Spatial Analysis of Oil Palm Expansion and its Impacts on Ecosystem Services in Bugala island, Uganda.

ALI ISSA BADUI
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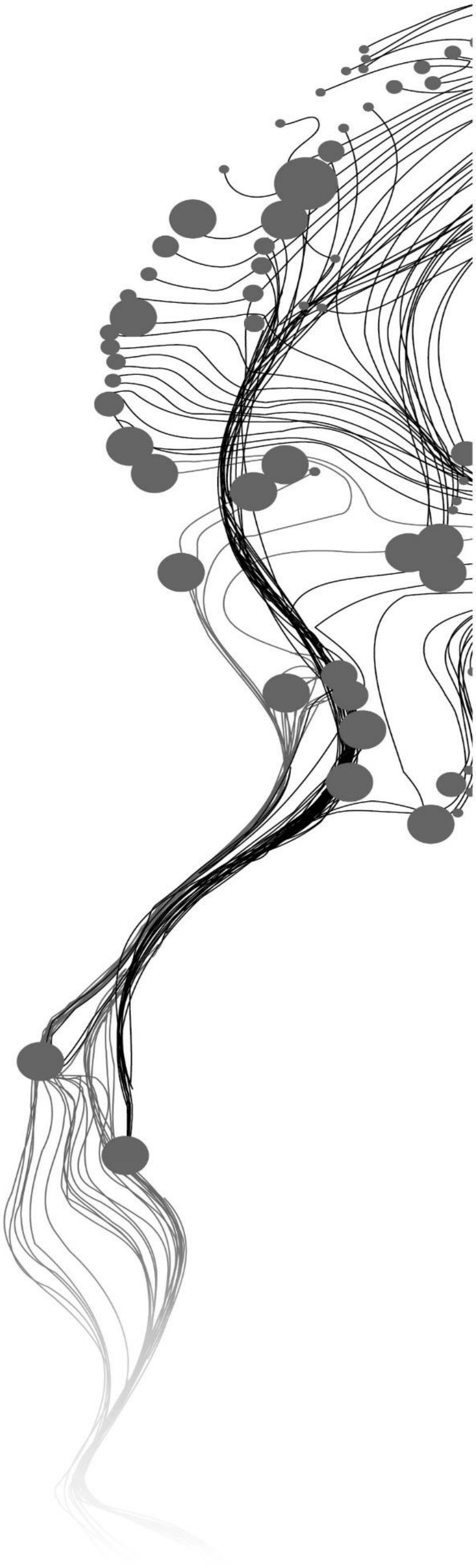

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Enschede, The Netherlands,
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Specialization: Natural Resources Management

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ABSTRACT

Livelihood is an essential consideration for human survival. One of the major source of livelihood for rural agrarian communities with forest cover is the benefits (ecosystem services) that they derive from the forest. However, under some circumstances, forest cover and natural vegetation compete with other land uses for space. One of such competing land uses is largescale commercial agriculture which often requires huge tract of land reduce forest cover and other land cover types as well as their associated ecosystem services. Bugala island, an agrarian rural community in Uganda, has lost a considerable amount of its forest cover and other land cover types due to the introduction of oil palm plantation in 2003. The extent to which the oil palm plantation changed other land cover types and ecosystem services after its establishment and the impacts on the livelihood of the people of Bugala were yet unknown. This study therefore explored the impacts of the oil palm plantation on ecosystem services after the land cover conversion.

To achieve this, the study used different methods which include land cover classification, land cover mapping, stakeholder survey, valuation of ecosystem services, Participatory GIS, ecosystem services matrix, and post-classification change detection. The application of these methods revealed interesting results. It was found that the forest cover which supplied the most valuable ecosystem services reduced by 4964.13 ha (about 31% of the original forest cover). The forest cover provides the most frequently used ecosystem service on daily basis- fuelwood/charcoal which is used for cooking. Other land cover types such as grassland, subsistence farmland, wetland and woodland have also reduced considerably resulting in the reduction of associated ecosystem services.

Based on the study findings, the livelihood of the community is in danger due to the oil plantation. Special attention need to be taken into consideration, in order to protect ecosystem services that stand as the source of livelihood. One of the consideration is the sustainable development oil palm plantation alongside providing alternative livelihood support. This will contribute toward the sustainable use of natural resources that serve as the main sources of ecosystem services upon which people depend for their livelihood.

Keywords: Ecosystem services, Bugala island, Oil palm, Valuation, Landcover, and Mapping.

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Ali I. Badui,
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1. INTRODUCTION

1.1. Background

Ecosystem services are the benefits that are provided by ecosystems to humans (Grunewald & Bastian, 2015). Usually, ecosystems provide a variety of services from which humans can benefit. These services include provisioning services like food, timber, water, regulating services like the regulation of climate, water quality, and cultural services like recreational opportunities (Millennium Ecosystem Assessment, 2005). Human well-being depends on the robust and fully functioning ecosystems that allow movement of benefits from its source (the ecosystem) to society (Burkhard & Maes, 2017). Humans influence largely to the degradation of ecosystems services in the past 50 years, due to rapid and extensively growing demands of foods, timber, fresh water, fuel and fibre (Millennium Ecosystem Assessment, 2005).

Human demand for cropland has led to the increase of deforestation and contributed to a loss of ecosystem services (Morton et al., 2006). In addition to that, the impacts on ecosystem services are widely influenced by the agricultural practices (Dale & Polasky, 2007). Agriculture is the backbone of human life, but on the other side it contributes to environmental degradation and to overcome this situation society should practice agriculture in a better way that will ensure the protection of ecosystem services (DeClerck et al., 2016). One of the main activities that contributes to the destruction of the forest land cover is the expansion of oil palm plantations(Hamilton et al., 2016; Sayer et al., 2012). Forests contribute to provide ecosystem services to people, such as helping in carbon sequestration, providing food for humans and animals, shelter to living organisms, and being a source of water. In other words, the forest is offer important for the supply of ecosystem services (Andriani et al., 2010). Land cover conversion, and especially forest loss, plays an important role in changes and decline of ecosystem services (Tolessa, Senbeta, & Kidane, 2017)

Worldwide, the area of land under oil palm plantation is growing very fast, especially in Malaysia and Indonesia (Fitzherbert et al., 2008). Oil palm expansion has influenced deforestation through the clearing of many tropical forest hectares and created disturbance in the ecosystem through habitat fragmentation, loss of biodiversity, air pollution, land cover change, soil erosion, and water pollution (Obidzinski et al., 2012). In addition to that, oil palm expansion by large plantations has led to a decrease in the supply of ecosystem services; especially it hinders other types of food production and the supply of other key ecosystem benefits (Petrenko, Paltseva, & Searle, 2016).

Mapping of the ecosystem services includes measuring, understanding and identifying the existing quantity of ecosystem services that has been used in a specific time (Burkhard et al.,2013). In addition to that, mapping ecosystem services can accelerate the planning of conservation of natural resources and better strategies for land use, to ensure sustainable utilization and management of ecosystem (Wolff, Schulp, & Verburg, 2015). Ecosystem services quantification accerelate decision making and monitoring ecosystem process. Ecosystem services can be quantified based on biophysical values, social values and economic values(Petteri et al., 2017; Boerema et al., 2017)

Monitoring and observing the environmental impacts of land cover changes caused by oil palm expansion have been broadly conducted using remote sensing images. There are a number of studies that explain the use of satellite images in mapping oil palm plantation to estimate the negative effects on the environment including deforestation, or decreasing of biodiversity and ecological connectivity. Examples include the use of PALSAR 50-m Orthorectified Mosaic images for mapping and classifying land cover where oil palm is grown (Li, Dong, Tenku, & Xiao, 2015), and the use of Landsat images with Google Earth Engine to detect oil palm plantations (Ser, Lee, Wich, Widayati, & Pin, 2016). Remote sensing contributes to monitoring and detecting changes that occur to a land cover because remote sensing data cover large areas of the earth surface (Cihlar, 2000).

Nowadays oil palm plantations are expanding in African countries, including Uganda. Uganda used to depend much on the imported vegetable oil. The government of Uganda decided to initiate the Vegetable Oil Development Project (VODP) which was supported by United Nations under International Fund for Agricultural Development (IFAD) to decrease the dependency on oil importation and to set a goal for increasing domestic production of vegetable oils. The project has the aim of increasing domestic production of vegetable oil with a special collaboration of government, private companies, and smallholder farmers, in a public-private partnership (IFAD, 2010). The VODP project was first implemented on Bugala island in Uganda in 2003, The project has the aim of setting up 40,000 ha oil palm plantation on Bugala island (BIDCO, n.d.)

1.2. Problem Statement

Based on Government policy, an oil palm plantation has been established in Bugala island to boost its economy and also to alleviate poverty of the people (Abonyo et al., 2007). Before establishment of the oil palm plantation, an Environmental Impact Assessment (EIA) was conducted on behalf of Ugandan Government. The EIA results showed that the oil palm plantation would have high impacts on deforestation and contribute to the loss of endemic species, food insecurity, reduction of windbreaks, an increase of siltation in the Lake Victoria, water pollution that threatens aquatic life due to use of chemical fertilizer, and reduction of the potential for eco-tourism (Environmental Assessment Consult Limited, 2003). The EIA results showed that the palm oil project is expected to have low impacts on climatic and hydrological factors on the Bugala island. Although EIA study has identified many negative impacts on palm oil plantation, the Ugandan government insists that the oil palm project went ahead for implementation (Kalangala NGO Forum, 2009). The project has generated resistance on the island community because the people feared losing their lands and the forest cover from which they support their families (NAPE, 2015).

