF at the boundary of croplands with their crowns inside the croplands were included during the inventory. Trees that were outside digitized croplands were excluded from the inventory. All trees within the digitized croplands were recorded as well as the location of each tree except trees with diameter at breast height of less than 10 centimeters and plantations trees such as oil palm, teak, and cocoa trees. The field observation form in (Appendix 1) shows the data collection sheet for recording longitude and latitude of each TOF in croplands.

3.2.2 TOF species inventory

The species inventory was conducted during field observations of every TOF by interviewing the local farmers or villagers and through a fieldwork assistant from Kwame Nkrumah University of Science and Technology with good knowledge of tree species. The local names of each TOF species were identified by the local farmers and a field assistant. The scientific name of each TOF species was identified through the help of the field assistant and Goaso forest district office experts, and by searching the internet (Ghana Forestry Commission, 2017). Tablet and smart phone were used to take photos of TOF in the field and to compare the pictures of TOF species with internet sourced pictures whether the TOF species are the same or not. See field observation form in (Appendix 1) for recording local or scientific names of TOF species.

3.3 Local level ecosystem services of TOF

3.3.1 Identification of local ecosystem services

A questionnaire containing both close-ended and open-ended questions was designed. The purpose of the questionnaire was to collect information about the ecosystem services supplied by each TOF species, their values and frequency of each ecosystem service used in croplands according to local farmers. Ecosystem service provided by each TOF species in croplands of the study area were identified through interview to the local beneficiaries during the field work. Gender and age categories of the interviewees was taken into account to identify the ecosystem services supplied by TOF to TOF beneficiaries.

The interviewees who are local farmers and reside in and around the croplands were selected purposely to get better information about the ecosystem services of TOF species. Most of the interviewees were asked during TOF inventory in the field on random basis. Some respondents who retain trees in their own croplands were asked at the village purposively and randomly. See field questionnaire form in (

Appendix 2) for collecting the ecosystem services of each TOF species and frequency of the each ecosystem services used. Photos of TOF in croplands were used to interviewees who cannot join in the field to collect data about local ecosystem services of TOF and their values.

The number of diverse ecosystem services supplied by each TOF species were analyzed in excel based on the list of ecosystem services identified by local beneficiaries for each TOF species. The analysis was conducted to identify the diversity and prevalence of ecosystem services and to define the level of multi-functionality TOF species to local beneficiaries in the study area.

3.3.2 Valuation of local ecosystem services

After identifying the ecosystem services of each TOF species according to the local beneficiaries, different categories of farmers/interviewees were asked to score the ecosystem services based on their importance to local beneficiaries. Each ecosystem service provided by each TOF species is scored on basis of 1, 2 and 3 meaning; 1= fairly important, 2= important, 3= Very important. Based on the score values the average value of each ecosystem service of TOF species is calculated. However, the average value does not consider the multi-functionality of ecosystem services provided by each TOF species. For instance, a single TOF species providing a single ecosystem service might get a score of 3 and therefore the average will be 3/1 =3, where 1 is the number of ecosystem service provided by a specific TOF species and 3 is the score value of the ecosystem service. On the other hand, a single TOF species providing 3 ecosystem services might get scores of 3, 1, and 2, therefore, the average will be (3+1+2)/3=2. This means that a single TOF species providing only one ecosystem service is valued high or very important and the second TOF species providing 3 different ecosystem services is scored less or important. This does not show good valuation and does not consider the multi-functionality of ecosystem services. Therefore, for better valuation and comparison among TOF total values, considering the multi-functionality of TOF, the average score of ecosystem services is multiplied by the number of ecosystem services provided by each TOF to get the total value of TOF species local ecosystem services. The total value was assigned to each TOF of the same species in the study area. The data analysis was done using pivot table in Excel 2013. The field questionnaire form in (Appendix 2) shows a column for recording the score of each ecosystem service benefits.

3.4 National level ecosystem services of TOF

3.4.1 Quantification of carbon stock as national level ecosystem services

During field inventory the diameter at breast height (DBH) and height of each TOF were measured. see on the field observation form in (Appendix 1) for recording DBH and height of TOF. Diameter tape and haga clinometer were used to measure DBH and tree height of each TOF. Tape meter was used to measure the distance from each TOF to the point the tree height is to be measured using haga clinometer. TOF with DBH of less than 10 cm were excluded from measurement. Allometric equations were applied to calculate above-ground biomass and carbon stock of each TOF in croplands based on the field measurements. The average amount of carbon stored in each TOF species was calculated to compare the results among all the TOF species. The total amount of carbon stock for each TOF species was also calculated. The total amount is according to the species occurrence (number of trees per species). Carbon content of each tree was therefore added to calculate the total carbon stored by a particular TOF species.

The following allometric equations (Equation 1) that were developed for Ghana and Sub-Sharan Africa were used to calculate the amount of carbon stock stored in each TOF in kilograms per tree. (Henry et al., 2010). The equation uses DBH and height parameters to calculate above-ground biomass.

Equation 1 Above-ground biomass

$$\text{Above-ground biomass (kg/tree)} = 0.17 \times dbh^{(1.97)} \times H^{(0.55)}$$

Where; dbh= diameter at breast height and H= height

The carbon stock is about 45 to 50 percent of the total above-ground biomass of a tree (Vashum, Jayakumar, & T. Vashum, 2012). Therefore, the carbon stock of each individual trees were calculated by multiplying by 0.47.

Equation 2 Above-ground carbon

$$\text{Above-ground carbon stock (kg/tree)} = 47/100 \times \text{Above-ground biomass (kg/tree)}$$

3.4.2 Valuation of carbon stock as national level ecosystem services

The carbon stock in TOF were valued based on the amount of carbon stored per individual TOF. The average amount of carbon stock per TOF species were calculated by dividing the total carbon of each species to the number of trees of that particular species. The total amount of carbon stock in the study area was calculated by adding carbon amounts of all TOF in croplands. The total carbon stock was divided by the total area of croplands to calculate the average amount of carbon per hectare. The carbon stock can be valued using carbon trading and price. Carbon stock is the ecosystem service quantity stored in trees in tons of carbon per tree or per hectare of land which can be valued in monetary terms (Rashid, 2012). The price (value) of carbon per ton of carbon ranges from 10 to 150 US dollars (Richards & Stokes, 2003, ,Cornelis Van Kooten, Eagle, Manley, & Smolak, 2004). The average market carbon price is USD 7.50 per ton of CO_2 emission and (Scharlemann et al., 2010). The value of carbon as a national level ecosystem service was normalized to 3 classes to allow for relative comparison with the values of local scale ecosystem services. The following formula was applied to normalize the values of carbon stock in to 3 classes according to (Crossman & Bryan, 2009).

Equation 3 Normalization

$$X' = (X - X_{min}) \times 2/(X_{max} - X_{min}) + 1$$

Where;
X' = transformed value for x
X min = minimum value for x
X max = maximum value for x
The values was calculated to each TOF based on the carbon stock amount to result in a map of TOF and values of carbon stock to each TOF in croplands.

3.5 Identifying key TOF species and locations for ecosystem services

3.5.1 Key TOF species and locations

Based on all the above procedures of the species names and locations, the ecosystem services and their normalized values at local and national levels, the most important locations (hotspots) and TOF species were identified. The normalized total local ecosystem service values and the normalized average carbon stock values were used to calculate the total value of each TOF species to local and national beneficiaries.

The local ecosystem services were normalized based on the total score given by local beneficiaries to each ecosystem service supplied by each TOF species. Each normalized total local ecosystem service score value of particular TOF species was assigned to all TOF individuals in the study area. This means the same total score was assigned to each TOF of the same species. The national ecosystem services were normalized based on the amount of carbon stock of each TOF. The normalized values of the local and national ecosystem services is assigned to each TOF individuals. The highest normalized values of local and national ecosystem services and their locations were selected as key species and locations (hotspots). The values were normalized in to three classes using the formula above (Equation 3).

Hot spot analysis was done in ArcGIS. The hotspot analysis tool identifies statistically significant spatial clusters of high values (hot-spots) and low values (cold spots) of the local and national ecosystem service normalized values. It produces a new output feature class with a z-score, p-value, and confidence level bin (Gi_Bin) for each feature in the input feature class (M.Giner, 2016). The hot-spot analysis does not consider the species types. It only considers the local and national ecosystem service values of each TOF.

3.5.2 Comparison between key species for local and national ecosystem services

The local scores of TOF were compared to the value of national level ecosystem services if there are differences and similarities among TOF species according to the normalized values of national and local ecosystem services. Differences and similarities among TOF species with top highest and lowest values of ecosystem services both for local and national level beneficiaries were also compared.

3.6 Methodological flowchart

The flowchart below (Figure 4) shows the procedures to achieve the general and specific objectives and answer each proposed research questions. A high resolution satellite image, field measurement and a questionnaire were the key information sources to address the four research questions.

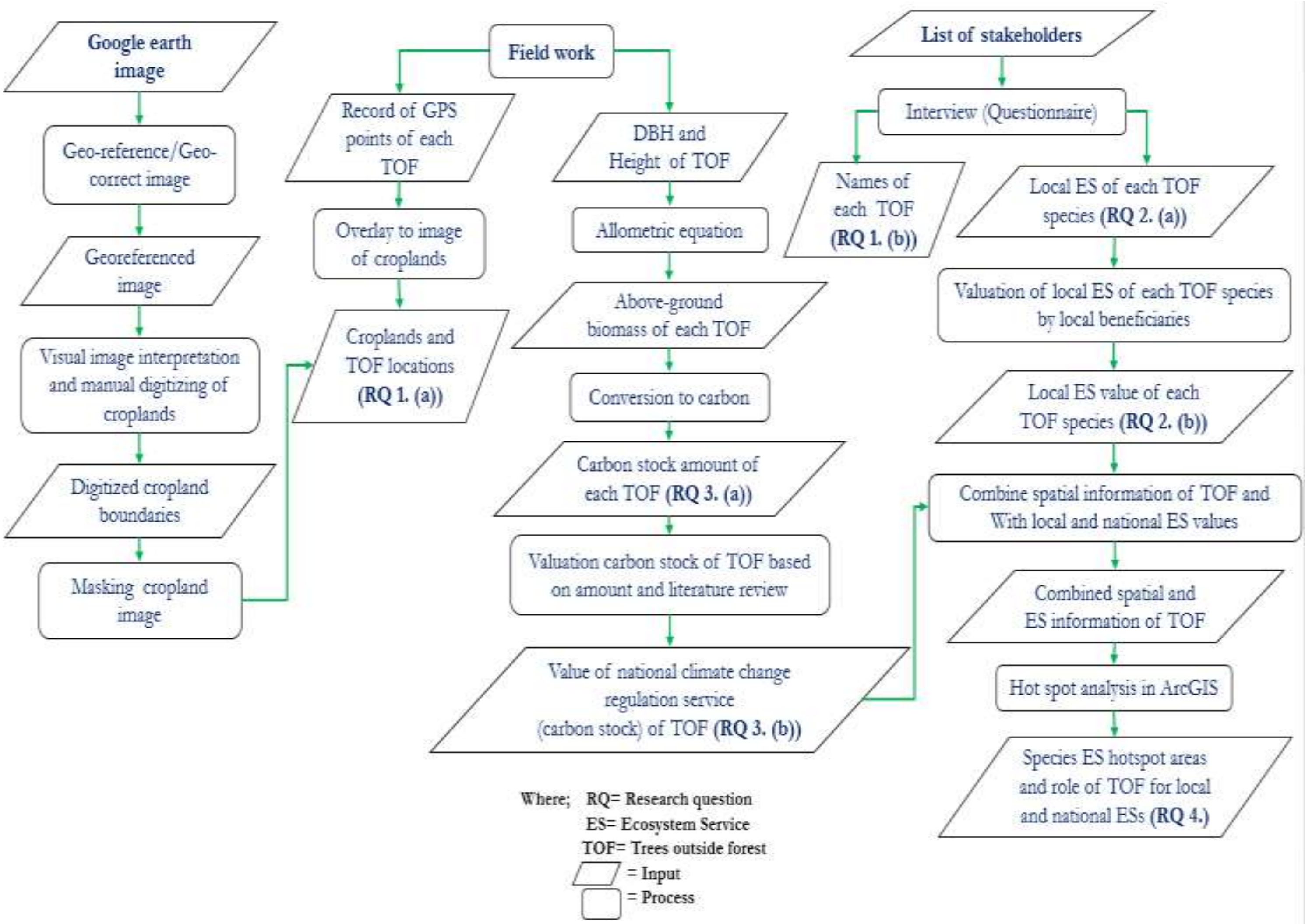

Figure 4 Research methodology flowchart

4. Results

4.1 Spatial TOF inventory

A total of 786 TOF individual observations and 50 different TOF species were identified and recorded in the croplands of the study area. The total area of the croplands is 147 hectares. The average number of TOF individuals per hectare is approximately 5 trees. The location of each inventoried TOF individuals in the croplands of the study area are shown in (Figure 5).

