ASSESSING THE IMPACTS OF OIL PALM EXPANSION ON ECOSYSTEM SERVICES UNDER DIFFERENT SCENARIOS, A CASE OF BUVUMA ISLAND, UGANDA

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ABSTRACT

Oil palm production was introduced in Uganda on Bugala island around 2003 under the Vegetable Oil Development Project (VODP) with the aim of boosting the economy of Bugala island and to reduce the import of vegetable oil to Uganda. The production of oil palm has led to a major land cover change on the island. The land cover change has led to different social and environmental impacts such as reduction of ecosystem services. The government of Uganda is planning to introduce oil palm on Buvuma island but there is lack of information on the ecosystem services (benefits from nature and farmlands) which are in danger of being impacted by the introduction of oil palm like on Bugala island. The ecosystem services are important because the local people depend on them to support their daily lives. The aim of this study is to describe and assess the ecosystem services which are likely to be impacted by the planned future oil palm expansion on Buvuma island.

The study identified several ecosystem services on Buvuma island using a questionnaire administered through the online Maptionnaire tool. Different stakeholders from the island participated in describing the ecosystem services on Buvuma island. The ecosystem services were then spatially described based on the land cover and presented in maps. The second step was to find where oil palm will likely be grown on Buvuma island. A logistic regression model was developed to explain the relationship between the oil palm locations and the spatial explanatory variables such as slope, soil type, and accessibility on Bugala island. The developed model was transferred to Buvuma island for future land cover modelling. The CLUMondo model was used to project the future land cover in 2025 of Buvuma island under three scenarios. The scenarios include i) Business as Usual (BAU) assuming no oil palm will be introduced on the island and the current trend of land cover change will continue, ii) a protection enhanced scenario assuming expansion of 5000 ha of oil palm while protecting the protected areas/forests reserves and iii) an economic enhanced scenario assuming the introduction of 10,000 ha of oil palm on Buvuma island. The areas of change were identified using the projected land cover maps of 2025 and the land cover map of 2015. The ecosystem services maps were then overlaid with the land cover change maps, to identify the locations where the ecosystem services are likely to be impacted (either positively or negatively) by land cover change under each scenario.

The results show that Buvuma island has several provisioning ecosystem services including grass for cattle, construction materials (timber), food production, food collection (fruits, hunting, and fishing), medicinal plants and fuelwood & charcoal. The locations of oil palm plantations were explained by seven explanatory variables, which are clay content in the soil, protected areas, distance to the road, distance to the lake, slope, elevation, and wetlands. The land cover change maps of 2025 show that for BAU scenario woodland will be mostly converted to subsistence farmland, followed by grassland and then bushland hence ecosystem services from these land cover types will be much impacted, but there will be an increase in food production. For the protection and economic enhanced scenario, most of the subsistence farmland will be converted to oil palm plantations hence food production will be most impacted. Woodland, grassland, and bushland will also be converted but mostly on the economic enhanced scenario hence ecosystem services from these land cover types will also be impacted. This study can be used for the future land use management plans because it provides an overview of where the ecosystem services are located on the island which are essential for the people's livelihood and the consequences of future land cover changes on those ecosystem services.

Keywords: Ecosystem services, Oil palm expansion, Land cover change, Impacts, CLUMondo model, Scenarios

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LIST OF ABBREVIATIONS

AUC – Area Under the Curve

CHIRPS – Climate Hazards Group Infrared Precipitation with Station data

CFR – Central Forest Reserve

CPO – Crude Palm Oil

DEM – Digital Elevation Model

IFAD – International Fund for Agriculture development

FOEI – Friends of Earth International

FOEE – Friends of Earth Europe

NAPE –National Association of Professional Environmentalists

NEMA – National Environmental Management Authority

ROC – Receiver Operating Characteristic

RSPO – Roundtable Sustainable Palm oil

SRTM – Shuttle Radar Topography Mission

LFR – Local Forest Reserve

PKO – Palm Kennel Oil

VODP – Vegetable Oil Development Project

1. INTRODUCTION

1.1. Background and Problem statement

Oil palm (*Elaeis guineensis*) is a tree crop mainly grown in the tropical areas which originated from central-west Africa (Corley & Tinker, 2003). The crop requires deep soil, and a moist climate with high temperatures throughout the year. Oil palm is mainly grown in large plantations for the production of vegetable oil of two types: crude palm oil (CPO) and palm kernel oil (PKO) (Verheye, 2010; Pacheco, Gnych, Dermawan, Komarudin, & Okarda, 2017). Palm oil is the most important vegetable oil in the world and is used in different products such as cosmetics, packaged and fast foods (Mancini et al., 2015; Vijay et al., 2016). Currently, it has been reported that palm oil accounts for 36% of the world vegetable oils (Woittiez, van Wijk, Slingerland, van Noordwijk, & Giller, 2017). Oil palm is considered an important crop because of its high economic value as it is easy to be established, involving low costs of production, and generates high output (Corley & Tinker, 2003; Khatun, Reza, Moniruzzaman, & Yaakob, 2017).

The economic values and growth of palm oil market in the world, for instance in China, India, Europe, and America, have been motivating the expansion of oil palm in tropical areas (Colchester et al., 2013). Oil palm expansion comes with some economic benefits in the producing countries which include improvement of local infrastructure and rural poverty reduction (Mosnier et al., 2017). Therefore, the governments of the producing countries have seen this as a potential for more development in their countries, hence keep supporting the expansion of oil palm plantations (Pacheco et al., 2017).

Oil palm production has expanded extremely in recent years making it one of the most rapidly growing crops in the world (Addo, 2012). The expansion of the global oil palm planting area has increased from 10 to 17 million hectares between 2000 and 2012 (Colchester et al., 2013; Pirker, Mosnier, Kraxner, Havlik, & Obersteiner, 2016). Different tropical parts of the world have experienced the expansion of oil palm plantations. Countries like Indonesia, Malaysia, Colombia, Ghana are leading in the production of palm oil. As agricultural land is limited, the expansion of oil palm plantations has occurred on existing cropland and in native tropical forests (Petrenko, Paltseva, & Searle, 2016).

The rapid expansion of this crop has been reported by many studies to be among the major drivers of land cover change in the areas where it is grown, as the crop requires large production areas (Dislich et al., 2016; Vijay et al., 2016; Sharma et al., 2017). As part of the land cover change, the rapid growth of oil palm has led to severe social and environmental consequences such as biodiversity loss, deforestation, soil erosion, and land ownership conflicts as people are evicted from their land for oil palm expansion (Verheye, 2010; Colchester et al., 2013; Pirker et al., 2016; Mosnier et al., 2017). World Wide Fund for Nature (2017) reported that large areas of forests and valuable ecosystems have been cleared for oil palm plantations, which caused a reduction in carbon stock and emissions of greenhouse gases (GHGs). Loss of forests in the tropics contributes to 10-20% of total GHGs emissions, which is the second largest GHG source in the earth (Petrenko et al., 2016).

Land cover change is also a driver of ecosystems destruction and ecosystem services reduction (Foley et al., 2005). Ecosystems include living and non-living organisms and their interactions. The benefits human beings obtain from ecosystems or nature are referred to as ecosystem services, which include provisioning, regulating, and cultural services. Due to land cover change over time from improper land use management plans the ecosystems are in danger of being destroyed (Millennium Ecosystem Assessment, 2005; Petz, 2014). Humans depend on the ecosystem services for their daily lives (Willemen, Drakou, Dunbar, Mayaux, & Egoh, 2013), so ecosystems providing these services need to be well-functioning. But, most ecosystems on earth have experienced land cover conversions and these changes caused a change in the services provided (De Groot, Alkemade, Braat, Hein, & Willemen, 2009; Sharma et al., 2017).

Therefore, the understanding of spatial patterns of land cover changes is important because the changes affect the environment such as climate and soil fertility (Prestele et al., 2016). Different models can be used to understand land cover changes. A model can simply be defined "as an abstract and simplified representation of reality used to understand a certain aspect of that reality" and modelling involves simulation and visualization of biophysical or socioeconomic processes by combining different elements, their behavior, and interactions (Petz, 2014). Land cover change models represent part of the complexity of land-use systems and they can also answer the issues of location of change and the rates/quantity of changes likely to progress in the future (Veldkamp & Lambin, 2001). As land cover change has an impact on the ecosystem services, it is crucial to assess impacts on key ecosystem services and analyze the possible future land use for oil palm expansion given the expected future growth (Sharma, Baral, Pablo, & Laumonier 2017). This can also be assessed through land use scenarios. Projecting future land cover change using scenarios allows mitigating the possible consequences on ecosystem services (Sohl & Sleeter, 2012). Scenarios are a useful tool to discover uncertain futures in ecological systems, as they describe alternative futures and allow examining the possible future conditions under several assumptions given our present understanding of the way different land cover drivers interact with the ecosystems (Sleeter et al., 2012).

Oil palm is still introduced on new locations. Uganda introduced oil palm around 2003 on Bugala island in Kalangala district (Figure 1) (Berg, 2016) under Vegetable Oil Development Project (VODP). The aim was to increase the production of domestic vegetable oil, hence raise the income of rural communities and ensure the supply of vegetable oil in Uganda and neighboring countries (Abonyo et al., 2007; IFAD, 2016). The VODP was undertaken by a private developer BIDCO and smallholder farmers supported by the government of Uganda and International Fund for Agriculture Development (IFAD) (Environmental Assessment Consult Limited, 2003). Kalangala district was selected as a starting point for implementation of VODP because it was one of the poorest districts in Uganda after experiencing the Tsetse fly incidence in the 1900s which led to delayed development of the area (Ministry of Finance, 2000). As reported by Ministry of Finance (2000) and NAPE (2011) the aim of the project was also to reduce over-dependence on fishing and subsistence agriculture, to create new jobs, and to increase smallholders income. Apart of being poor, Bugala island, the main island in Kalangala district was selected because of its favorable climatic conditions, soils and geomorphology, the land use and land availability (Environmental Assessment Consult Limited, 2003).

The VODP was planned to be implemented in different phases. The first phase of the project intended to plant 10,000 hectares (ha) of oil palm on Bugala island, which involved the change of more than one-quarter of the land of Bugala island (Friends Of The Earth (2011). A report by NAPE & FOEI (2012) reported that before the introduction of oil palm an Environmental Impact Assessment (EIA) was conducted and found that the project would have several consequences, such as reduction of forest cover and endemic species as well as food insecurity. Several unique species were observed on Bugala island during the EIA where some of the species are found only on Kalangala islands. Some of the mentioned species include mammals species such as *Pelomys isseli* species found only in Ssese islands, Vervet monkeys (*Cercopithecus aethiops*), and bird species such as Black-lored Babbler (*Turdordes sharpre*), Red-chested Sunbird (*Nectarinia erythrocerca*) and Northern Brown-throated Weaver (*Ploceus castanops*) (Environmental Assessment Consult Limited, 2003).

The introduction of oil palm on Bugala island, like other areas producing this crop, has also come with several consequences. Kalangala NGO Forum (2009), NAPE & FOEI (2012) and Rainforest Rescue (2016) states that the impacts observed and reported by Bugala islanders after the introduction of oil palm include land grabbing as the land belonging to the islanders was taken from them and some islanders were forced to sell their land for the low amount of money. This results in a reduction of land to cultivate food crops, hence islanders have to import food from the mainland leading to increased food prices and food insecurity. Before the introduction oil palm, the islanders used to grow different crops such as maize, beans, peas, yams, and bananas and export to sell some of the yields to other islands. Also, there are reports of clearance of tropical forests hence destruction of biodiversity on the island. Friend of Earth (2011) estimated that 3,600 ha of forest have been cleared for oil palm plantations, which include 100 ha of the Gala protected forest reserve. As a result, colobus monkeys were forced to find alternative sources of food, leading to damage of crops, including the oil palm fruits so the locals are forced to kill them. Other reported impacts of the introduced oil palm include increased erosion, topsoil loss, surface water drainage problems, clean water shortage as a result of pollution and inaccessibility, silting and pollution in Lake Victoria, loss of cultural values and norms (Abonyo et al., 2007).

The government of Uganda has allowed the second phase of oil palm production where it will be expanded into other areas including Buvuma island (Figure 1). According to the Kalangala NGO Forum (2009) the Government of Uganda is planning to introduce 10,000 ha of oil palm plantations on Buvuma island. 6500 ha of oil palm as the nucleus estates which will be operated by BIDCO and 3500 ha should be planted by out-growers/smallholders (Abonyo et al., 2007). There is a little delay of implementation of the second phase but the plan is by 2018 at least 2500 ha of smallholders land should be already planted with oil palm on the island (IFAD, 2016). Different stakeholders are worried that the problems reported and observed on Bugala island may also be experienced on Buvuma island (Rainforest Rescue, 2016). On their website, FOEI (2013) documented that the government of Uganda is willing to allow foreign companies involved in oil palm production to access the land on Buvuma island including forests which may lead to dislocation of local people and destroying their traditional living styles. Also the expansion is expected to reduce the arable land which may reduce the availability of food production on Buvuma island which may force people to encroach natural ecosystems (NEMA, 2014).

The experience of Bugala island indicates what might happen on Buvuma island if proper land use planning is not taken into account. On Buvuma island there is a lack of important information such as locations of the ecosystem services and what will be the impacts when oil palm will finally be expanded to these areas. Therefore, the areas where oil palm will most likely expand to have to be identified because this could help in land use planning, conservation of tropics and sub-tropical areas and provide insights about the sustainability of future expansion (Pirker & Mosnier, 2015). This will only be possible when we have information such as land cover and ecosystems services locations on Buvuma island, and information about the likely impacts of land cover changes. Different stakeholders on Buvuma island are aiming to avoid problems associated with land cover change from oil palm expansion so proper land use planning is necessary and the use of different scenarios can be a guide for the future land planning and management.

Therefore, this study aims at assessing the likely impacts of land cover change on ecosystem services based on different oil palm development scenarios on Buvuma island.

1.2. Green livelihood Alliance (GLA) project

This research is carried in line with Green livelihood Alliance (GLA). Different stakeholders under GLA with the aim of "*empowering the Civil Society Organisations (CSOs) so as to ensure sustainable forested landscapes and to restore degraded landscapes*" (Tropenbos International, 2015) operate in different countries including Uganda. In Uganda, the aim is to assess the impacts of oil palm production on Bugala island and prevent the future challenges in new areas where oil palm will be introduced through the involvement of the local people.

There is lack of knowledge and scientific research in Uganda concerning oil palm production and its impacts hence most of the information about the topic have been gathered from different organizations (websites) who are partners and non-partners of the GLA project. GLA partners include Tropenbos International (TBI), an NGO formed in 1986 in the Netherlands "*as response to protect tropical rain forests around the world*" (Trobenbos Intenational, 2017), National Association of Professional Environmentalists (NAPE), "*an NGO based in Uganda involved in finding solutions for the most challenging environmental and economic growth problems*" (NAPE, 2008) and Friends of Earth International (FOEI) an *"international federation of different countries based environmental organizations which promote solutions to create environmentally sustainable*" (NAPE & FOEI, 2012). FOEI has groups in different countries around the world including Uganda known as Friends of Earth Uganda or NAPE.

1.3. Research objectives and questions

The overall objective of this study is to assess the impacts likely to occur due to land cover change on ecosystem services from oil palm expansion under different development scenarios on Buvuma island. The overall objective will be addressed by four specific objectives and related research questions and each specific objective have its expectation as follows:

1) To describe ecosystem services related to land cover on Buvuma island. The questions are: i) What are the ecosystem services related to land cover on Buvuma island? and ii) Who is benefitting from these ecosystem services?. The expectation is that ecosystem services are not evenly distributed but are land cover dependent.

2) To identify the areas where oil palm will most likely expand to on Buvuma island based on Bugala island. The question is: Where are likely areas where oil palm will expand to on Buvuma island based on oil palm locations on Bugala island?. The expectation is that oil palm development locations can be explained by different spatial explanatory variables.

3) To model oil palm development towards 2025 under different scenarios using CLUMondo model. The question is: What are the possible development scenarios? and the expectation is scenarios results will show major variations of land cover change.

4) To assess the changes in ecosystem services likely to be impacted by land cover change under the three scenarios. The question is: What are the impacts of land cover change on ecosystem services and stakeholder groups under the three scenarios on Buvuma Island?. The expectation is that impacts of land cover change will be different among ecosystem services and stakeholder groups.

2. MATERIALS AND METHODS

This chapter presents the description of the study area, data used in the study, and different methods used to achieve the objectives of the study.

2.1. Study Area

2.1.1. Buvuma island

The study area is Buvuma island (Figure 1), found in Buvuma district, Uganda. Buvuma district is one of the newest districts in Uganda formed around July 2016 (UBOS, 2017). The area is located on geographical coordinates of latitude 0°14'05.1"N and longitude 33°16'52.5"E. Buvuma island is the largest island of 50 islands in Buvuma district with approximately of 55,000 ha area of land, the island is located in two sub-counties of Busamuzi and Nairambi, together they have roughly 56 villages (Human Right Focus, 2013), located about 90 kilometres (km) east of the capital city of Kampala.

In 2014 the population of Buvuma island was approximately 40,000 with roughly 9,150 households (UBOS, 2014). Buvuma island have diverse fauna and flora, with dense tropical forests and different species of birds, animals and plants with 28 gazetted forest reserves. The major economic activities of the islanders are fishing, agriculture, tourism, charcoal production and timber harvesting (Nangoli, 2009). Buvuma island is identified as one of the poor, illiterate and isolated places in Uganda with no access to electricity, running water, indoor plumbing, cable, or reliable cell phone service and limited access to education and poor sanitation (World Gospel Mission, 2018).

2.1.2. Bugala island

Oil palm development on the nearby Bugala island was used as a reference for this study. Bugala island (Figure 1), is found in Kalangala district. Bugala island is located on geographical coordinates 0° 25' 43.3992" S 32° 14' 33.72" E. It is the biggest (29,600 ha) of the 84 islands of Ssese islands in lake Victoria representing about 56% of total land in Ssese islands (Environmental Assessment Consult Limited, 2003; Kalangala District Local Government, 2005; Ssegawa & Nkuutu, 2006).

The population of Kalangala district was around 55,000 with roughly 20,000 households in 2014 (UBOS, 2014). Bugala island is covered with 13 central forests reserves (Environmental Assessment Consult Limited, 2003). The major economic activities on Bugala island include fishing, timber production, charcoal production, livestock keeping and subsistence agriculture with crops including bananas, beans, and sweet potatoes (Abonyo et al., 2007). The recently oil palm production have also facilitated other economic activities such as small-scale businesses like brewing and selling alcohol, shopkeeping, and running restaurants (Manyindo, 2003; Vogt et al., 2006; Abonyo et al., 2007). Bugala island is surrounded by beaches and different water sport activities are commonly taking place so tourism also takes place on the island (Kalangala District Local Government, 2005).

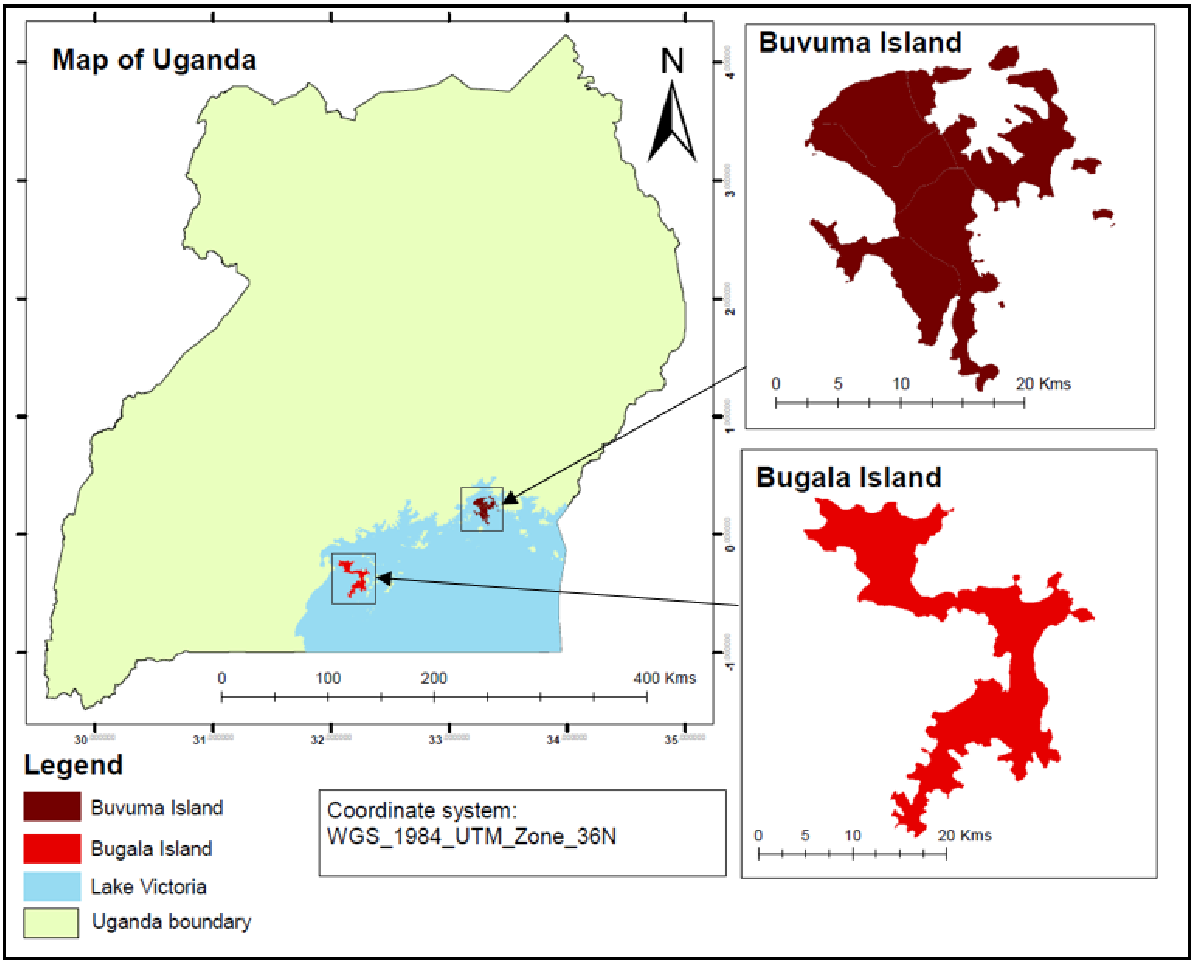

Figure 1: Map of the study areas. Boundaries were obtained from RCMRD Geoportal (http://geoportal.rcmrd.org/layers/)

2.2. Data

2.2.1. Land cover maps

The land cover maps for both Bugala and Buvuma islands of 1990, 2000, 2005, 2010 and 2015 were provided by National Forestry Authority (NFA) Uganda, Department of GIS and mapping unit. The maps have a resolution of 30 meters and coordinate system of WGS_1984_UTM_Zone_36N. All the land cover maps provided were classified similarly (Nangendo, 2018) and the description of the land cover types were adapted from NFA (1992).