However, since the establishment of the of the oil palm plantation in 2003, little is known about the ex-post impact of the oil palm plantation on the existing land covers which provide a variety of ecosystem services. The ex-ante assessments of the impacts of the oil palm plantation focused on broader environmental aspects of the project in descriptive terms without recourse to spatial approaches that enable the assessment of the project's impacts on specific ecosystem services. This study therefore investigated the ex-post impact of the oil palm plantation on ecosystem services. The study contributes to the body of knowledge that surrounds the project and also provide highlights for policy intervention.

1.3. Research Objectives

The main objective of this study is to explore impacts on ecosystem services changes caused by converting land into oil palm plantations. The following specific objectives and research questions will address this study:

Table 1: Specific Objectives and Research Questions

Specific Objectives	Research Questions (RQ)
1. Mapping and quantification of ecosystem services	1. What land cover product most accurately captures current land cover on Bugala? 2. What are the key ecosystem services in Bugala according to different stakeholders 3. What is the spatial distribution of the key ecosystem services? 4. What are the uses and values of ecosystem services?
2. To assess changes in ecosystem services in areas where oil palm plantations were introduced.	5. What are the changes in land cover since oil palm introduction? 6. What are the impacts land into oil palm plantations on ecosystem services?

2. METHODOLOGY

2.1. Study Area

Uganda is a landlocked country located in East Africa; it is surrounded by Kenya, Tanzania, Rwanda, DR Congo and South Sudan. Uganda is among three countries that share Lake Victoria. The Lake Victoria is located in southern part of the Uganda and contains 84 islands of Bugala is the largest.

The study area is the Bugala island which is located on a latitude of -0.382716° and a longitude of 32.264248° in the northwestern corner of Lake Victoria. The Island has an area of 275 square kilometre or 27,500 hectares.

The island is located in Kalangala District which has a total population of 54,293 people according to the census of 2014. Fishing, and agriculture (farming and livestock keeping) are the primary activities that take place in the Island. The main food crops cultivated include, maize, coffee, beans, millet, sweet potatoes and banana (matooke) (Uganda Bureau of Statistics, 2017).

The island is surrounded by the narrow flat-topped ridges that resulted after long-term land forming process. Main soil types include ferralitic, sandy, clay and loamy (Kalangala District Local Government, 2005). Furthermore, vegetation in the island comprise evergreen forest, grassland and shrubs. The climate of the island is humid throughout the year and experiences small seasonal variation in humidity, wind, and temperature because its located in Lake Victoria zone (Environmental Assessment Consult Limited, 2003; Kalangala District Local Government, 2005).

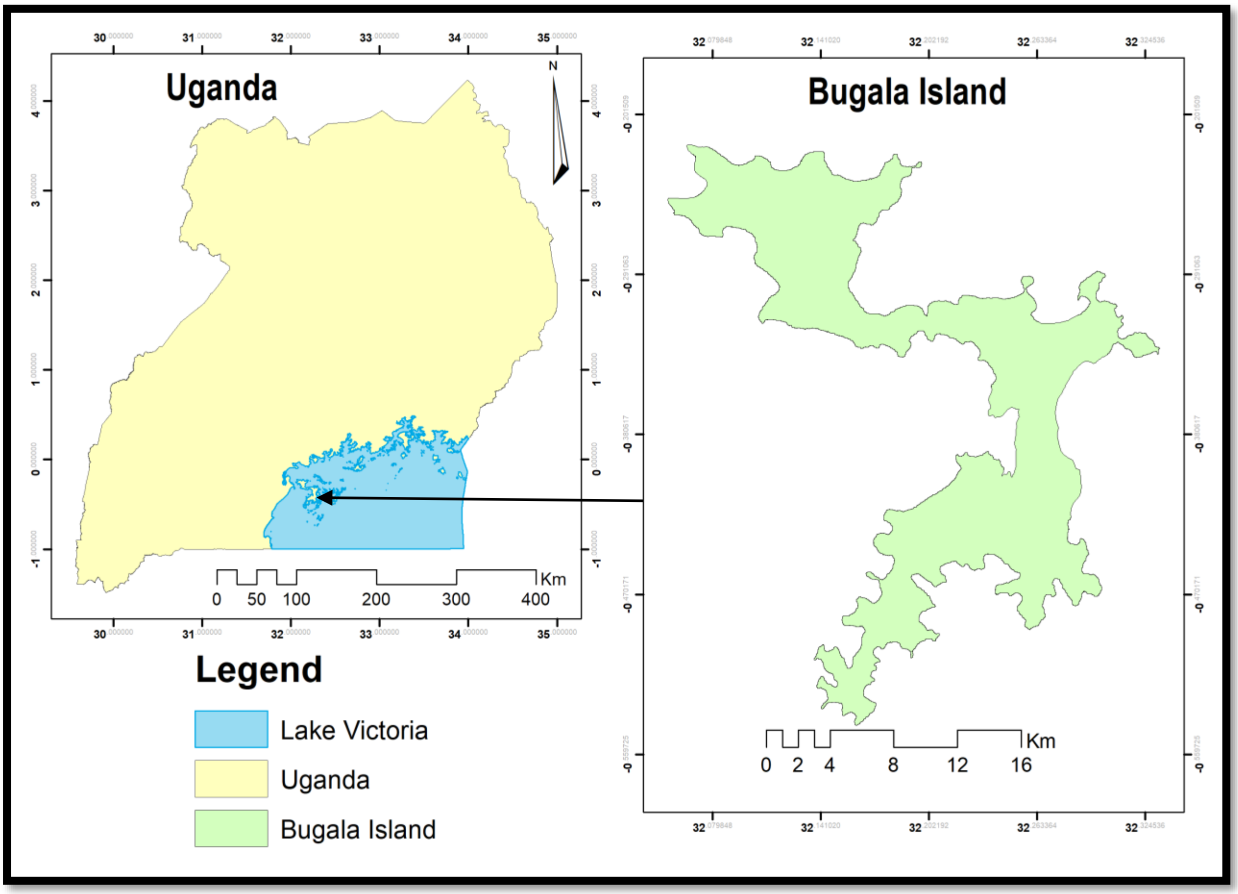

Figure 1: Study Area

2.2. Mapping and quantification of ecosystem services

2.2.1. Land cover accuracies

Land cover is a significant variable to identify ecosystem services (Burkhard et al., 2009). Mapping of ecosystem services requires an accurate land cover map, and land cover used for delineation the boundaries that separate different types ecosystem services within the land cover unit. Land cover maps are typically made using remote sensing data (Cihlar, 2000). For Bugala island, land cover maps were acquired from the National Forest Authority. These land cover map were made based on Landsat-7 images of 2000 and 2015, before and after oil palm introduction Supervised classification and expert knowledge was employed to make these land cover maps, but an accuracy assessment of these land cover maps lacked. The NFA map was chosen based on a two stage criteria, first, the NFA map was compared with a land cover map based on a higher resolution Sentinel-2 image, and secondly, an accuracy assessment was carried on the two images. For the Sentinel-2 based land cover map, a cloud-free image from 2016, the closest date to 2015, was downloaded from Copernicus open access hub.

The Sentinel-2 mission aims to monitor land by taking high-resolution images with resolutions varying from 10 to 60 meter (Addabbo, Focareta, Marcuccio, Votto, & Ullo, 2016). The classification of land cover aimed to differentiate forest, woodland, bushland, grassland, wetland, subsistence agriculture, oil palm plantation, and built-up areas, the same land cover types as 2015 NFA map. For the Sentinel 2 image classification, first layer stacking was performed using Erdas Imagine 2016 with bands B02, B03, B04, and B08. The combination of B08, B04, and B03 is good for visual interpretation of vegetation and classification which stand as false colour, and the combination B04, B03, and B02 is good for visual interpretation of land cover and classification in true colour (Addabbo et al., 2016; "Sentinel 2 EO products | Sentinel," n.d.). After stacking the four bands to make one image, the Bugala boundary was used to mask the study area. The image classification was based on a supervised classification method using the maximum likelihood classifier. Maximum likelihood classifier is the most common method for classification where the decision rule was made based on the specific probability that the pixel belongs to a certain class (Erdas, 1997; Goodman & Mcmichael, 1999; Otukei & Blaschke, 2010). This supervised image classification was performed by Erdas Imagine software. Before performing supervised image classification, 175 points were collected using random point in ArcGIS (sampling tool). Of these, 100 were used for supervised image classification as the training sample, whereby eight classes were classified, and 75 were used for the accuracy assessments. In the classification process, the Island was divided into eight land cover classes for the Sentinel 2 image and nine classes for the Landsat-7 image. The difference in the number of classes was because the Landsat-7 image has two classes for forest which were merged as one class in the Sentinel 2 image as shown in Table 2.

An accuracy assessment was done with the land cover maps based on the classified images of Sentinel-2 of 2016 and Landsat-7 of 2015. An error matrix was used to assess the accuracy. The validation points that were used for the Sentinel-2 image were also used for the Landsat-7 image to get the accuracy of the two images. The map with the highest accuracy was selected for further analyses of land cover change and ecosystem services change. Based on the validation points (test sample and training samples for land cover classification, the producer's accuracy; user's accuracy and overall accuracy were calculated (Congalton & Green, 2009). The results of the classification is characterized by two type of errors, namely; error of commission and error of omission. The error of commission, which is also known as inclusion errors, happens after an area is included in an incorrect class, while error of omission, which also known as exclusion errors, happens if some points are excluded from their classes (Congalton & Green, 2009; Lillesand, Kiefer, & Chipman, 2004)

Table 2: Land cover classes for Landsat -7 image and Sentinel-2 image

Landsat-7 image of 2015	**Land cover descriptions**	**Sentinel-2 image of 2016**
Tropical High Forest fully stocked	Normally stocked forest	Forest
Tropical High Forest depleted	Depleted/encroached forest	
Woodland	Trees and shrubs (average height>4m)	Woodland
Bushland	Bush, thickets scrub (average height <4m)	Bushland
Grassland	Rangelands, pastureland, open Savannah; Can include scattered trees shrubs, scrubs, and thickets	Grassland
Wetlands	Wetland vegetation; swamp areas, papyrus, and other sedges	Wetlands
Subsistence farmland	Farmland – mixed farmland, small holdings in use or recently used, with or without trees	Subsistence farmland
Uniform commercial farmland	Mono-cropped, non-seasonal farmland usually without any trees for example oil palm and sugar estates	Oil palm plantation
Built up area	Urban or rural built-up areas	Built up area

2.2.2. Key ecosystem services derived from the land cover type.

The key ecosystem services were identified by asking the key stakeholders who represent the people in Bugala island the importance of the various ecosystem services. This was done through questionnaire and phone interviews. The purpose of asking this question was to identify the key ecosystem services of which people benefited most for their daily livelihood.