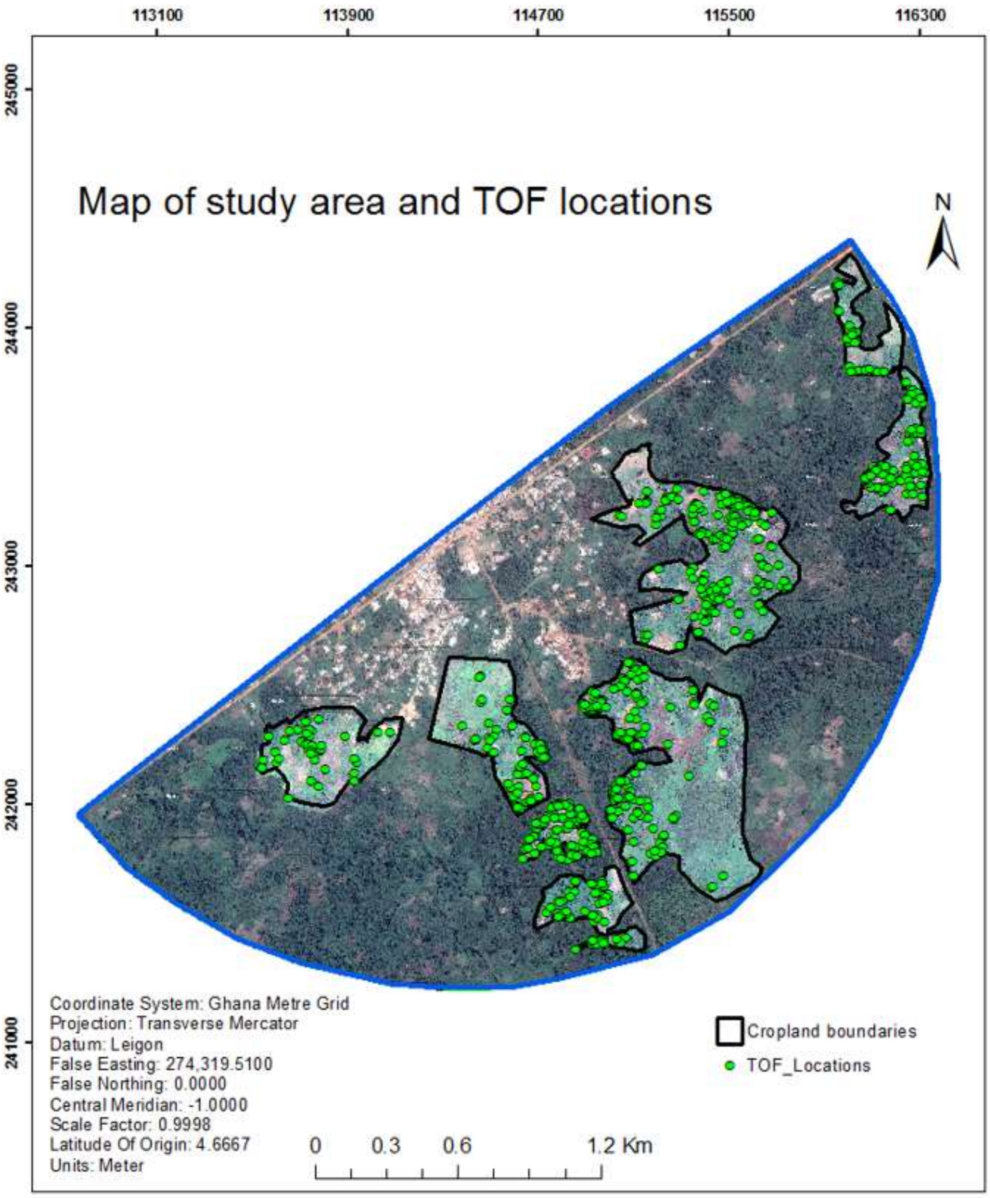

Figure 5 Map of study area and TOF locations

The local names of all the species were recorded during field observations and interviews. The scientific names were identified based on the local names. The local names of all TOF were identified. However, the scientific names of five TOF species could not be found. The list of TOF species in croplands and their local and scientific names are listed in (Appendix 3).

As it is clearly seen from the chart below (Figure 6), *Ficus exasperate, Morinda lucida, Ceiba pentandra, Spathodea campanulata, Mangifera indica, Sterculia tragacantha, Funtumia elastic, Ficus carpensis, Vernonia amygdalina* and *Trilipisium madagascariense* are the top ten most dominant species. These TOF species constitute 70.61% of the total number of TOF found in the study area.

Citrus spp., Nesogordonia papaverifera, Cylicodiscus gabunensis, Terminalia ivorensis, Nanclea diderrichii, Albizia adianthifolia and *Carica papaya* are rarely occurred in croplands of the study area accounting only 0.91% of the total number of TOF trees. Figure 6 shows the species counts per total number of TOF species (total count 786).

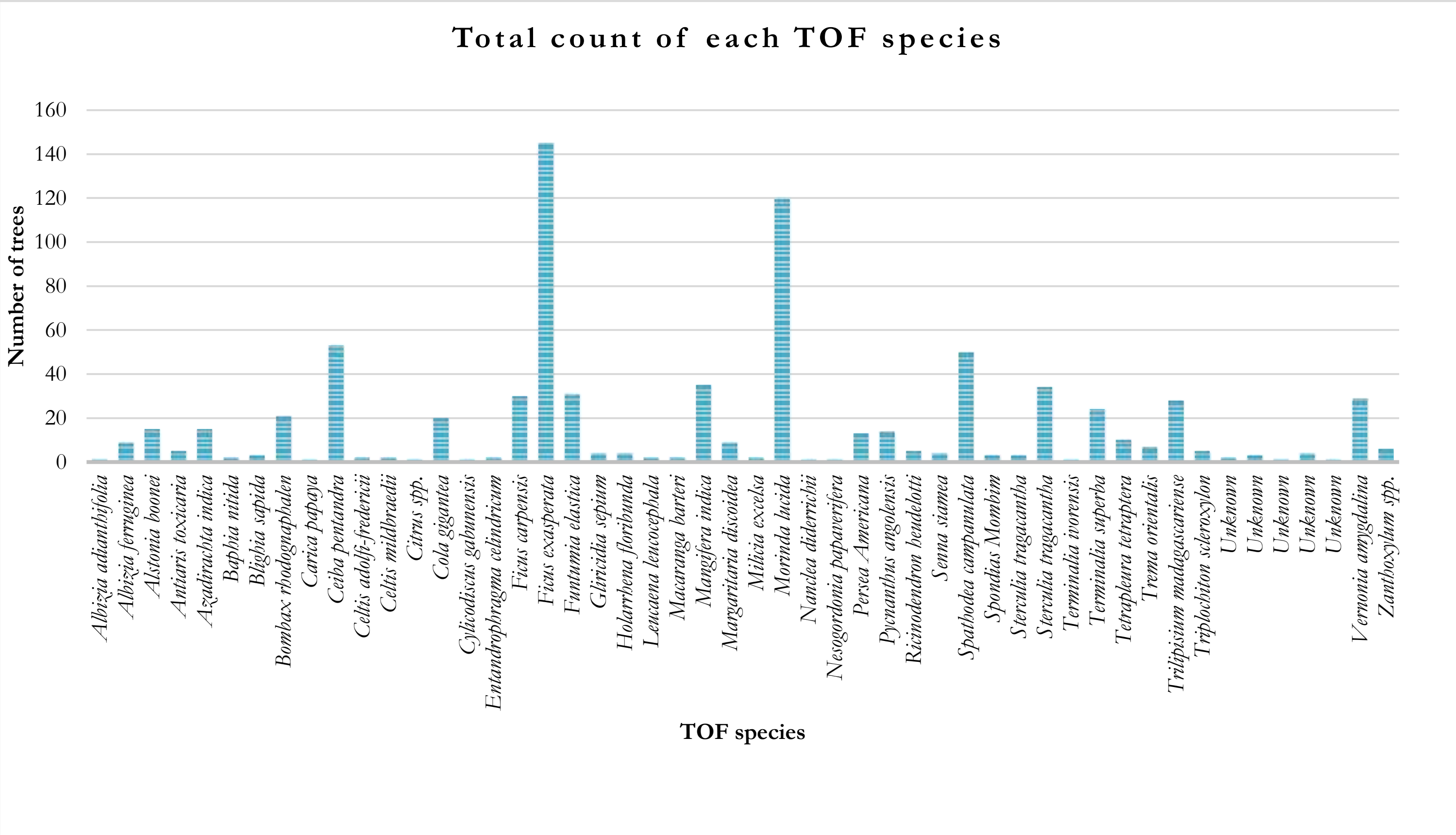

Figure 6 Total count of each TOF species

4.2 Local level ecosystem services of TOF

4.2.1 Type and number of TOF ecosystem services

Thirty-seven local beneficiaries were interviewed to gather information about supply of local ecosystem service by each TOF species, the value (score) of each ecosystem service and frequency of each ecosystem service used. Gender, age and education level of respondents are taken to consideration. Figure 7 shows interviewees characteristics in the study area.

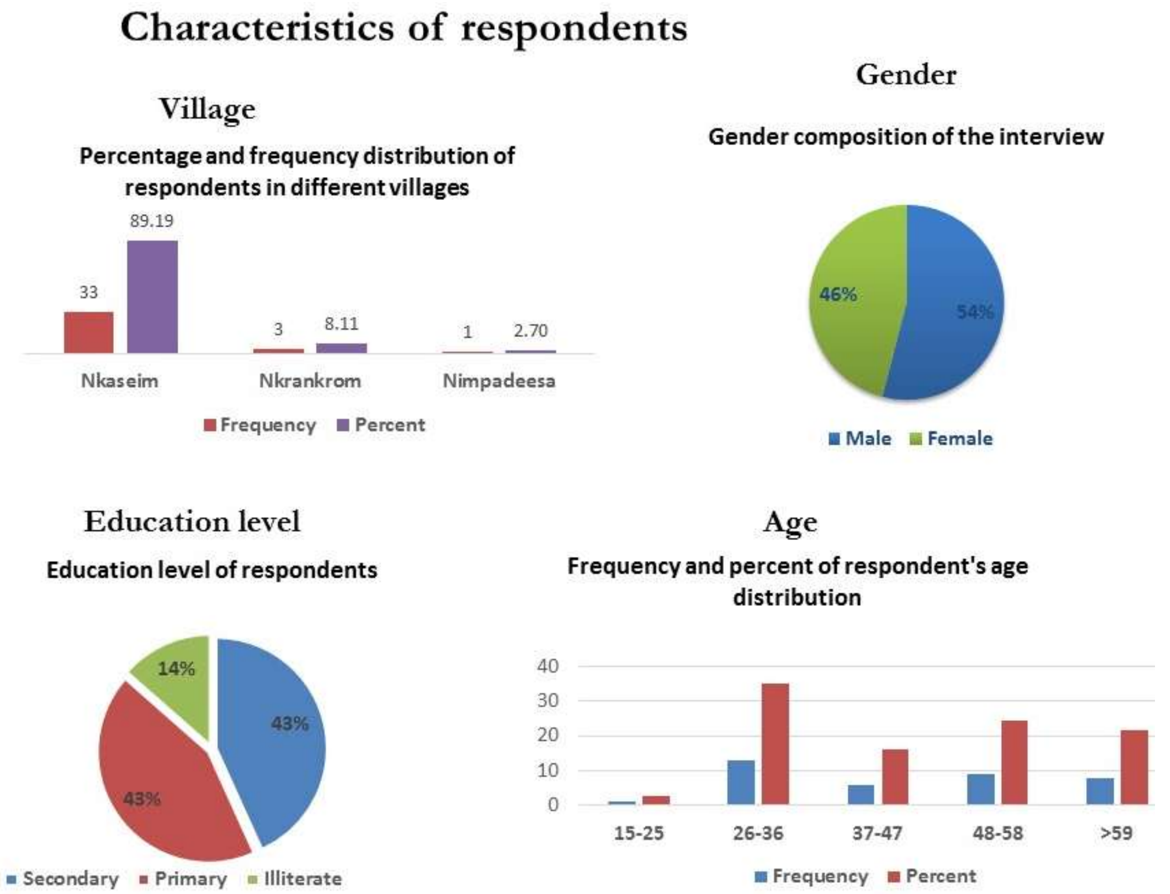

Figure 7 Characterstics of interviewees

A total of 15 different ecosystem services supplied by different TOF species were identified by the interviewees. Out of them, the provision of shade (by 44 TOF species), timber (32 species), medicine (24 species), soil fertility (15 species) and soil conservation (14 species) are the ecosystem services provided by most different TOF species. The total number of TOF species in the study area is 50. This means that a single TOF species can supply one or more ecosystem services. Only 6% of the TOF species provide a single ecosystem service the rest 94% of supply more than one ecosystem service according to the respondents. The list of ecosystem services supplied by TOF and the number of TOF species which provide a specific ecosystem service are shown in (Figure 8)

