Ecosystem services of church forests and wetlands: supporting rural human well-being in Lake Tana Basin, Ethiopia

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Abstract

The Lake Tana Biosphere reserve (6,935 km^2) is the most economically, historically and environmentally important headwater catchment of the Upper Blue Nile River System. This landscape comprises isolated patches of natural forest, wetlands, communal grasslands, agricultural lands and eucalyptus woodlots. This biosphere reserve is one of the 250 most important lake areas in the world for biodiversity that provides ecosystem services supporting human well-being. This study focuses on the ecologically important ecosystems of church forests and wetlands of the Lake Tana Biosphere reserve that provide multiple services to people. Most of the remaining patches of natural forests are found surrounding the churches and the wetlands are distributed around the periphery of Lake Tana *and estuaries. Rapidly growing population, environmental and social changes adversely affect the characteristics of local ecosystems. Consequently, the widespread alteration and fragmentation of the natural land cover became the greatest threat to the ecosystems. Ecosystem fragmentation, overexploitation of natural resources, overgrazing, and alien species (eucalyptus and water hyacinth) lead to significant reduction of ecosystem conditions and loss of ecosystem services and affect human well-being. There is lack of information and methods on the links between ecosystem condition and flows of ecosystem services from isolated ecosystems in space and time. This study will address this gap in four steps. First, an assessment of ecosystem condition will be carried out by combining measures of condition indicators to understand the ecosystem's capacity to generate services. Remote sensing and ground-survey information will be used to assess the ecosystem conditions of church forests and wetlands. Six relevant ecosystems services such as raw materials (reeds), pasture for livestock grazing, climate regulation, pollination, erosion control and tourism will be assessed. Second, this study will explore the best way to define and assess the spill over effect of ecosystem service flows from the two conservation ecosystems to the adjacent areas. Third, spatiotemporal ecosystem condition changes for the last 40 years will be quantified and mapped to evaluate the protection and management effectiveness. And lastly, scenarios for policy and ecosystem condition changes for the next 30 years will be developed to model impact on ecosystem services. Spatial assessments of the supply of ecosystem services from current and future ecosystems are valuable for policy and decision-making processes regarding the conservation and use of natural resources.*

Keywords: ecosystem condition, ecosystem service, remote sensing, spill over effect, human well-being

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1. Introduction

Ecosystems provide vital resources that support a wide set of ecosystem functions and services necessary for the livelihood and well-being of people (Costanza *et al.*, 1997; Pereira *et al.*, 2005; Ayanu *et al.*, 2012; Willemen *et al.*, 2012; Stave *et al.*, 2017; TEEB, 2018). The goods and services provided by ecosystems to people can be provisioning, regulating and cultural services (MEA, 2003). Forests and wetlands are among the most productive ecosystems in the world, and are important features in the landscape that provide critical and diverse ecosystem services and values to human society (Blumenfeld *et al.*, 2009). These ecosystem services include provision of food, clean water, natural fibres and forest products, pollination, the regulation of climate, pests and diseases, and recreational opportunities. The benefits to human well-being derived from these ecosystem services includes security, the basic materials for livelihood benefits, health, social and cultural relationships, and freedom of choice and action (Haines-Young and Potschin, 2010). The physical, chemical and biological condition or quality of an ecosystem at a particular landscape is strongly linked to human well-being through ecosystem services (Maes *et al.*, 2018). In addition, the availability of the ecosystem services also depends on the trade-offs and interrelations between different types of ecosystems services (De Groot *et al.*, 2002; MEA, 2005).

Ecosystems contribute to human well-being through the supply of ecosystem services (Vargas *et al.*, 2019). The sustainable provision of ecosystem services to human well-being at local and global levels is based on the performance of ecosystem conditions (Summers *et al.*, 2012; Maes and Jacobs, 2017; Willemen *et al.*, 2017). However, rapidly growing populations, environmental changes and social changes all adversely affect the characteristics and processes of ecosystems. The widespread alteration and fragmentation of natural land cover has become the greatest threat to ecosystems (Haddad *et al.*, 2015). Ecosystem fragmentation, overexploitation of natural resources, overgrazing, and alien species can lead to a significant reduction of ecosystem conditions. As a result, ecosystem condition determines both the capacity to supply and the flow of ecosystem services (Pereira *et al.*, 2005). All these environmental pressures greatly affect ecosystem condition and threaten ecosystem services and values (MEA, 2005). Ecologically important landscapes, such as forests, wetlands and grasslands, continue to be lost and degraded.

The Lake Tana Biosphere reserve in Ethiopia, is an ecologically important ecosystem of the Upper Blue Nile River System. This landscape comprises of isolated patches of natural forest, wetlands, communal grasslands, agricultural lands, eucalyptus woodlots and waterbodies.

Church forests and wetlands, the focus of this research, constitute the unique ecosystems of the landscape that provide various cultural, ecological, and socioeconomic benefits for local people (Wassie *et al.*, 2010; Reynolds *et al.*, 2017). Most of the remaining isolated patches of forests are found surrounding orthodox churches and are called church forests, while wetlands exist around Lake Tana and along its tributaries. Church forests and wetlands in the Lake Tana Biosphere are biodiversity hotspots and can be considered as vital ecosystems contributing to surrounding landscapes by spill over effects of ecosystem service flows.