The 2015 land cover of Buvuma island (Appendix 1) was used as a basis for land cover modelling and ecosystem services mapping. The land cover map was produced from Landsat 8 and the land cover types were maintained from the Uganda classes national description of 1990. The map has five classes including woodland, bushland, grassland, wetlands, subsistence farmlands and urban or built-up areas.

The description of the land cover types of Buvuma island land cover map of 2015 as obtained from NFA (1992) are as follows; **Woodland** are all the woody areas predominantly covered with trees and shrubs, and the trees must exceed 4m. **Bushland** occurs where vegetation is dominated by bush, shrubs, thickets (growing together) and do not exceed 4m. Some of the most common species in bushland include; *Lantana camara*, *Rhus natalensis*, *Rhus vulgaris*. **Grassland** includes grazing grounds, whether rangelands, improved pastures or natural savannah grassland. Few trees and shrubs may occur in these areas but grasses dominate. **Wetlands** are areas usually found along the lake shores and valleys accompanied with papyrus, reeds and wet grass. Sometimes they experience seasonal floods and the vegetation in these areas shows the presence of high water table. **Subsistence farmland** includes smallholder subsistence farm units with different cropping systems such as mixed cropping, multiple cropping and shifting cultivation. Scattered trees/tree clusters are also found here, especially near homesteads. **Urban or built-up areas** include towns, village trading centers, quarries, homesteads, school compounds, roads, bare rock and recreational grounds.

2.2.2. Other maps

For the modelling of land cover changes different maps were used in this study. A protected areas/forest reserves shapefile of Uganda was obtained, providing information on two types of forest reserves: Central Forest Reserves (CFR) owned by government and Local Forest Reserve (LCF) owned privately by local people. Buvuma island has 22 CFR and 6 LCF. The Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) of Uganda was obtained from RCMRD Geoportal in GeoTIFF format. The DEM was created by mosaicking of individual SRTM tiles for a particular country and clipping the mosaicked tiles using the country boundary extent (RCMRD Geoportal, 2015). Rainfall and temperature data were obtained from Climate Hazards Group Infrared Precipitation with Station data (CHIRPS). The population data of Uganda were downloaded from WorldPop website. The Bugala and Buvuma islands roads were digitized by hand from Google earth image (Image DigitalGlobe) of 15th January 2015. The digitized roads from the in kmz format were exported to ArcGIS software and converted to shapefile. Soil data including clay content, sand content and silt content were obtained from International Soil Reference and Information Centre (ISRIC). All the data for this study, their sources and specifications are summarized in Table 1.

For the purpose of this study all data need to have the same specifications, such as format, resolution and projection. From the Uganda boundaries, the study areas boundaries were extracted, and all the data layers including the land cover maps were masked to Bugala and Buvuma islands boundaries. Then all the input data were converted to raster format and projected to WGS_1984_UTM_Zone_36N. Then resampled to 100 meters (m) resolution for the modelling purposes.

Table 1: List of the input data used in this study

Data	Source	Resolution (m)	Year
Land cover maps	National Forestry Authority (NFA) Uganda	30	1990, 2000, 2005, 2010, 2015
Roads	Digitized Google earth imagery (Image DigitalGlobe)	30	2015
Protected areas shapefile	Protected Planet https://protectedplanet.net/	-	2017
Soil data (clay, sand and silt content)	International Soil Reference and Information Centre (ISRIC) – World Soil Information	250	2015
Population data	WorldPop http://www.worldpop.org.uk/	100	2015
Digital Elevation Model (DEM)	RCMRD Geoportal http://geoportal.rcmrd.org/layers/	30	2015
Rainfall and temperature data	Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS)	250	2015
Shapefile of Uganda boundary (including study areas)	RCMRD Geoportal http://geoportal.rcmrd.org/layers/	-	2015

2.3. Methods

The methods of this study are divided into four main parts. The first part focuses on describing the ecosystem services benefiting people of Buvuma island. The second part focuses on developing a logistic regression model which describes areas where oil palm will likely expand to on Buvuma island with reference to oil palm locations on Bugala island. The third part models the land cover change towards 2025 under three developed scenarios. The fourth part spatially describes the ecosystem services from the results of objective one and analyse the ecosystem services likely to be impacted by land cover change for each development scenario in 2025. The methods for each objective are summarized on the flowchart (Figure 2) and described below.

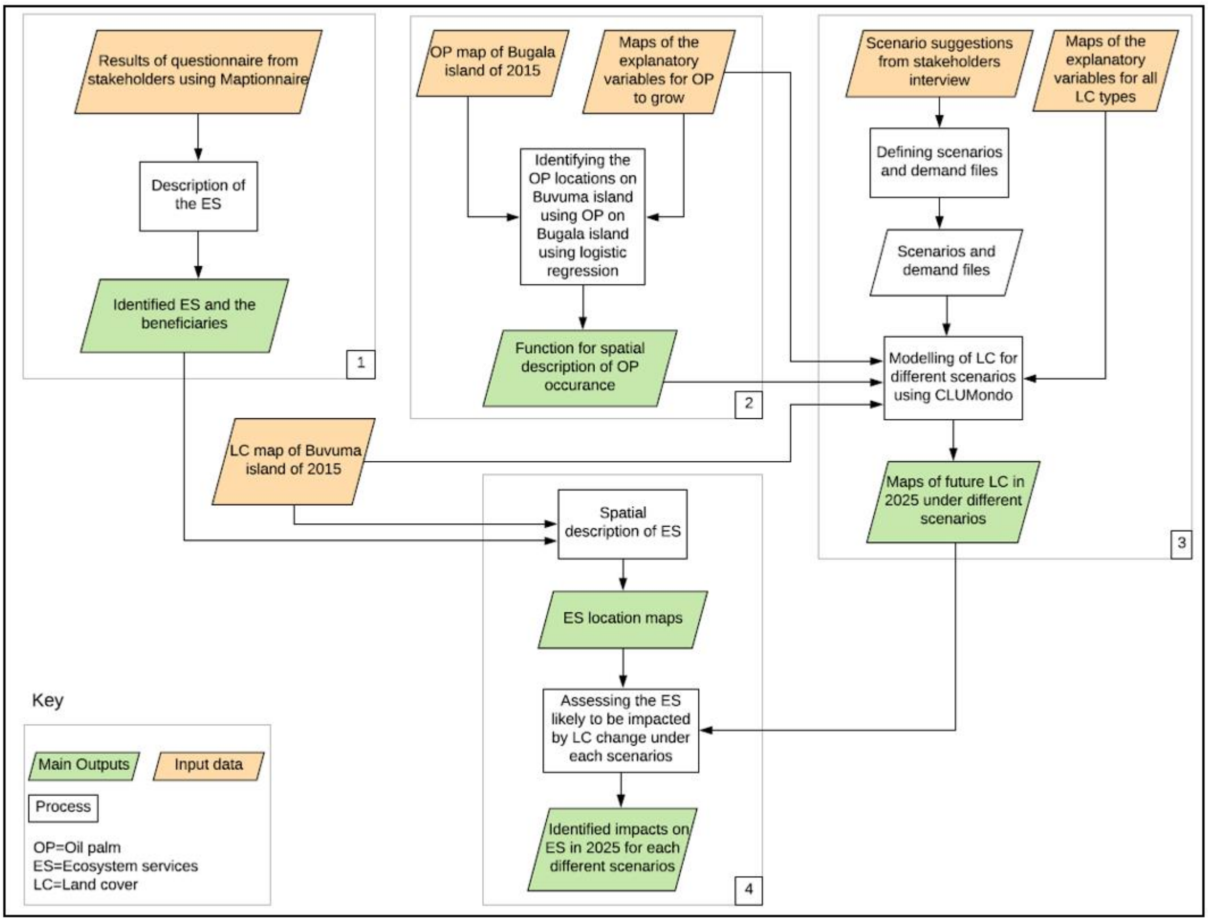

Figure 2: Flowchart of the research methods

2.3.1. Describing the ecosystem services related to land cover on Buvuma island

The ecosystem services on Buvuma island were described using a tool called Maptionnaire. Maptionnaire is an online participatory mapping tool which is a combination of map and questionnaires where a user can create map-based questionnaires. The tool allows users to ask questions, collect and analyse data, then collaborate, interact and discuss the data gathered (Emerson, 2016). This tool was used to obtain information from stakeholders because of not being able to go to the fieldwork on Buvuma island.

The questionnaire focuses on identifying the main ecosystem services (referred to as "benefits from nature and farmland" in the questionnaire) related to the land cover on Buvuma island. Questions include: What are the ecosystem services on Buvuma island?, Where do people collect the ecosystem services, if it is from their own land, private or protected land?, For what purposes (for home uses and/or for selling at the market) do people collect these ecosystem services?, and How far people travel to collect the ecosystem services? The details list of questions is shown in Appendix 2. A preliminary list of the potential ecosystem services was needed so as the stakeholders to select the ecosystem services on Buvuma island. The list was developed from Buvuma island land cover types and by looking at the economic activities on Buvuma island. To answer the question of the ecosystem services on the island the stakeholders had an option of selecting multiple ecosystem services from the list. A preliminary list of the ecosystem services related to the land cover used includes recreational services and eco-tourism, grass for cattle, construction materials (timber), food production, food collection (fruits, hunting and fishing), medicinal plants, fuelwood and charcoal.

Due to the nature of the study area being remote and low accessibility to the internet connection, sending the questionnaire to the local community was an impossible task. So the alternative plan was to involve different stakeholders who can represent the local community groups such as farmers, biodiversity conservation groups, fishermen, small-scale holders of oil palm plantations and large-scale holders of oil palm plantations. The initial stakeholders were identified with the assistance from GLA partners. The representatives selected had to either be originally from the Bugala and Buvuma islands or have visited the islands for fieldwork or projects. After participating in the questionnaire some of the stakeholders provided the names and contacts of other people who qualify to participate in the survey. The questionnaire was sent to 28 stakeholders representing all the groups and 17 stakeholders responded to the questionnaire.

The questionnaire had two sections, the first section included filling out the questions (Appendix 2) and the second section included mapping of the ecosystem service locations on the high resolution image available on the google map. The second section of the questionnaire was difficult to be implemented because it was difficult for people to draw the intended locations on the google map due to lack of experience in using maps. Also, other people indicated that they are not originally from the area so it will be difficult to identify the exact locations where people collect the ecosystem services. This was identified by the first few people participated in filling the questionnaire. So alternative question was developed with a table where people could indicate the land cover types where the ecosystem services are located or found (Question 7 part B in Appendix 2).

2.3.2. Identifying areas where oil palm will most likely expand to on Buvuma island based on Bugala island

Oil palm is not yet on Buvuma island so locations of oil palm plantations on Bugala island were used as a reference to find where oil palm plantations are likely to expand to on Buvuma island. The purpose of this is to assess where ecosystem services are likely to be impacted by the future expansion of oil palm plantations on Buvuma island. Bugala island was selected as a reference location because of the shared physical characteristics with Buvuma island such as weather, topography, and soil.

The oil palm locations on Bugala island were described by a logistic regression model. Logistic regression is often used to identify and quantify the relationship between the specific land cover type and set of different explanatory/location variables (Verburg, 2015). The method has been widely used in deforestation analysis, agriculture, urban growth and farmland modelling (Zeng, Wu, Zhan, & Zhang, 2008). The dependent variable in a logistic regression is binary and the independent variables can be continuous and categorical variables (Xie, Huang, Claramunt, & Chandramouli, 2005). For this objective, a logistic regression model of Bugala island explaining the relationship between the locations of oil palm plantations and the explanatory variables such as slope, clay content, and distance to the roads was developed in R (R Core Team, 2017).

Selection of the explanatory variables to be included in logistic regression can be based on the user's knowledge on where oil palm can be grown or the use of different literature (Verburg, 2015). For this case, different potential explanatory variables were selected from different literature explaining the likely locations in different parts of the world. Some of the characteristics include; the crop requires flat land, steep slope is not good because of the risk of erosion and cost of production, the ideal slope is up to 16 degrees and the common opinion is that slope above 25 degrees should be avoided at all (Pirker et al., 2016). Also, oil palm requires deep sandy (loam) and easily penetrable soil with 15-35% clay content (Sheil et al., 2009; Verheye, 2010; Pirker & Mosnier, 2015; Rhebergen et al., 2016).

2.3.2.1. Explanatory variables for Bugala and Buvuma islands

For a logistic regression model both categorical and numerical explanatory variables were tested (Table 2). The first task was to prepare and process the explanatory variables used in the model. Some of the variables are the input data explained in section 2.2 and others were extracted from the input data.

Distance to the road, distance to the lake and distance to the settlement maps were calculated from the digitized roads (Appendix 3), the lake extracted from the land cover map of 2015 and settlements from the land cover map of 2015 respectively. **Slope** map was extracted from DEM. The layer, **not protected areas** was obtained from the protected areas shapefile. For **not wetland**, the layer wetland was extracted from the land cover map of 2000 and hence develop the not wetland area map. For the **clay content**, the likely areas for oil palm have clay content of 15-35% (Verheye, 2010), so from the clay content map, the categorical map of clay content was developed. All the explanatory variables were converted to raster, resampled to 100 m resolution, projected to WGS_1984_UTM_Zone_36N, and converted to Ascii format for further analysis.

Table 2: The explanatory variables tested in the logistic regression model fit in R and land cover modelling. Not all the variable were included in the final fitted model. The table also shows the description and type of the data used.

Code	Type	Name	Description
0	Categorical	Clay (category)	Clay content, 15 – 35% as 1 and other values as 0
1	Numerical	Not protected	Non protected areas
2	Numerical	Road distance	Distance from the roads
3	Numerical	Lake distance	Distance from the lake
4	Numerical	Slope	Slope extracted from Digital Elevation Model (DEM)
5	Numerical	Elevation	Digital Elevation Model (DEM)
6	Numerical	Rain average	The average rainfall for the year 2015 in mm
7	Numerical	Rainfall sum	Sum of rainfall for the year 2015 in mm
8	Categorical	Not wetlands	The areas without wetlands as 1 and wetlands as 0
9	Numerical	Settle distance	Distance from the settlement
10	Numerical	Pop density	Population density

To describe the locations of oil palm (the dependent variable), oil palm map was created from a land cover map of Bugala island of 2015 (Appendix 4). Then a balanced sample of 10% of oil palm class to explain the presence and absence of oil palm on Bugala island was taken. A balanced sample means an equal number of locations with and without oil palm were sampled. 10% was decided because it was representative enough for the island.

A logistic regression model was fitted using a R function below. The explanatory variables were tested for multicollinearity because they should not be correlated with each other. Multicollinearity results when two or more correlated explanatory variables are used together in a regression model (Vatcheva, Lee, Mccormick, & Rahbar, 2016; Menard, 2017), this means the correlated variables measure the same phenomena, hence one or both variables have to be removed in the regression model (Jesshim, 2003). Different methods can be used to check for multicollinearity including tolerance value or Variance Inflation Factor (VIF) which shows how multicollinearity has increased the instability of the coefficient estimates. There is no universal threshold for a maximum allowed VIF, but for this study, the values with VIF greater than 5 were removed from the model.

The R function for the oil palm logistic regression model of Bugala island

$$glm.oilpalm <- glm(oilpalm \sim X1 \ + \ X2 + \cdots + Xn \, , data = d1, family = binomial(link = logit))$$

Where
glm = generalized linear model
X1, X2…Xn = the explanatory variables
d1 = File with data

Seven explanatory variables were needed in a logistic regression model which later are used for future land cover modelling (explained in the next objective). The land cover model allows only seven explanatory variables. All the ten explanatory variables in Table 2 were tested in a logistic regression while checking for multicollinearity using VIF. The explanatory variables with higher VIF were removed first. The final seven variables selected are also supported by different literature in explaining the presence of oil palm in different parts of the world as explained in section 2.3.2.

2.3.2.2. Assessing the performance and sensitivity of oil palm logistic regression model of Bugala island

To check the sensitivity and performance of a logistic regression model developed above, sampling was performed again for ten times. The logistic regression was performed for the ten sample datasets and the results were assessed to see the extent of variations among the ten sample datasets and the model developed above. Also, the oil palm probability maps were produced in R for a model developed above and for both ten sample datasets so as to compare the pattern of oil palm locations as predicted by the model and actual field locations of oil palm plantations.

Additionally, the Area Under the Curve (AUC) of the Receiver Operating Characteristic (ROC) was calculated to measure the ability of the model to properly specify location across a range of a threshold (Tayyebi et al., 2010). There are no clear values for the acceptable AUC of a logistic regression model but as a rule of thumb for values greater than 0.9 are excellent, 0.8 – 0.9 are good, 0.7 – 0.8 are fair 0.6 – 0.7 is poor and values smaller than 0.6 are not good (Verburg, 2015).

2.3.3. Land cover modelling under different scenarios using CLUMondo model

After identifying the likely locations of oil palm plantations on Buvuma island, CLUMondo model was used to model the land cover change towards 2025 under three development scenarios.

2.3.3.1. Possible development scenarios

Three development scenarios were formulated with the aim of assessing possible futures of the ecosystem services when experience land cover change. The scenarios were formulated by looking at the past trend, current situation as well as the future development plan of oil palm expansion on Buvuma island.
The scenarios formulated were communicated to GLA partner from Tropenbos International because of being familiar with the study area, the plans and policies. The feedback was useful for the improvement of the scenarios. One scenario aimed to assess the impact of a continuation of land cover change trend over time and two scenarios assuming the presence of oil palm plantations on Buvuma island.

The first scenario namely the **Business as usual (BAU)** scenario assumed there is no oil palm on Buvuma island. The aim of this scenario was to understand what will happen on the ecosystem services in 2025 based on the past land cover change trend. This scenario was developed by assessing area change of the past land cover maps of Buvuma island (Appendix 5). The second scenario namely the **protection enhanced scenario** assumed that oil palm will be expanded on Buvuma island while protecting the protected areas/forests reserves. So the assumption was that 5000 ha of oil palm will be expanded with the exception of the protected areas/forests reserves available on the island. This scenario was developed because different stakeholders from the conservation side are hoping that if oil palm will be expanded then there should be minimum impacts on the natural environment. The third scenario namely the **economic enhanced scenario** assumed that oil palm will be expanded on Buvuma island as per government plan. The plan is to expand up to 10,000 ha of oil palm on Buvuma island, 6500 ha and 3500 ha for small-scale out growers (FOEI, 2013). The aim of this scenario is to assess the impacts of oil palm expansion on ecosystem services if the government plan will be implemented.

2.3.3.2. Application of CLUMondo land cover change model

CLUMondo model is a dynamic and spatially explicit land-use model which was intended to simulate land use and land cover changes, based on land-use change drivers (Verburg, 2015). The CLUMondo model is a continuation of CLUE models which have capability of simulating diverse land-use types at the same time and the option of simulating different scenarios which can be used to evaluate the impact of land cover changes of local level conditions (Verburg et al., 2002). CLUMondo model is free and it was obtained from https://www.environmentalgeography.nl/site/data-models/models/clumondo-model/

The first step in CLUMondo model was to create a new application where the initial land cover map and region map are identified. For this study two models were developed separately, because of having two initial land cover maps of Buvuma island, one without oil palm for BAU scenario and the other with oil palm. Then, all the explanatory variables referred to suitability layer or application characteristics in the model (Table 2) were added. The allocation of land in CLUMondo model are based on combination of different drivers of land cover change as shown in Figure 3 (Verburg, 2015). The drivers are grouped into four categories and together they create land cover change over time using an iterative calculation procedure (Verburg, 2015). The drivers are described below.

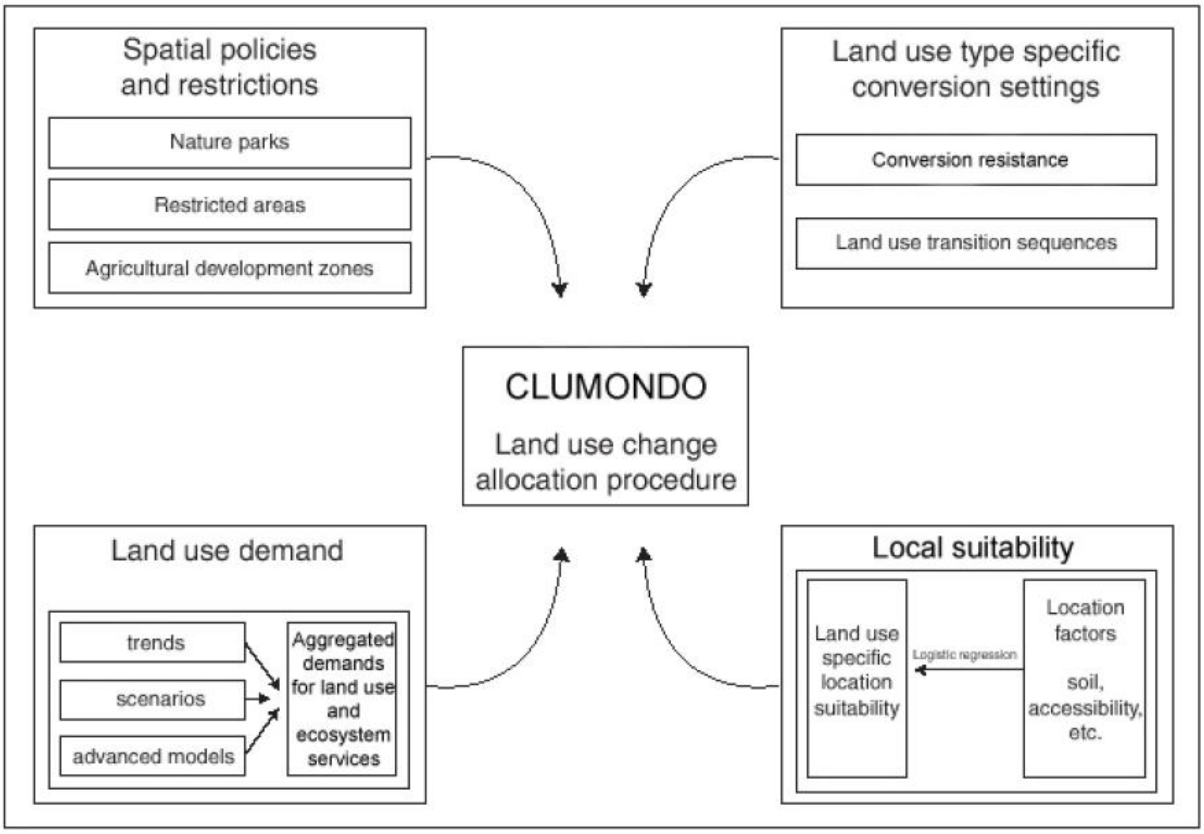

Figure 3: Structure of the information flow in the CLUMondo model. The structure is from (Verburg, 2015).