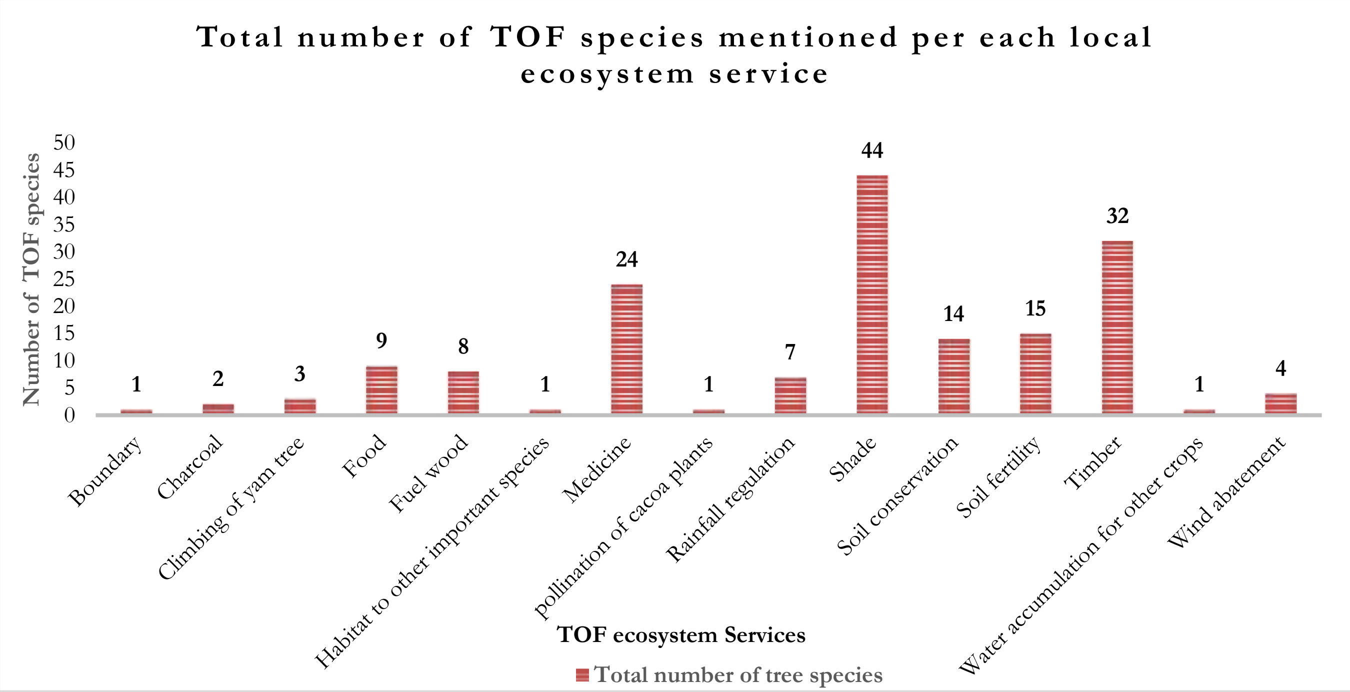

Figure 8 Total number of TOF species mentioned per each local ecosystem service

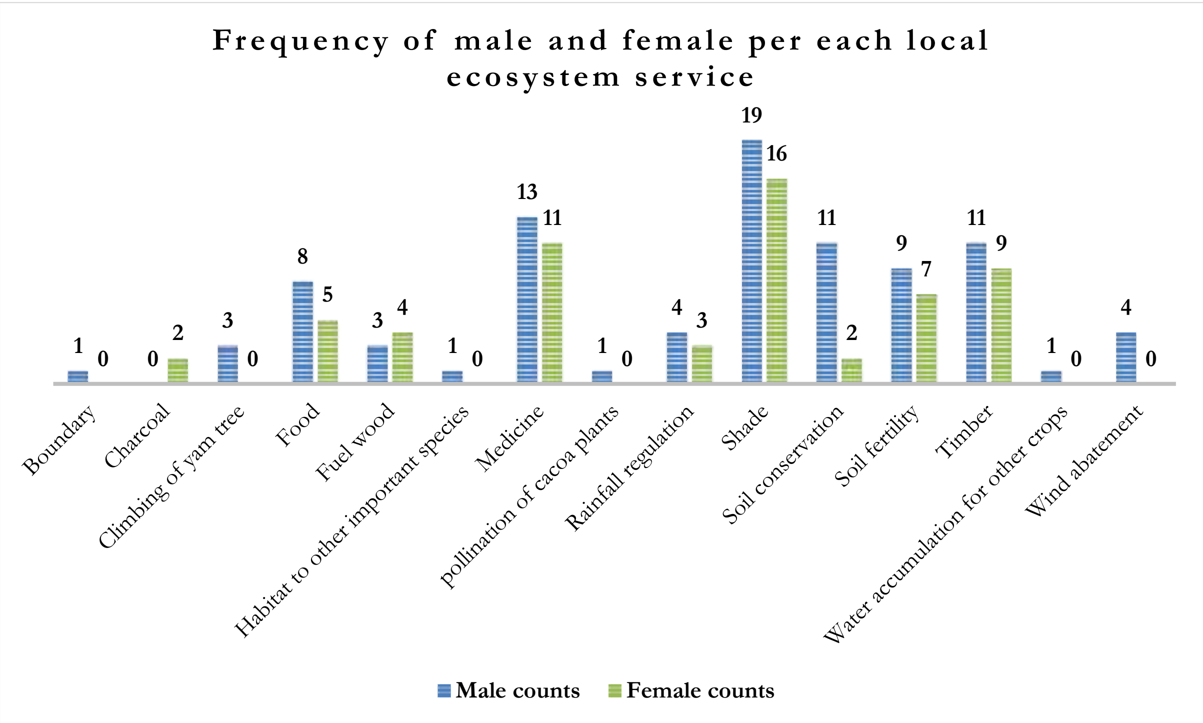

Figure 9 Frequency of male and female per each local ecosystem service

The number and type some ecosystem service identified by male and female are different. Females identified 9 of the 15 ecosystem services while males identified 14 of the 15 ecosystem services by different TOF species. Boundary, climbing of yam tree, habitat to other important species, pollination of cacao plants, water accumulation for other crops, wind abatement are the ecosystem service identified by males only. Charcoal is identified as ecosystem service by only females. The frequency of males and females per each local ecosystem service is also different (Figure 9).

Different TOF species supply different type's ecosystem services. The list of different types of ecosystem serviced supplied by different TOF species is listed in (Appendix 6). As it can be seen in (Figure 10) the number of ecosystem services differs from one TOF species to another. Most of the TOF species provide more than one type ecosystem service. The most multifunctional trees are shown in (Figure 11). Some TOF species provide only one type of ecosystem services. This was the case for *Azadirachta indica*, *Milicia excelsa* and *Sterculia tragacantha*. These species were only retained in croplands for medicine, timber and timber services respectively.

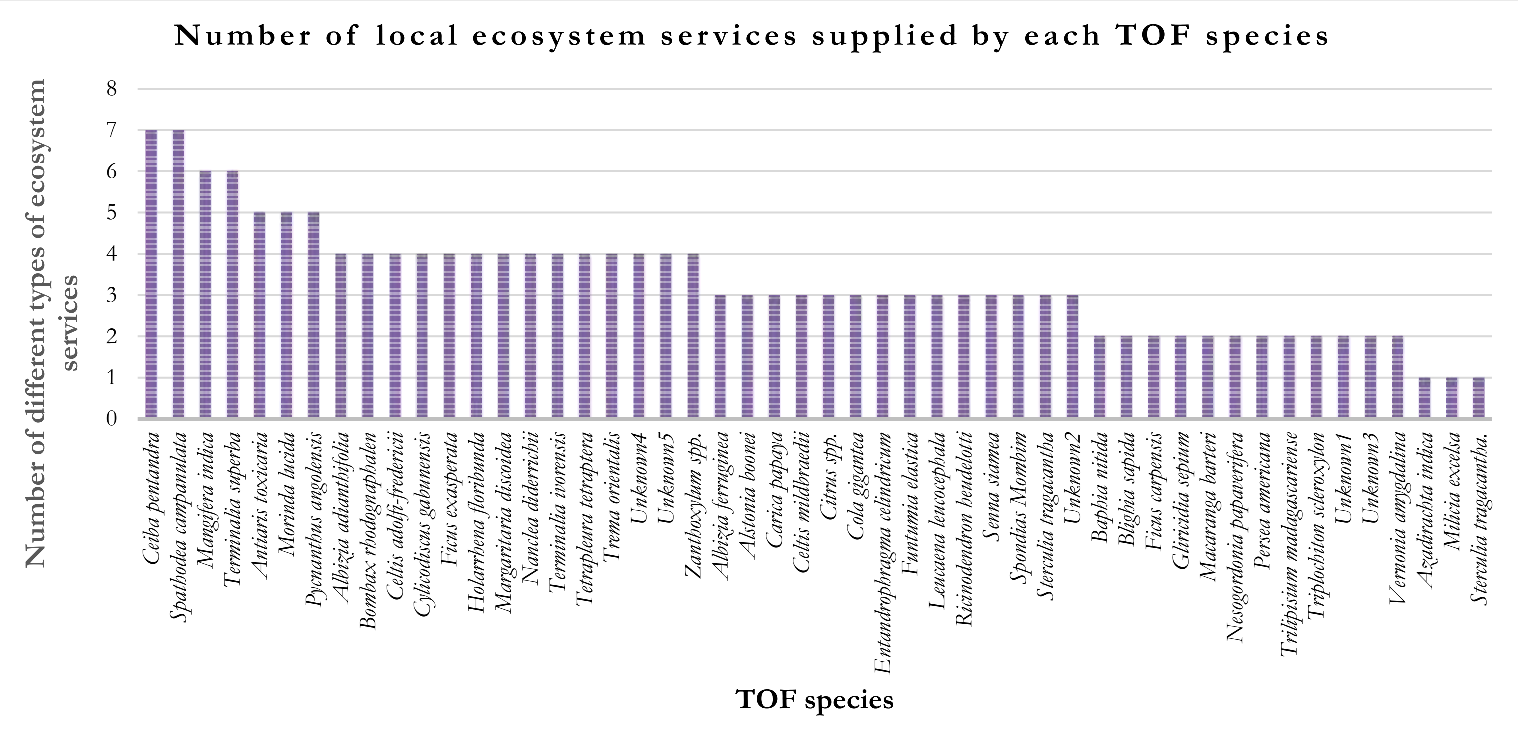

Figure 10 Number of local ecosystem services supplied by each TOF species

The top seven multifunctional TOF species which provide highest diversity of ecosystem services compared to other TOF species in the study area are shown (Figure 11). The diversity is in terms of number of different ecosystem services supplied.