Purposive sampling was used in the study to identify stakeholders who participated in earlier discussions and research on oil palm in Bugala and Buvuma islands. These stakeholders were people who do not live on the Island but have worked there and have experience about the local context of the Bugala island in terms of the forest, the oil palm plantation and the livelihood of the people. These stakeholders were invited to complete a semi-structured questionnaire with both closed and open-ended questions. The stakeholders were affiliates of the National Association of Professional Environmentalist (NAPE), Wildlife Conservation Society (WCS), National Forest Authority (NFA), Eco- Trends Limited, Makerere University and International Union for Conservation of Nature (IUCN). In all, 28 respondents were invited to fill the questionnaire, and 17 responded , out of 17 under 4 did not complete the survey. The list of stakeholder groups shown in the Appendix 2.

An online tool called Maptionnaire was used to collect information about the ecosystem services that are important in Bugala island. Maptionnaire was used as no research permit could be obtained in time. Telephone interviews were used to retrieve information from stakeholders. See the online questionnaire in Appendix 1.

The responses of the stakeholders were analysed to identify different ecosystem services that were accessed from different land cover types.

2.2.3. Spatial distributions of the key ecosystem services

Bugala island comprise of different types of land cover which provides ecosystem services that support people in their daily life. From each of the land cover type (forest, woodland, bushland, grassland, wetland, and farmland), different benefits are derived. The distribution of key ecosystem services was mapped through participatory GIS (PGIS) and land cover matrix by using Maptionnaire tool. PGIS is a method for mapping geographic phenomena through the involvement of stakeholders based on their local spatial knowledge of the studied phenomena (Fagerholm, Käyhkö, Ndumbaro, & Khamis, 2012). In addition to that, PGIS is one of the useful approaches in mapping ecosystem services (Brown & Fagerholm, 2014; Forrester & Cinderby, 2013).

The PGIS was done by using Maptionnaire which enbled respondents to indicate the locations of the various ecosystems services by drawing digitally on map panel.Data collection by drawing through PGIS was not easy for every stakeholder, this was due to lack of basic knowledge in GIS only one respondent able to draw. Through this situation I decided to use ecosystem services matrix instead of PGIS that was not well representative. The ecosystem services matrix is a method that allows the connection of land cover types with the quantification of ecosystem values (Burkhard, Kandziora, Hou, & Müller, 2014; Burkhard et al., 2009; Burkhard, Kroll, Nedkov, & Müller, 2012; Jacobs, Burkhard, Van Daele, Staes, & Schneiders, 2015).

The analysis of the spatial distribution of the key ecosystem services was performed by using a land cover based method, refered to as the ecosysem service matrix. On the matrix table, stakeholders indicated different ecosystem services and the respective land cover types that produced them. Based on the matrix table a land cover map was created to show the distribution of the different ecosystem services. To create the ecosystem map for each ecosystem service, I merged the land cover types that significantly provided that ecosystem service from which indicated by stakeholder.

2.2.4. Uses and values of ecosystem services.

The use and value of ecosystem services are a significant aspect in the quantification of ecosystem services. The information to assess the use and value of ecosystem services is obtained through closed-ended questions through Maptionnaire Respondents could indicate if an ecosystem service was very important, important, and not important. In addition, respondents were asked if an ecosystem service was used on a daily, weekly, monthly, yearly basis or never. The aim of this was obtain strong information regarding the values of ecosystem services based on people perception.

The measurement of the value of ecosystem services was based on the social valuation approach. With this approach, value is derived from the ways of expressing preferences, requirements of people in relation to ecosystem services (Santos-Martín et al., 2017). Based on the responses of the stakeholders, each ecosystem service was categorised into the three levels of importance namely; very important, important, and not important. The ecosystem services were also categorised into different frequency of uses namely; daily, weekly, monthly, yearly, or never. From this, the ecosystem services that were indicated very important and also used daily were accorded high value and vice versa.

2.3. Changes in ecosystem services due to oil palm plantation

2.3.1. Changes in land cover 2000-2015

Change detection is the technique that involves the process of recognising and observing the differences in a state of the object or phenomenon through critical observing it at different times(Singh, 1989). Change detection is an important technique in the field of remote sensing and GIS because it stands as the tool for better understanding the relationship and interaction between human activities and the natural environment for the aim of managing and ensure the use into sustainable way (Lu, Mausel, Brondízio, & Moran, 2004). Change detection comprises the use of multi-temporal datasets with the aim of analysing land cover and land use over time (Fichera, Modica, & Pollino, 2012). Change detection is a useful technique to detect the changes in ecosystem, since it involves the quantification of time-based phenomena from multi-date imagery that is most usually obtained by satellite-based multispectral sensors (Coppin, Jonckheere, Nackaerts, Muys, & Lambin, 2004)

Many techniques are used for change detection; this study focusses on one technique that is post-classification. Post-classification change detection, is the change detection technique that require comparison of two set of classified images which are differ in time, the major strength of post-classification change detection is having the ability of giving information on matrix change and minimize the effect that caused by atmospheric and environmental variations among the set of images from multi-temporal sources (Lu et al., 2004; Singh, 1989).

The Landsat classified images of 2000 and 2015 were used to run the process of change detection. Erdas imagine was used for the process of change detection. In doing this, matrix union tool used for the change detection analysis by using too two classified images as input. The output of this process shows the comparisons of land cover changes from one type to another type of land cover. There are number of studies that have used the technique of post-classification for change detection (Addo, 2012; Fichera et al., 2012; Rawat & Kumar, 2015), all of these studies used classified images of different years to perform matrix change that shows transformation from one type of land cover to another type.

2.3.2. Impacts of land cover change due to oil palm expansion on ecosystem services

Land cover changes that are caused by oil palm expansion influence the changes in ecosystem services in Bugala island. To determine the impact of the oil palm plantation on the ecosystem services, two methods were used to explain the changes/loss in ecosystem services, first, an assessment of the ecosystem service change based on the results obtained from the land cover changes between 2000-2015 and second, by the questionnaire in which representatives of the stakeholder groups were asked about the changes in ecosystem services. This was done by using change detection analyses to determine the areas where ecosystem services were located before the establishment of the oil palm plantation and the extent to which these ecosystem services have been lost. The perception of change by stakeholders was analysed by looking at the number of stakeholders who indicated a decrease, increased or no changes with respect to each ecosystem service after introduction of oil palm. The loss of ecosystem services found from the change analyses and that of the stakeholder perception were then compared for alignments or non-alignment.

2.4. Flowchart

The flowchart in figure 2, shows the step by step in methods that have been used to achieve the research objectives by answering the research questions.