For a long period of time, the cultural and spiritual tradition of the people to respect the environment have had an important role for the long term existence and conservation of the church forests (Wassie *et al.*, 2005) and wetland resources (Zur Heide, 2012) of the basin. However, the ecosystem conditions of the landscape are affected by land degradation. The major causes of ecosystem condition change are fragmentation, alien species (eucalyptus and water hyacinth), overexploitation of natural resources, overgrazing, lack of awareness, and absence of clear policy directions. An assessment of the supply of ecosystem services in response to ecosystem condition changes is essential for continuous monitoring and conservation of nature (Ayanu *et al.*, 2012).

There is lack of information and methods on the links between ecosystem condition and ecosystem service flows from isolated ecosystems in space and time. There is also lack of evidence to define and asses the spill over effects of ecosystem service flows from the church forest and wetland ecosystem types with the existing conceptual frameworks that have been developed. Spatially explicit ecosystem models can be used to assess the ecosystem conditions to supply ecosystem services, including look-up tables, causal relationships, spatial interpolation and environmental regression based on remote sensing data and ground-survey measurements (Bagstad et al., 2013; Schröter et al., 2015). Remote sensing-based information has become an essential tool for global monitoring of natural and anthropogenic patterns, processes, and trends in continuous and repeatable observations over large areas (Andrew *et al.*, 2014; Skidmore *et al.*, 2015). It has been increasingly used to monitor ecosystem conditions including vegetation biomass, natural areas fragmentation and carbon (Ayanu *et al.*, 2012; Skidmore *et al.*, 2015). Therefore, this study will explore the use of remote sensing data and ground-based measurements to assess the ecosystem conditions to supply ecosystem services.

1.1. Research objectives

The objective of this study is to assess the ecosystem conditions of church forests and wetlands and the flows of ecosystem services from these isolated ecosystems in space and time. Remote sensing data and ground-survey information will be used to assess the linkages between ecosystem condition, ecosystem services, and human well-being.

The proposed study will have the following specific objectives.

1. To assess ecosystem conditions and the link with flows of ecosystem services from church forest and wetland ecosystems
2. To explore the spill over effects of ecosystem service flows from church forest and wetland ecosystems to surrounding areas
3. To assess the spatiotemporal ecosystem condition changes and ecosystem services for the last 40 years to evaluate the protection and management effectiveness
4. To develop scenarios for policy and ecosystem condition changes for the next 30 years to model the impact on ecosystem services

1.2. Research Questions

This study will address the following research questions:

1. How is the current ecosystem condition and extent linked with supply of ecosystem services?
2. How to define and assess the spill over effects of ecosystem service flows from church forests and wetlands to the surrounding areas?
3. What are the ecosystem services affected by changes in ecosystem condition and extent during the past 40 years?
4. How do ecosystem condition changes and affect the supply ecosystem services in the next 30 years under plausible scenarios in the Lake Tana basin?

Conceptual Framework

In line with the above concepts, this study attempts to emphasize ecosystem conditions and ecosystem services. The conceptual framework is presented in Figure 1. Linking remote sensing data and ground-based measurements is a plausible approach to understand ecosystem conditions to supply ecosystem services.

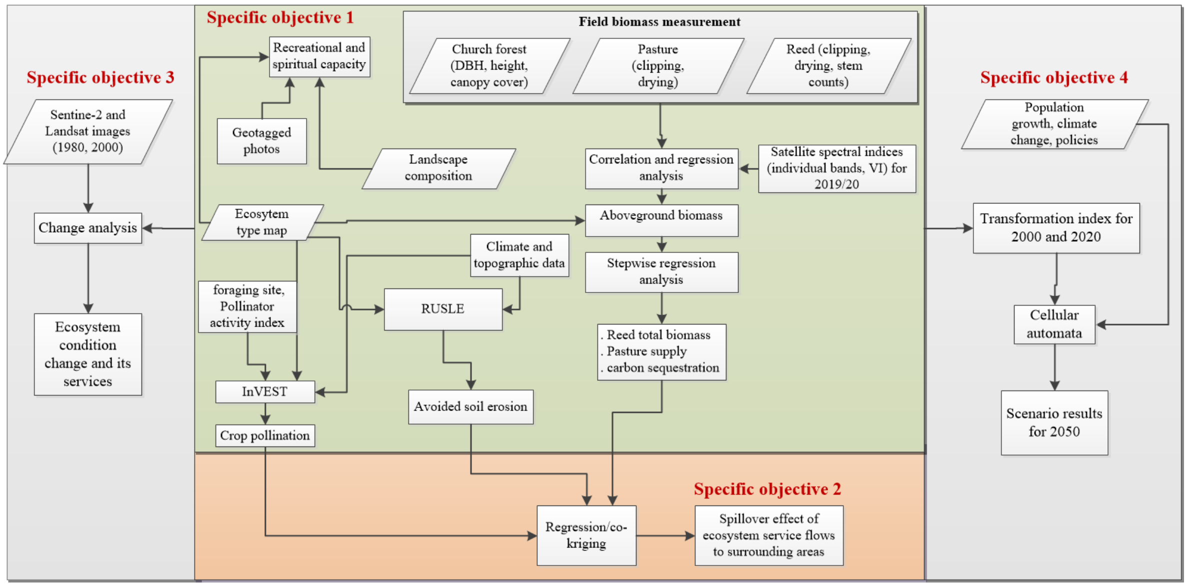

Figure 1. General methodological approach to be utilized in the proposed study for all objectives