1. **Land use demand**

The scenarios are represented by the demand of different land uses (Verburg, 2015). The demand depends on the land availability, the location conditions, and the competitive advantage of the different land systems (Liu, Verburg, Wu, & He, 2017). The demand can be area of land or tons of a certain crop produced. For this study the demand was expressed in terms of land area in ha. The initial demand is for the year 2015 and the final demand is for the year 2025. For the BAU the initial land area of 2015 was obtained from the land cover map of 2015, the area of 2025 was calculated with the assumption that subsistence farmland will continue to increase following the past land cover trend as obtained from the past land cover areas (Appendix 5). From the past trend the area of subsistence farmland on 2025 is assumed to be approximately 80% (around 17260 ha). The land cover trend is shown in Table 3.

Table 3: Trend of subsistence farmland of Buvuma island. The BAU scenario was developed following the trend of this land cover class.

Year	Area (ha)	Percentage (%)
1990	1785	8.29
2000	3767	17.71
2005	6035	27.72
2010	9052	41.45
2015	14566	67.50
2025	17260	80.00

For the two oil palm scenarios, a new initial land cover map was developed from the land cover of 2015 because oil palm is needed in these scenarios and oil palm is not yet on Buvuma island. This was done by introducing oil palm on few pixels of Buvuma island land cover map of 2015 (3 ha). Then the initial land area for the demand file for the year 2015 was 3 ha as obtained from a newly created map (Appendix 6). Therefore, the demand for the BAU is more land for subsistence farmland and for the two scenarios the demand is more land for oil palm plantations (Table 4).

Table 4: Demand for land in ha as input for the land cover change model all the three development scenarios

Year	Demand 1 - Business as usual – No oil palm - Increase of subsistence farmland (ha)	Demand 2 - Protection enhanced – Limited increase of oil palm (ha)	Demand 3 - Economic enhanced – Rapid increase of oil palm (ha)
2015	14499	3	3
2016	14775.1	502.7	1002.7
2017	15051.2	1002.4	2002.4
2018	15327.3	1502.1	3002.1
2019	15603.4	2001.8	4001.8
2020	15879.5	2501.5	5001.5
2021	16155.6	3001.2	6001.2
2022	16431.7	3500.9	7000.9
2023	16707.8	4000.6	8000.6
2024	16983.9	4500.3	9000.3
2025	17260	5000	10000

2. **Land use type-specific conversion settings**

Conversion resistance relates to changes of the land cover in relation to the demand. The land cover with high value or high environmental impacts when changed are not easily converted (Verburg, 2015). 1 means that the conversion is totally restricted and 0 means the conversion is full allowed. For the BAU scenario the assumption was that all the land cover types may be converted to subsistence farmland to reach the demand of 80 % in 2025. But the exception was that others (urban areas and wetlands) will not be converted to subsistence farmland. The reason behind is that people need areas to live and expansion on wetlands is not allowed as they are protected by law of Uganda. For the protection and economic enhanced scenario the assumption is that subsistence farmland will be easily converted to oil palm plantations compared to other land cover types. Also subsistence farmland covers large percent of land and the plan of the government of Uganda is to buy more land from the farmers (Ssebwami & Ssenkabirwa, 2018). So subsistence farmland was given value 0.20, woodland 0.80, grassland 0.80 and bushland 0.90. Also expansion was restricted on others (urban areas and wetland). Other studies have also suggested that areas with permanent vegetations such as woodland are not converted easily (Soepboer, 2001; Willemen, 2002).

Conversion matrix indicates in which land cover types the conversions are allowed by the model. The file has rows and column where rows indicates present land cover and columns potential future land cover type. A value 1 shows that conversion is allowed and 0 shows conversion is not allowed (Verburg, 2015). For the BAU scenario conversion was allowed from all the land cover classes to subsistence farmland but restricted from the class others (urban or built up & wetlands) as shown in Table 5. This is because wetlands are protected by law and the assumption was built up areas will not be converted to subsistence in the next ten years (Table 5).

Table 5: Land conversion matrix used in CLUMondo model for the business as usual scenario and the table on the right shows the code for each land cover type

Land cover	0	1	2	3	4
0	1	0	0	1	0
1	0	1	0	1	0
2	0	0	1	1	0
3	0	0	0	1	0
4	0	0	0	0	1

Code	Land cover
0	Woodland
1	Bushland
2	Grassland
3	Subsistence farmland
4	Others (Wetland and Urban/Built-up areas)

For protection and economic enhanced scenarios the conversion matrix was defined assuming the conversion is allowed from all the land cover types to oil palm and also not allowed from the others class (urban or built up and wetlands). The conversion matrix for the two scenarios is shown in Table 6.

Table 6: Land conversion matrix used in CLUMondo model for the two oil palm scenarios and the table on the right shows the code for each land cover type

Land cover	0	1	2	3	4	5
0	1	0	0	0	1	0
1	0	1	0	0	1	0
2	0	0	1	0	1	0
3	0	0	0	1	1	0
4	0	0	0	0	1	0
5	0	0	0	0	0	1

Code	Land cover
0	Woodland
1	Bushland
2	Grassland
3	Subsistence farmland
4	Oil palm farmlands
5	Others (Wetland and Urban/Built-up areas)

3. Spatial policies and restrictions

These show areas where specific land cover changes are not allowed (Verburg, 2015). In CLUMondo these areas are added as maps and referred to exclusion layers. For this study in the protection enhanced scenario, the assumption is to protect all the protected areas/forests reserves found on Buvuma island. So the protected areas layer was added in CLUMondo model as the exclusion layer for land cover modelling.

4. Local suitability

Land cover is converted with the expectations to take place in areas with the higher preference for each land cover type (Verburg, 2015). This is done by performing the logistic regression analysis so as to find a relationship between a certain land cover type and a set of explanatory variables. For this study the logistic regression procedure is explained in detailed in objective 2 above (section 2.3.2).

After running the model for each scenario, using the land cover maps of 2025 produced on CLUMondo model and a land cover map of 2015, a land cover change matrix and land cover change maps were developed for each scenario. This was done so as to identify the areas of change and the amount of land changed from one land cover type to another.

2.3.4. Analysis of ecosystem services change under different scenarios

For the last objective, the aim was to analyse what will be the impact of land cover change on the ecosystem services under each scenario. From the results of the questionnaire in objective one, the ecosystem services were spatially described by combining the land cover types where the ecosystem services are obtained (Appendix 2 question 7) and the distance from the settlement for each ecosystem services (Appendix 2 question 2). The land cover types were derived from the Buvuma island land cover map of 2015 and the distance from the settlement map was one of the explanatory variables in the land cover modelling. The land cover types and the distance selected to describe the ecosystem services are the ones mentioned more by the stakeholders in the questionnaire. So the ecosystem services maps were created by combining the land cover type(s) mentioned within the indicated distance from the settlement.

Then the ecosystem services maps developed were overlaid with the land cover change maps developed on objective three so as to identify if there are any ecosystem services likely to be impacted in the locations experiencing land cover change. For the ecosystem services likely to be impacted the area was calculated so as to understand the magnitude of the impact for each scenario.

3. RESULTS

This part presents different outputs generated from the research methodology part including the described ecosystem services, results of a logistic regression model, and the analysis of land cover change and the impacts on the ecosystem services under each scenario.

3.1. The ecosystem services related to land cover on Buvuma island

The 17 stakeholders replied to questionnaire of which 4 represented farmers group and 13 represented the biodiversity conservation group. The stakeholders representing fishermen, smallholders oil palm producers and large-scale producers of oil palm were not included. From a list of the preliminary data, Buvuma island has several ecosystem services as indicated in Figure 4 where fuelwood & charcoal and construction materials (timber) are most mentioned by the stakeholders. For the recreational services and eco-tourism the majority of people benefiting from this service are not from the island but visitors from other places. So recreational services and eco-tourism locations were not described further in this study. The information on the ecosystem services is elaborated below. The information include the ecosystem services on Buvuma island, distance to where people travel to reach the ecosystem services, the uses of the collected ecosystem services, type of land and the land cover classes where the ecosystem services are located.

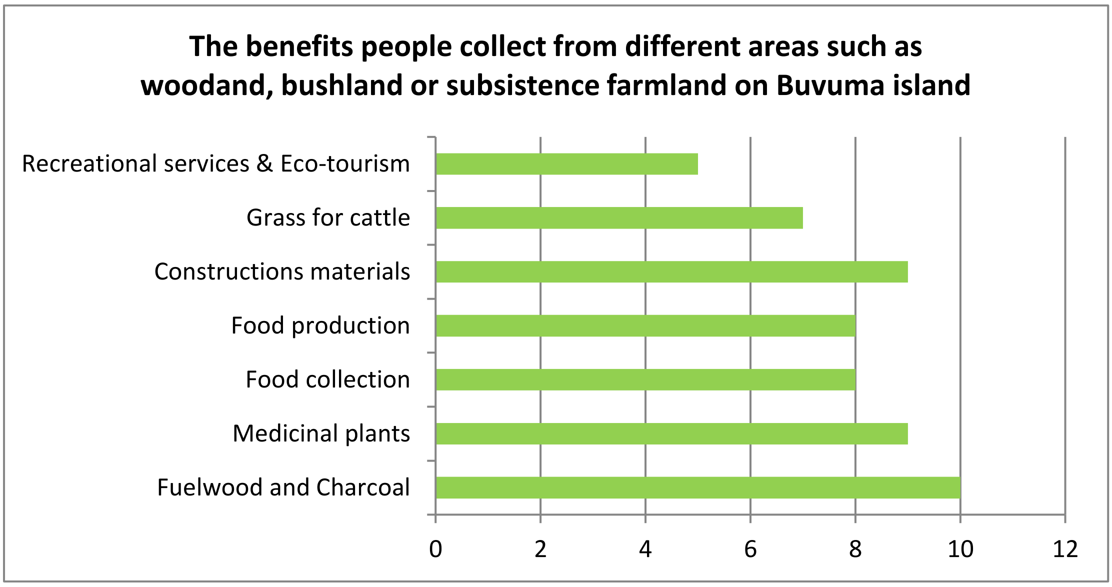

Figure 4: The ecosystem services on Buvuma island. The X-axis shows the number of times the ecosystem service was selected.

Grass for cattle

Grass for cattle is available on Buvuma island and the stakeholders indicated that to reach this ecosystem service people travel up to 5 kilometers (km) (Figure 5). People collect fodder grass mainly for the home uses (Figure 6) from their private land (Figure 7). And its derived mostly from grassland and wetlands (Figure 8).

Construction materials

For construction materials (timber) the stakeholders reported that people travel mostly up to 5 km from their settlement but other stakeholders reported that other people travel long distance (Figure 5). They are collected mostly for both home and selling at the market (Figure 6) mainly from the protected land (Figure 7). The land cover types where construction materials are collected are mainly woodland, bushland, and wetland (Figure 8).

Food production

The stakeholders reported that for food production, people travel mostly within one km but other stakeholders indicated that some people travel up to five km from their settlement (Figure 5). Food is mostly produced in their private land (Figure 7) for both home use and selling at the market (Figure 6). The land cover type where most of the food is produced is subsistence farmland (Figure 8).

Food collection (fruits, hunting, and fishing)

Food is collected mainly within five km from the settlements but other stakeholders reported that some people travel up to 15 km (Figure 5). Food is mostly collected from private land and protected land (Figure 7) for both home uses and selling at the market (Figure 6). The land cover types are woodland, bushland and wetlands (Figure 8).

Medicinal plants

Medicinal plants are also a benefit people obtain from nature on Buvuma island and collected within five km from settlements, but other stakeholders reported that some people travel up to ten km (Figure 5). Medicinal plants are mostly collected for both home uses and selling at the market (Figure 6) mainly from the protected land (Figure 7) and collected from several land cover types but mainly in woodland and bushland (Figure 8).

Fuelwood and charcoal

Fuelwood and charcoal are collected within five km mainly from the settlements (Figure 5). Fuelwood and charcoal are mostly collected for both home uses and selling at the market (Figure 6) mainly from their private land and protected land (Figure 7). Firewood and charcoal are obtained mainly from woodland and bushland (Figure 8).

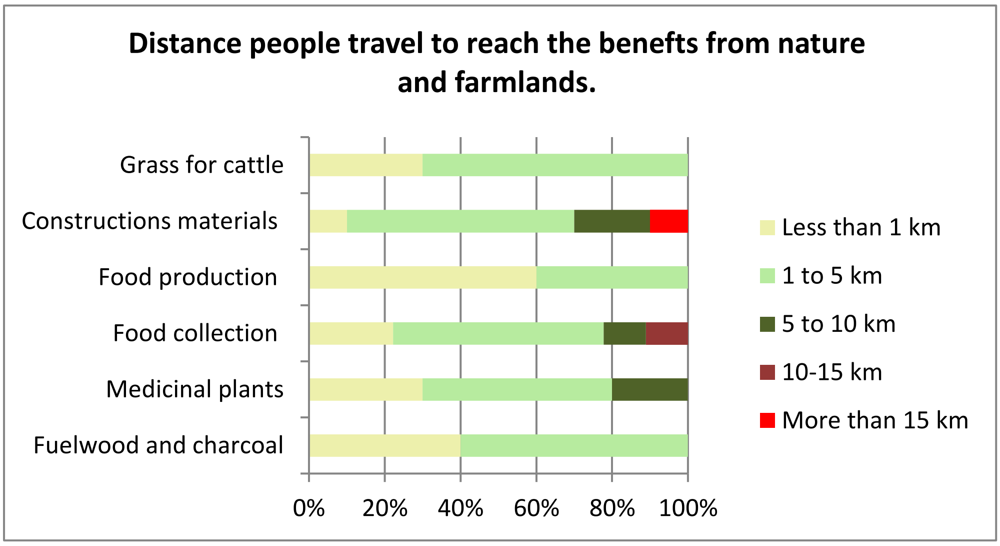

Figure 5: The distance people travel to reach the ecosystem services. The X-axis shows the stakeholders responses summarized in percentage (%)

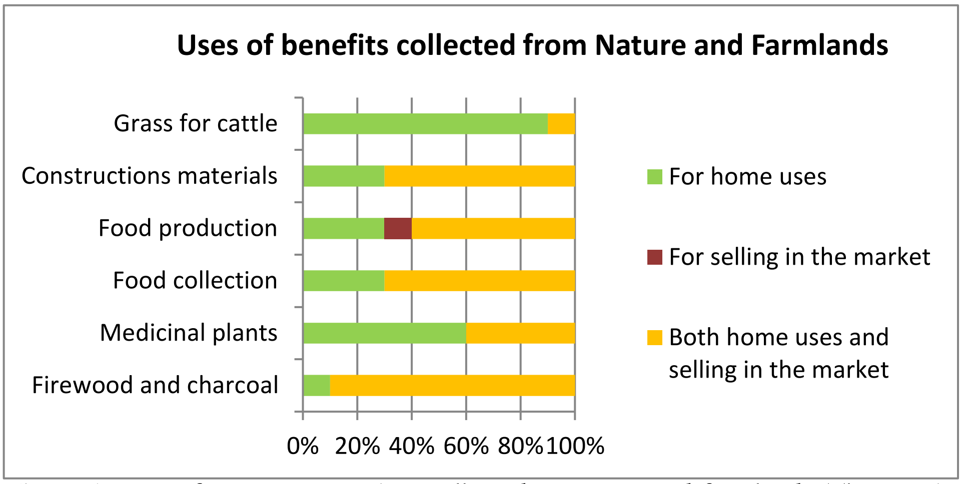

Figure 6: Uses of ecosystem services collected on nature and farmlands. The X-axis shows the stakeholders responses summarized in percentage (%)

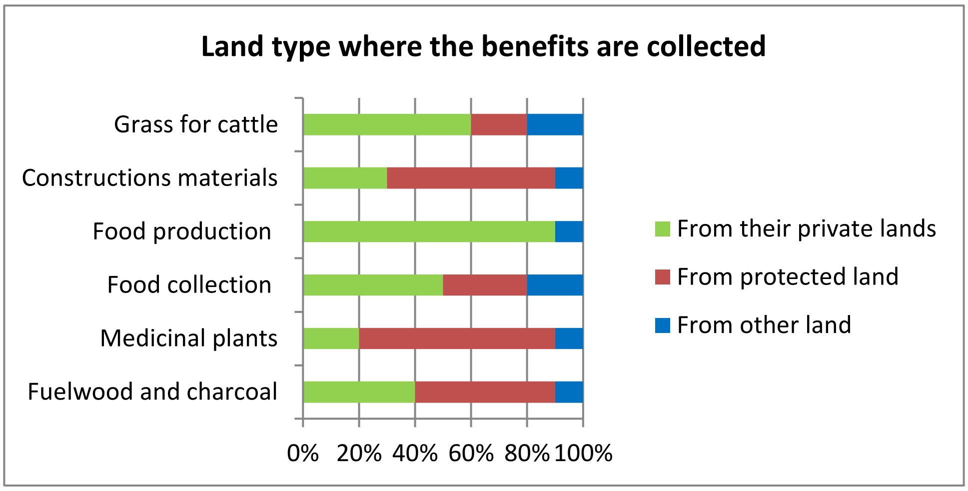

Figure 7: Land type where the ecosystem services are collected. The X-axis shows the stakeholders responses summarized in percentage (%)

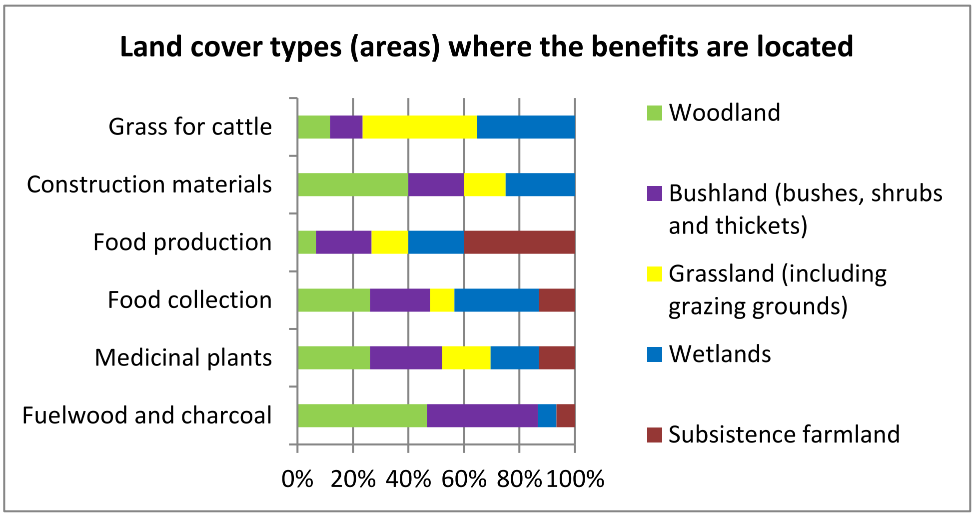

Figure 8: The land cover (areas) where the ecosystem services are collected. The X-axis shows the stakeholders responses summarized in percentage (%)

Table 7 shows the different ecosystem services from each land cover type as developed from Figure 8. The land cover considered on the table are the ones mentioned more by the stakeholders to provide a particular ecosystem service. The results show that most of the ecosystem services people depend on are coming from woodland, bushland, and wetlands which include construction materials, food collection, firewood and charcoal. Different local groups benefit from these ecosystem services including farmers, charcoal producers, timber producers and all the local people collecting food, firewood, and grasses for cattle from these land cover types.

Table 7: Land cover types with the ecosystem services they provide

Land cover	**Ecosystem services**	**Count**
Woodland	Construction materials, food collection, medicinal plants, firewood, and charcoal	4
Bushland	Construction materials, medicinal plants, firewood and charcoal	3
Grassland	Grass for cattle	1
Subsistence farmland	Food production	1
Wetlands	Construction materials, food collection, and grass for cattle	3

3.2. Areas where oil palm will most likely expand to on Buvuma island based on Bugala island

A logistic regression model for oil palm locations on Bugala island which was transferred to Buvuma island had seven variables. The seven variables selected were used on Buvuma island for land cover modelling in CLUMondo model. Seven variables is the maximum number allowed in CLUMondo model. The explanatory variables and the coefficients of the logistic regression model are shown in Table 8. Some of the explanatory variables have positive and some have negative correlation with the locations of the oil palm plantations on Bugala island. Because of the multicollinearity problem the explanatory variables with VIF greater than 5 were removed in the regression model such as rainfall sum and average rainfall. The explanatory variables remained had VIF less than five as shown in Table 9.

Oil palm is likely found in areas with clay content ranging from 15 – 35 % (Verheye, 2010). From Table 8 showing the coefficients of the logistic regression model, Clay content (categorical) shows negative value/coefficient which means that for Bugala island the condition 15-35% of clay content is not in agreement with where oil palm is planted. This means oil palm is also planted in areas with high clay content (36 – 46 %). For 'not protected' layer and 'not wetlands' the coefficients show positive values which means the model depicts that oil palm is found in areas which are not protected and not wetlands. Distance to the road and distance to the lake have positive coefficients which means that oil palm plantations are distributed as you go away from the road as well as away from the lake. For elevation, the coefficient is negative. This means oil palm plantations are found less in areas with higher elevations. Slope have shown positive relationship with oil palm locations which means oil palm plantations are more distributed as slope increases. The explanatory variables are shown in Figure 9.