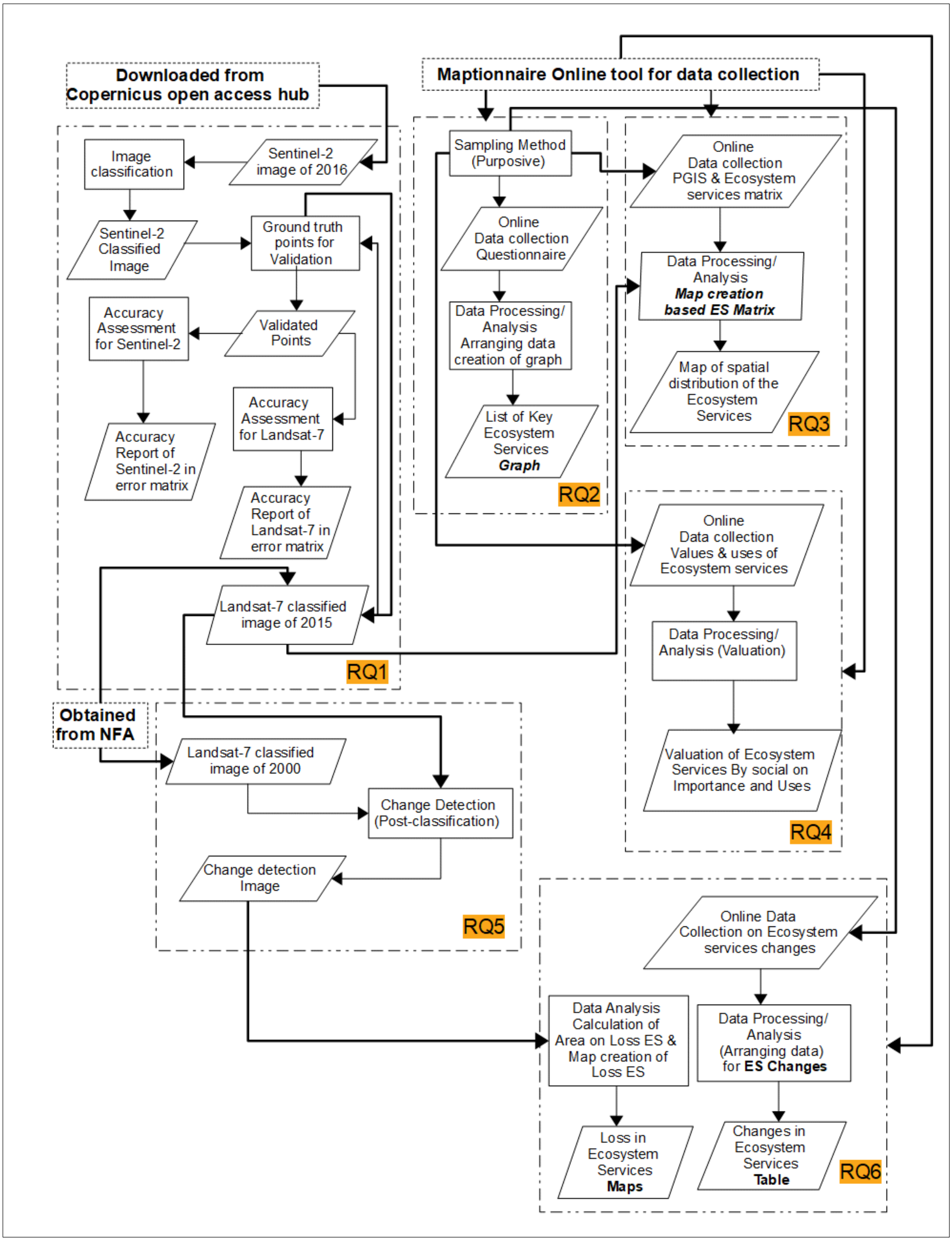

Figure 2: Methodological Flowchart

3. RESULTS

3.1. Mapping and quantification of ecosystem services

3.1.1. Land cover accuracies

To set a firm basis for this study, a comparison was made between two sources of land cover in order to identify the best product that accurately captures the current land cover on Bugala island. These sources of land cover included Sentinel 2 for 2016 and Landsat-7 for 2015. The comparison was based on the accuracy assessment of the two images. First, random selection point was used to generate the sample points on ArcMap using the Landsat-7 image as the base image. These points were then used to clasify the Sentinel 2 image. Finally, the sample points were used assess the accuracy of the two images. The Landsat-7 of 2015 produced an accuracy 91%. The Sentinel-2 image produced an accuracy of 86%. Based on the accuracy assessment, the Landsat-7 image was selected for the assessment of ecosystem services because it has high accuracy. The classified Sentinel 2 image and the Landsat -7 image are shown as figures 3 & 4.

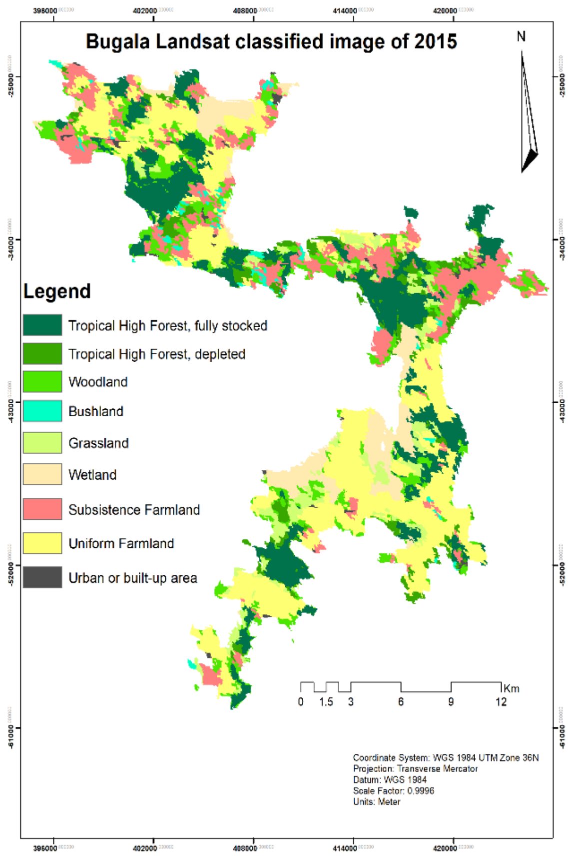

Figure 3: Bugala land cover map of 2015

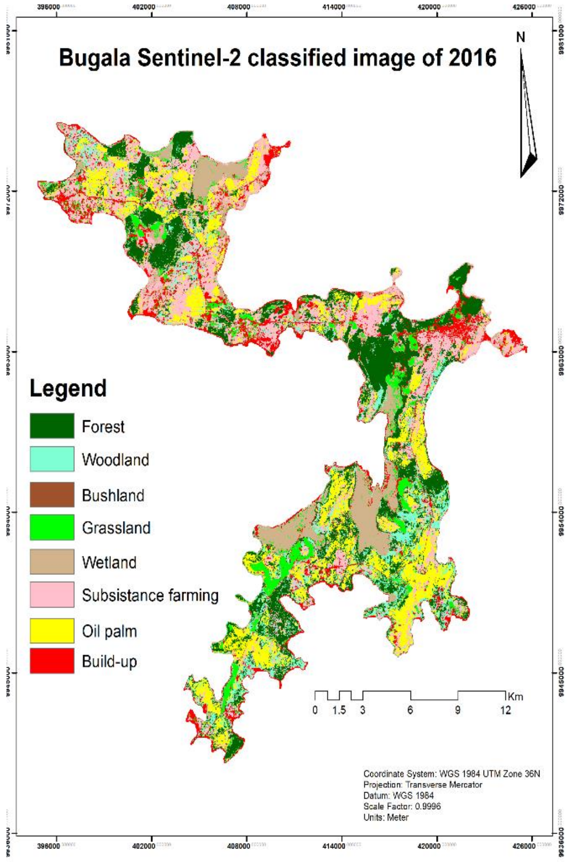

Figure 4: Classified image of 2016 from sentinel-2 image

Two error matrix table were generated namely; Tables 3 and 4. Table 3 is the error matrix table that shows the classification of the land cover for Sentinel-2 image and table 4 shows the error matrix of the classification of the land cover for Landsat-7 image. Both error matrix tables show the comparisons the accuracy assessments of the two classified images. Comparing the two tables, the number corrected classified points for the Landsat-7 image is higher than the Sentinel 2 image and makes the Landsat -7 image the most accurate product that captures the current land cover on Bugala island.

Table 3: Error matrix table for land cover classification of Sentinel-2 image of 2016 with accuracy assessment

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Forest	10	13	10	100%	77%
Woodland	5	5	5	50%	100%
Bushland	10	4	4	80%	100%
Grassland	10	11	10	100%	91%
Wetland	10	8	8	80%	100%
Subsistence farming	10	11	9	90%	82%
Oil palm	10	9	9	90%	100%
Built-up	10	14	10	100%	71%
Totals	**75**	**75**	**65**		

Overall Classification Accuracy = 86.67%

Table 4: Error matrix table for land cover classification of Landsat-7 image of 2015 with accuracy assessments

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Forest	10	10	10	100%	100%
Woodland	5	11	10	100%	91%
Bushland	10	5	5	100%	100%
Grassland	10	10	10	100%	100%
Wetland	10	10	10	100%	100%
Subsistence farming	10	15	10	100%	67%
Oil palm	10	11	10	100%	91%
Built-up	10	3	3	30%	100%
Totals	**75**	**75**	**68**		

Overall Classification Accuracy = 91%

3.1.2. Key ecosystem services derived from the land cover type.

The ecosystem services found in the Bugala island vary according to land cover type. When the stakeholder representatives were asked about the key ecosystem services that benefited people the most, 17 respondents mentioned food production (subsistence farming), food collection (fruits, hunting and fishing), and fuel (wood or charcoal). 16 respondents mentioned constructions materials (timber), medicinal plants, climate regulation and water regulation. 15 respondents mentioned grass for cattle and recreational/enjoyment. These responses are presented in figure 4.

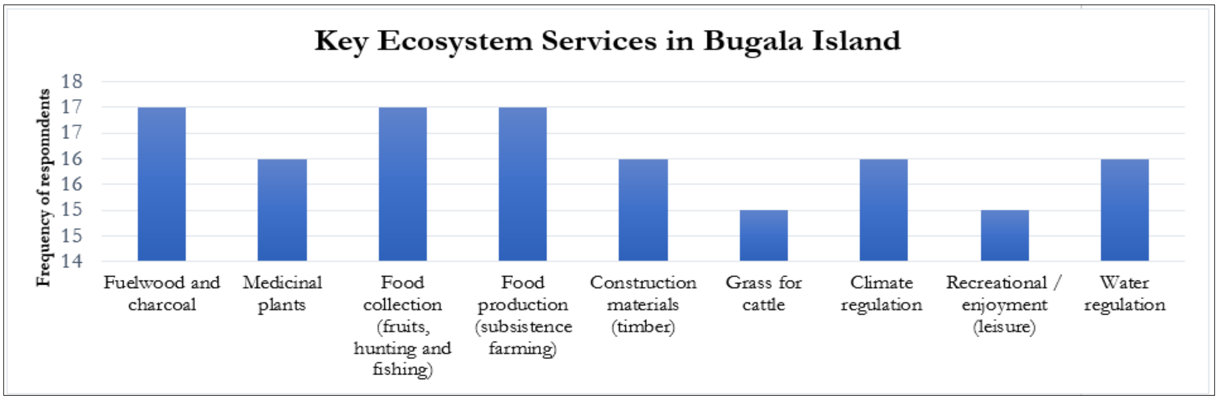

Figure 5: Key ecosystem services available in Bugala

3.1.3. Spatial distributions of the key ecosystem services

Respondents indicated different places within the Bugala island where they derived different ecosystem services. From the results, most of the respondents derived ecosystems services from the forest land cover followed by woodland, grassland, bushland and wetland. Subsistence farmland and lake land cover provided the least ecosystem services. These responses were compiled together to create matrix table that linked together ecosystem services with the land cover and to come with the final output of the map that show the distribution of ecosystem services on Bugala island. **Table 5** represents ecosystem services within the land cover.