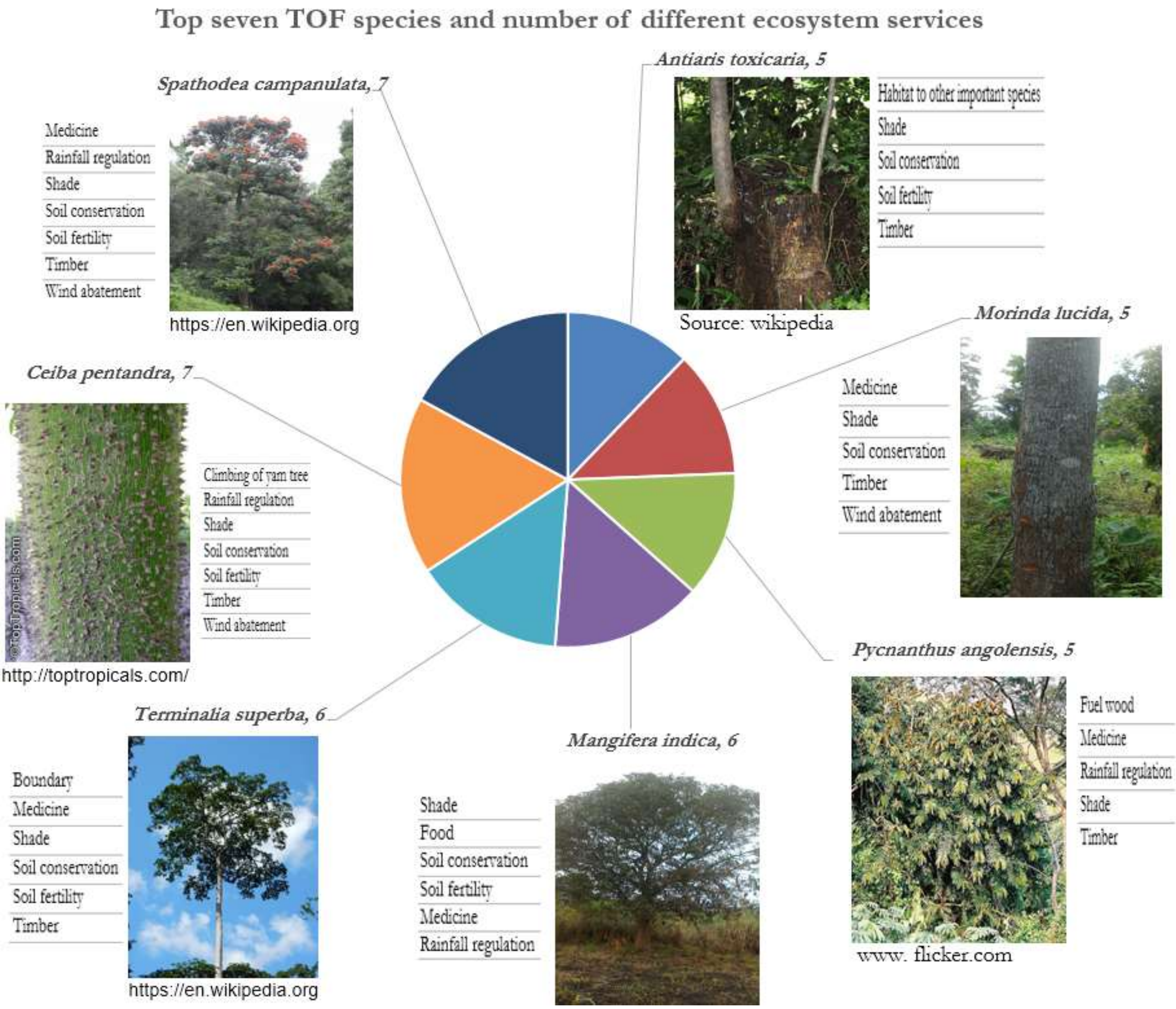

Figure 11 TOP seven TOF species which supply diverse number and type of local ecosystem services

4.2.2 Valuation of TOF local ecosystem services

The local ecosystem services of TOF are valued based on their importance for local beneficiaries. *Ceiba pentandra, Spathodea campanulata, Morinda lucida, Terminalia superba, Mangifera indica, Ficus exasperate, Pycnanthus angolensis, Antiaris toxicaria* and *Trema orientalis* are the top TOF species scored with highest score values. *Milicia excelsa, Azadirachta indica, Sterculia tragacantha,* Unknown3 (Local name: Asusumaasa)*, Vernonia amygdalina, Baphia nitida, Blighia sapida, Ficus carpensis, Gliricidia sepium and Macaranga barteri* are the top ten lowest scored TOF species. The total score value of each TOF species is shown in (Figure 12). All most multifunctional TOF species listed in (Figure 11) are scored highest values.

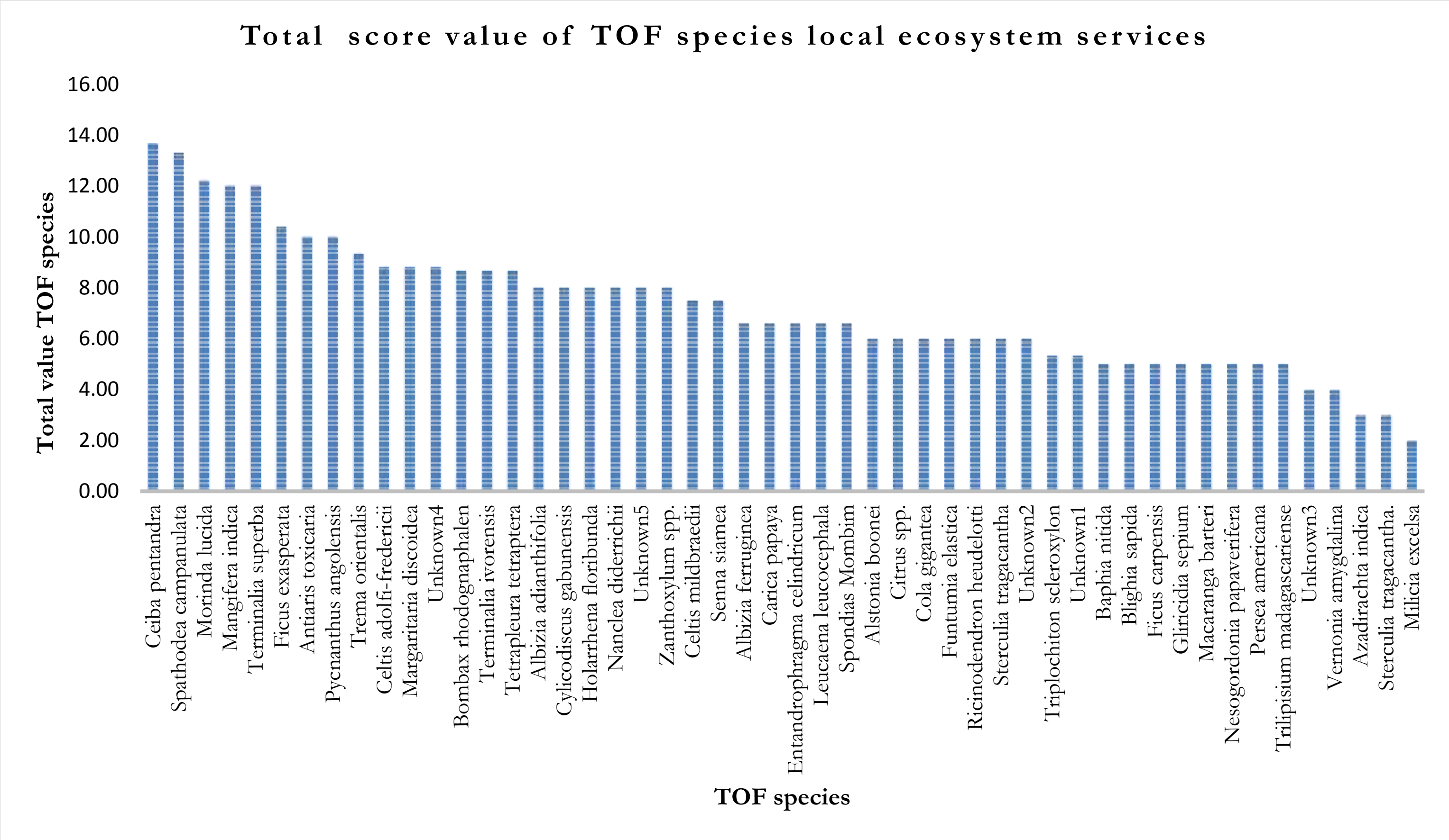

Figure 12 Total score value of TOF species local ecosystem services

The value of the 15 ecosystem services supplied by TOF species is calculated based on the average score values. Shade (supplied by 44 TOF species), charcoal (2 species) and pollination of cacao plants (1 species), are the highest scored ecosystem services. Boundary and habitat to other important species are the least scored ecosystem services each supplied by one TOF species. However, the average score does not consider the multi-functionality of TOF species because the score value for each ecosystem services of multifunctional species is relative. The average score of each ecosystem service and count of TOF species for each ecosystem service provision are shown in (Table 3).

Table 3 Average scores of TOF local ecosystem services and count of TOF species suppling a particular ecosystem service

List of ecosystem services	Average score of ecosystem services	Count of TOF species providing a particular ecosystem services
Boundary	1.00	1
Charcoal	2.50	2
Climbing of yam tree	2.00	3
Food	2.00	9
Fuel wood	1.89	8
Habitat to other important species	1.00	1
Medicine	2.03	24
Pollination for cacao plants	3.00	1
Rainfall regulation	1.78	7
Shade	2.74	44
Soil conservation	1.81	14
Soil fertility	1.72	15
Timber	1.82	32
Water accumulation for other crops	3.00	1
Wind abatement	1.50	4

4.2.3 Gender and valuation of local ecosystem services

A paired two tail t-test is conducted whether the list of individual scores given by male and female to each local ecosystem service are the same between male and female respondents. Equal list of count scores given by female and male to each ecosystem service are compared. The comparison between male and female scores is performed to each ecosystem service that are only identified by both male and female (Figure 9**Error! Reference source not found.**). Shade, timber, food, fuel wood, medicine, soil conservation, soil fertility and rainfall regulation are the ecosystem services identified by both male and female. The statistical result of the paired t-test shows that the score values of all the ecosystem services are not statistically significant between males and females. As it can be seen in (

Table 4) the t-statistic is less than the t critical two tail and the P-value is much greater than 0.05 (at 95% confidence interval) for all ecosystem services. This shows that there is no significant difference between the score values assigned to ecosystem services by men and women.

Table 4 Paired two sample t-Test of gender score values of ecosystem services

TOF ecosystem services	Female (average score)	Male (average score)	P-Value
Food	2.40	1.78	0.305
Fuel wood	2.00	1.80	0.625
Medicine	1.93	2.08	0.277
Rainfall regulation	1.67	1.83	0.578
Shade	2.72	2.76	0.164

Soil conservation	2.00	1.79	0.5
Soil fertility	1.63	1.80	0.356
Timber	1.93	1.77	0.782

4.2.4 Local ecosystem service score values and use frequency

The use frequency of different ecosystem services is different. Some of the ecosystem services supplied by TOF species are used on daily basis while others are used rarely. The average score of the ecosystem services based on the use frequency are shown in the box plot (Figure 13). Most of the short term ecosystem services are scored high values compared to the long term benefits TOF. The complete table showing the list of ecosystem services, the use frequency and average score of ecosystem services is shown in (Appendix 5)

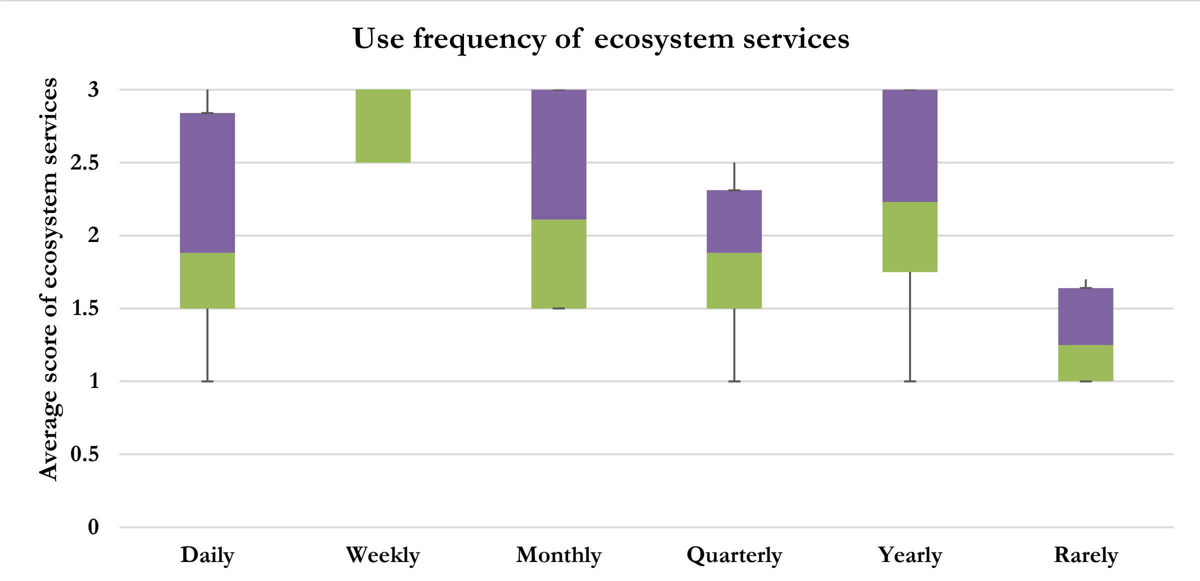

Figure 13 Box plot of average score and use frequency of ecosystem services

4.3 National level ecosystem service and valuation

The amount of carbon stock is calculated using allometric equation based on field measurements of DBH and height of each TOF in croplands. The total amount of carbon stored by TOF in the study area of 147 ha is 759 ton of carbon. On average 5.15 tons of carbon is stored per ha of croplands in the study area. The national ecosystem service of climate change is valued based on carbon market price per ton of carbon. The top and least ten species based on the average amount of carbon stock stored per each TOF species and the carbon stock price/value is listed in (Table 5 and Table 6).