2. Materials and methods

Description of the study area

This study will be conducted in the church forest and wetland landscapes of Lake Tana Basin. The study basin is the most economically, historically and environmentally important headwater catchment of the Upper Blue Nile River System in Ethiopia (Figure 2). Geographically, it is located between 36°44'40" and 38°13'13" North and 10°56'17" and 12°44'55" East. The basin is characterized by ecologically important ecosystems that support the rural well-being of humans. For this research, the Lake Tana biosphere reserve is selected because the lake area and its surrounding is one of the global top 250 lake areas for most important for biodiversity (LakeNet, 2004) that supports multiple ecosystem services benefiting the rural people. In addition, this area is known for its naturalness and biologically diverse ecosystems. The rivers Megech, Rib, Gumara and Gilgel Abbay are the main permanent tributaries of the Lake Tana. There are also other prominent seasonal rivers found in Lake Tana basin.

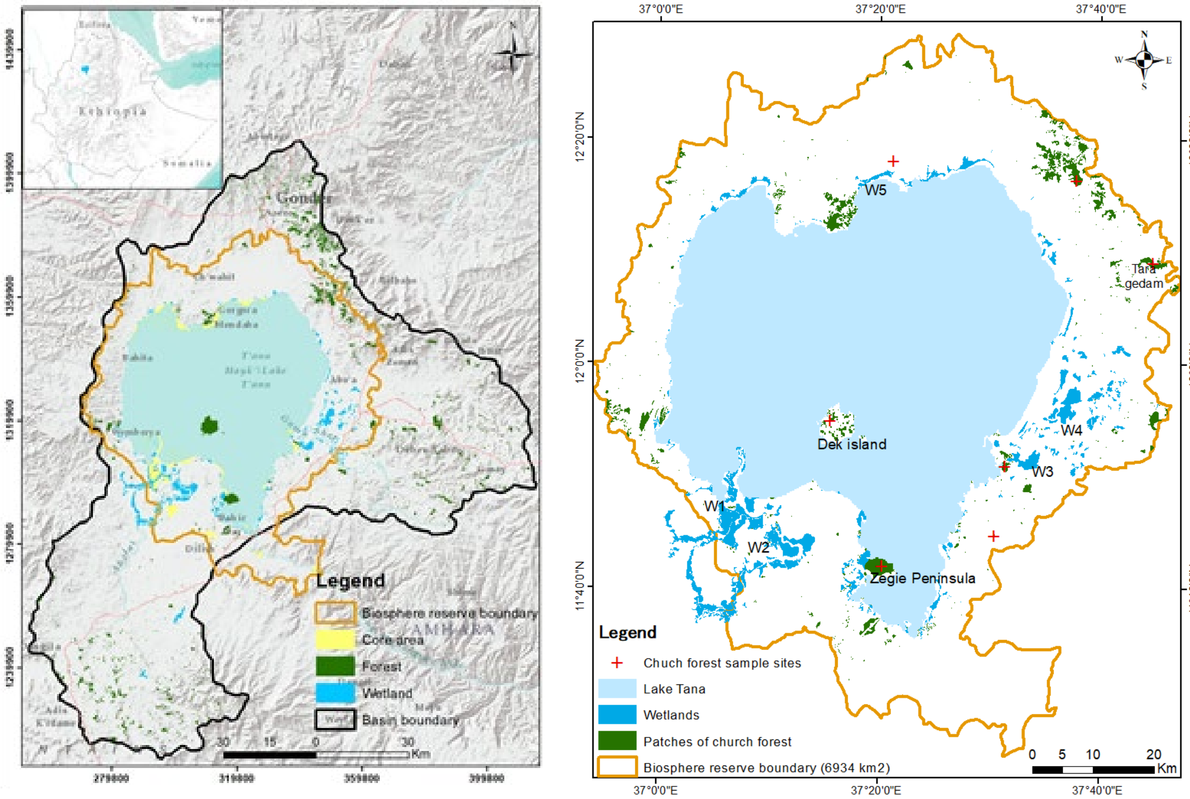

Figure 2. Location of the study area (left) sampling sites (right) (the seven red crosses show sample sites for church forests and the letters W1, W2, W3, W4 and W5 represent sample sites for wetland assessment)

According to different sources, three million people (Vijverberg *et al.*, 2009) are living adjacent to the lake and its catchment. More than 500,000 people are directly and indirectly provided with a livelihood by the lake, the flanking wetlands and forests (Vijverberg *et al.*, 2009). Areas to the northeast, south and south west of Lake Tana have high population density. This has resulted in a high population dependence on the resources of the basin. The Lake Tana area consists of 37 islands and 16 peninsulas, giving home to 21 churches and monasteries with strong cultural and religious heritage which is the first reference for settlement in the Lake Tana basin. About 55% of the total terrestrial area of the Lake Tana basin is under cultivation, 21 % is water area, 10 % is grassland, 1.6 % is wetland/swampy area and 0.4 % is natural forest (IFAD, 2007). The cultivated area is used for growing cereals (teff, wheat, barley, maize, finger millet and rice), pulses (faba bean, field pea, chickpea, lentil, grass pea, haricot bean and lupin) oil crops (linseed, rapeseed and safflower), horticultural crops (potato, pepper, tomato, cabbage, onion, black cumin and ginger) and perennial crops (coffee, sugarcane, orange, papaya, mango, avocado and banana) (IFAD, 2007). Livestock production constitutes a major part of the farming system next to crop production.