Table 5: Land cover types and the ecosystem services they produce

Ecosystem services	Forests	Woodland	Bushland	Grassland	Wetlands	Subsistence farmland	Lake
Fuelwood and charcoal	12	6	4	1	1	0	0
Medicinal plants	12	4	6	4	4	1	0
Food collection	11	4	5	7	6	0	6
Food production	3	3	4	2	2	8	0
Construction materials	13	9	2	3	5	1	0
Grass for cattle	1	3	5	11	4	2	0
Recreational	5	1	0	1	0	0	5

Figures 6 and 7 Figure show the distribution of the ecosystems services within the different land cover types. Figure 6 shows the distribution of land for food production, grass for cattle and construction materials/fuelwood/charcoal. Figure 7 shows the distribution of land for medicinal plants and food collection. From figure 6, it is observed that the land for food production surrounds the built-up areas where people live. Because, walking is the main means of transport on the Island, people make their farms close to their houses so that they can easily commute. Also, because the people rely on the forest land cover for most ecosystem services they build their houses near the forest so that they can easily access the ecosystem services.

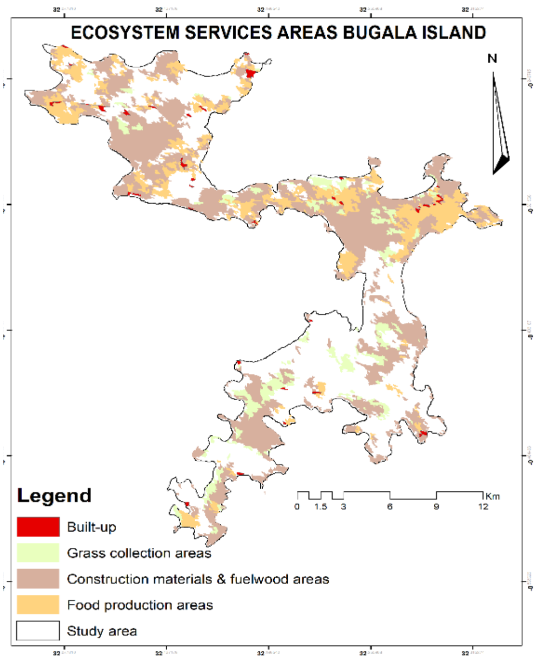

Figure 6: Distribution of Grass and Construction materials/Fuelwood/charcoal collection

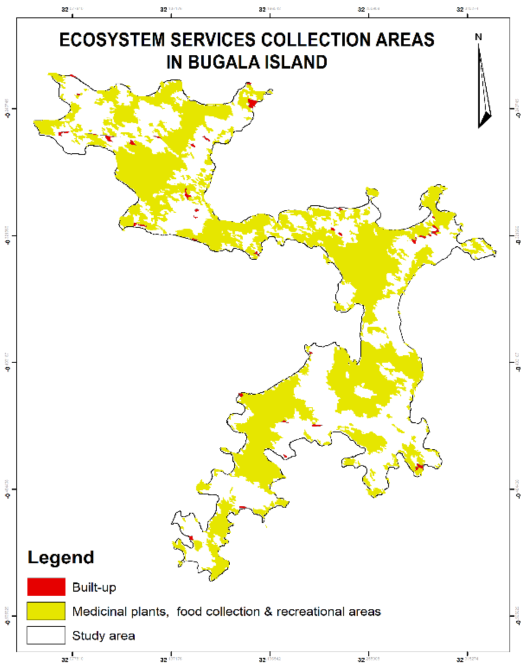

Figure 7: Location of Medicinal plants, Food collection and recreational area

3.1.4. Uses and values of ecosystem services.

The quantification of ecosystem services in this study is done based on social values, where it includes perceptions on the importance of ecosystem services and the frequency of use. The perception of importance is presented first, followed by the use frequency. Starting with an aspect of the importance of ecosystem services to the community of Bugala, three level of importance considered as (very important, important, and not important). For each ecosystem service, different respondents indicated how important it is. From figure 8, most respondents (14) valued fuelwood/charcoal to be very important compared to the other ecosystems services. Few respondents (4, 3 and 2 respectively) valued ecosystems services such as medicinal plants, grass for cattle and recreational to be very important. Most respondents did not consider medicinal plants, food collection, grass for cattle and recreational/enjoyment to very important, instead they considered it to be important. Therefore, it can be observed that the ecosystem services that were used daily for their livelihood were given high values as important and very important than those that are used occasionally and do not constitute source direct livelihood of the people.

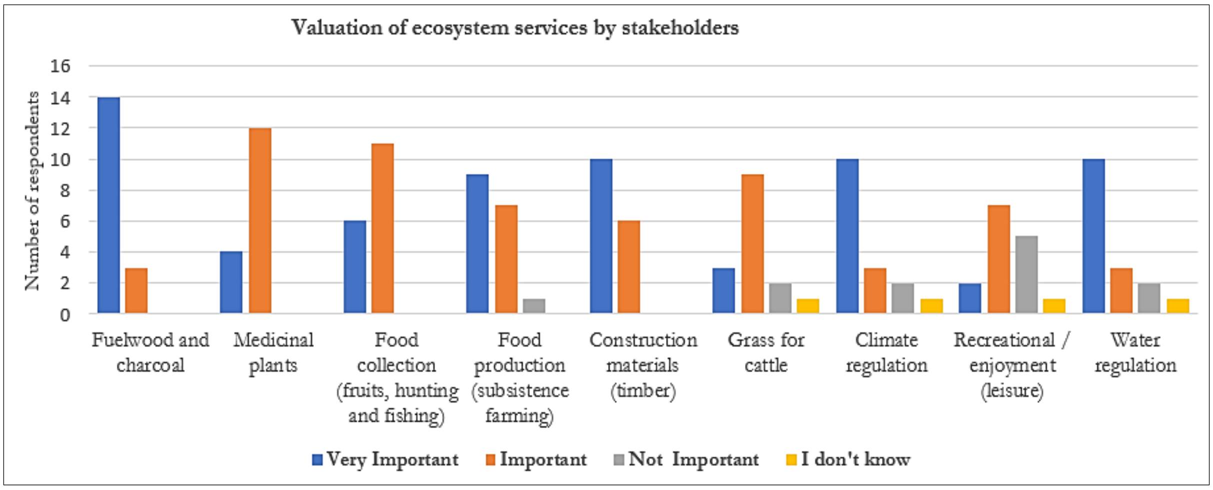

Figure 8: Valuation of ecosystem services by stakeholders according to different levels of importance.

Figure 9 shows the frequency in the use of ecosystem services which is another aspect that is considered in the valuation of ecosystem services. In this category, five levels (daily, weekly, monthly, yearly, and never) of frequency have been used to assess the value of ecosystem services. From figure 8, the daily use is high for all the ecosystem services. Whereas recreational and medicinal plants are the least used ecosystem services on daily basis, respondents indicated that they use fuelwood/charcoal mostly on daily basis but not weekly, monthly or yearly.

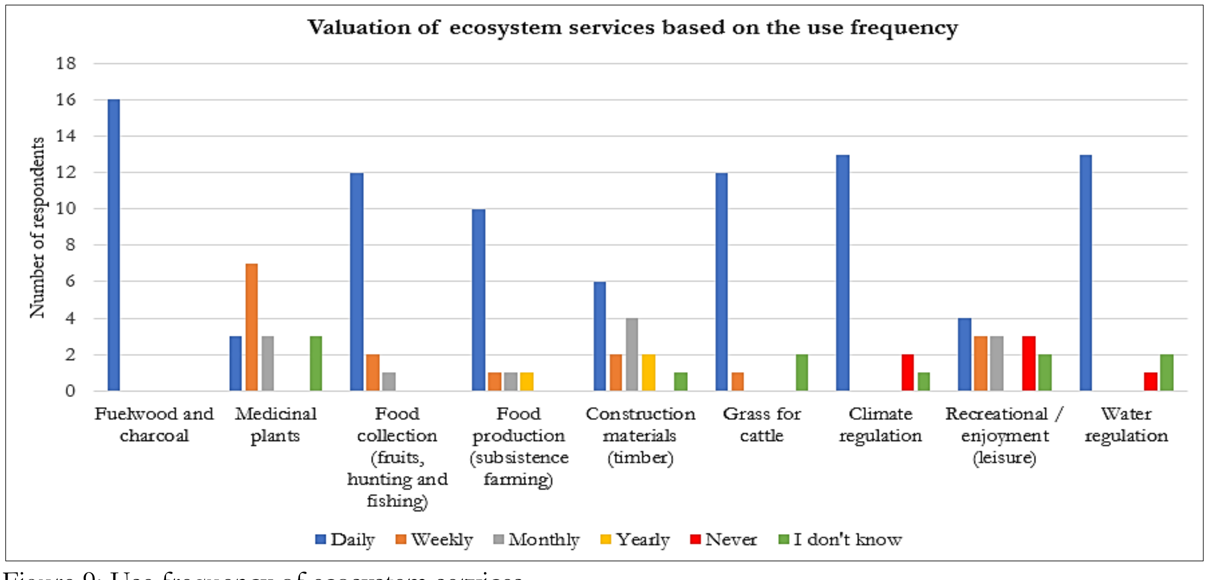

Figure 9: Use frequency of ecosystem services

3.2. Changes in ecosystem services due to oil palm plantation

3.2.1. Changes in land cover 2000-2015

The ecosystem services on the Bugala island have changed between the year 2000 to 2015. Comparing the different land cover types that provide ecosystem services before and after the establishment of the oil palm plantation, significant changes can be observed. From Table 6 and figure 10 show the land cover situation before the introduction of oil palm on Bugala island and Table 7 and refer to figure 3 show the land cover situation after the establishment of the oil palm plantation. Comparing Tables 6 and 7 it can be observed that, after the establishment of the oil palm plantation, 54% of the grassland cover was lost, 41% of the woodland cover was lost and 31 % of forest cover was lost. Wetland cover and subsistence farmland cover lost the least land; 12% and 19% respectively. The overall change in land cover over the period of 2000 to 2015 is presented in a change detection map as shown in figure 11 and the areas of land cover change due to the oil palm plantation are shown in Table.