Table 5 Top 10 TOF species with highest average amount of carbon stock per tree

S.No	Species scientific name	Average amount of carbon (kg/tree)	Carbon price/value in $ (US dollars)
1	*Cola gigantea*	4488	40.4- 672
2	*Ricinodendron heudelotti*	3635	36. 3-545
3	*Ceiba pentandra*	3564	35.6-534
4	*Celtis mildbraedii*	3201	32-480
5	*Zanthoxylum spp.*	2447	24.4-366
6	*Celtis adolfi-fredericii*	2440	24.4-366

7	*Pycnanthus angolensis*	2293	22.9-345
8	Unknown2 (Local name: Amangyedua)	2078	20.7-310
9	*Bombax rhodognaphalen*	2039	20.3-304
10	*Entandrophragma celindricum*	1681	16.8-252

Table 6 Top 10 TOF species with lowest average amount of carbon stock per tree

S.No	Species scientific name	Average amount of carbon (kg/tree)	Carbon price/value in $ (US dollars)
1	*Milicia excelsa*	24.10	0.24-3.6
2	*Vernonia amygdalina*	54.87	0.54-8.2
3	*Trema orientalis*	61.03	0.61-9.1
4	*Baphia nitida*	72.65	0.72-10.9
5	*Holarrhena floribunda*	89.91	0.89-13.5
6	Unknown3 (local name: Asusumaasa)	105.26	1.05-15.8
7	*Carica papaya*	128.82	1.29-19.3
8	Unknown4 (local name: Odwini)	128.84	1.29-19.3
9	*Citrus spp.*	143.85	1.43-21.5
10	*Albizia ferruginea*	143.97	1.44-21.6

4.4 Key TOF species and locations

4.4.1 Comparison of local and national TOF species and ecosystem services

Based on the total score value of local ecosystem services and price/value of carbon stock for national ecosystem services 30 % of the top 10 TOF species with highest scores and values are the same for local and national beneficiaries. The rest 70 percent are different. 30 % of the least 10 TOF species with lowest scores and values are also the same. See the list of TOF species with highest and lowest score value local ecosystem services and price/values of national ecosystem service (Table 7).

S.No	Top ten TOF species with highest average carbon stock	TOP ten TOF species with highest local ecosystem services scores
1	*Cola gigantea*	*Ceiba pentandra**
2	*Ricinodendron heudelotti*	*Mangifera indica*
3	*Ceiba pentandra**	*Morinda lucida*
4	*Celtis mildbraedii*	Unknown4 (local name: Odwini)
5	*Zanthoxylum spp.*	*Spathodea campanulata*
6	*Celtis adolfi-fredericii*	*Pycnanthus angolensis**
7	*Pycnanthus angolensis**	*Trema orientalis*

8	Unknown2 (Local name: Amangyedua)	*Bombax rhodognaphalen**
9	*Bombax rhodognaphalen**	*Ficus exasperata*
10	*Entandrophragma celindricum*	*Terminalia ivorensis*

Table 7 Top ten TOF species with highest national and local ecosystem services values

The total score value of the local ecosystem service is compared with the national climate change regulation service value of average carbon stock for each TOF species using scatter plot. The values of the ecosystem services shows that that there is a poor correlation (R^2 = 0.0469) between the local and national ecosystem services. Only 4.69 percent of the variability of the data can be explained by the model fitted to the scatterplot.

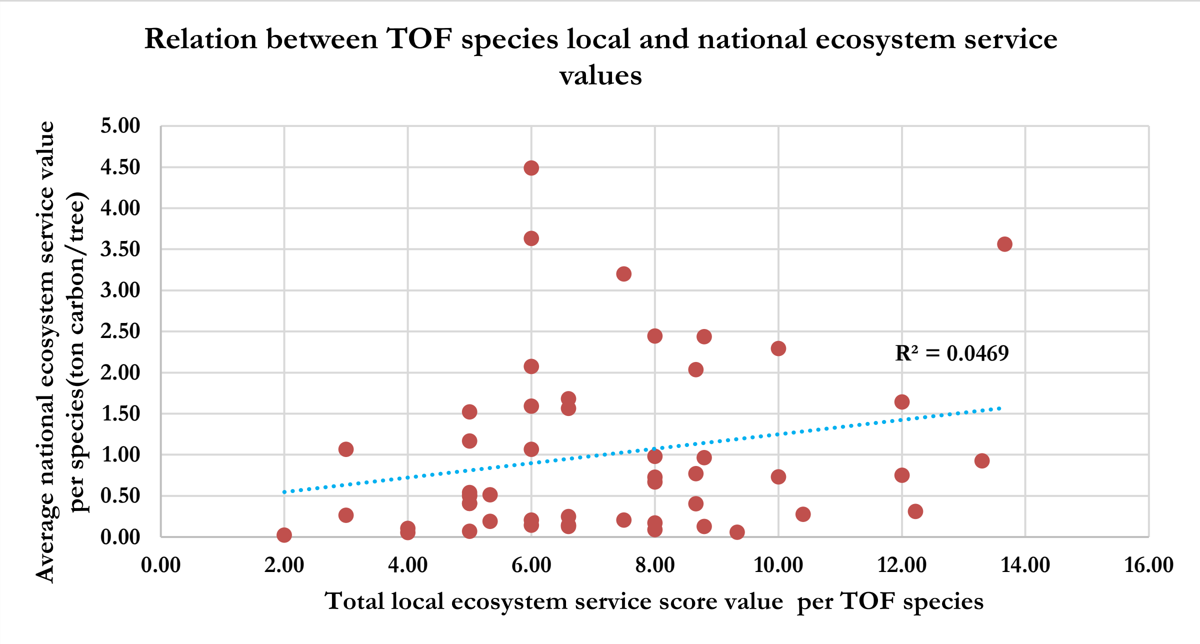

Figure 14 Scatter plot showing the correlation between TOF species local and national ecosystem service values

4.4.2 Local and national ecosystem service hotspot areas

The key TOF locations are identified based on the total score values of local ecosystem services and the amount of carbon stock of each TOF using hotspot analysis in ArcGIS. The total local ecosystem service score values are calculated for each TOF species and assigned to each corresponding TOF individuals based on the particular species value in the study area.

The map and location of local and national ecosystem service hotspot areas are shown in (Figure 15). The places depicted in red are the TOF with high local ecosystem service values and national carbon stock ecosystem service values compared with the surrounding other TOF whereas the areas displayed with light brown/yellow color are the TOF with lowest local and national ecosystem service values. The pattern shows that some hotspot areas are the same for local and national ecosystem service beneficiaries. However, most of the hotspot areas for national beneficiaries are not hotspots for local beneficiaries see the pattern on the map in (Figure 15)

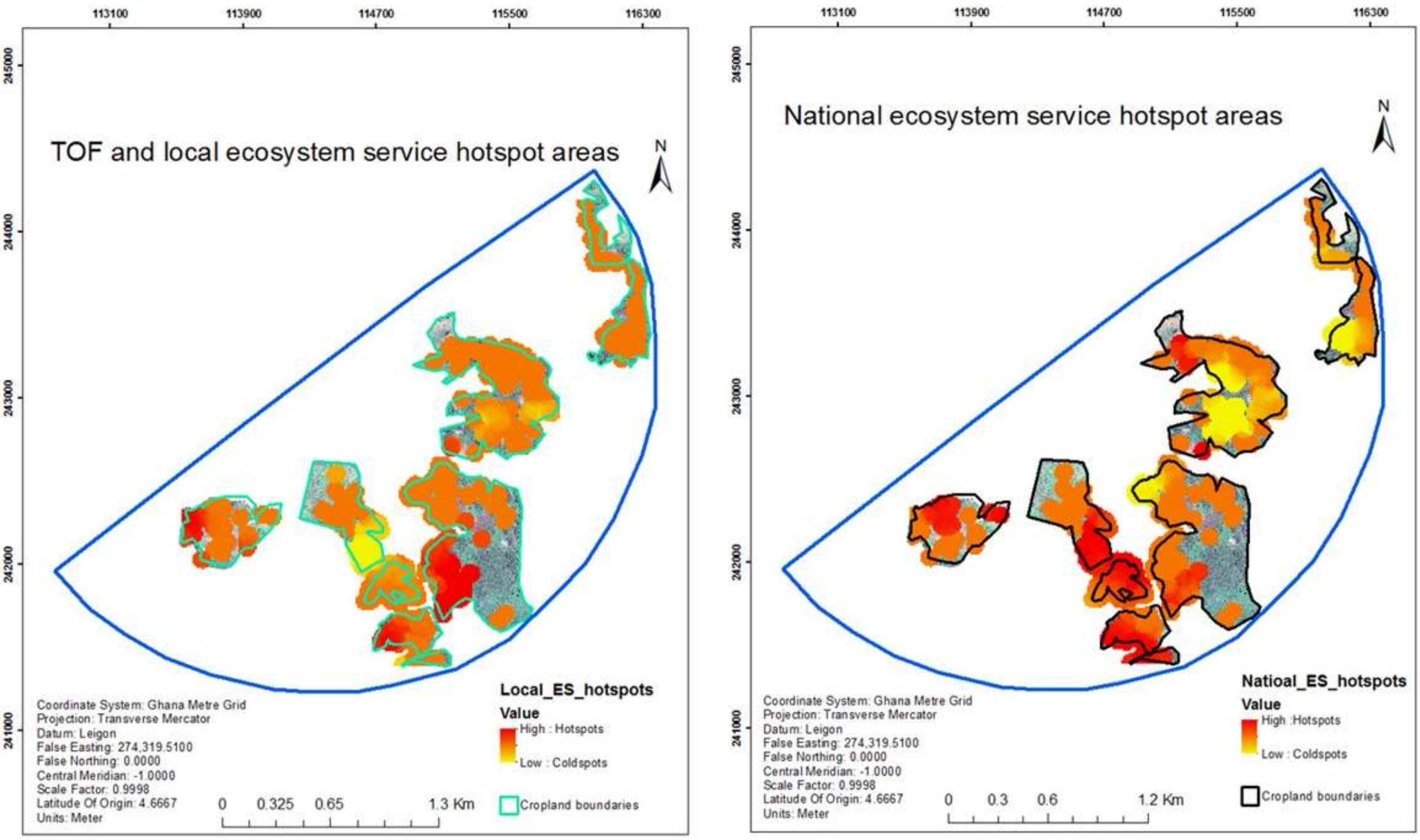

Figure 15 Local and national ecosystem service hotspot areas

5. Discussion

5.1 Mapping and assessing ecosystem services of TOF

The three key issues regarding the mapping and assessment of ecosystem services supplied by TOF such as; spatial TOF inventory and key ecosystem service findings and challenges, key ecosystem service valuation findings and challenges, and transferability of the methods will be discussed under the following headings.