Table 8: Coefficients of the logistic regression model for oil palm locations on Bugala island

Explanatory variable	**Coefficients**
Clay content (15 – 35 %) Categorical (0/1)	-0.1565917
Not protected areas (0/1)	2.2977669
Distance to Road (m)	0.0001110
Distance to Lake (m)	0.0006418
Slope (degrees)	0.0294266
Elevation (m)	-0.0016236
Not wetlands (0/1)	1.6512658
Intercept/Constant	-2.2808603
AUC of ROC	0.75

Table 9: The VIF values for the final variables used in the logistic regression model for oil palm plantation on Bugala island

Explanatory Variables	**VIF**
Clay content (15 – 35%) Categorical (0/1)	1.040451
Not protected areas (0/1)	1.076174
Distance to Road (m)	1.110461
Distance to Lake (m)	1.145709
Slope (degrees)	1.090149
Elevation (m)	1.324210
Not wetlands (0/1)	1.200066

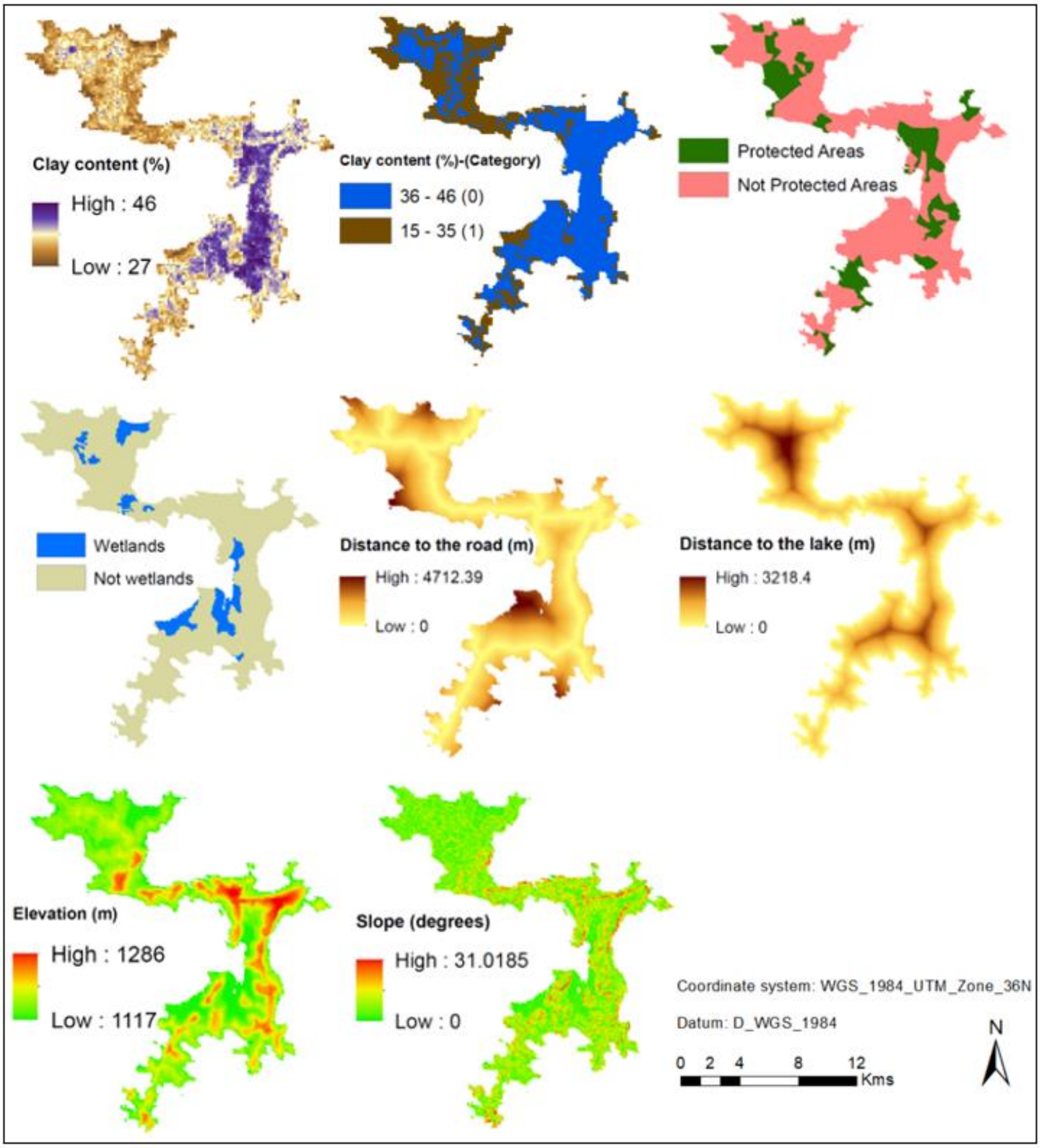

Figure 9: The explanatory variables for oil palm plantation locations on Bugala island

3.2.1. Explanatory variables for Buvuma island

The explanatory variables for Bugala island to describe land cover were used for Buvuma island. For the land cover modelling on CLUMondo model, each land cover class needs to have it is own logistic regression model. The coefficients and AUC of ROC for each land cover type are shown in Table 10 and the explanatory variables are shown in Figure 10. The AUC of ROC close to 1 means a model is the best, and it will reduce to 0.5 for a random model (Ngo & See, 2012). For the woodland and bushland, the models are fair and good, for grassland the model is fair and for the subsistence farmland the model is excellent. For the subsistence farmland, this can be due to the fact that this land cover type is distributed in most parts of the island compared to other land cover types.

Table 10: The logistic regression coefficients of land cover types of Buvuma island

Explanatory variables/land cover	Woodland	Bushland	Grassland	Subsistence Farmland
Intercept	-1.725763	-20.559276	-56.623943	36.78079
Clay category				-0.578666
Not protected	-0.703864	0.305505	-0.284558	0.472778
Road distance	0.000008	-0.000223	0.000101	-0.000190
Lake distance	0.000258	-0.000812	-0.000443	0.000005
Slope	0.078078	0.028236	0.015741	-0.047140
Elevation		0.014812	0.004257	
Rain average			0.350473	-0.252968
Settlement distance	-0.000092	-0.000060	-0.000231	0.000194
AUC	0.70	0.75	0.84	0.91

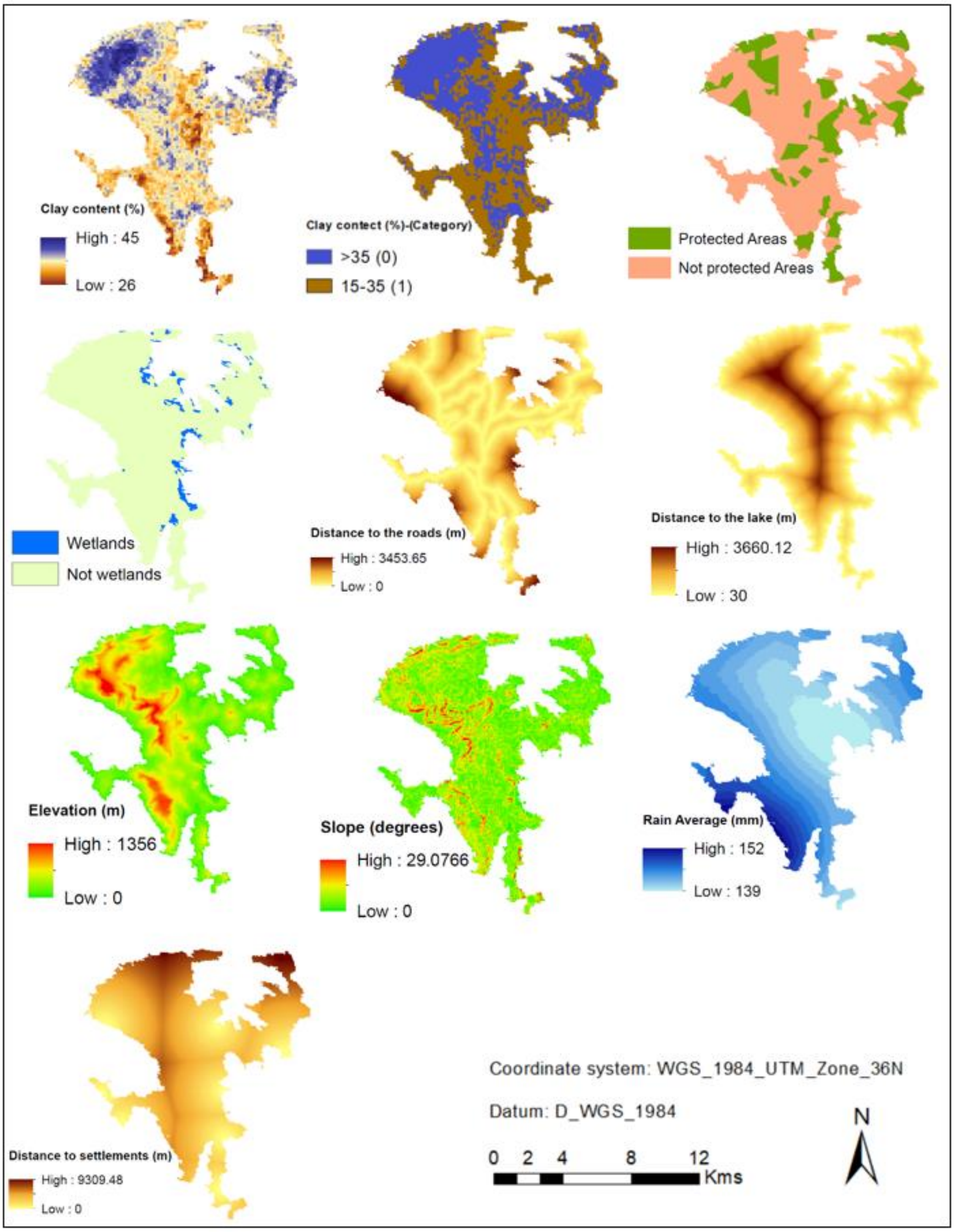

Figure 10: The explanatory variables used for Buvuma island to model land cover change.

3.2.2. The performance and sensitivity of oil palm logistic regression model of Bugala island

The AUC of the ROC for a logistic regression model used was 0.75 (Appendix 7) which means the model is good, successful and acceptable. So the oil palm locations on Bugala island were well described and predicted by the selected explanatory variables. To compare the oil palm locations depicted by a logistic regression model and the actual locations on Bugala island, oil palm probability map developed in R and the oil palm map from the land cover map of Bugala island in 2015 are shown in Figure 11. Generally, there is a similar pattern between the depicted model and where oil palm is located in the field which means a logistic regression model was successful.

For the ten different sample datasets performed to test the robustness and sensitivity of a logistic regression model, the coefficients are nearly similar among the sample datasets. And the AUC of the ROC was between 0.73 – 0.75 for the all of the samples (Table 11). The probability maps for the ten sample datasets also shows similar pattern among themselves. To illustrate this four out of ten probability maps are shown in Appendix 8. So the different logistic regression models developed from the ten sample datasets were also fair and successful.

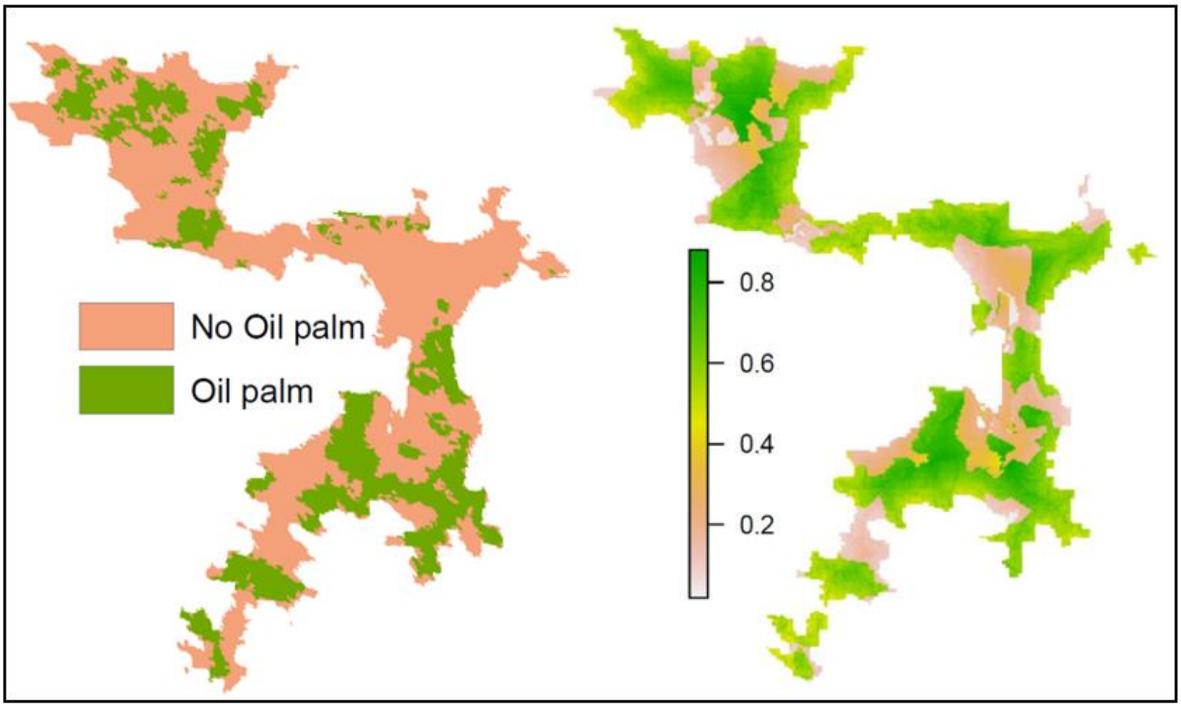

Figure 11: The actual field location of oil palm in the field (left) and the probability map of oil palm (right) generated in R software based on the explanatory variables.

Table 11: The coefficients for ten sample datasets to assess the performance and sensitivity of oil palm logistic regression model of Bugala island performed in R. The last columns shows the mean and standard deviation (SD) of the sample datasets.

	Sample 1	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**	**Sample 6**	**Sample 7**	**Sample 8**	**Sample 9**	**Sample 10**	**Mean**	**SD**
Intercept	0.8732	2.2866	-1.2930	-2.5267	-1.7953	-2.6540	0.1960	2.4755	-1.5928	-1.2464	-0.5277	1.8793
Clay category	-0.1580	-0.1578	-0.1570	-0.1957	-0.2336	-0.1980	-0.1272	-0.1976	-0.3765	-0.1574	-0.1959	0.0704
Not protected	2.2526	2.2821	2.3231	2.3111	2.5563	2.2942	2.2352	2.1521	2.2267	2.1775	2.2811	0.1115
Road distance	0.0001	0.0002	0.0002	0.0001	0.0002	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002	0.0000
Lake distance	0.0005	0.0006	0.0005	0.0003	0.0005	0.0005	0.0005	0.0006	0.0005	0.0006	0.0005	0.0001
Slope	0.0467	0.0265	0.0295	0.0150	0.0156	0.0243	0.0192	0.0362	0.0404	0.0418	0.0295	0.0113
Elevation	-0.0042	-0.0058	-0.0025	-0.0011	-0.0020	-0.0012	-0.0037	-0.0054	-0.0022	-0.0021	-0.0030	0.0017
Not wetlands	1.6141	1.9849	1.7197	1.5652	1.4903	1.6308	1.8175	1.3952	1.7419	1.2277	1.6187	0.2164
AUC	0.73	0.75	0.75	0.72	0.74	0.74	0.74	0.73	0.74	0.73	0.7370	0.0095

3.3. Land cover modelling results under the development scenarios

CLUMondo model calculated land cover maps per each year of simulation and a text file which shows the area allocated to each land cover type per each year of simulation (Appendix 9). The final map of 2025 for each scenario was taken for the analysis.

3.3.1. Land cover change under the scenarios

For the **BAU scenario** it was assumed that 80% of land will be covered by subsistence farmland by 2025. The model results shows that subsistence farmland will likely to increase by 2677 ha (Table 12). The expansion of agricultural land will be at the expense of woodland, bushland and grassland as shown on the land cover map of 2015 and BAU map of 2025 in Figure 12. Woodland will experience more conversion followed by grassland and then bushland (Table 12 and Figure 13). Most of woodland and bushland will be converted in central and western parts of the island (Figure 13). Grassland will be converted mostly in the central and southern parts of the island. The northern and eastern parts of the island are already covered by farmlands in 2015 as shown in Figure 12. So woodland, bushland and grassland close to subsistence farmland are the locations likely to be converted in the BAU scenario. But there are few areas of woodland which are not converted to agricultural land regardless of being close to existing subsistence farmland. These areas can be observed on Figures 12 (BAU 2025) on the central and western parts. These areas are the protected areas refer to Figure 10 showing the explanatory variables (protected areas map) and the results of the logistic regression of subsistence farmland on Table 11 which shows positive coefficient meaning that most of subsistence farmlands are not located on the protected areas.

For the **protection enhanced scenario**, the assumption was to have up to 5000 ha of oil palm on Buvuma island in 2025 while protecting the protected areas/forests reserves on the island. The results shows that subsistence farmland will experience more conversion to oil palm plantations compared to other land cover types (Table 12 and Figure 13). Approximately 4029 ha of subsistence farmland will likely decline in this scenario mostly in the central, western and north-western parts of the island, also few changes are observed in the eastern part of the island (Figure 13). There is also reduction in woodland, bushland, and grassland mostly in the central part of the island. The amount of ha reduced are shown in Figure 13 and Appendix 10. The pattern of the oil palm locations may be influenced by combination of explanatory variables. But it seems that the distance to the lake map (Figure 10) have influenced the oil palm locations (Figure 12 – Protection 2025) because of the similar pattern between the two maps. Results of logistic regression shows that oil palm are likely distributed away from the lake (Table 8) and its where the model predicted most of oil palm for Buvuma island. All the protected areas are safe from the expansion of oil palm because they were treated as exclusion layer in the modelling process refer to Figure 10 and Figure 12.

For the **economic enhanced scenario** the plan was to expand up to 10,000 ha of land as per government plan. The model predicted much decline in subsistence farmland, approximately 7270 ha (Table 12 and Figure 13) mostly in the central, western and northern parts of the island and few areas in the eastern part. So this implies that if this scenario will be implemented oil palm plantations will cover the majority of the land on Buvuma island (Table 12). Also, there is decline in woodland, bushland and grassland. Woodland and bushland are converted most in the central and north-western parts of the island and grassland in the central and southern parts. The model needed to allocate large areas of land in this scenario but there are some few areas of woodland and subsistence farmland which were skipped as observed on Figure 12 (Economic 2025). The areas includes few areas of woodland in the central and north-western parts of the island, subsistence farmland in the north-eastern and grassland in southern part of the island. For the woodland and the subsistence farmland these are the protected areas, refer to Figure 10, and the results of logistic regression model (Table 8). The CLUMondo model followed the regression of Bugala island where most of oil palm locations are not on the protected areas. But for the grassland part one of the reason could be the areas are located in higher elevation which is not ideal for oil palm plantations (Figure 10).

When comparing the three scenarios, the BAU scenario results in a strong loss of woodland and gain of agricultural land. For the two oil palm scenarios, most conversions are happening at the expense of agricultural land. But more agricultural land will be lost in the economic enhanced scenario. For the economic enhanced scenario there is also strong loss of woodland, grassland and bushland as in the BAU scenario than in the protection enhanced scenario (Figure 12 and Figure 13). The conversions for each scenario are also shown in Appendix 10.

Table 12: Area in ha and percentage for each land cover type in 2015 and 2025 for all scenarios[1]

Land cover class	Land cover 2015 ha (%)	BAU scenario 2025 ha (%)	Protection enhanced scenario 2025 ha (%)	Economic enhanced scenario 2025 ha (%)
Woodland	3176 (14.80)	1473 (6.87)	2507 (11.68)	1454 (6.78)
Bushland	623 (2.90)	323 (1.51)	525 (2.45)	335 (1.56)
Grassland	2213 (10.30)	1539 (7.17)	2029 (9.46)	1536 (7.16)
Subsistence farmland	14499 (67.58)	17176 (80.06)	10470 (48.80)	7229 (33.69)
Oil palm	0 (0)	0 (0)	4980 (23.21)	9957 (46.41)
Others	944 (4.40)	944 (4.40)	944 (4.40)	944 (4.40)

[1] For the protection and economic enhanced scenarios, few pixels of oil palm had to be introduced in the land cover map of 2015. So for oil palm in 2015 it is 3 ha and grassland is 2010 ha.