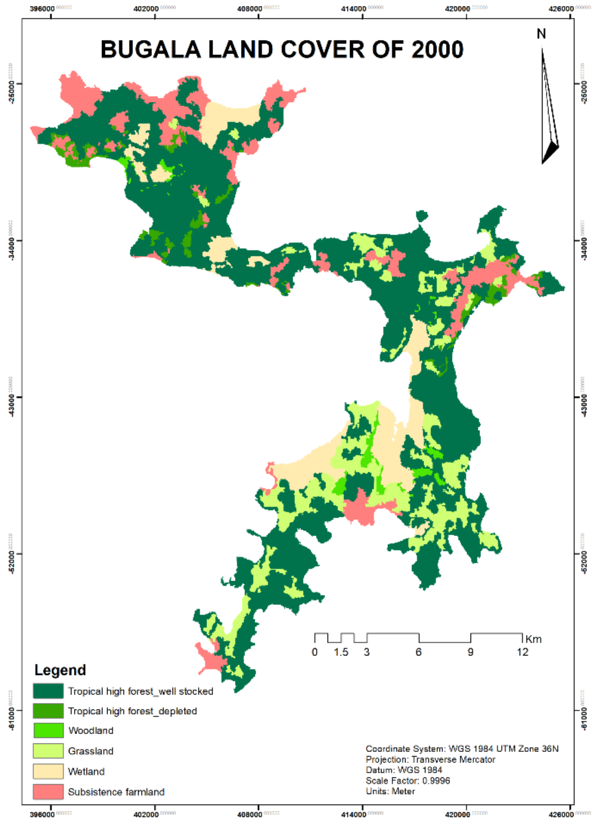

Figure 10: Bugala land cover map of 2000

Table 6: Area of 2000 Land cover map

Land cover 2000	**Area in ha**
Tropical high forest fully stocked	15250
Tropical high forest depleted	820.17
Woodland	443.7
Grassland	3683.52
Wetland	2848.77
Subsistence farmland	3185.42

Table 7: Area of 2015 Land cover map

Land cover 2015	**Area in ha**
Tropical high forest fully stocked	5197.41
Tropical high forest depleted	1554.12
Woodland	2936.25
Bushland	389.97
Grassland	1701.81
Wetland	2393.37
Subsistence farmland	3829.14
Uniform farmland/oil palm	8193.15
Urban or Built-up area	216.63

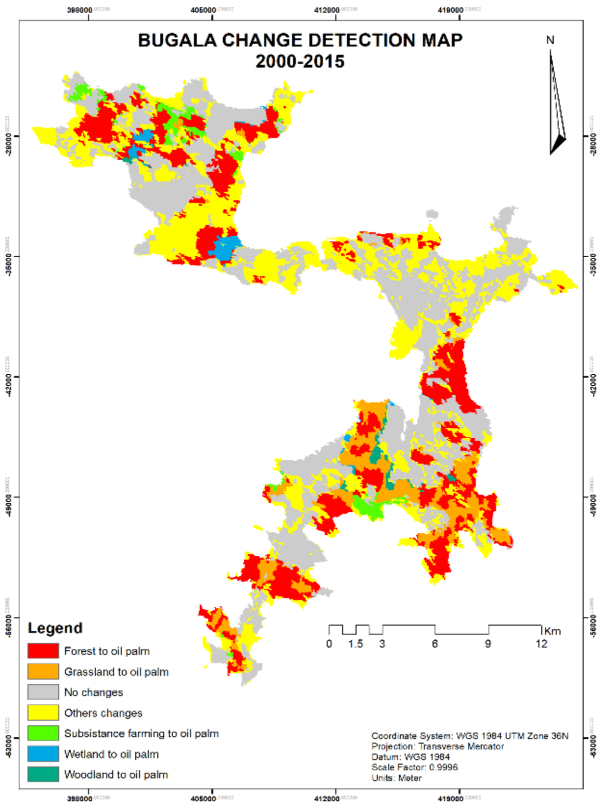

Figure:11 Change Detection map of Bugala 2000-2015

Table 8: Area of land cover changes

Land cover changes	Area in ha
Forest to oil palm	4964.13
Woodland to oil palm	181.08
Grassland to oil palm	1987.56
Wetland to oil palm	337.5
Subsistence farmland to oil palm	613.8
Other changes	8026.83
No changes	9510.93

3.2.2. Impacts of land cover change due to oil palm expansion on ecosystem services

The impact of land cover changes on ecosystem services due to oil palm expansion are numerous. Comparing the outcomes of the change analyses in figure 11 and that of the perceptions of stakeholders in Table 9 reveal similarities on the impacts of the oil palm plantation on ecosystem services. The findings show that all respondents agreed that there is a decrease in fuelwood and food collection ecosystem services which are located in the forest cover. This aligns with the patterns observed on the change analyses map. There is also a similarity between the responses and the change analyses map with respect to the conversion of large tracts of land in the northern and south-eastern parts of Bugala island to oil palm which use to provide other ecosystems services. Table 8 shows that 4964.13 ha of forest cover and 1987.56 ha of grassland cover are lost to the oil palm plantation. These two land cover types lost the most supply of ecosystem services. Thus, the impact of the oil palm on the Island is felt much at the northern and south-eastern parts.

Table 9: Perceived changes in ecosystem services by stakeholders

N= number of respondents

Ecosystem services	Decrease	N	Increase	N	No changes	N
Construction materials (timber)	86%	12	14%	2	0%	0
Food collection (fruits, hunting and fishing)	100%	14	0%	0	0%	0
Food production (subsistence farming)	71%	10	21%	3	7%	1
Fuelwood and charcoal	100%	14	0%	0	0%	0
Grass for cattle	86%	12	0%	0	14%	2
Medicinal plants	93%	13	0%	0	7%	1
Recreational / enjoyment	38%	5	23%	3	38%	5

Figures 12, 13 show the loss of ecosystem services within the Bugala island. They show the locations where specific ecosystem services have been lost due to the establishment the oil palm. Figure 12 shows the loss of grass, food production, fuelwood & construction material areas, figure 13 shows the loss of medicinal plants and food collection and recreational areas. From these figures it can be seen that the overall loss of ecosystem services caused by the oil palm is enormous.

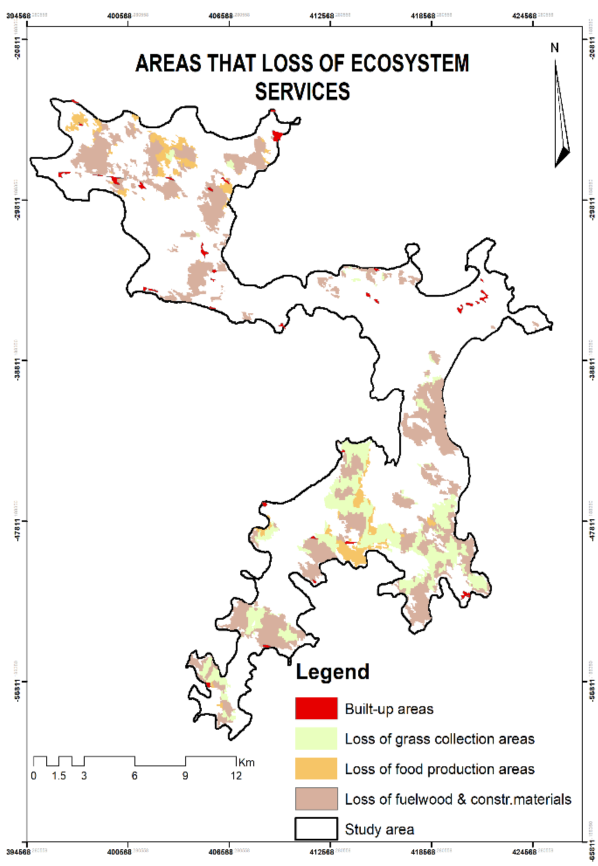

Figure 12: Loss of ecosystem services between 2000-2015 (grass, food production, fuelwood & construction material areas) after oil palm introduction.

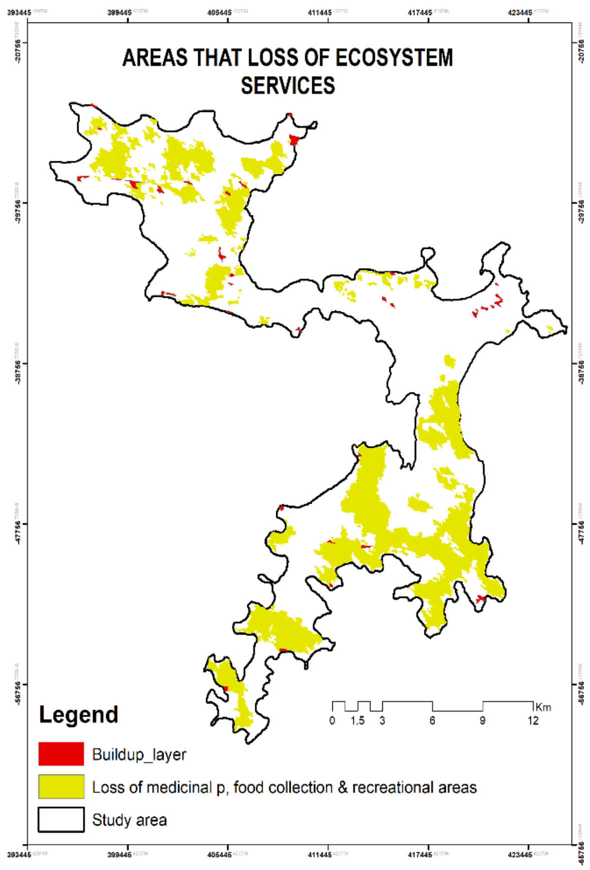

Figure 13: Loss of ecosystem services between 2000-2015 (medicinal plants and food collection and recreational areas).