5.1.1 Spatial TOF inventory and key ecosystem service findings and challenges

The first step to conduct a species and spatial inventory of TOF were visiting the croplands of the study area to record the local names and GPS locations of each individual tree using navigation tools such as maps of the study area. The local names of all TOF individuals were identified by the local farmers and the locations of each TOF individuals was recorded. Based on the local names, the field assistant from Kwame

Nkrumah university of Science and technology with good knowledge of tree species and searching the internet the scientific names of each species except five species was identified. The exceptions can be because of the local names that are not recognized scientifically. Identifying TOF species names was the key step to conduct species based ecosystem service mapping and assessment. Recording the local names and the locations of each TOF individuals in some of the croplands was difficult and time consuming due to patchy roads and croplands. However, on the satellite image available from Google Earth some of the patchy croplands was not clearly visible. This can be clearly linked to the difference between the fieldwork time and time of image acquisition, shift in land use/cover such as from cropland to fallow and vice versa) and to some extent the resolution of the available image. The time of image acquisition was date 4/2/2015 whereas the time of field work was from 27/09/2016 to 14/10/2016. Knowledge of the study area through different sources and if possible the actual study area prior to the actual field work visit can be important to get an impressions of the challenges and solutions instead of solely depending on satellite images.

Fifty different TOF species and 786 TOF individuals were found in croplands of the study. This shows how diverse the croplands are in terms of species diversity. The locally diverse species can play important roles in surviving and adapting climate variabilities (Dawson, 2014). The percentage occurrence of these TOF species varies from one species to another. Some species in the study area are very dominant while others are scarce in terms of number of occurrence as shown in (Figure 6). The top ten most dominant species constitute 70. 61 % of the total TOF individuals found in the study area. The difference in occurrence is related to the ecosystem services (importance) and multi-functionality of the species to local farmers.

Ecosystem services are the benefits people obtain from ecosystem service provider/s which are referred as TOF. Different TOF species in croplands provide various types of ecosystem services. The local ecosystem services of each TOF species were identified through participatory research with different stakeholder categories such as gender, age and education level. For this research the ecosystem services are grouped into local ecosystem services and national ecosystem services. The local ecosystem services are services provided directly or indirectly by TOF to the local beneficiaries which can be identified by themselves whereas national ecosystem services are climate change regulation services of carbon stock that cannot be identified by local beneficiaries. The study showed that a total of 15 different local ecosystem services were identified from all the TOF species based on local beneficiaries' knowledge of TOF ecosystem services. All the local ecosystem services are considered as use ecosystem services which are direct and indirect services such as provisioning and regulating services respectively (Hein et al., 2006, TEEB, 2010). Cultural ecosystem services were not identified by local people. However, a study conducted in forest reserves of a different region in western part of Ghana revealed that cultural ecosystem services such as spiritual and religious, and recreational ecosystem services values were identified by local farmers (Boon & Ahenkan, 2013). This can be related to the fact that local farmer's should get a service from the trees directly or indirectly unless their existence for spiritual and recreation values is not considered as an ecosystem service. Shade, timber, medicine, soil fertility and soil conservation are the top ecosystem services supplied by most of the TOF species in the study area respectively (Figure 8). Timber, fuelwood and medicine has been identified as ecosystem services of tree resources (a forest reserve and surrounding off reserve areas) in a different district in Ghana (Hapsari, 2010). From the total 15 different ecosystem services 9 of the total were identified by women, 14 of the total were identified by men and 8 of the total was identified by both men and women. Men were able to recognize and list more ecosystem services compared to women. The difference can be because men are more familiar with TOF species and their services than women.

The multi-functionality of TOF species differs from one TOF species to another (Figure 10 and Appendix 6). However, some TOF species provide one or more the same local ecosystem services as other TOF species. Most of the dominant top ten TOF species are multifunctional species which provide highest diversity and number of local ecosystem services. This shows the most multifunctional TOF species are kept in croplands of the study area. All the least occurring TOF species provide less diversity and number of local ecosystem services compared to the dominant ones, but they are not the least multifunctional TOF species. This implies that the least occurring TOF species are suppling more diverse types and number of ecosystem services than TOF species with medium occurrence.

The national ecosystem service in this study is the amount of above ground carbon stock of TOF. Carbon stock was not mentioned by local beneficiaries. However, some of the local beneficiaries have listed shade, rainfall regulation, timber, soil fertility and soil conservation which can have national level benefits. The amount of carbon stock for each tree was calculated using allometric equations developed for Ghana and Sub-Sharan Africa according to field measurements of height and DBH (Equation 1). Using both height and DBH of trees in allometric equations to calculate above-ground biomass yields better estimate compared to using DBH only (Brown, Andrew J. R. Gillespie, & Ariel E. Lugo, 1989). DBH and height of each TOF individuals was collected in the field and the equation is selected because it yields good result. Inclusion of DBH, height and wood density in allometric equations improves the accuracy of above-ground biomass estimation and results in best estimate (Henry et al., 2010). However, wood densities of most of the TOF species could not be found. As a result, the wood density was not applied in the calculation of carbon stock.

The total amount of above ground carbon stored in all TOF in the study area of 147 ha is 759 tons. On average the total amount of above ground carbon stored per hectare of land in croplands of the study area is 5.15 tons of carbon (tC ha^{-1}). This amount of carbon stock is lower than what is found in different land uses of tropical regions. Average carbon stored by agroforestry practices in tropics has been estimated as 9, 21, 50 and 63 tC ha^{-1} for semiarid, sub-humid, humid and temperate regions (Montagnini & Nair, 2004). The above ground carbon in tropical dry forests has been estimated from 22.97 to 33.27 tC ha^{-1} (Bijalwan, Swamy, Sharma, Sharma, & Tiwari, 2010). The differences are resulted from the land use/cover types, study area locations and the biomass estimation methods.

5.1.2 Key ecosystem service valuation findings and challenges

Based on the local beneficiaries' valuation the most dominantly occurred top ten TOF species and the most multifunctional TOF species are scored highest. Shade, charcoal, pollination to cacao plants, timber, medicine, soil fertility and soil conservation are scored the highest average values as the top most important ecosystem services according to local beneficiaries (Table 3). This implies how important these particular ecosystem service are to local beneficiaries and why they local beneficiaries are retaining TOF species in their croplands. For example; the beneficiaries are retaining TOF to get an ecosystem service of shade mainly to their cacao plantations and future plan of cacao farming. This indicates that local beneficiaries are obtaining more benefits from the TOF species mainly because of these dominant local ecosystem services. The values of the key ecosystem services in this MSc research is to some extent related to a study carried out in Sui-Forest Reserves in western Ghana which identified food production, cacao production, climate regulation and protection of river sources, timber were the most highly ranked ecosystem services supplied by forest reserves respectively (Boon & Ahenkan, 2013). A study conducted in a forest reserve and surrounding off reserve areas in another region of Ghana revealed fuelwood as most important ecosystem services (Hapsari, 2010). However, in this study charcoal is one of the most important ecosystem services than fuel wood.

A statistical paired t-test conducted on the 8 ecosystem services identified both by men and women showed that there is no significance difference among all values between men and women. The statistical test shows that there was similar understanding about the values of the ecosystem services that are identified by both men and women.

TOF can be valued using carbon market prices (Richards & Stokes, 2003, Rashid Rashid, 2012). The price of one ton of carbon ranges 10 to 150 US dollars (Stokes, 2003). This means, the TOF species with highest carbon stock are valued the highest and the lowest are valued the lowest based on the carbon price/value. The top and least ten TOF species are therefore valued as most important and key species for climate change regulation service of carbon stock for national beneficiaries. These TOF species play vital roles in mitigating climate change by storing more carbon compared to other species in the study area.

Three of the top ten most important TOF species are key for both local and national beneficiaries. There is poor correlation between the key species of the national and local beneficiaries (Figure 14). As a result, the key TOF species that have great importance to national beneficiaries but not for local beneficiaries could be under treat of illegal cutting and deforestation. In other hand, the key TOF species that are very crucial to local beneficiaries but not for national beneficiaries (carbon stock as climate change regulation benefit) might cause conflicts of interest between both beneficiaries (Table 7). Therefore, the key TOF species for local farmers/ beneficiaries should be communicated well with the Forest Commission of Ghana to ensure a government protection. The local and national ecosystem service of key hotspots locations were mapped based on the total local ecosystem scores of each TOF species which were assigned to each tree in the study area and the value of carbon stock of each TOF in the study area. The pattern of the key TOF locations implies that most of the hotspot areas for local beneficiaries are different from hotspots of national beneficiaries (Figure 15).

5.1.3 Transferability of the methods

The study was conducted in a small study area. The method for assessing the ecosystem services of TOF species and measuring field data for each and every TOF individuals was time consuming and costly. This makes the method challenging to work on large areas. Sampling for validation and using remote sensing with high resolution satellite images from satellite image providers to estimate above ground carbon could be a solution to carry out TOF studies in large areas.

5.2 Implications for tree management in Ghana

Mapping ecosystem services is important to understand the distribution to visualize locations, patterns and distribution of important ecosystem services at various geographical scales (Maes et al., 2012, Troy & Wilson, 2006, Nemec & Raudsepp-Hearne, 2013, Ecosystems Knowledge Network, 2017, Biodiversity information system for Europe, 2017). Maps are believed to be an important communication tool to easily communicate and discuss about ecosystem services with beneficiaries of a particular ecosystem service provider/s. In this study the supply of provisioning and regulating ecosystem services for local and national beneficiaries by TOF was identified, mapped and assessed. TOF provide different ecosystem services for their beneficiaries. The most important TOF species and locations (hotspots) based on their importance to local and national beneficiaries were identified (Table 7).

The information about the location and ecosystem service values of TOF are important to national beneficiaries to understand the most important TOF locations that need special attention and monitoring. For example TOF species; such as *Ceiba pentandra**, *Mangifera indica, Morinda lucida,* Unknown4 (local name: Odwini), *Spathodea campanulata, Pycnanthus angolensis**, *Trema orientalis, Bombax rhodognaphalen**, *Ficus exasperate, Terminalia ivorensis* are the most important key species for local beneficiaries wheras *Cola gigantean, Ricinodendron heudelotti, Ceiba pentandra**, *Celtis mildbraedii, Zanthoxylum spp., Celtis adolfi-fredericii, Pycnanthus angolensis**, Unknown2 (Local name: Amangyedua), *Bombax rhodognaphalen**, *Entandrophragma celindricum* are the top ten most valuable trees for national beneficiaries. The tree species with a '*' sign refers to the common key important TOF species both for local and national beneficiaries. Identification of the key species can help for policy and decision makers aware of local and national interests, and the ecosystem service values of TOF and their location for proper conservation and utilization of TOF.

6. Conclusion

Integrating TOF ecosystem services into planning and decision making requires a better understanding the spatial location, type of TOF species and the ecosystem services, and their values to local and national beneficiaries. A better understanding of the most multifunctional and valuable TOF species and locations can support to policies linked to the management and use of TOF. The overall objective of this MSc study was to map and assess the ecosystem services of TOF and their contribution to local and national level beneficiaries. Reflecting on the four specific objectives, it can be concluded that;

TOF in croplands of Nkaseim, Goaso are common and diverse. A total of 786 TOF individuals and 50 different TOF species were identified in 147 ha of the croplands. On average 5 TOF individuals were found per hectare of a cropland. However, the 10 TOF species were the most dominant species which covers 70.61% of the total TOF occurred in the study area. The most common species were the most multifunctional trees according to local farmers (beneficiaries).

TOF provided 15 different local ecosystem services of which shade, charcoal, pollination to cacao plants were valued most. However, shade, timber, medicine, soil fertility and soil conservation were the top five most common TOF ecosystem services in the study area. These ecosystem services are provided by most of the TOF species compared to other ecosystem services supplied by TOF. The local ecosystem services of TOF species is valued according to their importance to local beneficiaries.

TOF stored 759 tons of carbon to contribute to climate regulation. On average the amount of carbon stored per hectare is 5.15 tons of carbon. The carbon stock amount is valued based on carbon market. According to Cornelis Van Kooten et al., (2004), the total price/value of 759 ton of carbon stock ranges from 7590 to 113850 US dollars. The carbon price/value can be of great importance for the government (Forest commission) of Ghana whenever incentives can be acquired by REDD for improvements in tree cover to create awareness to local farmers for better management and benefit of TOF.