Methodology objective 1: To quantify and map the ecosystem services of church forests and wetlands that support rural human well-being in the Tana Lake basin.

Current methods to map ecosystem services rely on the support of remote sensing for spatially explicit quantitative estimates of biophysical variables, such as biodiversity, plant traits, vegetation condition, ecological processes, soil properties and hydrological variables (Andrew *et al.*, 2014) or as a proxy for other ecosystem service indicators, like recreation, carbon sequestration or it can be combined with in situ observation data and modelled to produce ecosystem service maps (Martínez-Harms *et al.*, 2016). This objective will assess the current condition of church forest and wetland ecosystems and their services and the importance of these services for the livelihood and well-being of rural people. To address this objective, the following two steps will be used: (i) integrate remote sensing and field-based data to assess the ecosystem conditions of church forests and wetlands; (ii) assess ecosystem services linked to ecosystem conditions. The methodology to be applied is described below:

Assessment of ecosystem conditions

The assessment of the current condition of ecosystems will be carried out by combining measures of condition indicators with ecosystem extent to understand the ecosystem's capacity to generate services. The major broad land cover classes of the study area will be classified into ecosystem type for which the condition is going to be assessed. Remote sensing will be the primary source of data for mapping the extent and condition of ecosystems across the Lake Tana Biosphere reserve. The recent Sentinel-2 mission (since 2015) has great potential for the detailed classification and monitoring of ecosystem types on local scales (Ramoelo *et al.*, 2015). It offers innovative features for environmental remote sensing (Immitzer *et al.*, 2016). The Sentinel-2 satellite carries a multispectral sensor with 13 bands where the visible and the NIR bands are at a 10 m spatial resolution and four red-edge bands at 20 m spatial resolution are also available for vegetation mapping and monitoring (Immitzer *et al.*, 2016). For this study, a detailed ecosystem type map will be generated from Sentinel-2 satellite images acquired for 2019/2020. Following a hierarchical approach, image segmentation will be employed to generate detailed categories of ecosystem types as shown in Table 1. This classification will be supported using ground-based survey to map the ecosystem units of the study area. Classification precision report will be prepared for each classified image using the ground reference data and orthophotographs to check the quality of classification.

Table 1. Ecosystem type categories of the study area that will be generated.

Land covers types	**Ecosystem types**
Cropland	Cultivated lands
Forest	Deciduous forest
	Coniferous forest
	Mixed forest
	Eucalyptus
Grassland	Grassland dominated by forbs
Heathland and shrub	Scrub
	bushes
	Heathland scrub
	very sparse vegetation
Wetlands	Riverine
	Lacustrine and palustrine
	water hyacinth
Water bodies	Rivers, lakes

In particular, the characteristics of church forest and wetland conditions will focus on aboveground vegetation biomass, fragmentation of habitats and alien species. The vegetation biomass is indicates the productivity and is most easily be measured in terms of above ground biomass, which can be estimated from remotely sensed VI (Hansen and Schjoerring, 2003). Habitat fragmentation is a measure of the degree to which an ecosystem is divided into smaller areas by human built infrastructures and cultivated fields. For wetlands, general measures of vegetation condition can be assessed by the extent of invasive species. Having mapped the ecosystem types, the conditions of church forest and wetland ecosystems such as symptoms of degradation will be assessed (Cordingley *et al.*, 2015; Haddad *et al.*, 2015; Adhikari and Hansen, 2018). The condition of forest and wetland ecosystems that compromise the ecosystem services can be assessed in terms of the importance of the ecosystem in its contribution to the ecosystem service delivery (Adhikari and Hansen, 2018).

Indicators for ecosystem condition are selected according to their importance in determining the supply of ecosystem services of the study area. The indicators, data and methods used for assessing ecosystem conditions and their services are summarized in Table 2.

Mapping ecosystem services

The first step in mapping ecosystem services is the identification of the relevant provisioning, regulating and cultural ecosystem services for the study area. At the end of 2017, a preliminary field survey was conducted in the Lake Tana Basin to provide basic background information on the study area, such as existing land cover types, topography and livelihood information. Based on the preliminary field survey, site-specific knowledge and peer-reviewed literature, ecosystem services obtained from church forests and wetland ecosystems are selected according to the nomenclature standards of the Common International Classification of Ecosystem Services (CICES). These services include raw materials, fodder and livestock grazing, climate regulation, crop pollination, erosion prevention and soil retention and ecotourism (Table 2).