4. DISCUSSION

This section discusses the empirical findings of the study hand in hand with relevant existing scientific literature. The section is divided into three subsections that discuss (1) the impacts of oil palm plantation (2) the methods used, and (3) the relevance of the study findings.

4.1. Impacts of oil palm plantation

Land cover in Bugala island changed due to the establishment of of oil palm plantation. This study shows that different land cover types were transformed to oil palm. A study by Abonyo et al., (2007) reveals that, the most important factors that accelerate deforestation and the transformation of land cover in Ssese islands was oil palm plantation. Before the introduction of oil palm in Bugala island, 16,070 ha was covered by forest.

Studies on large scale agriculture and natural forest ecosystems in different contexts have revealed that the large scale agriculture has adverse effect on natural forest (Andriani et al., 2012; Fitzherbert et al., 2008; Saswattecha et al., 2016). Similar to their findings, in the case of Bugala island it was found that the establishment of the oil palm plantation has taken over 15,133 ha of land that previously provided key ecosystem services. These ecosystem services include fuelwood, charcoal, construction materials, grass for cattle, area for subsistence farming, medicinal plants, and food collection area. Among these ecosystem services, fuelwood/charcoal and food collection were the ecosystms that was lost the most. This has adversely affected the livelihood of the people of Bugala as they rely much on the forest resources for survival. This aligns with the study of Obidzinski et al., (2012) in Indonesia who found that oil palm plantation affected livelihood of people greatly especially for food collection.

The expectation of the study was that mosly forest would be lost due to oil palm plantation, but the results show changes of other land cover like grassland, woodland, subsistance farming and wetland to oil palm plantation. For example, 54% of the grassland cover and 41% of the woodland were lost due to the oil palm plantation.These other land cover types provide the people with food and feed for their livestock in addition to what they derive from the forest. The findings show that the parts of the Island that are not built-up are the areas dedicated for subsistence farming and livestock rearing which have now been turned into the oil palm plantation. Loosing these land covers leaves the people handicaped in terms of their livelihood as the mainstay of the Island is subsistence agriculture. This conforms to the findings of Obidzinski et al., (2012) in Indonesia that plantation agriculture affect access to forest resources and croplands. The findings of this study can bring more awareness on the magnitude of the impacts that are caused by the oil palm plantation. This may supplement the efforts of Green Livelihood Alliance at reducing the impacts and causal factors that affect forest degradation.

4.2. Methods

4.2.1. Land cover maps

As land cover is a key proxy for ecosystem services supply, land cover maps are important input data for this ecosystem services change study. The outcome of the accuracy assessment of the two images deviates from the studies of Baker et al., (2013); Fisher et al., (2017) who argued that higher accuracy assessment of a classified image depends on higher spatial resolution image. This study shows an inverse relationship between high accuracy and high spatial resolution. The reason for this inverse relationship is that the accuracy of the classified Landsat-7 image was done using random sample points generated from it. The same points were used to classify the Sentinel-2 image and to assess its accuracy. The Landsat-7 image produced a higher accuracy because the sample points were generated from it. However, the accuracy of both images fall within a recommended range as proposed by Foody et al., (2002). The classified land cover maps formed the basis for the assessment of ecosystem services distribution and loss of the land cover that provided the different ecosystem services.

4.2.2. Stakeholder consultation

Participatory GIS is one of the best ways in identifying ecosystem services, because it allows the reconstruction of spatial phenomenon based on local spatial knowledge of stakeholders and/or inhabitants of their own environment (Brown & Fagerholm, 2014). As mentioned by Fagerholm et al., (2012), the local spatial knowledge of stakeholders is very useful in identifying community livelihood problems as they act as key informants in the assessment of ecosystem services. Thus, this study engaged stakeholders from different organisations in Uganda through questionnaire. These stakeholders group were selected based on their involvement in GLA activities aimed at reducing forest degradation due to oil palm plantation in Bugala island. The initial plan for this study was to directly involve the local people of Bugala to seek their views on the ongoing plantation of oil palm, but this was not succesful due to my inability to obtain an in-time fieldwork permit from the Ugandan National Council for Science and Technology (UNCST). To overcome this, problem I engaged with the stakeholders using Maptionnaire, a tool that enables the collection of an integrated GIS-Questionnaire information from stakeholder groups. The use of Maptionnaire has proven to be useful in the study, because it simplified data the collection process without visit to the area for field work. However, it has some limitation in the use of its GIS drawing features particularly by people who do not have knowledge of GIS mapping. By this, it makes it difficult to acquire some information regarding the study area. Also, it only captured the views of people who could read and write and also have access to internet as it is an online tool. This, coupled with the inability of some respondents to respond to the questionnaire resulted in accessing only two out of the five stakeholder groups initially intended. As a result of the reduction in the number of stakeholder groups, the diversity of comparing many stakeholder groups as the perspectives of some stakeholders (fishermen, smallholder, and largescale palm oil growers) within the island could not be accessed. However, the results obtained from the two stakeholder groups are fairly representative of the existing situation of the ecosystem services, because, most people on the island option to multiple sources of livelihood as a diversification strategy. For example, some farmers also do fishing and vice versa and they have knowledge of both sources of livelihood and how the oil palm plantation affects them Vrieling et al. (2016). This also conforms with the findings of Abonyo et al., (2007) in Ssese island in Uganda where they found that inhabitants rely on multiple sources of livelihood from the forest and other land cover types that provide ecosystem services.

The responses from the stakeholder groups on the distribution of ecosystem services were categorised in terms of the location of the land cover types where they derive the different ecosystem services. The output of this is presented in the form of ecosystem distribution maps. This approach using land cover to create ecosystem services is similar to the study of Kandziora et al., (2014).

4.2.3. Ecosystem services valuation

The valuation of ecosystem services in Bugala island was based on the preception of stakeholder groups with different backgrounds, knowledge, and experience in the area. Bugala island provides many ecosystem services, but due to the expansion of the oil palm plantation, the supply of ecosystem services has declined. This negative correlation between the expansion plantation agriculture and ecosystem service decline has also been reported in the study of Dale & Polasky (2007). According to Petteri et al., (2017) ecosystem services valuation can be performed in three ways (biophysical, social, and economic valuation). This study was based on social valuation. By using the social valuation approach, the study investigated the perception of stakeholder representatives on the importance and uses of ecosystem services. Findings from Fagerholm et al., (2012) indicate that ecosystem services that support the daily livelihoods of people are often valued high. This aligns with the case of Bugala island where stakeholder groups highlight the importance of

fuelwood as it is used for cooking daily. The ecosystem services which do not directly contribute to livelihood like recreational/enjoyment(leisure) were rated low in terms of their importance
The choice of the social valuation approach in this study was appropriate, because the ecosystem services valuation was based on stakeholders' perceptions. The application of social valuation method gives the results that vary between stakeholder groups. But these variations are based on their understanding of the nature and the ecosystem services (Petteri et al., 2017).

4.3. Relevance to the world

The study findings reveal the impacts that are caused by the oil palm plantation on ecosystem services in Bugala island. The communities of Bugala depend on their natural surrounding for their daily livelihood. This means that access and utilization of ecosystem services around the area is an important thing to the community livelihood. But the oil palm plantation in Bugala brought adverse impacts on the ecosystem services due to the depletion of the forest and other land cover types. The impacts of oil palm that occur in Uganda could also be observed in other parts of the world. Studies by Fitzherbert et al., (2008); Saswattecha et al., (2016) highlight the environmental impacts of oil palm plantations in different contexts to include deforestation, habitat fragmentation, greenhouse emission, food production.

The study results in Bugala island, show adverse impacts of oil palm plantation to local community's livelihood. Going forward, useful lessons can be drawn from the Bugala context to guide the extension of the oil palm plantation to other islands within the Ssese islands especially for Buvuma Island which is the next target of BIDCO, the company that owns the oil palm plantation. These lessons can be in the form of (i) enhanced implementation processes for achieving a balance between plantation agriculture and ecosystem services availability and (ii) provision of alternative livelihood schemes to cover for the loss of employment through subsistence farming and animal husbandry This will not only secure the livelihoods of the people in terms of ecosystems services but to a greater extent it will also stimulate a more sustainable approach for the development of the oil palm and plantation agriculture in general within the Ssese island.

5. CONCLUSIONS & RECOMMENDATIONS

5.1. Conclusion

This study sets out to explore the impacts of the establishment oil palm plantation in Bugala island on ecosystem services changes. This was done by using a satellite image. The findings reveal that Landsat-7 image of 2015 was the best product that showed the land cover situation of the Bugala island compared to Sentinel 2 image of 2016. Based on the Landsat-7 image it was found that a greater portion of different land cover types within the Island has been transformed to oil palm and accordingly, the ecosystem services which were provided by these land covers also changed. The study revealed that the forest cover which provides fuelwood/charcoal (the most valued ecosystem service) has reduced by 4964.13 ha (about 31% of the original forest cover). The forest cover provides the most frequently used ecosystem service on daily basis- fuelwood/charcoal which is used for cooking. By doing change analyses, it was found that all the land cover types have decreased after the establishment of the oil palm plantation which resulted in the reduction of associated ecosystem services. This was demonstrated in both the change analyses and the responses of the stakeholders which means that the impact is already felt by the people. The impact of these changes on the livelihood of the people of Bugala is enormous as the local economy is agrarian and most people rely on the benefits from the available land covers for livelihood. Therefore, If the oil palm extension continuous without alternative livelihood support, possible implications are that, there will be loss of jobs, loss of livelihood and food insecurity. Thus, as the land covers that provide key ecosystem services diminish the livelihood of the people be in danger.