Three of the top ten most important TOF species are key for both local and national beneficiaries. There is poor correlation between the key species of the national and local beneficiaries (Figure 14). As a result, the key TOF species that have great importance to national beneficiaries but not for local beneficiaries could be under treat of illegal cutting and deforestation. In other hand, the key TOF species that are very crucial to local beneficiaries but not for national beneficiaries (carbon stock as climate change regulation benefit) might cause conflicts of interest between both beneficiaries (Table 7). Therefore, the key TOF species for local farmers/ beneficiaries should be communicated well with the Forest Commission of Ghana to ensure a government protection. The pattern of the key TOF locations implies that most of the hotspot areas for local beneficiaries are different from hotspots of national beneficiaries (Figure 15).

References

Basuki, T. M., van Laake, P. E., Skidmore, A. K., & Hussin, Y. A. (2009). Allometric equations for estimating the above-ground biomass in tropical lowland Dipterocarp forests. *Forest Ecology and Management*, *257*(8), 1684–1694. http://doi.org/10.1016/j.foreco.2009.01.027

Bijalwan, A., Swamy, S. L., Sharma, C. M., Sharma, N. K., & Tiwari, A. K. (2010). Land-use, biomass and carbon estimation in dry tropical forest of Chhattisgarh region in India using satellite remote sensing and GIS. *Journal of Forestry Research*, *21*(2), 161–170. http://doi.org/10.1007/s11676-010-0026-y

Bonham, C. D. (2013). *Measurements for Terrestrial Vegetation* (2nd ed.). Oxford, UK: John Wiley & Sons, Ltd. http://doi.org/10.1002/9781118534540

Boon, E., & Ahenkan, A. (2013). Assessing Climate Change Impacts on Ecosystem Services and Livelihoods in Ghana: Case Study of Communities around Sui Forest Reserve. *Journal of Ecosystem & Ecography*, *3*(2). http://doi.org/10.4172/2157-7625.S3-001

Bryan, B. A., Raymond, C. M., Crossman, N. D., & Hatton Macdonald, D. (2010). Targeting the management of ecosystem services based on social values: Where, what, and how? *Landscape and Urban Planning*, *97*, 111–122. http://doi.org/10.1016/j.landurbplan.2010.05.002

Chan, K. M. A., Satterfield, T., & Goldstein, J. (2012). Rethinking ecosystem services to better address and navigate cultural values. *Ecological Economics*, *74*, 8–18. http://doi.org/10.1016/j.ecolecon.2011.11.011

Chave, J., Andalo, A. C., Brown, A. S., Cairns, A. M. A., Chambers, J. Q., Eamus, A. D., … Kira, T. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia*, *145*, 87–99. http://doi.org/10.1007/s00442-005-0100-x

Cornelis Van Kooten, G., Eagle, A. J., Manley, J., & Smolak, T. M. (2004). *How Costly are Carbon Offsets? A Meta-Analysis of Forest Carbon Sinks*.

Costanza, R., D 'arge, R., De Groot, R., Farberk, S., Grasso, M., Hannon, B., … Van Den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *NATURE*, *387*(15).

Crossman, N. D., & Bryan, B. A. (2009). Identifying cost-effective hotspots for restoring natural capital and enhancing landscape multifunctionality. *Ecological Economics*, *68*(3), 654–668. http://doi.org/10.1016/j.ecolecon.2008.05.003

Crossman, N. D., Burkhard, B., Nedkov, S., Willemen, L., Petz, K., Palomo, I., … Maes, J. (2013). A blueprint for mapping and modelling ecosystem services. *Ecosystem Services*, *4*, 4–14. http://doi.org/10.1016/j.ecoser.2013.02.001

Daily, G. C., Polasky, S., Goldstein, J., Kareiva, P. M., Mooney, H. A., Pejchar, L., … Shallenberger, R. (2009, February). Ecosystem services in decision making: time to deliver. http://doi.org/10.1890/080025

David.W. Pearce, & and Kerry Turner. (1990). Economics of Natural Resources and The Environment.

Dawson, I. K. (2014). Seeing the trees as well as the forest: The importance of managing forest genetic resources. *Forest Ecology and Management*. http://doi.org/10.1016/j.foreco.2014.08.014

Duarte, G. T., Ribeiro, M. C., & Paglia, A. P. (2016). Ecosystem Services Modeling as a Tool for Defining Priority Areas for Conservation. *PloS One*, *11*(5), e0154573. http://doi.org/10.1371/journal.pone.0154573

Er, J. (2014). Improved allometric models to estimate the aboveground biomass of tropical trees. http://doi.org/10.1111/gcb.12629

Evans, K., De Jong, W., Cronkleton, P., Sheil, D., Lynam, T., Kusumanto, T., & Colfer, C. J. P. (2006). *Guide to Participatory Tools for Forest Communities*. Jakarta, Indonesia: Center for International Forestry Research.

FAO. (1998). *FRA 2000 on definitions of forest and forest change*. Retrieved from http://www.fao.org/docrep/006/ad665e/ad665e06.htm

FAO. (2013). Assessing Trees Outside Forests | Natural Resources Policy & Practice | IISD Reporting Services. Retrieved May 23, 2016, from http://nr.iisd.org/news/fao-working-paper-addresses-issues-on-assessing-trees-outside-forests/

Felipe-Lucia, M. R., Comín, F. A., & Escalera-Reyes, J. (2015). A framework for the social valuation of ecosystem services. *Ambio*, *44*(4), 308–18. http://doi.org/10.1007/s13280-014-0555-2

Ferraro, P. J., Hanauer, M. M., Miteva, D. A., Nelson, J. L., Pattanayak, S. K., Nolte, C., … Polasky, S. (2014). Estimating the impacts of conservation on ecosystem services and poverty by integrating modeling and evaluation. http://doi.org/10.1073/pnas.1406487112

Fisher, B., Christie, M., Aronson, J., Braat, L., Gowdy, J., Haines-Young, R., … Shmelev, S. (2010). Integrating the ecological and economic dimensions in biodiversity and ecosystem service valuation.

Ghana Forestry Commission. (2017). Ghana timber and wood products and applications. Retrieved February 1, 2017, from http://www.ghanatimber.org/applications.php

Gibbons, P., Lindenmayer, D. B., Fischer, J., Manning, A. D., Weinberg, A., Seddon, J., … Barrett, G. (2008). *The Future of Scattered Trees in Agricultural Landscapes*. *Conservation Biology* (Vol. 22). http://doi.org/10.1111/j.1523-1739.2008.00997.x

Guo, Z. D., Hu, H. F., Pan, Y. D., Birdsey, R. A., & Fang, J. Y. (2014). Increasing biomass carbon stocks in trees outside forests in China over the last three decades. *Biogeosciences*, *11*(15), 4115–4122. http://doi.org/10.5194/bg-11-4115-2014

Hansen, C. P., Treue, T., & Lund, J. F. (2009). Challenges and opportunities in implementing REDD at the national level: The case of Ghana. In *IOP Conference Series: Earth and Environmental Science* (Vol. 6, p. 252006). http://doi.org/10.1088/1755-1307/6/5/252006

Hapsari, A. (2010). *Assessing and Mapping Ecosystem Services in Offinso*. University of Twente Faculty of Geo-Information and Earth Observation (ITC), MSc thesis, Enschede, The Netherlands. Retrieved from http://www.itc.nl/library/papers_2010/msc/nrm/hapsari.pdf

Hein, L., van Koppen, K., de Groot, R. S., & van Ierland, E. C. (2006). Spatial scales, stakeholders and the valuation of ecosystem services. *Ecological Economics*, *57*(2), 209–228. http://doi.org/10.1016/j.ecolecon.2005.04.005

Henry, M., Besnard, A., Asante, W. A., Eshun, J., Adu-Bredu, S., Valentini, R., … Saint-Andr??, L. (2010). Wood density, phytomass variations within and among trees, and allometric equations in a tropical rainforest of Africa. *Forest Ecology and Management*, *260*(8), 1375–1388. http://doi.org/10.1016/j.foreco.2010.07.040

Herrera-Fernández, B. (2003). *Classification and modeling of trees outside forest in central American landscapes by combining remotely sensed data and GIS*. *Forstwissenschaftliche Fakultät*.

Kremen, C. (2005). Managing ecosystem services: what do we need to know about their ecology? *Ecology Letters*, *8*(5), 468–479. http://doi.org/10.1111/j.1461-0248.2005.00751.x

Liu, S., Costanza, R., Troy, A., D'Aagostino, J., & Mates, W. (2010). Valuing New Jersey's Ecosystem Services and Natural Capital: A Spatially Explicit Benefit Transfer Approach. *Environmental Management*, *45*(6), 1271–1285. http://doi.org/10.1007/s00267-010-9483-5

Locus Map - knowledge base. (2016). Locus Map Basics. Retrieved February 1, 2017, from http://docs.locusmap.eu/doku.php

M.Giner, S. H. (2016). Finding Hot Spots Using ArcGIS Online: Minimizing the Subjectivity of Visual Analysis. Washington DC.

Meneguzzo, D. M., Liknes, G. C., & Nelson, M. D. (2013). Mapping trees outside forests using high-resolution aerial imagery: a comparison of pixel- and object-based classification approaches. *Environmental Monitoring and Assessment*, *185*(8), 6261–6275. http://doi.org/10.1007/s10661-012-3022-1

Millennium Ecosystem Assessment. (2003). *Ecosystems and Human Well-being*. (Millennium Ecosystem Assessment, Ed.). Washington DC.

Millennium Ecosystem Assessment(MA). (2005). *Ecosystems and Human Well-being*. Retrieved from http://www.millenniumassessment.org/documents/document.356.aspx.pdf

Montagnini, F., & Nair, P. K. R. (2004). Carbon sequestration: An underexploited environmental benefit of agroforestry systems. *Agroforestry Systems*, *61–62*(1–3), 281–295. http://doi.org/10.1023/B:AGFO.0000029005.92691.79

Ning, Z. H., & Abdollahi, K. K. (2005). *Perils on the Road to Participatory Research in Community Forestry*. (Z. H. N. and K. K. Abdollahi, Ed.).

Pagiola, S., & Bishop, J. (2004). *Assessing the Economic Value of Ecosystem Conservation*. *October* (Vol. 58). Retrieved from http://www.cbd.int/doc/case-studies/inc/cs-inc-iucn-nc-wb-en.pdf

Paudyal, K., Baral, H., Bhandari, S. P., & Keenan, R. J. (2015). Participatory assessment and mapping of ecosystem services in a data-poor region: Case study of community-managed forests in central Nepal. *Ecosystem Services*, *13*, 81–92. http://doi.org/10.1016/j.ecoser.2015.01.007

Plummer, M. L. (2009). Assessing benefit transfer for the valuation of ecosystem services. *Frontiers in Ecology and the Environment*, *7*(1), 38–45. http://doi.org/10.1890/080091

Rashid Rashid, P. S. Assessment of cArbon stocks As An ecosystem service At rusenski Lom nAture PArk (2012).

Raymond, C. M., Bryan, B. A., MacDonald, D. H., Cast, A., Strathearn, S., Grandgirard, A., & Kalivas, T. (2009). Mapping community values for natural capital and ecosystem services. *Ecological Economics*, *68*(5), 1301–1315. http://doi.org/10.1016/j.ecolecon.2008.12.006

Richards, K. R., & Stokes, C. (2003). A REVIEW OF FOREST CARBON SEQUESTRATION COST STUDIES: A DOZEN YEARS OF RESEARCH.