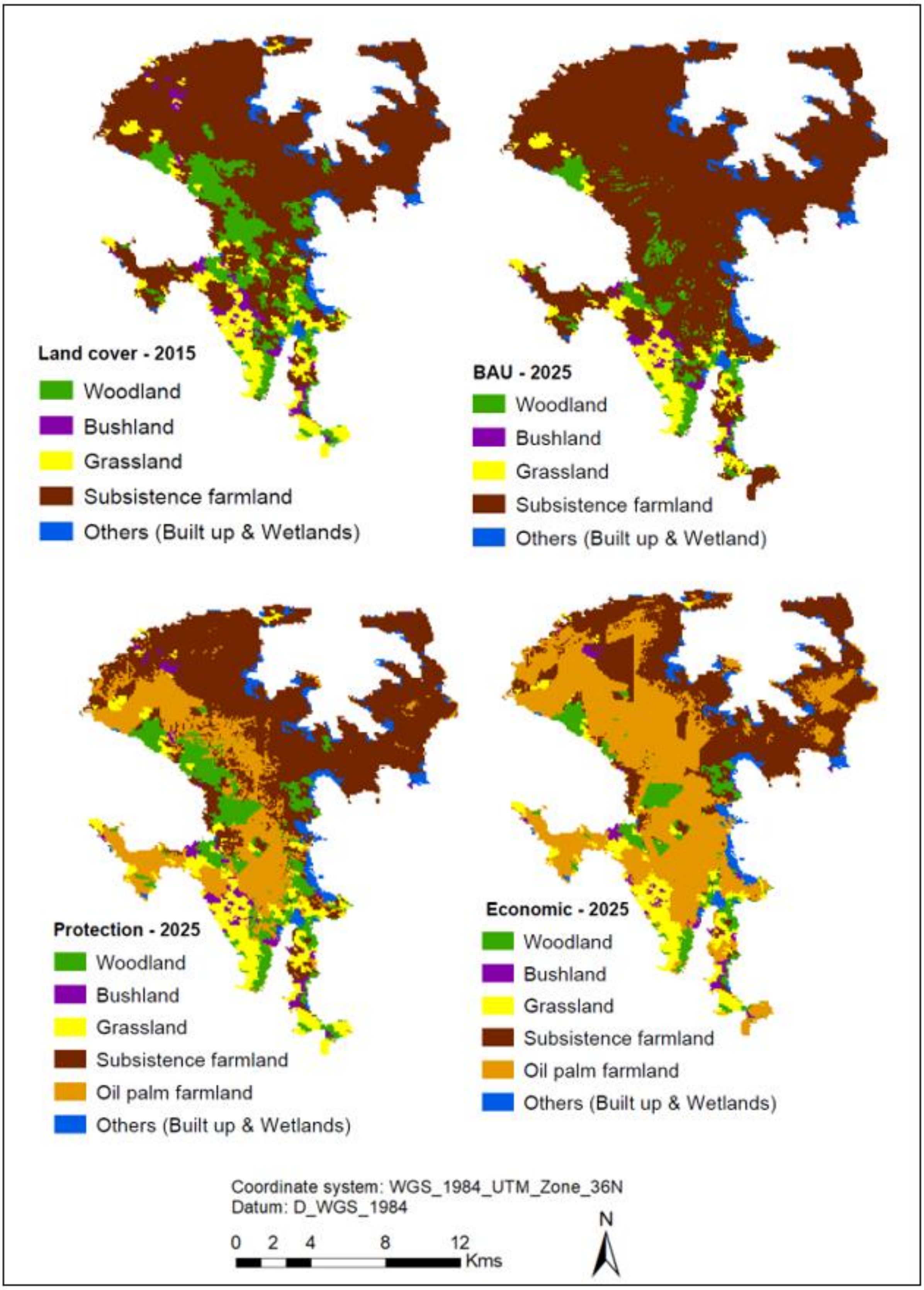

Figure 12: The Buvuma land cover map of 2015 and 2025 for each development scenario

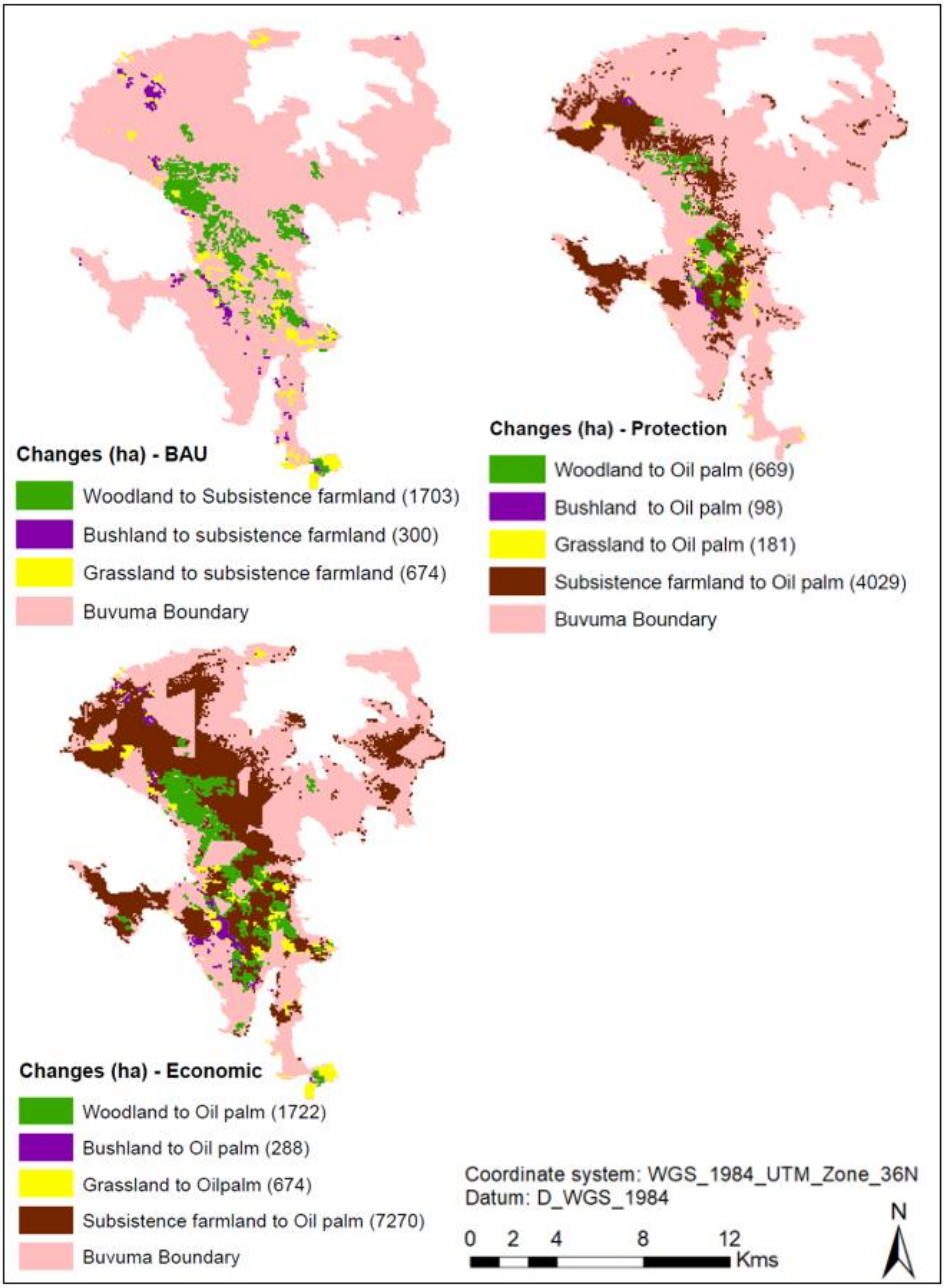

Figure 13: Land cover change (area in ha) for each development scenario on Buvuma island

3.4. Analysis of ecosystem services change under the scenarios

This part shows the spatial description of the ecosystem services and the likely impacts of land cover change on the ecosystem services.

3.4.1. Spatial description of the ecosystem services

The land cover types where ecosystem services are obtained (Figure 8) and the distance from settlement (Figure 5) were used to spatially describe the ecosystem services, as summarized in Table 13. Some of the ecosystem services locations are overlapping because they are provided by the same land cover types and they are within the same distance from the settlement. For example construction materials and food collection areas are mainly provided by woodland, bushland and wetland and they are located mostly within ten km from the settlement. Recreational services and eco-tourism were not spatially described as most of the stakeholders indicated that most islanders are not directly benefiting from this service. Locations of recreational services and eco-tourism services are visited mostly by tourists from outside the island. Distance from the settlement was not considered for food production, so all the subsistence farmlands were described as the locations for food production.

Table 13: Land cover types and the distance to the settlement used to spatially describe the ecosystem services available on Buvuma island

Ecosystem service	Land cover classes	Distance from settlement (km)
Grass for cattle	Grassland, Wetlands	<= 5
Construction materials	Woodland, Bushland, and Wetland	<= 10
Food production	Subsistence farmland	N/A
Food collection (Fruits, hunting, and fishing)	Woodland, Bushland, and Wetland	<= 10
Medicinal plants	Woodland and Bushland	<=10
Fuelwood and Charcoal	Woodland and Bushland	<= 5

The ecosystem services maps developed from the results of the questionnaire from the first objective are shown in Figure 14. Grasses for cattle are mostly located in the central and southern parts of Buvuma island and they are also distributed along the lake. This is because grasses are also collected from the wetlands which are located along the lake (Figure 10 – 'not wetlands layer'). Construction materials, food collection areas, medicinal plants, fuelwood and charcoal are distributed most in the central, southern and north-western parts of Buvuma island. The reasons is that these ecosystem services are mostly obtained from woodland and bushland which are mostly distributed in these parts. Construction materials and food collection are also located along the lake on the wetlands. Food production which is the ecosystem service covering the largest area in 2015 on Buvuma island (Table 14) is mostly distributed in the central and northern parts of Buvuma island.

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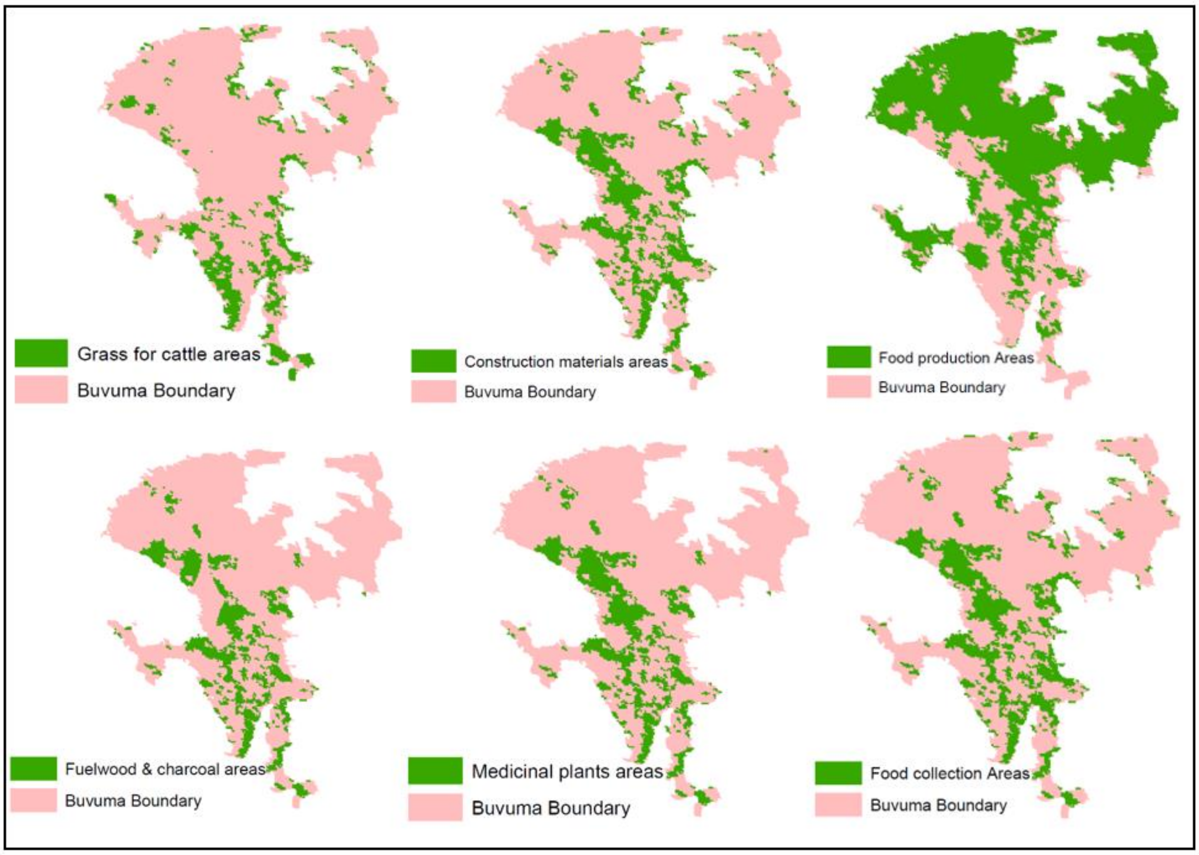


Figure 14: The spatial description of the ecosystem services on Buvuma island.

3.4.2. Ecosystem services and stakeholders impacted by land cover change under each scenario

From the analysis done by overlaying the ecosystem services maps (Figure 14) and the areas of change maps (Figure 13), the results shows that all the ecosystem services on Buvuma island will be impacted by the land cover changes in 2025. The magnitude of the impact is different for each ecosystem service and scenario. Table 14 shows the area covering each ecosystem service in 2015, the area of ecosystem services lost or gained and the remaining area of each ecosystem service under each scenario in 2025.

For the BAU scenario most of the ecosystem services impacted are those collected from woodland and bushland such as construction materials, food collection, medicinal plants, fuelwood and charcoal in the central part of the island (Figure 15). There is much decline in construction materials, food collection and medicinal plants followed by fuelwood and charcoal (Table 14) hence the users such as charcoal producers, timber producers and people collecting food will be likely impacted by the reduction of these ecosystem services. There is decline in grass for cattle areas mostly in the central and southern parts of Buvuma island (Figure 15). Grasses along the lake where wetlands are located are not impacted as the wetlands were not included in the conversion. Therefore, the livestock keepers on the island especially who are located far from the wetlands will be impacted by the decline in grass for cattle. There is an increase in food production by 13 % (Table 14) in the central, southern and western parts of the island as shown in Figure 13 because of the increase in subsistence farmland. This means farmers will benefit most because they will have addition land for cultivation.

For the protection enhanced scenario, food production will be impacted the most as shown in Table 14 and Figure 15 due to the expansion of oil palm. Major impacts are observed in the central and north-western parts of the island (Figure 15). There are small decline in grass for cattle, construction materials, food collection, medicinal plants, fuelwood and charcoal in the central part of the island. In this scenario farmers are mostly impacted compared to other users of the ecosystem services because there is about 20% decline of agricultural land. So the famers producing food for selling at the market (Figure 6) will also experience reduction in income due to reduction of crops produced.

For the economic enhanced scenarios major impacts are observed on food production as shown in Table 14 and Figure 15. The results show there is decline in subsistence farmland from 68% in 2015 to 34% in 2025 (Table 12). The areas of food production impacted are mostly in the central and north-western parts of the island, also few areas on the eastern part (Figure 15). This means that farmers will experience major loss of land for production of different crops. This will affects the availability of food in the homes and reduction of income from selling different crops. Also there will be a major loss of construction materials, food collection, medicinal plants, fuelwood and charcoal (Table 14) mostly in the central and north-western parts of the island (Figure 15). These ecosystem services are collected for both home uses and selling at the market (Figure 6), therefore it may lead to decline in income of the Buvuma islanders who sell these ecosystem services. There is also decline in grass for cattle mostly in the central and southern parts (Figure 15). Livestock keepers may have to depend on the grasses from the wetlands which may not likely be impacted by the oil palm expansion which may cause competition and more shortage of grasses.

Table 14: The estimated area in ha for each ecosystem services in 2015 and the approximate area of ecosystem services lost or gain in ha (the area remained) from the land cover change in 2025 for each development scenario

Ecosystem services	**Area (ha) 2015**	**BAU 2025**	**Protection enhanced 2025**	**Economic enhanced 2025**
Grass for cattle	2136	-658 (1478)	-185 (1951)	-683 (1453)
Construction materials	4691	-1964 (2727)	-778 (3913)	-2005 (2686)
Food production	14499	+2677 (17176)	-4029 (10470)	-7270 (7229)
Food collection	4691	-1964 (2727)	-778 (3913)	-2005 (2686)
Medicinal plants	3816	-1964 (1852)	-778 (3038)	-2005 (1811)
Fuelwood and charcoal	3395	-1611 (1784)	-715 (2680)	-1660 (1735)

Generally, Figure 15 shows that most of the ecosystem services lost are located in the central to the north-western parts of the island compared to the north-eastern parts. So this means people located in these areas are more likely to be impacted by the increase of subsistence farmland in the BAU scenario and the oil palm expansion in the protection and economic enhanced scenarios. More impacts are observed on the economic enhanced scenario, followed by BAU scenario and then protection enhanced scenario.

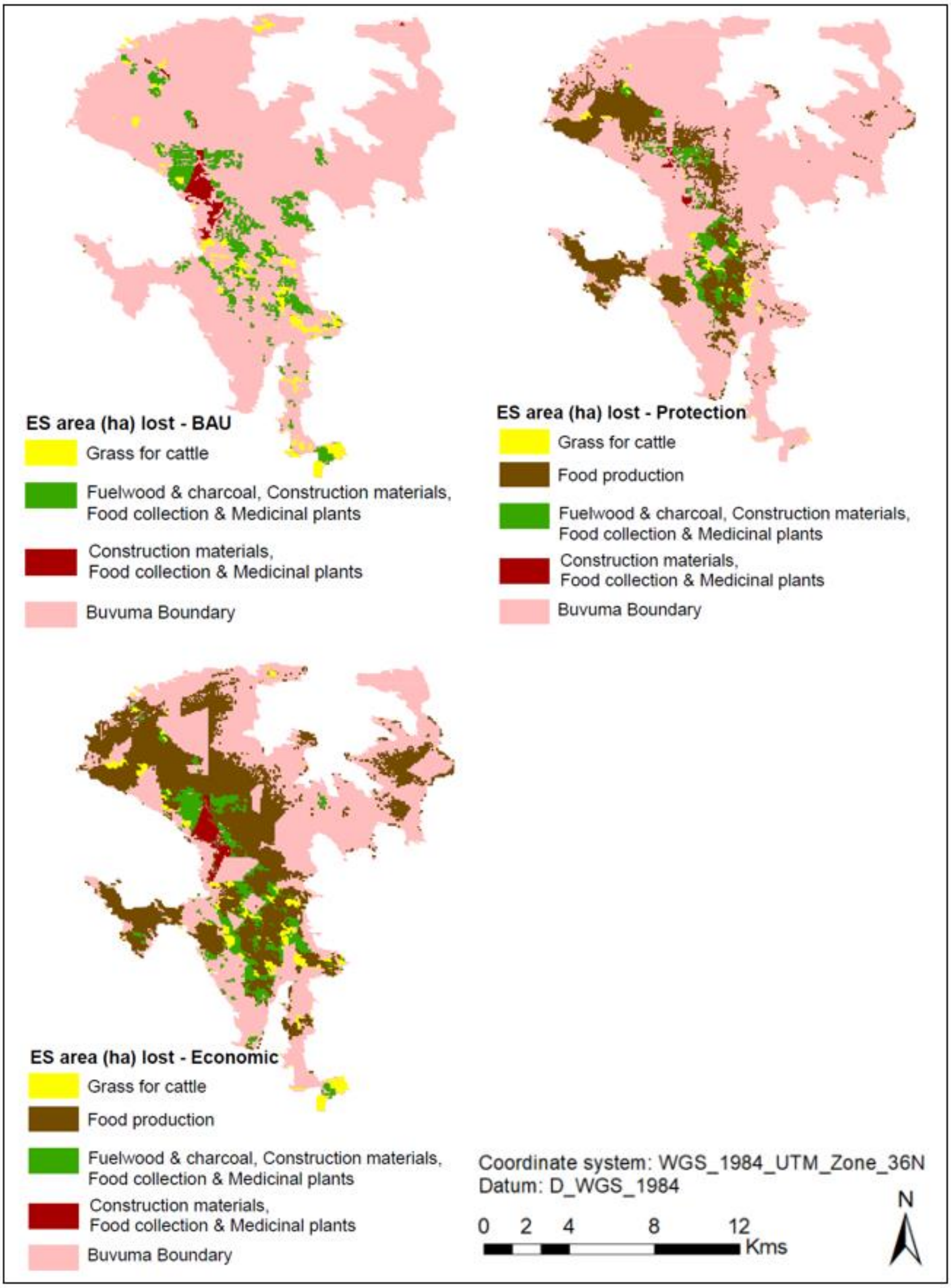


Figure 15: Ecosystem services impacted by land cover change under each development scenario on Buvuma island.

4. DISCUSSION

This chapter focuses on implications of the results of this study to Buvuma island and Uganda, the applicability of the methods and the application of the study to the rest of the world.

4.1. Implications of the study for Buvuma island and Uganda

With oil palm being one of the fastest growing crops and one of the main agents of land cover change, it is important to conduct impact assessment of oil palm expansion on the ecosystem services. This is because local people who are the users of the ecosystem services are vulnerable to different impacts from oil palm expansion. Land cover change caused by oil palm expansion threatens ecosystem functions and services (Saswattecha, Hein, Kroeze, Jawjit, & Crossman, 2016). As oil palm production is expected to be introduced on Buvuma island it is important to project the future land cover change in the presence of oil palm plantations. Projecting future land cover change provides an input to the development of future land management strategies (Sohl & Sleeter, 2012). This study identified the future impacts of oil palm expansion on the ecosystem services on Buvuma island as well as assessing the impacts of the current land cover change trend.

Each scenario has been reported to have impacts on the ecosystem services in this study. But there is potential for positive impacts of agricultural expansion. Willemen, Jones, Estrada Carmona, & DeClerck (2017) reported that agricultural practices and the expansion of agricultural areas bring major threat to healthy ecosystems but if agriculture is well planned and managed, it can become an important means to protect the ecosystem services. So Buvuma island may have potential benefits if agriculture expansion is well planned and managed. Different groups who may benefit are summarized in Table 15.

Table 15: The potential benefits of each development scenario for Buvuma island[2]

Stakeholders	**BAU**	**Protection enhanced scenario**	**Economic enhanced scenario**
Local community	-More land for farmers -Availability of more food crops for home use and selling in the market	Potential land for reforestation	-Improved infrastructures and markets -Reduce the level of poverty
National government		-Tax and tariffs from producers -Income from exportation of oil	-More tax and tariffs from producers -More income from exportation of oil
Smallholder oil palm producers		Raise in income	Raise in income
Large-scale oil palm producers (BIDCO)		Production of more products from palm oil	More production of different products from palm oil

[2] The table summarizes the potential benefits for each scenarios. The table was developed from the results of this study and different literature. But the benefits were not investigated further in this study. So further research is needed on Buvuma island.

On Buvuma island the ecosystem services are linked to different land cover types. Some of the land cover types provide more ecosystem services compared to others. For instance woodland, bushland and wetlands provide more ecosystem services than grassland and subsistence farmland. Apart from land cover types distance from settlement was a useful variable to describe the locations of these ecosystem services. This information obtained is useful as Buvuma island is likely to experience massive land cover change from oil palm expansion in the near future. Land cover changes may have direct and indirect impacts on the ecosystem services on Buvuma island as shown in this study. Different studies have also reported that changes on land cover have impacts on the ecosystem services and lead to loss of their economic values (Mendoza-González, Martínez, Lithgow, Pérez-Maqueo, & Simonin, 2012; Zhang, Zhao, Liu, Liu, & Li, 2015; Mamat, Halik, & Rouzi, 2018). This has been also proved on Buvuma island where change in the land cover have resulted in the loss of ecosystem services.

Different land cover types are expected to be converted in each of the scenarios but there are major variations among the scenarios. For the BAU scenario more change are expected to occur on woodland, grassland and bushland. But for the protection and economic enhanced scenarios oil palm will be expanded at the expense of subsistence farmland more than other land cover types. But major land cover changes in 2025 will likely to occur in the economic enhanced scenario where oil palm will cover approximately 46% of the land cover of Buvuma island leading to a loss of several ecosystem services most likely food production. For the protection enhanced scenario approximately 23% of land cover will be converted to oil palm plantations.

In the economic enhanced scenario, approximately 50% of food production will be impacted by the expansion of oil palm on the island, this implies that farmers will be likely to be impacted more by these changes. Decline in food production may be a direct impact of oil palm expansion but it may be associated with other impacts. Decline in food production may lead to food insecurity on Buvuma island which people are worried about (Friend of Earth Europe, 2015). People may have to import food from other areas which may also reduce the income of the people of Buvuma island. This situation have also been reported on other places where oil palm is produced such as Indonesia (Sirait, 2009; Petrenko et al., 2016). Also the major expansion of oil palm may discourage foreign tourism as most of the areas will be covered with oil palm plantations.