5.2. Recommendation

The results of this thesis contribute to the understanding of the impacts of plantation agriculture on ecosystem services. Specifically, the study highlights the effects of oil palm plantation on ecosystem services on Bugala island. It shows that different land cover types have been changed to oil palm plantation. The following are recommended for the further studies :-

- The study focuses more on the impact of oil palm plantation in provisional ecosystem services. More research needed to consider on the other aspects of ecosystem services, like regulating and cultural ecosystem services. This is because regulating ecosystem services have influence on community livelihood, so it's necessary to study in this angle. In addition to that, cultural ecosystem services are important part for the community livelihood. Because it includes spirituals, recreational areas people connect to in different ways. Its recommended that further study to look at this direction, aiming on measuring the impacts of ecosystem services on oil palm plantation in different angle and perspectives.

- Field work have great role in research, because it provides better observation of the study area and hence to the best results/findings. In this study, different options and alternatives have been applied so as to come out with the accepted results/findings. I would recommend that PGIS tools need to be complemented with fieldwork. Reliance on only online PGIS tools can creates room for difficulties and missing of important information that could be useful for the study. Moreover, it is recommended that sample points for image classification, validation, and accuracy assessment should be collected on field.

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APPENDICES

Appendix 1: List of questions for the stakeholders

The questions on this page will refer to the situation on Bugala island only.

1. 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)

Please answer all questions in to reflect people of your selected stakeholder group only

2. From your knowledge, what are the most important benefits that people receive from nature (forest, woodland, bushland or grassland) and farmlands in Bugala island?

List of benefits	Very Important	Important	Not Important	I don't know
Fuelwood and charcoal	○	○	○	○
Medicinal plants	○	○	○	○
Food collection (fruits, hunting and fishing)	○	○	○	○
Food production (subsistence farming)	○	○	○	○
Construction materials (timber)	○	○	○	○
Grass for cattle	○	○	○	○
Recreational / enjoyment (leisure)	○	○	○	○
Climate regulation	○	○	○	○
Water regulation	○	○	○	○

3. How often do people use these benefits from nature and farmlands in Bugala island?

List of benefits.	Daily	Weekly	Monthly	Yearly	Never	I don't know
Fuelwood and charcoal	○	○	○	○	○	○
Medicinal plants	○	○	○	○	○	○
Food collection (fruits, hunting and fishing)	○	○	○	○	○	○
Food production (subsistence farming)	○	○	○	○	○	○
Construction materials (timber)	○	○	○	○	○	○
Grass for cattle	○	○	○	○	○	○
Recreational / enjoyment (leisure)	○	○	○	○	○	○
Water regulation	○	○	○	○	○	○
Climate regulation	○	○	○	○	○	○

4. By what are the most common means of transport do people travel to nature and farmland for certain benefits in Bugala island?

List of benefits..	By foot	By bicycle	By cow/donkey cart	Motor vehicle	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 / enjoyment	☐	☐	☐	☐	☐	☐

5. How far do people travel for the benefits listed below in Bugala island?

List of benefits...	Less than 1 km	1-5 km	5-10 km	10-15 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 / enjoyment	○	○	○	○	○	○

6. Where do people collect the benefits from nature and farmlands in Bugala island?

List of benefits,	From their own land	From protected land	From other	Not applicable
Fuelwood and charcoal	○	○	○	○
Medicinal plants	○	○	○	○
Food collection (fruits, hunting and fishing)	○	○	○	○
Food production (subsistence farming)	○	○	○	○
Construction materials (timber)	○	○	○	○
Grass for cattle	○	○	○	○
Recreational / enjoyment	○	○	○	○

7. What are the main uses of collected benefits from nature and farmlands in Bugala island?

List of benefits,,	For home uses	For selling in the markets	For both home uses and selling	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	○	○	○	○	○

8. Are there any changes in the availability of benefits from nature and farmlands after the introduction of oil palm plantations in Bugala island?

List of benefits....	Increase	Decrease	No changes
Fuelwood and charcoal	○	○	○
Medicinal plants	○	○	○
Food collection (fruits, hunting and fishing)	○	○	○
Food production (subsistence farming)	○	○	○
Construction materials (timber)	○	○	○
Grass for cattle	○	○	○
Recreational / enjoyment	○	○	○

8. Are there any changes in the availability of benefits from nature and farmlands after the introduction of oil palm plantations in Bugala island?

List of benefits....	Increase	Decrease	No changes
Fuelwood and charcoal	○	○	○
Medicinal plants	○	○	○
Food collection (fruits, hunting and fishing)	○	○	○
Food production (subsistence farming)	○	○	○
Construction materials (timber)	○	○	○
Grass for cattle	○	○	○
Recreational / enjoyment	○	○	○

9. How well do you know Bugala island?

○ I am from there
○ I have visited the island
○ I have done fieldwork/project(s) on the island
○ I have never been there but I read about it

10. Where do people in Bugala island go 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 Bugala island.

List of benefits,..	Natural forests	Woodland	Bushland (bushes, shrubs and thickets)	Grassland (including grazing grounds)	Wetlands	Subsistence farmland	Lal
Fuelwood and charcoal collection	☐	☐	☐	☐	☐	☐	☐
Medicinal plants collection	☐	☐	☐	☐	☐	☐	☐
Food collection (wild fruits, huting and fishing)	☐	☐	☐	☐	☐	☐	☐
Food production (subsistence farming)	☐	☐	☐	☐	☐	☐	☐
Construction materials (timber) collection	☐	☐	☐	☐	☐	☐	☐
Cattle grass collection	☐	☐	☐	☐	☐	☐	☐
Recreational and enjoyment	☐	☐	☐	☐	☐	☐	☐

Please draw these areas on the map?

The areas that you will draw can be overlapping

Locations for fuelwood and charcoal collection
Please draw

Locations for medicinal plants collection
Please draw

Locations for food collection (wild fruits, huting and fishing)
Please draw

Locations for food production (subsistence farming)
Please draw

Locations for construction materials (timber) collection
Please draw

Locations for cattle grass collection
Please draw

Location for recreational and enjoyment
Please draw

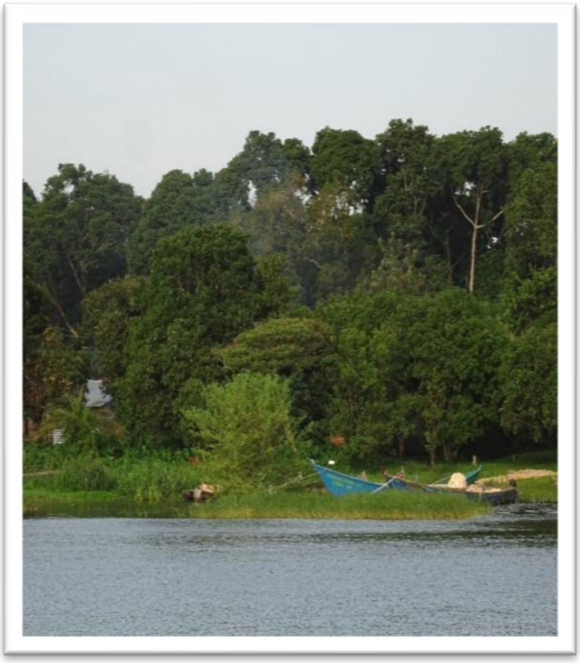
Appendix 2: List of stakeholders

Name of organisation	Number of participants
Makerere University	4
Ecotrends	1
Wildlife Conservation Society	2
KADINGO	1
NAPE	1
IUCN Uganda	1
ENR Africa Network	1
Kalangala Oil Palm Growers Trust (KOPGT)	3
BIDCO Uganda Ltd/ Oil Palm Uganda Ltd	1
Buvuma DLG	4
UCSD	1
KAWOYDA	1
Busitema University	1
Ensibuuko	1
World gospel mission - Buvuma	1
NFA	8
Friend of the Earth Uganda	1

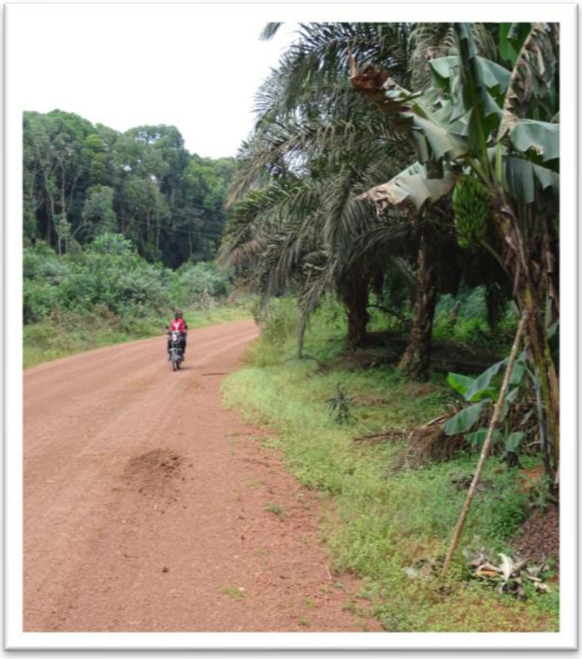
Appendix 3: Pictures of oil palm plantation in Bugala Island

Source: Tropenbos International

Appendix 4: Pictures of nature and ecosystem service in Bugala Island



Source: Tropenbos International



Source: Tropenbos International

Source: Tropenbos International