Scharlemann, J. P. W., Kapos, V., Campbell, A., Lysenko, I., Burgess, N. D., Hansen, M. C., … Miles, L. (2010). Securing tropical forest carbon: the contribution of protected areas to REDD. *Oryx*, *44*(3), 352–357. http://doi.org/10.1017/S0030605310000542

Schnell, S. (2015). *Integrating Trees Outside Forests into National Forest Inventories*. Integrating Trees Outside Forests into National Forest Inventories Sebastian Schnell Faculty of Forest Sciences Department of Forest Resource Management Umeå Doctoral Thesis Swedish University of Agricultural Sciences. Retrieved from http://pub.epsilon.slu.se/12011/1/schnell_s_150320.pdf

Schnell, S., Kleinn, C., & Ståhl, G. (2015a). Monitoring trees outside forests: a review. *Environmental Monitoring and Assessment*, *187*(9), 600. http://doi.org/10.1007/s10661-015-4817-7

Schnell, S., Kleinn, C., & Ståhl, G. (2015b). Monitoring trees outside forests: a review. *Environmental Monitoring and Assessment*, *187*(9), 600. http://doi.org/10.1007/s10661-015-4817-7

Sinare, H., & Gordon, L. J. (2015). Ecosystem services from woody vegetation on agricultural lands in Sudano-Sahelian West Africa. *Agriculture, Ecosystems and Environment*, *200*, 186–199. http://doi.org/10.1016/j.agee.2014.11.009

TEEB. (2010). *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB*.

UNFCCC. (2008). Kyoto Protocol Reference Manual, Bonn, Germany.

van Breugel, M., Ransijn, J., Craven, D., Bongers, F., & Hall, J. S. (2011). Estimating carbon stock in secondary forests: Decisions and uncertainties associated with allometric biomass models. *Forest Ecology and Management*, *262*(8), 1648–1657. http://doi.org/10.1016/j.foreco.2011.07.018

Vashum, K. T., Jayakumar, S., & T. Vashum, K. (2012). Methods to Estimate Above-Ground Biomass and Carbon Stock in Natural Forests - A Review. *Journal of Ecosystem & Ecography*, *2*(4), 1000116. http://doi.org/10.4172/2157-7625.1000116

Vieilledent, G., Vaudry, R., Andriamanohisoa, S. F. D., Rakotonarivo, O. S., Randrianasolo, H. Z., Razafindrabe, H. N., … Rasamoelina, M. (2012). A universal approach to estimate biomass and carbon stock in tropical forests using generic allometric models. *Ecological Applications*, *22*(2), 572–583. http://doi.org/10.1890/11-0039.1

World Agroforestry Centre. (2011). Retrieved January 25, 2017, from http://www.worldagroforestry.org/news/tree-ownership-hindering-redd-ghana

Zahidi, I. (2015). Object-based classification of QuickBird image and low point density LIDAR for tropical trees and shrubs mapping. *European Journal of Remote Sensing*, *48*, 423. http://doi.org/10.5721/EuJRS20154824

Appendices

Appendix 1. Field data collection sheet in Nkaseim, Goaso, Ghana

Field data collection sheet in Nkaseim, Goaso, Ghana				Mapping and Assessing the Ecosystem Services of TOF in Croplands		
Date:				Observers:		
S.No	Species Name (local or Scientific)	DBH (cm)	Height (m)	GPS points		Remarks
				X (longtiude)	Y (latitude)	
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						

Appendix 2. Questionnaire and data collection sheet in Nkaseim, Goaso, Ghana

Education level: Illiterate ( ) Read and write ( ) Primary ( ) Secondary ( ) Tertiary ( ) **Gender:** Female ( ) Male ( ) **Age:** 15-25 ( ) 26-36 ( ) 37-47 ( ) 48-58 ( ) Above 59 ( )		**Occupation:** **Village name:**
Date of interview and data collection:		**Questionnaire No:** **Cropping system:** **Observer(s):**
Species Name (Local or Scientific Name):		

S.No	**Which ecosystem benefit(s) are supplied by the specific tree?**	**Score the benefits(s)**	**How often do you use or enjoy the benefits?**							**Remarks**
			daily	**weekly**	**monthly**	**quarterly**	**yearly**	**rarely**	**never**	
	Food ( )									
	Shelter/shade ( )									
	Medicine ( )									
	Fuel wood ( )									
	Soil conservation ( )									
	Spritual ( )									
	Historical use ( )									
	Aesthetic ( )									
	Recreational ( )									
	Soil fertility ( )									
	Habitat for other important species ( )									
	If others Specify___________________ ( )									

Appendix 3. List of TOF species in croplands and their local and scientific names in the study area.

Species local name	Scientific name
Akata	*Bombax rhodognaphalen*
Akrusen	Unknown1
Akuokuoninsuo	*Spathodea campanulata*
Akutuo	*Citrus spp.*
Akyee	*Blighia sapida*
Amangyedua	Unknown2
Apruo/Odanta/Danta	*Nesogordonia papaverifera*
Asusumaasa	Unknown3
Atoa	*Spondias Mombim*
Avocado/Pear	*Persea Americana*
Awiemfosamina	*Albizia ferruginea*
Awonwne	*Vernonia amygdalina*
Danya	*Cylicodiscus gabunensis*
Emire	*Terminalia ivorensis*
Esa kosua	*Celtis adolfi-fredericii*
Esa/Osa	*Celtis mildbraedii*
Foto	*Sterculia tragacantha.*
Funtum	*Funtumia elastica*
Gliricidia spp	*Gliricidia sepium*
Konkroma	*Morinda lucida*
Kusia	*Nanclea diderrichii*
Kyenkyen	*Antiaris toxicaria*
Leucaena spp	*Leucaena leucocephala*
Mango	*Mangifera indica*
Neem tree	*Azadirachta indica*
Nyamedua	*Alstonia boonei*
Nyankyerene	*Ficus exasperata*
Odoma	*Ficus carpensis*
Odum	*Milicia excelsa*
Odwen	*Baphia nitida*
Odwini/Odwino	Unknown4
Ofram/Framo	*Terminalia superba*
Okure	*Trilipisium madagascariense*
Onyina	*Ceiba pentandra*
Opam	*Macaranga barteri*
Otepruo	Unknown5
Otie	*Pycnanthus angolensis*
Oyaa	*Zanthoxylum spp.*
Pampena	*Albizia adianthifolia*
Papaya/Pawpaw	*Carica papaya*
Pepea	*Margaritaria discoidea*
Prekese	*Tetrapleura tetraptera*
Sapele	*Entandrophragma celindricum*
Senna spp	*Senna siamea*
Sese	*Holarrhena floribunda*
Sesea	*Trema orientalis*
Sofo/ Foto	*Sterculia tragacantha*
Wama/Woma	*Ricinodendron heudelotti*
Watapuo	*Cola gigantea*
Wawa	*Triplochiton scleroxylon*

Appendix 4. Top 10 TOF species with highest and lowest amount of total carbon stock

Top 10 TOF species with highest amount of total carbon stock

S.No	**Species scientific name**	**Total amount of carbon (kg/tree)**
1	*Alstonia boonei*	23876.37
2	*Bombax rhodognaphalen*	42810.21
3	*Ceiba pentandra*	188914.71
4	*Cola gigantea*	89768.24
5	*Ficus exasperata*	40150.90
6	*Mangifera indica*	57484.37
7	*Morinda lucida*	37374.88
8	*Pycnanthus angolensis*	32098.82
9	*Spathodea campanulata*	48326.48
10	*Sterculia tragacantha*	35882.18

Top 10 TOF species with lowest amount of total carbon stock

S.No	**Species scientific name**	**Total amount of carbon (kg/tree)**
1	*Baphia nitida*	145.29
2	Carica papaya	128.82
3	*Citrus spp.*	143.85
4	*Cylicodiscus gabunensis*	170.61
5	*Holarrhena floribunda*	359.66
6	*Milicia excelsa*	48.20
7	*Terminalia ivorensis*	406.99
8	Trema orientalis	427.19
9	*Unknown1*	387.22
10	*Unknown3*	105.26

Appendix 5. Use frequency and average score of ecosystem services

Use frequency and average of score of ecosystem services							
TOF ecosystem services	**daily**	**weekly**	**monthly**	**quarterly**	**yearly**	**rarely**	**Grand total average**
Boundary	1.00						1.00
Charcoal			3.00	2.00			2.50
Climbing of yam tree	2.00						2.00
Food				1.67	2.20	1.00	2.00
Fuel wood			1.50	2.25	2.00	1.50	1.89
Habitat to other important species					1.00		1.00
Medicine	2.17	2.50	2.11	1.75	3.00	1.63	2.03
pollination of cacao plants	3.00						3.00
Rainfall regulation	1.88			1.00			1.78
Shade	2.74				3.00		2.74
Soil conservation	1.87					1.00	1.81
Soil fertility	1.76					1.00	1.72
Timber	1.00			2.50	2.25	1.70	1.82
Water accumulation for other crops	3.00						3.00
Wind abatement	1.50						1.50
Grand total average	**2.37**	**2.50**	**2.09**	**2.05**	**2.22**	**1.63**	**2.16**

Appendix 6. TOF species and types of local ecosystem services supplied by each TOF

TOF species and types of ecosystem services supplied			
Albizia adianthifolia	Rainfall regulation	***Celtis mildbraedii***	Timber
	Shade		Fuel wood
	Soil fertility		Shade
	Timber	***Citrus spp.***	Timber
Albizia ferruginea	Medicine		Food
	Shade		Fuel wood
	Timber	***Cola gigantea***	Shade
Alstonia boonei	Medicine		Shade
	Shade		Soil conservation
	Soil conservation	***Cylicodiscus gabunensis***	Soil fertility
Antiaris toxicaria	Habitat to other important species		Charcoal
	Shade		Fuel wood
	Soil conservation		Medicine
	Soil fertility	***Entandrophragma celindricum***	Timber
	Timber		Medicine
Azadirachta indica	Medicine		Shade
Baphia nitida	Medicine	***Ficus carpensis***	Timber
	Shade		Food
Blighia sapida	Shade	***Ficus exasperata***	Fuel wood
	Timber		Climbing of yam tree
Bombax rhodognaphalen	Food		Medicine
	Medicine		Rainfall regulation
	Shade	***Funtumia elastica***	Shade
	Timber		Shade
Carica papaya	Food		Soil fertility
	Medicine	***Gliricidia sepium***	Timber
	Shade		Shade
Ceiba pentandra	Climbing of yam tree	***Holarrhena floribunda***	Soil conservation
	Rainfall regulation		Medicine
	Shade		Shade
	Soil conservation		Soil fertility
	Soil fertility	***Leucaena leucocephala***	Timber
	Timber		Rainfall regulation
	Wind abatement		Shade
Celtis adolfi-fredericii	Fuel wood	***Macaranga barteri***	Soil fertility
	Shade		Climbing of yam tree
	Soil fertility	***Mangifera indica***	Shade
	Timber		Food
	Medicine		Soil conservation
			Soil fertility
			Medicine
			Rainfall regulation

Margaritaria discoidea	Medicine	***Sterculia tragacantha.***	Timber
	Shade	***Terminalia ivorensis***	Charcoal
	Soil fertility		Medicine
	Timber		Shade
Milicia excelsa	Timber		Timber
Morinda lucida	Medicine	***Terminalia superba***	Boundary
	Shade		Medicine
	Soil conservation		Shade
	Timber		Soil conservation
	Wind abatement		Soil fertility
Nanclea diderrichii	Medicine		Timber
	pollination of cacao plants	***Tetrapleura tetraptera***	Food
	Shade		Medicine
	Timber		Shade
Nesogordonia papaverifera	Shade		Timber
	Timber	***Trema orientalis***	Medicine
Persea americana	Food		Shade
	Shade		Soil conservation
Pycnanthus angolensis	Fuel wood		Timber
	Medicine	***Trilipisium madagascariense***	Fuel wood
	Rainfall regulation		Shade
	Shade	***Triplochiton scleroxylon***	Shade
	Timber		Timber
Ricinodendron heudelotti	Shade	**Unknown1 (local name: Akrusen)**	Shade
	Soil conservation		Timber
	Timber	**Unknown2 (Amangyedua)**	Food
Senna siamea	Shade		Medicine
	Soil conservation		Shade
	Soil fertility	**Unknown3 (Asusumaasa)**	Medicine
Spathodea campanulata	Medicine		Timber
	Rainfall regulation	**Unknown4 (Odiwino)**	Fuel wood
	Shade		Medicine
	Soil conservation		Shade
	Soil fertility		Water accumulation for other crops
	Timber	**Unknown5 (Otepruo)**	Shade
	Wind abatement		Soil conservation
Spondias Mombim	Food		Timber
	Shade		Wind abatement
	Soil fertility	***Vernonia amygdalina***	Shade
Sterculia tragacantha	Shade		Timber
	Soil fertility	***Zanthoxylum spp.***	Medicine
	Timber		Shade
			Soil conservation
			Timber