There may be other indirect impacts from large conversion of oil palm expansion in the economic enhanced scenario on Buvuma island. There may be introduction of new people which implies new culture which may affect the traditional way of Buvuma island. On Bugala island since the introduction of oil palm there have been increase in alcoholism and HIV/AIDS which require intervention (Bennett et al., 2015). Also there may be new demand for land for new infrastructures such as housing for new people. Demand for more land may lead to more shortage of land for islanders. Also oil palm growing requires the use of chemicals and fertilizers which may be washed into the lake and may reduce the amount of fish which could affect the fishermen on Buvuma island (Koh & Wilcove, 2008; Bennett, Hendriks, Zevenbergen, Mkumbwa, & Antonio, 2015). Air pollution and more greenhouse gases (GHGs) from open burning may be another indirect impact of oil palm expansion. Open burning is normally applied by farmers to clear a new land before planting oil palm (Saswattecha et al., 2016). Hence people are exposed to high levels of air pollution, resulting in respiratory infections such as asthma (Schrier-uijl et al., 2013). Also this may lead to people especially women to travel far when there is reduction in the ecosystem services such as firewood which used to be collected nearby.

Despite the negative impacts of oil palm expansion on Buvuma island, the large-scale development of oil palm plantations may lead to economic benefits as shortly described in Table 15. Also the benefits may include construction of infrastructure and provision of houses, health, roads and educational services (Twiggs & Bertule, 2009). As a result Buvuma islanders may have easier access to local markets, schools, hospitals, and villages. But for the smallholders farmers this may be only short term benefit. For the long term this is still unsure especially when there will be fluctuations in palm oil prices (Schrier-uijl et al., 2013). On-going rapid expansion of oil palm around the world could lead to lower prices for palm oil in the future, while increase in price of other ecosystem services such as timber due to increasing scarcity (Sumarga & Hein, 2016). There are employment opportunities from oil palm plantations but still unsure if it will benefit the Buvuma islanders. From Bugala island experience the majority of workers were employed from outside the island, from Northern and Southern parts of Uganda which brought tension between the new comers and islanders (Bennett et al., 2015). Another example is from Indonesia where there is a tendency of companies to hire migrant workers from areas with a stronger agricultural tradition which lead to ethnic conflict between foreigners and natives (Schrier-uijl et al., 2013).

The protection enhanced scenario offers more available land for the islanders than economic enhanced scenario where they may continue with their economic activities even with the presence of oil palm. But also, as Buvuma island is facing the problem of deforestation, most of their forests have disappeared there is opportunity for reforestation on the island. Monitor reporters (2017), reports a statement from one government official mentioning "*we will also take responsibility and plant trees in other areas of Buvuma to recover the already depleted forest cover*". So this scenario may offer a chance for the reforestation scheme in different areas especially in the protected areas. According to Willemen et al. (2013) when protected areas are carefully planned, they can be a good strategy for protecting and conserving the ecosystem services.

For Buvuma island even without the presence of oil palm the island may experience more land cover change in the future. This has been observed on the BAU scenario which followed the past trend of the land cover change and hence subsistence farmland is projected to be 80% in 2025. More woodland, bushland and grassland will be impacted by land cover change. Different stakeholders especially on the conservation side are worried that oil palm will cause destruction of ecosystem services especially from natural vegetation as reported by Rainforest Rescue (2016). But the observed results from BAU scenario have indicated that even without oil palm ecosystem services such as grass for cattle, construction materials, food collection, medicinal plants, fuelwood and charcoal may be impacted as well. Hence more assessment should be on the current land cover trend and what should be done to avoid rapid future land cover changes and its impacts.

On Buvuma island much of it is forest is gone even before the introduction of oil palm (Appendix 5). So other land cover types will be converted to oil palm as shown in the scenarios results in this study. This has been also reported in other source in different areas where oil palm is produced. Oil palm often replaces other cash or subsistence crops (Koh & Wilcove, 2008; Carlson et al., 2012; Gatto, Wollni, & Qaim, 2015). For Buvuma island the rate of increase of subsistence farmland is high so for this case most of the farmers will be affected on the island. This was also observed on the two oil palm scenarios where food production will be likely more affected than other ecosystem services. So for the case of Buvuma island farmers should be considered when allocating land for oil palm expansion and how are they going to be compensated for the land they will lose.

Buvuma island has an added advantage as they have Bugala island as a reference point on what has happened since the introduction of oil palm. From Bugala island it shows the decline in most of the ecosystem services since the introduction of oil palm (Badui, 2018). Oil palm on Bugala island has expanded to the areas covered by grasslands, wooded grasslands and forests mainly (Abonyo et al., 2007). For Buvuma island the results have shown that conversion of oil palm will be on areas covering woodland, bushland, grassland as well as subsistence farmland. The difference between the two islands is that forests were present when oil palm was introduced on Bugala island but almost all forests have disappeared before the introduction of oil palm on Buvuma island. Also for Bugala island most of the protected areas/forest reserves are still covered with forests but on Buvuma island they are covered with other land cover types such as subsistence farmland. So it was difficult to identify the protected areas with unique biodiversity or any important natural resources on Buvuma island. So for this study all the protected areas regardless of what is in the ground were treated as the exclusion layer for the protection enhanced scenario. For further study this can be taken into consideration and if it is possible to identify exact location of important ecosystem services in the protected areas which should be excluded from the expansion.

The results of this study reflect on what is happening on locations where oil palm is produced around the world. For Buvuma island there is lack of scientific research concerning oil palm expansion, so this study may be an eye opener that there are different ecosystem services on Buvuma island and their potential locations and what will be the danger of losing these ecosystem services to the people and to the environment. Zhang, Zhao, Liu, Liu, & Li (2015) reported that assessing the value of ecosystem services that influence humans wellbeing is important to promote and encourage sustainable economic growth. The ecosystem services maps produced in this study may facilitate land use planning process for the future policies and plans because now the parts of Buvuma islands which provide more ecosystem services than other areas are known. So this allows the land use planners to evaluate the consequences if these area will be changed. Maps of ecosystem services has a significant role in land management in rural areas and the maps can be used to visualize how the services operate, to assess the impacts on the ecosystem services and can facilitate negotiations between stakeholders which including payment schemes (Willemen et al., 2017). For Buvuma island where there is a need for negotiations between land owners and the government hence maps may be important. For the land cover changes, the results may be used by land use planners to evaluate different land use policy options and their consequences (Willemen, 2002). Using this study Buvuma island land use planners have an idea on what will likely happen if any of the policy will be implemented such as the government plan of introducing 10,000 ha of oil palm.

4.2. Reflection on the methods used in the study

4.2.1. Capturing diverse stakeholders views on the ecosystem services of Buvuma island

The Maptionnaire tool was used to capture the views of different stakeholders on the ecosystem services of Buvuma island due to the limitation of going to the field. This study was able to capture the views of two stakeholder groups. But the plan was to involve more stakeholder representatives such as representing fishermen, but due to the limitation of time and the willingness of the respondents to participate in this study it was not possible to get the views of other stakeholder groups. The ecosystem services mentioned correlate with the economic activities available on Buvuma island from different sources as mentioned on the study area (section 2.1.1). It would have been important to catch the views of the local people/islanders because they are also the main users of the ecosystem services on the island so probably more information for better results could have been generated. Mapping ecosystem service while involving the community representatives enables identification of areas of local value and concern and likely to empower local involvement in environmental management (Raymond et al., 2009). Also best participatory mapping of ecosystem services ecosystem services promote the link between ecosystems and people and should include multiple societal interests and values (Brown & Fagerholm, 2015; Willemen, Burkhard, Crossman, Drakou, & Palomo, 2015). But using Maptionnaire tool it was impossible to catch the views of community members because the tool needs access to internet, electricity and knowledge to use computer or other ICT facilities. Also for the reliable results the respondents need to have a sic understanding on the use of online maps so as to identify the exact location of the intended feature on the field.

For the ecosystem services this study focuses on the provisioning ecosystem services which are used directly by the local community. Provisioning ecosystem services are more easily understood because they are products that are directly consumed (Logsdon & Chaubey, 2013). Also they can quantified directly compared to most regulating, supporting, and cultural services which are less straightforward to put them in the maps (Maes et al., 2012). The information from the stakeholders participation serves as an important input for the spatial description of ecosystem services. The ecosystem services which are indirectly used by humans and probably unknown to the local community and stakeholders were left out on this study because of time constraint and limitation of the fieldwork. So the consequence is that there may be important ecosystem services which were not described on Buvuma island. For the future study focus may also include the ecosystem services which are indirectly benefits the local people.

4.2.2. Empirical analysis and the CLUMondo model

Finding empirical relations between oil palm development areas and location characteristics was a useful method in this study because oil palm is not on Buvuma island yet. A logistic regression model has shown reasonable results by showing a similar pattern of oil palm depicted by the model and what is in the field on Bugala island (Figure 9). A similar study was done where data were unavailable for suitability for oil palm in Brazil, in which suitability for oil palm was based on studies based in Southeast Asia (Yui & Yeh, 2013). Transferring of empirical relations of Bugala island to Buvuma island was chosen because of the similarities between the two islands. The spatial explanatory variables used in this study are also commonly used in different land cover modelling studies. Elevation, slope, distance to a residential area, distance to road, density to forest edge and population density are the most common variables included in land use modelling (Nurwanda, Zain, & Rustiadi, 2015; Pinuji, 2015; Pontius & Schneider, 2001). Also, some variables are considered as constraints in land cover modeling for instance protected areas or certain land cover type, example wetland and urban areas for this study. But regardless of importance, the choice of the explanatory land cover modelling depends on the quality data of the study area (Pinuji, 2015). Also the data are more suitable if they are from the same year. This study did not include social or political factors such as land rights. Probably incorporating these variables could results in other areas for oil palm expansion or could come up with more areas to be avoided such as important traditional places.

Some of the variables selected for a logistic regression model correlate with what is written in most literature such as oil palm is located on flat elevation but some differ from the literature and the expectations. For example the expectation was roads will be close to the plantations so as the products to reach the processing industry easily which is in Jinja (outside the island). Access to an oil palm mill is important in oil palm production, because the fruits are perishable and have to be milled within 48 hours after harvest (Gaveau et al., 2009; Gatto et al., 2015). But the results of this study have shown that the plantations are away from the road. The reason could be that the roads on Bugala island near the plantations are still not developed as planned before the introduction of oil palm and only the old road still exists. For the clay content the expectation was that oil palm will likely be located in clay content ranging from 15 – 35% but for Bugala island oil palm are distributed even in the higher clay content.

CLUMondo model was used because it has been also used by many studies around the world and has provided good results (Eitelberg, van Vliet, Doelman, Stehfest, & Verburg, 2016; Ornetsmuller et al., 2016; Liu et al., 2017). The model uses empirically derived relations based on existing land use patterns for the allocation of land cover change (Verburg, 2015). Buvuma island does not have oil palm yet, hence modelling the future oil palm was not possible. The solution was to use the empirical relations from the area with very similar features (Verburg et al., 2002) which is supported by CLUMondo model. So the empirical relations for oil palm locations found on Bugala island were used to determine areas where oil palm will most likely expand to on Buvuma island. Also the ability of the model to simulate different scenarios was an added advantage in this study. As scenarios describe possible futures under different sets of assumptions given our current understanding of the way drivers of land cover interact and affect ecosystems (Sleeter et al., 2012). The scenarios in this study have been useful to show consequences of the choices which will be made on Buvuma island. For the two oil palm scenarios this study considered the conversion of different land cover types to oil palm only. A similar study and settings was done by Sumarga & Hein (2016) where their model only predicts the probability of an area to be converted into oil palm. But in reality land may also be converted to other land cover types even in the presence of oil palm on Buvuma island. So for future study, different other scenarios can be developed depending on the trend of the land cover change in the few years to come especially when oil palm is already introduced. For example a scenario to consider oil palm expansion with a combination of BAU scenario. Another added advantage of the model is the ability to exclude the important areas such as protected areas/forest reserves for the protection enhanced scenario for this study. So this model can also be used for all the studies aiming at projecting land cover change while excluding important areas.

One limitation of CLUMondo model in this study was inability to allocate the required final land demand in 2025 for each scenario (Appendix 9). From the results it shows that 114 ha were not allocated in the BAU scenario to reach 80% in 2025, 20 ha in the protection enhanced scenario to reach 5000 ha and 46 ha in the economic enhanced scanario to reach 10,000 ha of oil palm (Table 12). So this means for each scenario the mentioned ha may also be covered with the ecosystem services. Prestele et al. (2016) in they study which compared different models, they found that CLUMondo model had very different results compared to other models.

4.2.3. Uncertainties and sources of errors

Some of the uncertainties and errors on the results of this study may be from input data used and model parameters settings. For the land cover maps, there can be possible errors from classification process which may lead to errors also on the model results generated. The producers of the maps (NFA – Department of GIS and mapping unit) validated the land cover maps of both islands used in this study by visiting the field. Another source of error may come from hand digitization of the roads as the digitized roads were not validated on the field. Also resampling of land cover maps and other input data may be another source of error as resampling reduces the resolution of the maps. For a logistic regression model, some of the uncertainty may come from the random sampling process. But generally a logistic regression model was robust because of the sample datasets results shown in Table 11 and the probability maps on Appendix 8.

Other sources of uncertainty may come from the setting of the parameters during the modelling process using the CLUMondo model. From the demand files, for BAU scenario the trend of the land cover change was from the land cover maps provided. So uncertainty may occur when the maps used had some errors. Also for the BAU scenarios only subsistence farmland was assumed to increase and for the two scenarios the assumption was that only oil palm will be increasing but in reality other land cover types will also be changing even in the presence of oil palm. So if the demand could be changed also the results could be different. For the conversion resistance some of the land cover types were given higher values compared others which could lead to biased results. For the future study consultation of more expertise and policy makers could help in the improvement of the results.

Also another uncertainty could come from the results from the stakeholders views and perception on the questionnaire. It is difficult to identify among the stakeholders who was right and who was wrong. The validation of the locations of ecosystem services was not done in this study. A study by (Brown & Fagerholm, 2015) reported that there still no standards to assess the positional accuracy and completeness of the mapped ecosystem services in different literature.

4.3. Sustainable palm oil production

Despite all the reported impacts of oil palm production around the world, replacing palm oil with other types of oil for now is not possible solution due to its unique properties and its uses (Green Palm Sustainability, 2018). Apart from being a highest provider of vegetable oil worldwide, oil palm cultivation has also brought positive effects on the incomes and livelihoods of farming families and hence the development of some rural areas where it is produced (Seegräf, May, Breuer, & Schukat, 2011). So there is a need for other possible solutions such as sustainable palm oil production. Sustainable palm oil production aims at minimizing social and environmental impacts of oil palm production and ensures more benefits for both people and the environment. Also, sustainable palm oil production aims at protecting people's land rights and livelihood by ensuring that local people are not robbed of their land (Green Palm Sustainability, 2018). This means oil palm is produced and certified under sustainability criteria related to social, environmental and good economic practice (Green Palm Sustainability, 2018). Sustainability may lead to more oil from the existing plantation areas and encourage expansion without deforestation or other environmental hazards (Khatun et al., 2017).

The idea of sustainable palm oil production was initiated in 2004 by the Roundtable on Sustainable Palm Oil (RSPO), an the international initiative on sustainably certified palm oil. It was established as a joint initiative with WWF and other different companies involved directly or indirectly in palm oil sector (RSPO, 2013). Sustainable palm oil production is comprised of legal, economically viable, environmentally appropriate and socially beneficial management and operations (RSPO, 2013). RSPO has several standards which prohibit clearing of primary forest or any land which is important to the community and wildlife. Also, the standards address soil erosion, pollution, health and safety, also promote inclusion and support of smallholders (RSPO, 2013). Smallholder farms play a major role in global agriculture so they need support to improve and secure their income (Seegräf et al., 2011). RSPO also encourages improvement of production conditions so as to increase yields and employment, ensures social working conditions are consistent with industry standards and ensure minimum wages must be paid (Seegräf et al., 2011).

Since the introduction of this initiative, some positive feedback has been observed in the areas where it is practiced such as Indonesia, Malaysia and Thailand. So far over 20% palm oil around the world have been certified, approximately over 3.2 M ha around the world out of 20 M ha (Green Palm Sustainability, 2018). This initiative has managed to preserve around 189.777 ha of highly valuable forest and more producers have become more respectful of the environment and communities (Green Palm Sustainability, 2018). The deforestation rate has reduced on Indonesia by 33% since the introduction of sustainable palm oil production and the rate of using fire in certified plantations have reduced (Seegräf et al., 2011; Bennett, Hendriks, Zevenbergen, Mkumbwa, & Antonio, 2015).

For Buvuma island and Uganda as a whole, the concept of sustainable palm oil production is not applied. On Buvuma island where oil palm is not yet introduced there are already reports of people being forced to sell their land which is against the land right standard of RSPO. A report by Ssebwami & Ssenkabirwa (2018), states that approximately 5000 Buvuma islanders have rejected a proposal of selling their lands to the government because of the low payment. Also, the report added that the government had reserved 3,500 ha of private forests on Buvuma island for oil palm plantations and the reason was due to a shortage of the farmland in the areas. So from these examples it shows that the standards of sustainable palm oil production on Buvuma island are not present. But sustainable palm oil production may be a potential solution for minimization of the social and environmental problems on Buvuma island.

The information obtained from this study can be useful for sustainable palm oil production. Sustainable palm oil approach protects the right of people and environment. In this study the areas with important ecosystem services benefiting the local community have been described. For the environment, it was shown that agricultural land can be expanded and still protecting the protected areas/forest reserves. Future projection can also be useful for the planning of sustainable palm oil production. For this study, a protection enhanced scenario may be an example of the oil palm expansion with the minimum social and environmental impacts. But in reality sustainable palm oil for Buvuma island may not be an option for now because it needs some prior knowledge such as the individual farming practices need to be documented transparently and in full (Seegräf et al., 2011). But if this will be considered for Buvuma island it may bring long-term benefits as it involves the improved methods of cultivation and harvesting which helps to increase yields hence more income and employment opportunities. Sustainability certification also makes easier to access international markets which may bring more development in rural areas of the producer countries (Seegräf et al., 2011).

However, when considering sustainable palm oil production the focus should be on both producer groups in the area. This means both smallholders and large-scale producers. Different research have identified that in certification most of the large-scale producers of oil palm tend to benefit more compared to smallholders producers. Hidayat, Glasbergen, & Offermans (2015) have reported a case in Indonesia and states that most of the smallholders do not possess legal land documentation which is needed for certification, also for smallholders certification may lead to raise in palm oil price but does not guarantee the stable price, also smallholders do not have understanding of the global market like the large-scale producers. So even for Buvuma if this will be an option then the smallholders needs have to be taken into consideration.

5. CONCLUSION AND RECOMMENDATION

This study found through the stakeholder consultation that Buvuma island provide several ecosystem services that contribute the people's wellbeing including; grass for cattle, construction materials (timber), food production, food collection (fruits, hunting, and fishing), medicinal plants, fuelwood and charcoal. The ecosystem services are land cover dependent. Grass for cattle is collected mostly on grassland and wetlands, construction materials and food collection from woodland, bushland, and wetlands, medicinal plants, fuelwood and charcoal from woodland and bushland and food production from subsistence farmland. Most of the ecosystem services are collected within five km from settlements, but others are collected far from the settlements. People benefiting from these ecosystem services are livestock keepers, timber producers, farmers, charcoal producers as well as other local people collecting food and firewood. They collect the ecosystem services for both home uses and selling at the market. This study through empirical relations analysis found that oil palm development locations may be explained by different spatial explanatory variables. Possible areas where oil palm will likely expand to include; areas with both low and high clay content, not protected areas, not wetlands, away from the road and the lake, at lower elevations and likely to be distributed as the slope increases. From the land cover change using scenarios in 2025, the results show major variations between the scenarios especially between protection and economic enhanced. For the BAU scenario, subsistence farmland will likely increase by 13% where woodland will be converted more, followed by grassland and then bushland in the central, western and southern parts of the island. The conversions will lead to a decline in grass for cattle, construction materials, food collection, medicinal plants, fuelwood and charcoal but it will lead to increase in food production. Farmers will benefit because of additional land but livestock keepers, timber producers and people collecting food and medicinal plants will be impacted. For the protection enhanced scenario 19% of subsistence farmland is expected to be converted into oil palm in the central, western and north-western parts of the islands which will lead to reduction in food production and hence farmers will be impacted. Also there is small decline of woodland, bushland and grassland mostly in the central part of the island. For the economic enhanced scenario, 34% of subsistence farmland is expected to be converted into oil palm plantations in the central, western and northern which will lead to 50% decline in food production which affects farmers who produce food for home uses and selling at the markets. Other land cover types are also expected to be converted to oil palm. 3% of grassland, 8% of woodland and 2% of bushland are expected to be converted in the central, southern and north-western parts of the islands. This lead to the reduction in ecosystem services from these land cover types and impact the users of these ecosystem services. From the analysis the impacts of land cover change will be different among the ecosystem services and stakeholders groups. The results of this study may be used for the future land use management plans because it has provided an overview of locations of some of the important provisional ecosystem services on the island which are essential for the people's livelihood and the consequences of future land cover change on those ecosystem services.

For further research the recommendation include; a detailed analysis on how the impacts will affects the vulnerable groups such as women and children. Also more research should focus on how people of Buvuma island will benefit from the introduction of oil palm such as on the opportunity for sustainable palm oil production.

LIST OF REFERENCES

Abonyo, C. K., Isabirye, M., Mfitumukiza, D., Magunda, M. K., Poesen, J., Deckers, J., & Kasedde, A. C. (2007). Land use change and local people's perception of the effects of change in Ssese islands, Uganda. *National Agricultural Research Organisation, Uganda*.

Addo, I. A. (2012). *Spatial analysis of oil palm expansion in Ghana: A case study of the socioeconomic impact assessment of oil palm expansion in Ejisu Juaben municipality; Msc Thesis - Unpublished*. University of Twente Faculty of Geo-Information and Earth Observation (ITC), Enschede.

Badui, A. (2018). *Spatial Analysis of Oil Plam Expansion and its Impacts on Ecosystem services in Bugala island, Uganda - Unpublished*. University of Twente.

Bennett, R. M., Hendriks, B. O. B., Zevenbergen, J., Mkumbwa, S., Antonio, D., Augustinus, C., … Kyofa, K. (2015). Pro-poor land records, palm oil , and prosperity: any proof from Bugala island, Uganda? In *Linking land tenure and use for shared prosperity, proceedings of the annual World Bank conference on land and poverty, 23-27 March 2015, Washington DC, United States* (pp. 1–21). Washington D.C.: The World Bank.

Berg, A. van den. (2016). *Participation of Communities and CSOs in Sustainable Management of Bugala Island, MSc Thesis*. Wageningen University.