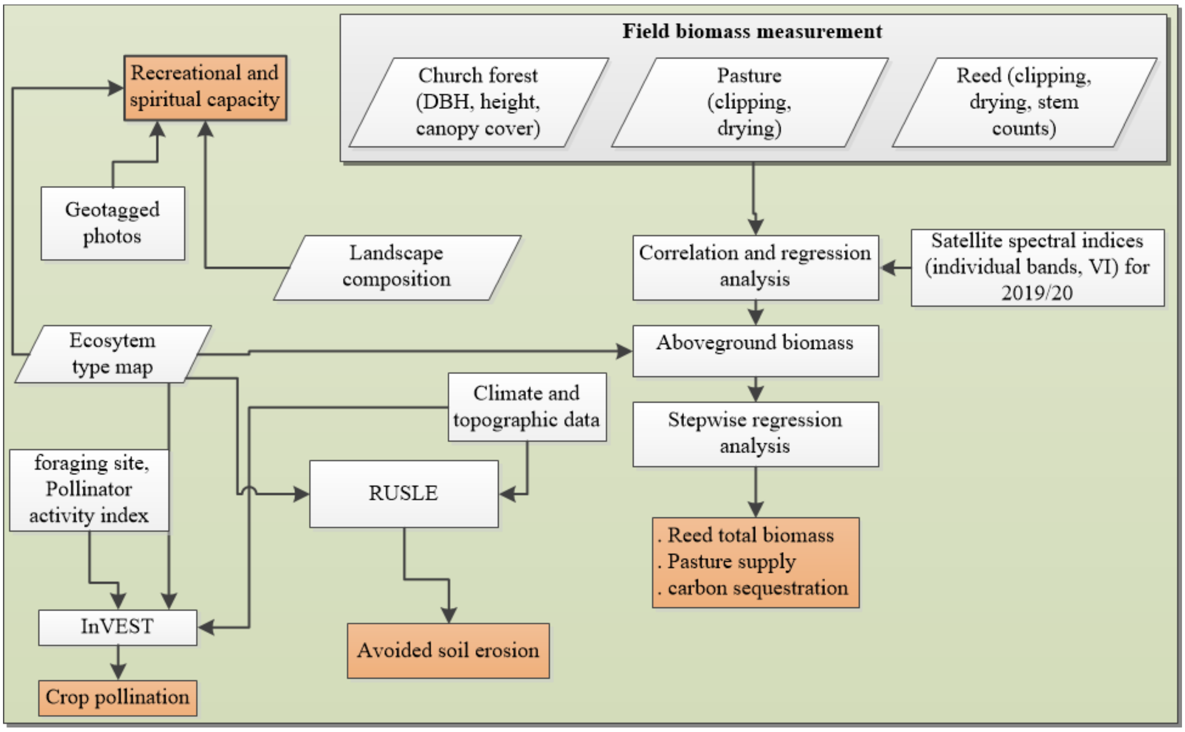

Figure 3. Flowchart of the methodological approach for ecosystem condition characterization and their corresponding ecosystem services.

In order to map ecosystem services, indicators are selected by taking into account the relevance and availability of ecosystem services data. As shown in Fig. 3, a link will be established between specific ecosystem conditions and their capacity to generate services using the ecosystem type map, ground-based measurement and socio-economic information. The maps for all ecosystem services will finally be normalized to the same categorical range between 0 and 5 (Liquete *et al.*, 2015). The individual ecosystem service maps will be combined together and cold spots and hotspots will be distinguished to identify core habitats for priorities for sustainable conservation (Egoh *et al.*, 2008; Willemen *et al.*, 2017; Korpilo *et al.*, 2018).

Table 2. Types of data to be collected and sampling sizes for each ecosystem service from the forests and wetland ecosystems are shown below (forage production data will be collected two times when vegetation productivity reaches maximum in September and during the dry month in January).

Ecosystem condition	Ecosystem service	Indicator	Required data	Field sampling	Models	Equipment needed	Time and efforts required	Maps
Reed biomass	Raw materials	Total biomass (t ha^{-1})	Ecosystem map, reed biomass and LAI	9 transect directions perpendicular to the lake to establish 27 plots with 2 m × 2 m plot size with 10 m distance. Height of reeds, plant counts, and centre coordinate will be recorded and 52 reed stems for dry biomass.	Regression modelling	Tape, balance, drying oven	Sept 20 – Oct 10/ 2019 (2 assistants)	Aboveground biomass estimation
Aboveground Net Primary Productivity (ANPP)	Pasture grazing livestock	Grassland to supply pastures	Sentinel-2 VI, Pasture biomass data and grazing livestock data	10 linear and non-linear transect directions will laid out. 40 sample sites with 0.5 m x 0.5 m plot size on five grass dominated wetlands sites. Aboveground pasture will be harvested for oven-dried and weighed.	Regression modelling and livestock grazing capacity	Tape, sensitive balance, drying oven	May 15 – 30/ 2019 and Sept 20 – 30/ 2019 (2 assistants)	Map for ANPP and grazing density
Net ecosystem production	Climate regulation	carbon sequestration (t ha^{-1})	VI, land cover classes, biomass, NPP, Rh	Radial transect from the centre to the edge on 28 plots from seven church forest sites (*Nested plots:50 x 50 m grid area for > 50 cm DBH; 20 * 20 m grid area for 10 - 20 cm DBH, 10 * 10 m grid area for 2 - 10 cm DBH)*	Regression model	Tape, clinometer, calliper, clipboard	Sept 10 – Oct 10/ 2019 (3 assistants)	Carbon storage
relative abundance	Pollination	Crop pollination (%)	Ecosystem maps, pollinator dependent crop maps, foraging ranges, physical barrier to pollinators, Species abundance and diversity	Radial transect from the centre to the edge on 28 plots from seven church	InVEST	Insect nets (pitfall traps), Hand lens, insect pins and boxes	Sept 10 – Oct 10/ 2019 and Jan 20 – 30/ 2020 (3 assistants)	Relative pollination capacity
Vegetation cover	Erosion control service	Avoided soil erosion (ton/ha)	Land cover, climate data, topographic data, soil, and NDVI	Sentinel 2 image, conservation status from agricultural offices	RUSLE		Sept 10 – Oct 10/ 2019	soil erosion control service map
Landscape composition	Tourism	Recreational and spiritual capacity	geotagged photos, water bodies, relief, monuments, protected areas, infrastructure	Regional tourism bureau, Tana sub-basin organization	Generalized effect mixed model	Binocular	Aug 10 – 20/ 2019	spatial patterns of landscape capacity for tourism

The detailed description of the required data, data collection processes, mapping of ecosystem services and analysis are documented in the following sub-sections.

Reed Materials

In wetlands, reed vegetation plays an important role in wetland ecosystem services, such as raw materials for local commodities, carbon storage, nutrient cycling and absorption of heavy metal elements. In the wetlands of Lake Tana, reeds are perennial plants found on the edge of the lake. Given that the stand is always close to the water, it is reasonable to assume that it is never subjected to hydrological stress during the growth periods (Mundt, 2011). Estimation of the aboveground biomass (AGB) of reed plants is a key premise in order to maintain the sustainable supply of ecosystem services from reeds to support rural human well-being in the study area.

The papyrus (*Cyperus papyrus*) and typha (*Typha latifolia*) plants are the most economically important wetland species of Lake Tana (Zur Heide, 2012) and are used for fuel, as a source of animal feed, as building material, for handicrafts and for the construction of reed boats for rural communities. This section focuses on the assessment of biomass production for reeds, which is estimated using AGB data collected from the field. Field survey data will be obtained for three sites of wetland reed covers within the wetland periphery in the southern part of Lake Tana. Grassland vegetation gradually declines away the lake side. therefore, location of the transect sites will be chosen randomly and transect direction will also be laid out at a right angle to the reed stands following the main ecological gradient from the lake and ending at the end of reed stands. Depending on the transect size, aboveground biomass will be measured from reed plants on 10 m distance on 2 m x 2 m plot size. All transect and sample sites will be recorded by GPS measurements. Approximately, nine representative transects are expected to be laid out, and measurement of reeds from 27 plots will be done. The number of reed stands within the plot will counted and recorded. The height of each stand will be determined using measuring tape. 52 reed stems will be cut and dried in the laboratory to determine the biomass of each stem. For the remaining stems, a regression equation will be used to evaluate statistical relationships between field measurements and dried biomass. Correlation and regression analysis will be used to map the spatial distribution of the AGB of reed plants in the wetlands of Lake Tana.

Pasture for grazing livestock

The capacity of wetland and adjacent meadow ecosystems to supply pastures for farmers living in the surrounding area depends on ecosystem conditions (e.g. land-cover, grass species), and net primary production (NPP) allocation (Knapp *et al.*, 2014). NPP provides important insights into the function of ecosystem conditions. In the study area, pastures are a mix of different grass species such as *Nymphaea nouchali, Ipomoea aquatica and Echinochloa (Mundt, 2011; Zur Heide, 2012)*. The assessment of the grassland condition of the wetland being investigated is based on the condition of grazing land for grazing purposes. Vegetation index (VI) of Sentinel-2 imagery and widely distributed ground-based aboveground net primary productivity (ANPP) estimates will be used to assess the ecosystem conditions to supply ecosystem services.

In areas where grasslands are the main pasture resources that support extensive livestock production, accurate ANPP estimates are considered essential for adjusting grazing pressure and improving sustainable management. For the grassland in the wetland, the supply of aboveground biomass during the rainy season (summer) and dry season (winter) will be assessed using ANPP. Location of the transect sites will be chosen randomly and 10 linear (on the lake periphery) and non-linear (riverside) transect directions will be laid out at a right angle to the grassland areas following the main ecological gradient from the lake or river and ending at the farmlands. This layout can help to get representative data for the reed vegetation where stem density and height decrease away from the waterbody. Aboveground pasture biomass samples will be collected from five wetland sites with 0.5 x 0.5 m plot size for a total of 40 sample sites within the study area. For each sample, aboveground pasture will be harvested by clipping peak live plant material at ground level. The collected samples will be oven-dried in the laboratory and weighed (dry weight). All transect and sample sites will be recorded by GPS measurements. The annual ANPP will be estimated using the dry and wet seasons data by applying the model proposed by Kumar and Monteith (1982) for the grasslands in Lake Tana region wetland areas.

The total ANPP estimated from grassland cover will be related with the carrying capacity of the area to assess the ecosystem service delivery. The existing grassland ecosystem to supply pastures will be assessed by using the supply ANPP and the average annual pasture intake per livestock/year. The carrying capacity of the grassland for domestic stock (number of livestock per grassland site) will determined from six wetland areas following the work of Reyers *et al.* (2009)**.** The supply of pastures grazed by livestock will be calculated by multiplying the annual biomass intake with the number of livestock heads per grassland area.