Brown, G., & Fagerholm, N. (2015). Empirical PPGIS/PGIS mapping of ecosystem services: A review and evaluation. *Ecosystem Services*, *13*, 119–133. https://doi.org/10.1016/J.ECOSER.2014.10.007

Burkhard, B., & Maes, J. (Eds). (2017). Introduction. In *Mapping Ecosystem services* (Vol. 16, pp. 25–27). Bulgaria: Pensoft Publishers. https://doi.org/http://dx.doi.org/10.1016/S0075-7535(08)70222-5

Carlson, K. M., Curran, L. M., Ratnasari, D., Pittman, A. M., Soares-Filho, B. S., Asner, G. P., … Rodrigues, H. O. (2012). Committed carbon emissions, deforestation, and community land conversion from oil palm plantation expansion in West Kalimantan, Indonesia. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(19), 7559–64. https://doi.org/10.1073/pnas.1200452109

Colchester, M., Chao, S., Fon Achobang, C., Alaza, L., Ale, N., Anderson, P., … Priyani Widjaya, A. (2013). *The oil palm sector at a crossroads ConfliCt or*. Retrieved from http://www.forestpeoples.org/sites/fpp/files/publication/2013/11/conflict-or-consentenglishlowres.pdf

Corley, R., & Tinker, P. (2003). *The oil palm* (4th ed). Iowa, USA: Blackwell Science. Retrieved from http://eu.wiley.com/WileyCDA/WileyTitle/productCd-0470750367.html

De Groot, R. S., Alkemade, R., Braat, L., Hein, L., & Willemen, L. (2009). Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity*, *7*, 260–272. https://doi.org/10.1016/j.ecocom.2009.10.006

Dislich, C., Keyel, A. C., Salecker, J., Kisel, Y., Meyer, K. M., Auliya, M., … Wiegand, K. (2016). A review of the ecosystem functions in oil palm plantations, using forests as a reference system. *Biological Reviews*, *49*, 1539–1569. https://doi.org/10.1111/brv.12295

Eitelberg, D. A., van Vliet, J., Doelman, J. C., Stehfest, E., & Verburg, P. H. (2016). Demand for biodiversity protection and carbon storage as drivers of global land change scenarios. *Global Environmental Change*, *40*, 101–111. https://doi.org/10.1016/j.gloenvcha.2016.06.014

Emerson, K. (2016). Maptionnaire: Promoting public participation and civic engagement with map-based questionnaires | UBIQUE. Retrieved December 12, 2017, from http://ubique.americangeo.org/company-and-not-for-profit-spotlights/maptionnaire-promoting-public-participation-and-civic-engagement-gis-research-tools/

Environmental Assessment Consult Limited. (2003). Environmental Impact Statement for the proposed oil palm project, Bugala island, Kalangala District.

FOEI. (2013). Uganda: Oil palm plantations Archives. Retrieved August 5, 2017, from http://www.foei.org/journalistic-resources/uganda-plantations

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., … Snyder, P. K. (2005). Global Consequences of Land Use, *8*(July), 570–575. https://doi.org/10.1126/science.1111772

Friend of Earth. (2011). Palm oil landgrab in Uganda: Wilmar International's violations in Kalangala Island, (5). Retrieved from http://libcloud.s3.amazonaws.com/93/7b/3/3078/Issue_Brief_5_-_Wilmar_in_Uganda.pdf

Friend of Earth Europe. (2015). No news is bad news: land grabs and palm oil expansion in Uganda | Friends of the Earth Europe. Retrieved February 1, 2018, from http://www.foeeurope.org/no-news-bad-news-land-grabs-palm-oil-uganda

Gatto, M., Wollni, M., & Qaim, M. (2015). Oil palm boom and land-use dynamics in Indonesia: The role of policies and socioeconomic factors. *Land Use Policy*, *46*, 292–303. https://doi.org/10.1016/j.landusepol.2015.03.001

Gaveau, D. L. A., Wich, S., Epting, J., Juhn, D., Kanninen, M., & Leader-Williams, N. (2009). The future of forests and orangutans (*Pongo abelii*) in Sumatra: predicting impacts of oil palm plantations, road construction, and mechanisms for reducing carbon emissions from deforestation. *Environmental Research Letters*, *4*(3), 34013. https://doi.org/10.1088/1748-9326/4/3/034013

Green Palm Sustainability. (2018). GreenPalm :: What do we mean by sustainable palm oil? Retrieved January 26, 2018, from http://greenpalm.org/about-palm-oil/sustainable-palm-oil

Hidayat, N., Glasbergen, P., & Offermans, A. (2015). Sustainability Certification and Palm Oil Smallholders' Livelihood: A Comparison between Scheme Smallholders and Independent Smallholders in Indonesia. *International Food and Agribusiness Management Review Hidayat*, *18*(3). Retrieved from https://www.ifama.org/resources/Documents/v18i3/Hidayat-Glasbergen-Offermans.pdf

Human Right Focus. (2013). Subcounties in Buvuma District, Uganda. Retrieved August 15, 2017, from http://www.lcmt.org/uganda/buvuma/

IFAD. (2016). Republic of Uganda Vegetable Oil Development Project – Phase 2 Supervision report Main report and appendices, *2*(May), 9–20.

Jesshim, K. (2003). Multicollinearity in Regression Models. *Multicollinearity Doc*, 1–8. https://doi.org/10.1111/j.1467-9787.1988.tb01087.x

Kalangala District Local Government. (2005). DISTRICT. Retrieved from http://www.nemaug.org/district_reports/Kalangala_DSOER_2004.pdf

Kalangala NGO Forum, K. (2009). A study to identify key issues for engagement about the oil palm project in ssese islands Kalangala district: A case study of Buggala and Bunyama island in Kalangala district. Retrieved from http://wrm.org.uy/oldsite/countries/Uganda/Kalangala.pdf

Khatun, R., Reza, M. I. H., Moniruzzaman, M., & Yaakob, Z. (2017). Sustainable oil palm industry: The possibilities. *Renewable and Sustainable Energy Reviews*, *76*, 608–619. https://doi.org/10.1016/j.rser.2017.03.077

Koh, L. P., & Wilcove, D. S. (2008). Is oil palm agriculture really destroying tropical biodiversity? *Conservation Letters*, *1*(2), 60–64. https://doi.org/10.1111/j.1755-263X.2008.00011.x

Liu, Z., Verburg, P. H., Wu, J., & He, C. (2017). Understanding Land System Change Through Scenario-Based Simulations: A Case Study from the Drylands in Northern China. *Environmental Management*, *59*(3), 440–454. https://doi.org/10.1007/s00267-016-0802-3

Logsdon, R. A., & Chaubey, I. (2013). A quantitative approach to evaluating ecosystem services. *Ecological Modelling*, *257*, 57–65. https://doi.org/10.1016/j.ecolmodel.2013.02.009

Maes, J., Egoh, B., Willemen, L., Liquete, C., Vihervaara, P., Philipp, J., … Bidoglio, G. (2012). Mapping ecosystem services for policy support and decision making in the European Union. *Ecosystem Services*, *1*, 31–39. https://doi.org/10.1016/j.ecoser.2012.06.004

Mancini, A., Imperlini, E., Nigro, E., Montagnese, C., Daniele, A., Orr??, S., & Buono, P. (2015). Biological and nutritional properties of palm oil and palmitic acid: Effects on health. *Molecules*, *20*(9), 17339–17361. https://doi.org/10.3390/molecules200917339

Manyindo, J. (2003). Forestry Series 3 Diversifying Commercial Forest Values for Forest Conservation and Improved Livelihoods on the Ssese Islands, (January).

Menard, S. (2017). An Introduction to Logistic Regression Analysis and Reporting, *96*(1), 3–14. https://doi.org/http://dx.doi.org/10.4135/9781412983433

Mendoza-González, G., Martínez, M. L., Lithgow, D., Pérez-Maqueo, O., & Simonin, P. (2012). Land use change and its effects on the value of ecosystem services along the coast of the Gulf of Mexico. *Ecological Economics*, *82*, 23–32. https://doi.org/10.1016/j.ecolecon.2012.07.018

Millennium Ecosystem Assessment. (2005). Ecosystem and human well-being. Summary for decision makers. *Ecosystems and Human Well-Being: Synthesis*, 1–24. https://doi.org/http,//www.maweb.org/.

Ministry of Finance, P. and E. D. (2000). Uganda participatory poverty assessment process, Kalangala district report, (January), 1–126. Retrieved from http://s3.amazonaws.com/zanran_storage/www.finance.go.ug/ContentPages/19284037.pdf

Monitor reporters. (2017). 3,500 hectares of forest land destroyed for oil palm growing - Daily Monitor. Retrieved January 31, 2018, from http://www.monitor.co.ug/News/National/3-500-hectares-of-forest-land-destroyed-for-oil-palm-growing/688334-4047736-130ql3pz/index.html

Mosnier, A., Boere, E., Reumann, A., Yowargana, P., Pirker, J., Havlik, P., & Pacheco, P. (2017). Palm oil and likely futures: Assessing the potential impacts of zero deforestation commitments and a moratorium on large-scale oil palm plantations in Indonesia, (177), 1–8. https://doi.org/10.17528/cifor/006468

Nangendo, G. (2018). Land use changes (1990-2015) in Kalangala and Buvuma districts, southern Uganda. In *Ssemmanda, R., & Opige, M (eds.) Oil palm plantations in forest landscapes: impacts, aspirations and ways forward in Uganda.*

Nangoli, F. (2009). Buvuma the united states of Uganda. Retrieved August 10, 2017, from https://web.archive.org/web/20140515064451/http://www.newvision.co.ug/D/8/12/680677

NAPE. (2008). Who we are - National Association of Professional Environmentalists (NAPE). Retrieved August 19, 2017, from http://www.nape.or.ug/index.php/about-us/who-we-are

NAPE. (2011). The UN Social and Environment Compliance Unit Faults Bidico on Bugala Farmers - National Association of Professional Environmentalists (NAPE). Retrieved July 25, 2017, from http://www.nape.or.ug/index.php/news-events/latest-news/140-the-un-social-and-environment-compliance-unit-faults-bidico-on-bugala-farmers

NAPE, & FOEI. (2012). Land, life and justice Food sovereignty Land, life and justice. Retrieved from http://www.foei.org/resources/publications/publications-by-subject/food-sovereignty-publications/land-life-and-justice

NEMA. (2014). State of the Environment Report for Uganda. Retrieved from http://nema.go.ug/reports/FINAL NSOER 2014 mail.pdf

NFA. (1992). National Biomass Study , Phase I, (December 1991).

Ngo, T. A., & See, L. (2012). Calibration and Validation of Agent-Based Models of Land Cover Change. In *Heppenstall A., Crooks A., See L., Batty M. (eds) Agent-Based Models of Geographical Systems* (pp. 181–197). Springer, Dordrecht. https://doi.org/10.1007/978-90-481-8927-4_10

Nurwanda, A., Zain, A. F. M., & Rustiadi, E. (2015). Analysis of land cover change and landscape fragmentation in Batanghari Regency, Jambi Province, *227*(2016), 87–94. Retrieved from https://ac.els-cdn.com/S1877042816307327/1-s2.0-S1877042816307327-main.pdf?_tid=323de374-0a80-11e8-8317-00000aab0f01&acdnat=1517840815_6908aa53527c43ff1d71ad3f00c79748

Ornetsmuller, C., Verburg, P. H., & Heinimann, A. (2016). Scenarios of land system change in the Lao PDR: Transitions in response to alternative demands on goods and services provided by the land. *Applied Geography*, *75*, 1–11. https://doi.org/10.1016/j.apgeog.2016.07.010

Pacheco, P., Gnych, S., Dermawan, A., Komarudin, H., & Okarda, B. (2017). The palm oil global value chain Implications for economic growth and social and environmental sustainability. *Cifor*, *Working Pa*.

Petrenko, C., Paltseva, J., & Searle, S. (2016). Ecological Impacts of Palm Oil Expansion in Indonesia, 28. Retrieved from http://www.theicct.org/sites/default/files/publications/Indonesia-palm-oil-expansion_ICCT_july2016.pdf

Petz, K. (2014). *Mapping and modelling the effects of land use and land management change on ecosystem services. From local ecosystems and landscapes to global biomes, Msc Thesis*. Wageningen University. Retrieved from http://library.wur.nl/WebQuery/wurpubs/fulltext/295633

Pinuji, S. (2015). *Predicting Oil Palm Land Use Following Deforestation Using Available Spatial Parameters*. Wgeningen University. Retrieved from http://edepot.wur.nl/351170

Pirker, J., & Mosnier, A. (2015). Global oil palm suitability assessment, 1–35.

Pirker, J., Mosnier, A., Kraxner, F., Havlik, P., & Obersteiner, M. (2016). What are the limits to oil palm expansion? *Global Environmental Change*, *40*, 73–81. https://doi.org/10.1016/j.gloenvcha.2016.06.007

Pontius, R. G., & Schneider, L. C. (2001). Land-cover change model validation by an ROC method for the Ipswich watershed, Massachusetts, USA. *Agriculture, Ecosystems & Environment*, *85*(1–3), 239–248. https://doi.org/10.1016/S0167-8809(01)00187-6

Prestele, R., Alexander, P., Rounsevell, M. D. A., Arneth, A., Calvin, K., Doelman, J., … Verburg, P. H. (2016). Hotspots of uncertainty in land-use and land-cover change projections: a global-scale model comparison. *Global Change Biology*, *22*(12), 3967–3983. https://doi.org/10.1111/gcb.13337

R Core Team. (2017). R: The R Project for Statistical Computing. Retrieved February 17, 2018, from https://www.r-project.org/

Rainforest Rescue. (2016). Uganda: stop the destruction of Buvuma Island - Rainforest Rescue. Retrieved July 24, 2017, from https://www.rainforest-rescue.org/petitions/1065/uganda-stop-the-destruction-of-buvuma-island#campaign

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*, 1301–1315. https://doi.org/10.1016/j.ecolecon.2008.12.006

RCMRD Geoportal. (2015). Uganda SRTM 30 Meters — GeoNode. Retrieved December 13, 2017, from http://geoportal.rcmrd.org/layers/servir%3Auganda_srtm30meters

Rhebergen, T., Fairhurst, T., Zingore, S., Fisher, M., Oberthür, T., & Whitbread, A. (2016). Climate, soil and land-use based land suitability evaluation for oil palm production in Ghana. *European Journal of Agronomy*, *81*, 1–14. https://doi.org/10.1016/j.eja.2016.08.004

RSPO. (2013). Principles and Criteria for the Production of Sustainable Palm Oil. *Report Submitted by the RSPO Executive Board for the Extraordinary General Assembly*, *2013*(25th April), 1–70.

Saswattecha, K., Hein, L., Kroeze, C., Jawjit, W., & Crossman, N. (2016). Effects of oil palm expansion through direct and indirect land use change in Tapi river basin, Thailand Effects of oil palm expansion through direct and indirect land use change in Tapi river basin Effects of oil palm expansion through direct and indirect. *Carolien Kroeze & Warit Jawjit International Journal of Biodiversity Science Ecosystem Services & Management*, *12*(4), 291–313. https://doi.org/10.1080/21513732.2016.1193560

Schrier-uijl, a. P. A. P., Silvius, M., Parish, F., Lim, K. H. H., Rosediana, S., Anshari, G., & Box, P. O. (2013). Environmental and Social Impacts of Oil Palm Cultivation on Tropical Peat a Scientific Review. *Roundtable on Sustainable Oil Palm*, (April), 131–168.

Seegräf, M., May, D., Breuer, T., & Schukat, P. (2011). Palm Oil – sustainability is possible ! Promotion and certification of smallholders.

Sharma, S. K., Baral, H., Pablo, P., & Laumonier, Y. (2017). Assessing impacts on ecosystem services under various plausible oil palm expansion scenarios in Central Kalimantan, Indonesia, (176). https://doi.org/10.17528/cifor/006479

Sheil, D., Casson, a, Meijaard, E., Van Noordwijk, M., Gaskell, J., Sunderland-Groves, J., … Kanninen, M. (2009). The impacts and opportunities of oil palm in Southeast Asia. *Africa*, 80. https://doi.org/10.17528/cifor/002792

Sirait, M. T. (2009). Indigenous Peoples and Oil Palm Plantation Expansion in West Kalimantan, Indonesia. Retrieved from http://www.worldagroforestry.org/downloads/Publications/PDFS/RP16385.pdf

Sleeter, B. M., Sohl, T. L., Bouchard, M. A., Reker, R. R., Soulard, C. E., Acevedo, W., … Zhu, Z. (2012). Scenarios of land use and land cover change in the conterminous United States: Utilizing the special report on emission scenarios at ecoregional scales. *Global Environmental Change*, *22*, 896–914. https://doi.org/10.1016/j.gloenvcha.2012.03.008

Soepboer, W. (2001). CLUE-S An application for Sibuyan Island, The philippines. *Environmental Sciences*, (January).

Sohl, T. L., & Sleeter, B. M. (2012). Land-Use and Land-Cover Scenarios and Spatial Modeling at the Regional Scale Challenges for Land-Cover Modeling. Retrieved from https://pubs.usgs.gov/fs/2012/3091/FS2012-3091.pdf

Ssebwami, D., & Ssenkabirwa, A.-M. (2018). Buvuma palm oil project: 5,000 reject compensation for land - Daily Monitor. Retrieved January 31, 2018, from http://www.monitor.co.ug/News/National/Buvuma-palm-oil-project--5-000-reject-compensation-for-land/688334-4272720-14obwl9z/index.html

Ssegawa, P., & Nkuutu, D. N. (2006). Diversity of vascular plants on Ssese islands in Lake Victoria, central Uganda. *African Journal of Ecology*, *44*(1), 22–29. https://doi.org/10.1111/j.1365-2028.2006.00609.x

Sumarga, E., & Hein, L. (2016). Benefits and costs of oil palm expansion in Central Kalimantan, Indonesia, under different policy scenarios. *Regional Environmental Change*, *16*(4), 1011–1021. https://doi.org/10.1007/s10113-015-0815-0

Tayyebi, A., Delavar, M. R., Yazdanpanah, M. J., Pijanowski, B. C., Saeedi, S., & Tayyebi, A. H. (2010). A Spatial Logistic Regression Model for Simulating Land Use Patterns: A Case Study of the Shiraz Metropolitan Area of Iran. https://doi.org/10.1007/978-90-481-9085-0_3

Trobenbos Intenational. (2017). About us - Tropenbos International. Retrieved August 20, 2017, from http://www.tropenbos.org/about_us

Tropenbos International. (2015). The Green Livelihoods Alliance signs Strategic Partnership with the Ministry of Foreign Affairs - Tropenbos International. Retrieved August 19, 2017, from http://www.tropenbos.org/news/the+green+livelihoods+alliance+signs+strategic+partnership+with+the+ministry+of+foreign+affairs+

Twiggs, L. D., & Bertule, M. (2009). Sustainability of Smallholder Palm Oil Production in Indonesia. Retrieved from https://core.ac.uk/download/pdf/12517779.pdf

UBOS. (2014). National Population and housing Census - Provisional Results. *Uganda Bureau of Statistics*, 73 pp. Retrieved from http://www.ubos.org/onlinefiles/uploads/ubos/NPHC/NPHC 2014 PROVISIONAL RESULTS REPORT.pdf

UBOS. (2017). National Population and Housing Census 2014, Area specific profiles. Retrieved from http://www.ubos.org/onlinefiles/uploads/ubos/2014CensusProfiles/BUVUMA.pdf

Vatcheva, K. P., Lee, M., Mccormick, J. B., & Rahbar, M. H. (2016). Multicollinearity in Regression Analyses Conducted in Epidemiologic Studies HHS Public Access. https://doi.org/10.4172/2161-1165.1000227

Veldkamp, A., & Lambin, E. F. (2001). Predicting land-use change. *Agriculture, Ecosystems & Environment*, *85*(1–3), 1–6Veldkamp, a, Lambin, E. . (2001). Predicting. https://doi.org/10.1016/S0167-8809(01)00199-2

Verburg, P. H. (2015). The CLUMondo land use change model Manual and exercises, (December).