Climate regulation

The vegetation condition indicates the capacity of a vegetation unit to produce a range of goods and services (Yapp *et al.*, 2010). In a natural landscape, vegetation can be maintained or replaced to meet the changing needs of society, giving mosaics of vegetation types and condition classes that can range from intact native ecosystems to highly modified systems (Yapp *et al.*, 2010). These various condition classes will produce different levels of ecosystem services. The biophysical characteristics of the church forest are then interpreted according to the perspective of vegetation biomass and extent of native vegetation types to assess the climate regulating services.

Measurement of tree diameter at breast height (DBH) and total height (H) will be determined from the field from 44 plots with the size of each plot 50 m x 50 m. Sample plots will be randomly selected in the church forests. Aboveground biomass (AGB) will be calculated using existing allometric equations for the species of the area (Basuki *et al.*, 2009; Wondrade *et al.*, 2015). To extrapolate the AGB, a relationship will be created with the Sentinel-2 VI. As shown in research works of Tabarelli *et al.* (2008) and Numata *et al.* (2011) since the edge effects can reduce the aboveground and belowground biomass of forest classes and this effect will be taken into consideration by reducing the biomass on the edge of forest areas.

Forests play an important role in the global carbon cycle by sequestering large amounts of atmospheric carbon and offer a mitigation strategy to reduce global warming (Schimel *et al.*, 2001; Luyssaert *et al.*, 2007). Gross primary productivity of an ecosystem represents the gross uptake of CO_2 that is used for photosynthesis. The amount of photosynthesis that is not used for respiration and is available for other processes is defined as NPP. Therefore, the capacity of church forest ecosystems to sequester carbon can be determined by the imbalance between NPP and heterotrophic respiration (Rh). This is represented by the net ecosystem production (NEP) which is the measure of the ecosystem capacity to sequester carbon (Poulter *et al.*, 2014). As Naidoo *et al.* (2008) stated, the amount of carbon sequestered by the ecosystem and added to terrestrial biomass can be taken as an avoided supply of carbon to the atmosphere. Therefore, The ecosystem services supply is considered as equal to the capacity of ecosystems to sequester carbon (Schröter *et al.*, 2014). The NEP refer to net primary production minus carbon losses in Rh:

$$NEP = NPP - R_h \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

The ecosystem service carbon sequestration is included based on the potential opportunities it presents for restoration activities (Reyers *et al.*, 2009).

Crop pollination

Many wild and agricultural crops depend on pollinating insects that also play also an important role in maintaining plant diversity (Klein *et al.*, 2006; Liquete *et al.*, 2015). Pollination by wild insects is an important ecosystem service with high natural and economic value (Noriega *et al.*, 2018). The crop pollination model uses the method of Zulian *et al.* (2013) to simulate pollination service provides an index of relative pollination potential, which is defined as the relative capacity of ecosystems to support crop pollination. This study will assess the ecosystem service of crop pollination by considering the habitat conditions of the study area. The pollinator dependant crops (such as fruit, vegetable, spice and oil crops) grown around the forest patches and wetlands will be identified and assessed. As shown in Fig. 4, different input data will be used to model the service derived from pollination.