Verburg, P. H., Soepboer, W., Veldkamp, A., Limpiada, R., Espaldon, V., & Mastura, S. S. A. (2002). Modeling the spatial dynamics of regional land use: The CLUE-S model. *Environmental Management*, *30*(3), 391–405. https://doi.org/10.1007/s00267-002-2630-x

Verheye, W. (2010). Growth and production of oil palm. *Land Use, Land Cover and Soil Sciences*. Retrieved from https://biblio.ugent.be/publication/1009126/file/1009127.pdf

Vijay, V., Pimm, S. L., Jenkins, C. N., Smith, S. J., Walker, W., Soto, C., … Rodrigues, H. (2016). The Impacts of Oil Palm on Recent Deforestation and Biodiversity Loss. *PLOS ONE*, *11*(7), e0159668. https://doi.org/10.1371/journal.pone.0159668

Vogt, N., Bahati, J., Unruh, J., Green, G., Banana, A., Gombya-Ssembajjwe, W., & Sweeney, S. (2006). Integrating remote sensing data and rapid appraisals for land-cover change analyses in Uganda. *Land Degradation and Development*, *17*(1), 31–43. https://doi.org/10.1002/ldr.692

Willemen, L. (2002). *Modelling of land cover changes with CLUE-S in Bac Kan province, Vietnam - MSc Thesis*. Wageningen University. Retrieved from http://asia-uplands.org/Sam/Sam/pdf/2002_MScWillemen_E.pdf

Willemen, L., Burkhard, B., Crossman, N., Drakou, E. G., & Palomo, I. (2015). Editorial: Best practices for mapping ecosystem services. In *Ecosystem Services* (Vol. 13, pp. 1–5). https://doi.org/10.1016/j.ecoser.2015.05.008

Willemen, L., Drakou, E. G., Dunbar, M. B., Mayaux, P., & Egoh, B. N. (2013). Safeguarding ecosystem services and livelihoods: Understanding the impact of conservation strategies on benefit flows to society. *Ecosystem Services*, *4*, 95–103. https://doi.org/10.1016/j.ecoser.2013.02.004

Willemen, L., Jones, S., Estrada Carmona, N., & DeClerck, F. (2017). Ecosystem service maps in agriculture. In *B. Burkhard, & J. Maes (Eds.), Ecosystem service maps in agriculture* (pp. 319–323). Sofi: Pensoft. Retrieved from https://webapps.itc.utwente.nl/library/2017/scie/willemen_eco.pdf

Woittiez, L. S., van Wijk, M. T., Slingerland, M., van Noordwijk, M., & Giller, K. E. (2017). Yield gaps in oil palm: A quantitative review of contributing factors. *European Journal of Agronomy*, *83*, 57–77. https://doi.org/10.1016/j.eja.2016.11.002

World Gospel Mission. (2018). Uganda - Buvuma Islands Ministries - World Gospel Mission. Retrieved January 18, 2018, from https://www.wgm.org/buvuma

World Wide Fund for Nature. (2017). Environmental & social impacts of palm oil production. Retrieved May 21, 2017, from http://wwf.panda.org/what_we_do/footprint/agriculture/palm_oil/environmental_impacts/

Xie, C., Huang, B., Claramunt, C., & Chandramouli, M. (2005). Spatial Logistic Regression and GIS to Model Rural-Urban Land Conversion. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.474.1171&rep=rep1&type=pdf

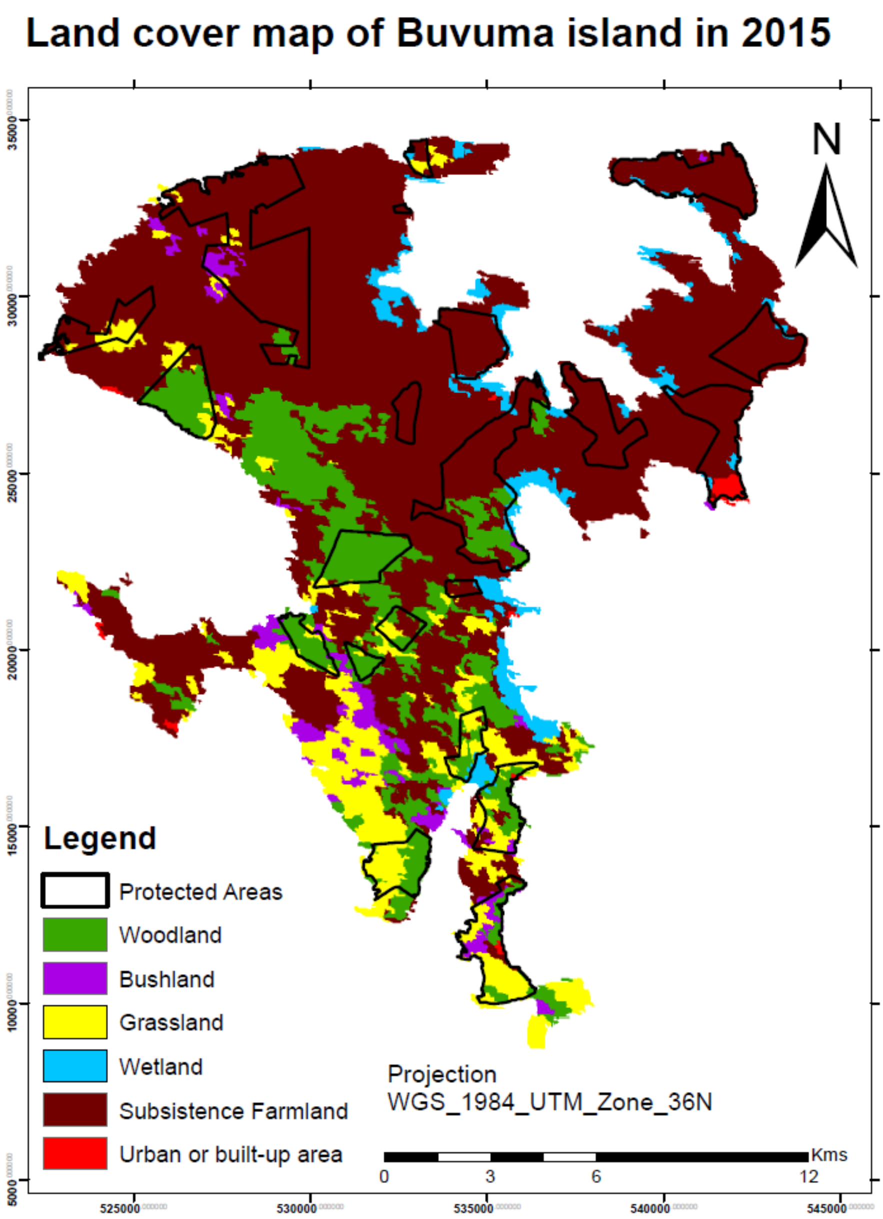
Yui, S., & Yeh, S. (2013). Land use change emissions from oil palm expansion in Pará, Brazil depend on proper policy enforcement on deforested lands. *Environmental Research Letters*, *8*(4), 44031. https://doi.org/10.1088/1748-9326/8/4/044031

Zeng, Y. N., Wu, G. P., Zhan, F. B., & Zhang, H. H. (2008). Modeling spatial land use pattern using autologistic regression. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *37*(B2), 115–118.

Zhang, Y., Zhao, L., Liu, J., Liu, Y., & Li, C. (2015). The impact of land cover change on ecosystem service values in urban agglomerations along the coast of the Bohai Rim, China. *Sustainability (Switzerland)*, *7*(8), 10365–10387. https://doi.org/10.3390/su70810365

APPENDICES

Appendix 1: Buvuma land cover map of 2015 provided by NFA Uganda, Department of GIS and mapping unit



Appendix 2: List of questions for the stakeholders

Questionnaires for different stakeholders in Buvuma island

What stakeholder group can you represent?

- Farmers
- Fishermen
- Biodiversity conservation groups
- Smallholders of oil palm plantations (smaller than 3 hectares)
- Large holders of oil palm plantations (Commercial)

1. What are the benefits people collect from different areas such as woodland, bushland or substance farmland in Buvuma island
   - Fuelwood and charcoal
   - Medicinal plants
   - Food collection (fruits, hunting and fishing)
   - Food production (subsistence farming)
   - Construction materials (timber)
   - Grass for cattle
   - Recreational services and eco-tourism

2. From your knowledge, how far do people travel to reach the benefits available in Buvuma island?

Benefits	Less than 1 km	1 to 5 km	5 to 10 km	10 to 15 km	More than 15 km	Not applicable
Fuelwood and charcoal						
Medicinal plants						
Food collection (fruits, hunting and fishing)						
Food production (subsistence farming)						
Construction materials (timber)						
Grass for cattle						
Recreational services and eco-tourism						

3. What are the main uses of collected benefits from nature and farmlands in Buvuma island

Benefits	For home uses	For selling in the market	Both home uses and selling in the market	I don't know	Not applicable
Fuelwood and charcoal					
Medicinal plants					
Food collection (fruits, hunting and fishing)					
Food production (subsistence farming)					
Construction materials (timber)					
Grass for cattle					
Recreational services and eco-tourism					

4. Where do people collect these benefits in Buvuma island?

Benefits	From their private lands	From the protected areas	From other lands	Not applicable
Fuelwood and charcoal				
Medicinal plants				
Food collection (fruits, hunting and fishing)				
Food production (subsistence farming)				
Construction materials (timber)				
Grass for cattle				
Recreational services and eco-tourism				

5. What are the activities allowed in the protected areas/forest reserves in Buvuma island?
……

6. How well do you know the island
   - I am from here
   - I have visited the island
   - I have done fieldwork/project(s) on the island
   - I have never been there but I read about it
7. Where do people in Buvuma island to collect benefits from nature and farmlands?

From this question, you can select either filling the table below or draw the locations of benefits in nature and farmlands in Buvuma island
From your knowledge, in which areas these benefits from nature and farmlands are located in Buvuma island?

Benefits	Natural forests	Woodland	Bushland (bushes, shrubs and thickets)	Grassland (including grazing grounds)	Wetlands	Subsistence farmland
Fuelwood and charcoal						
Medicinal plants						
Food collection (fruits, hunting and fishing)						
Food production (subsistence farming)						
Construction materials (timber)						
Grass for cattle						
Recreational services and eco-tourism						

Please draw these areas on the google map
The areas that you will draw can be overlapping
a) Location of firewood and charcoal collection
b) Location of tourists attractions

c) Location of timber harvesting (construction materials)
d) Locations of important biodiversity (plants and animals)
e) Location of food collection (fruits, hunting and fishing)

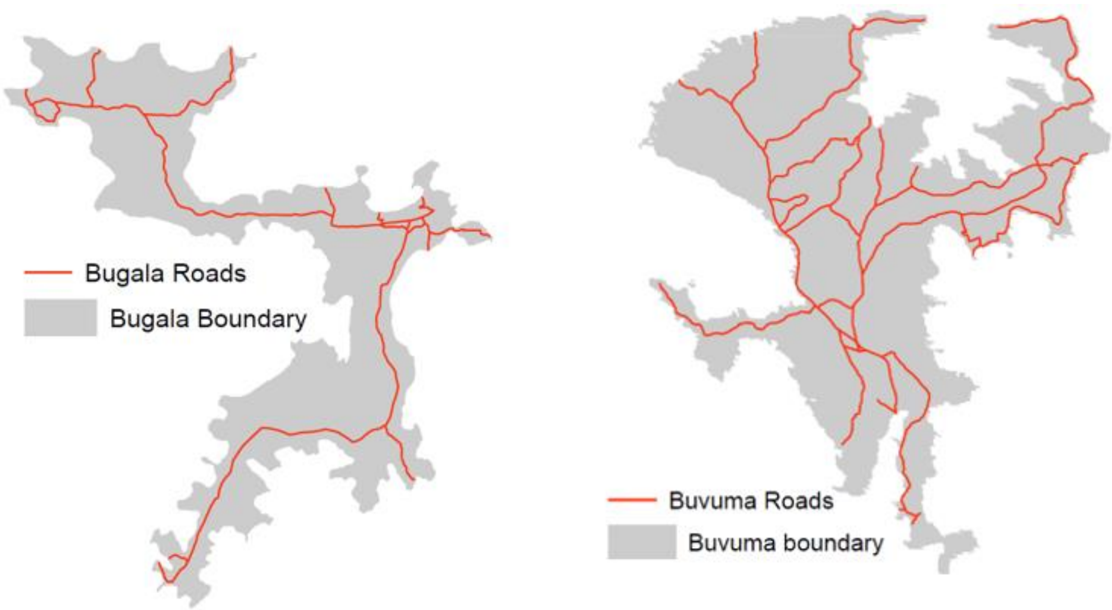
What are the organization are you affiliated with?

………

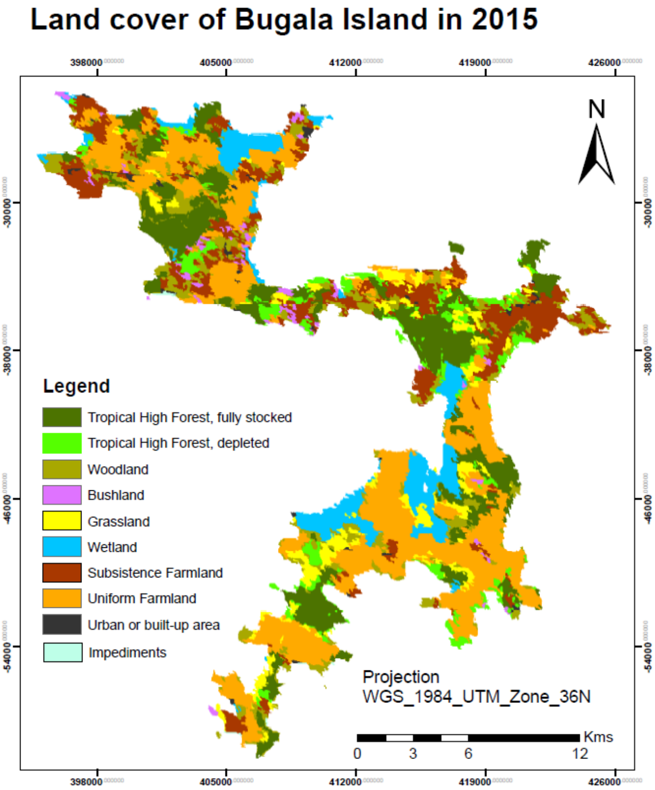
Thank you very much again for taking your time to complete this survey. Can you please mention your name in box below

………

Appendix 3: The digitized roads of Bugala and Buvuma islands from google map of January 2015 with resolution of 30 meters



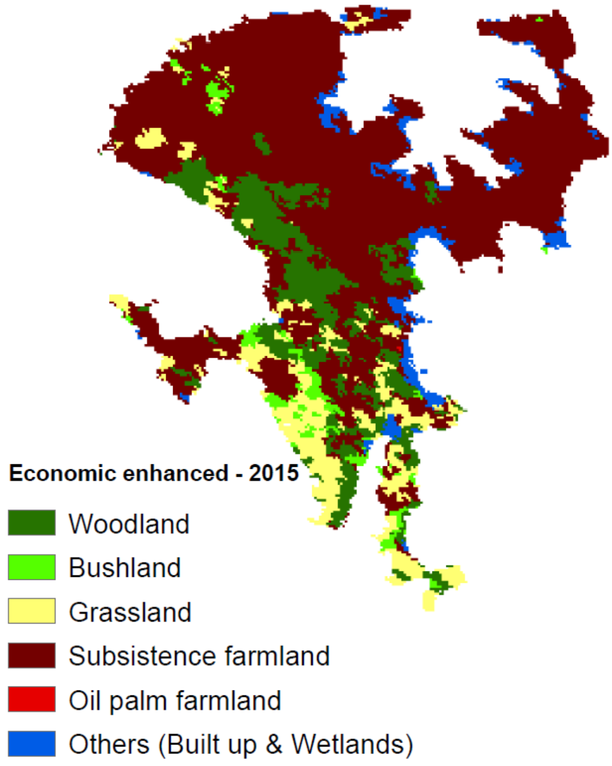
Appendix 4: Land cover map of Bugala island. The oil palm plantations class (uniform farmland) was used in the regression analysis in R software



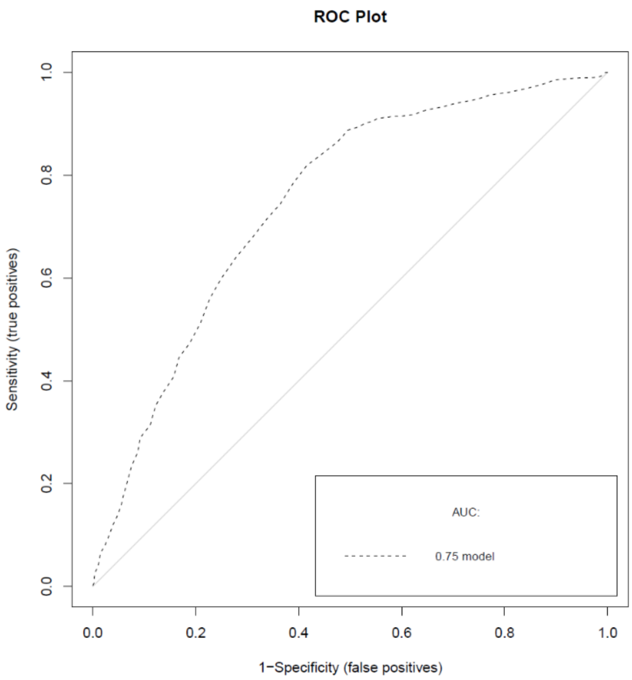
Appendix 5: The trend of land cover area for the five maps of Buvuma island. The trend was used to create a Business of Usual scenario. The land cover maps were obtained from National Forestry Authority (NFA) Uganda

Buvuma Land cover	Area 1990 (ha)	Area 2000 (ha)	Area 2005 (ha)	Area 2010 (ha)	Area 2015 (ha)
Tropical High Forest, fully stocked	11479	10715	0	0	0
Tropical High Forest, depleted	4176	1931	764	108	0
Woodland	154	2166	11674	9126	3177
Bushland	93	1834	0	308	621
Grassland	2631	99	2143	2169	2257
Wetland	1205	740	903	919	858
Subsistence Farmland	1785	3767	6035	9052	14566
Uniform farmland	0	0	0	10	0
Urban or built-up area	3	16	184	131	100
Open Water	15100	15356	14855	14788	15045
Impediments			66	13	
Total	**36626**	**36624**	**36624**	**36624**	**36624**
Protected areas					**5894.74***

Appendix 6: The new land cover map with 3 ha of oil palm artificially included as input for Protection and Economic enhanced scenarios

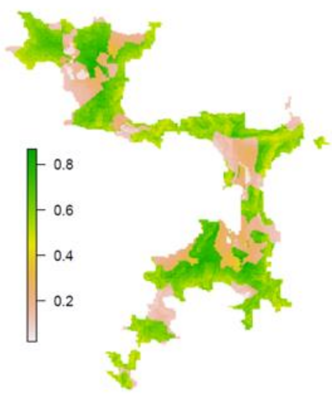


Appendix 7: The ROC plot generated from the logistic regression model for Buvuma island

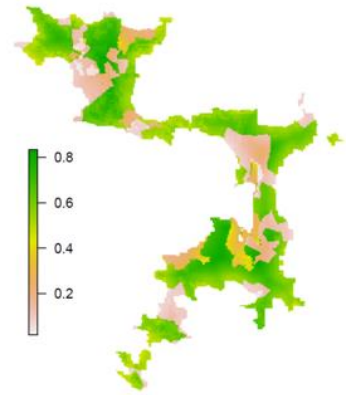


Appendix 8: Probability maps for four samples selected randomly among ten samples

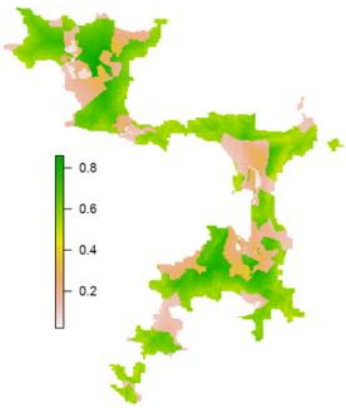
Sample 1



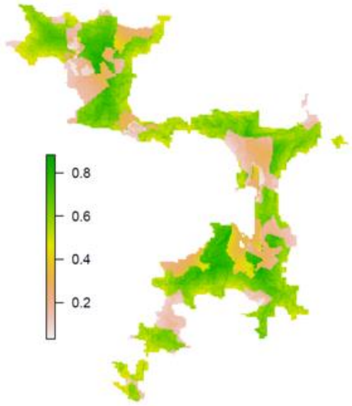
Sample 5



Sample 7



Sample 10



Appendix 9: Text files generated by CLUMondo model showing the areas of land allocated for each land cover type for each development scenario (a) Business as Usual scenario (b) Protection enhanced scenario and (c) Economic enhanced scenario.

(a) Business as Usual scenario

Area allocated to each of the land use systems for Business-As-Usual Scenario

Year	Woodland	Bushland	Grassland	Subsistence farmland	Others
2015	3176.0000	623.0000	2213.0000	14499.0000	944.0000
2016	2954.0000	525.0000	2124.0000	14908.0000	944.0000
2017	2867.0000	514.0000	2099.0000	15031.0000	944.0000
2018	2682.0000	497.0000	2034.0000	15298.0000	944.0000
2019	2493.0000	478.0000	1974.0000	15566.0000	944.0000
2020	2319.0000	453.0000	1904.0000	15835.0000	944.0000
2021	2124.0000	432.0000	1849.0000	16106.0000	944.0000
2022	1938.0000	415.0000	1788.0000	16370.0000	944.0000
2023	1779.0000	393.0000	1701.0000	16638.0000	944.0000
2024	1613.0000	363.0000	1628.0000	16907.0000	944.0000
2025	1473.0000	323.0000	1539.0000	17176.0000	944.0000

(b) Protected enhanced scenario

Area allocated to each of the land use systems for Protected Enhanced Scenario

Year	Woodland	Bushland	Grassland	Subsistence farmland	Oil palm farmland	Others
2015	3176.0000	623.0000	2210.0000	14499.0000	3.0000	944.0000
2016	3176.0000	623.0000	2202.0000	14005.0000	505.0000	944.0000
2017	3168.0000	623.0000	2189.0000	13531.0000	1000.0000	944.0000
2018	3166.0000	615.0000	2167.0000	13066.0000	1497.0000	944.0000
2019	3130.0000	603.0000	2150.0000	12635.0000	1993.0000	944.0000
2020	3042.0000	595.0000	2141.0000	12238.0000	2495.0000	944.0000
2021	2932.0000	580.0000	2125.0000	11887.0000	2987.0000	944.0000
2022	2823.0000	562.0000	2109.0000	11530.0000	3487.0000	944.0000
2023	2714.0000	552.0000	2092.0000	11167.0000	3986.0000	944.0000
2024	2614.0000	538.0000	2061.0000	10811.0000	4487.0000	944.0000
2025	2507.0000	525.0000	2029.0000	10470.0000	4980.0000	944.0000

(c) Economic enhanced scenario

Area allocated to each of the land use systems for Economic Enhanced Scenario

Year	Woodland	Bushland	Grassland	Subsistence farmland	Oil palm farmland	Others
2015	3176.0000	623.0000	2210.0000	14499.0000	3.0000	944.0000
2016	3168.0000	623.0000	2189.0000	13531.0000	1000.0000	944.0000
2017	3129.0000	603.0000	2150.0000	12634.0000	1995.0000	944.0000
2018	2930.0000	580.0000	2125.0000	11885.0000	2991.0000	944.0000
2019	2714.0000	552.0000	2092.0000	11168.0000	3985.0000	944.0000
2020	2507.0000	524.0000	2029.0000	10466.0000	4985.0000	944.0000
2021	2301.0000	500.0000	1958.0000	9776.0000	5976.0000	944.0000
2022	2076.0000	467.0000	1859.0000	9137.0000	6972.0000	944.0000
2023	1865.0000	432.0000	1735.0000	8517.0000	7962.0000	944.0000
2024	1652.0000	388.0000	1627.0000	7884.0000	8960.0000	944.0000
2025	1454.0000	335.0000	1536.0000	7229.0000	9957.0000	944.0000

Appendix 10: The land cover change matrix (Area in ha) for all the three scenarios

(a) Business as Usual (BAU) scenario

		To				
	Land cover	**Woodland**	**Bushland**	**Grassland**	**Subsistence farmland**	**Others**
From	**Woodland**	-	-	-	1703	-
	Bushland	-	-	-	300	-
	Grassland	-	-	-	674	-
	Subsistence farmland	-	-	-	-	-
	Others	-	-	-	-	-

(b) Protection enhanced scenario

		To					
	Land cover	**Woodland**	**Bushland**	**Grassland**	**Subsistence farmland**	**Oil palm**	**Others**
From	**Woodland**	-	-	-	-	669	-
	Bushland	-	-	-	-	98	-
	Grassland	-	-	-	-	181	-
	Subsistence farmland	-	-	-	-	4029	-
	Oil palm	-	-	-	-	-	-
	Others	-	-	-	-	-	-

(c) Economic enhanced scenario

		To					
	Land cover	**Woodland**	**Bushland**	**Grassland**	**Subsistence farmland**	**Oil palm**	**Others**
From	**Woodland**	-	-	-	-	1722	-
	Bushland	-	-	-	-	288	-
	Grassland	-	-	-	-	674	-
	Subsistence farmland	-	-	-	-	7270	-
	Oil palm	-	-	-	-	-	-
	Others	-	-	-	-	-	-