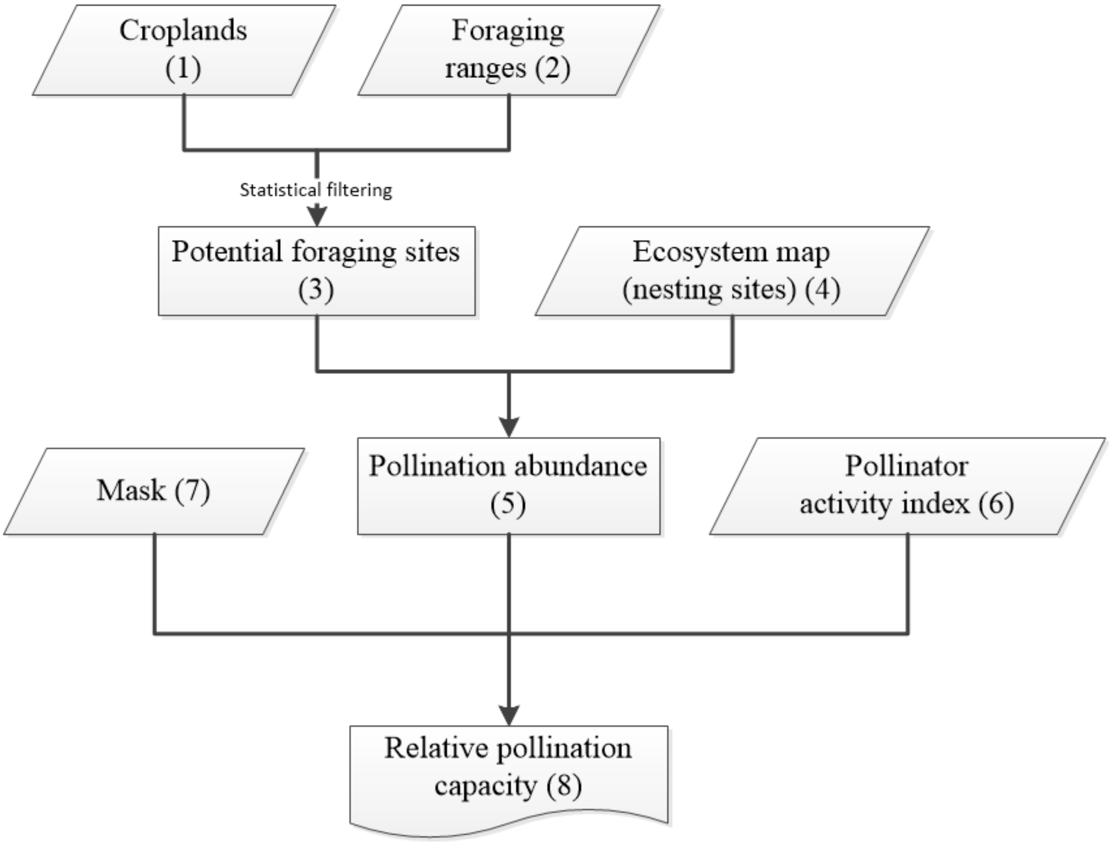

Figure 4. The crop pollination model will estimate the services on the on the surrounding croplands and on the forest and wetland areas.

As shown in Fig. 4, the steps are: (1) pollinator dependent crops extracted from ecosystem maps; (2) foraging range is the threshold of maximum flight range of a specific guild of pollinators from the scientific literature (Klein *et al.*, 2006); (3) the potential foraging sites in and around the forest and wetland habitats can be determined with statistical kernel filtering; (4) potential pollinator nesting sites will identified based on presence and absence of pollinators; based on a combination of the relative pollinator abundance (5), pollinator activity index (6) and masking layer (7), final map of relative pollination potential will be assessed for the study area. The final map of relative pollination capacity will be produced by considering the existing habitat condition map of the study area (adapted from the InVEST crop pollination deterministic model). Maps of relative pollination potential can be produced for each pollinator species provided that parameters about flight distance and activity are available. Weighted overlay analysis will used to aggregate individual pollination maps of each pollinator species.

Soil erosion prevention and sediment retention

Soil erosion is one of the major forms of land degradation that affects sustainability of ecosystem services in the Lake Tana basin. In the study area, soil erosion prevention by forests and wetlands is a key ecosystem service supply. Erosion prevention assessment will be done using the framework of the Revised Universal Soil Loss Equation (RUSLE) (Wischmeier and Smith, 1978; Renard *et al.*, 1997). The result is a dimensionless indicator that shows the capacity of ecosystems to prevent soil erosion. Climate data, topographic aspects, existing soil data and vegetation cover data will be used to for quantifying this ecosystem service.

Tourism

Data obtained from social media and web-based photo sharing platforms have been used to identify highly valued recreation and tourism destination locations (Wood *et al.*, 2013; Willemen *et al.*, 2015). Geotagged photos uploaded to social media and web-based photo sharing sites were found to be correlated to actual visitation rates to warrant the photo sharing website as a good indicator of landscape visitation rates (Wood *et al.*, 2013; Van Zanten *et al.*, 2016). Geotagged photos uploaded to web-based photo sharing platforms, Google Earth, Flickr and the mobile photo sharing application Instagram will be used to establish a model for the tourism ecosystem service using photos as a proxy for number of visitors. All photo data will be mapped and aggregated by the count of unique user photo uploads. The availability of high density photos show high landscape recreation and tourism values. Information such as accessibility, degree of naturalness, water bodies, biodiversity hotspot areas, protected areas, presence of infrastructures will be collected.

Locations of recreational and spiritual values will be estimated using regression models to characterize the locations of recreation and on-site tourism services observed in web-based and photo-sharing platforms. Predictor variables will be selected based on recreational and spiritual preference for the natural and social landscape features. The predictor variables include landscape features (land cover types, rivers, lakes, terrain) (Brown and Brabyn, 2012), context variables (travel time to the nearest city) (Nelson, 2008; Weiss *et al.*, 2018) will be analysed to assess the landscape quality. A Generalized Mixed Effects Model (GME) will be used to understand the spatial relationships between natural and cultural landscape features and locations of recreational and spiritual values. In this model, high density photos are assumed to be a function of the characteristics of landscape composition and accessibility. This will help support sustainable management of landscapes for recreation and spiritual activities.

Methodology for objective 2: To explore the spill over effects of ecosystem service flows from church forest and wetland ecosystems to surrounding areas

Ecosystem services are strongly related with ecosystems conditions to produce benefit for human well-being (MEA, 2005; Serna-Chavez *et al.*, 2014). Information on where services are provided and benefits are received is required for effective environmental management and for payments for ecosystem services as well (Guariguata and Balvanera, 2009). In this research, the use of the term 'spill over effect' is refers to the path of ecosystems service flow from service providing areas (spatial unit of source of ecosystem service) to benefiting areas (maximum distance from the edge of the service provisioning area up to a distance where services are delivered to beneficiaries). The study of spill over effect of ecosystem service flows can identify challenges and options to restore church forest and wetland ecosystem conditions and their service delivery to beneficiaries. Most ecosystem service assessment methodologies have relied on static indicators of service provision and the spatial relations with the benefiting areas is missed. This study will explore the best way to define and assess the spill over effect of ecosystem service flows from the two conservation ecosystems to the adjacent areas. Spatial assessments of the spill over effect of the service provisioning areas on the benefiting areas can provide information about the ecosystem condition and supply of ecosystem services.

The spill over effects of ecosystem service such as pollination, climate regulation, soil erosion control and tourism services to people will be assessed in this work. A spatially-explicit regression model will be used to explore the spatial relationships between services provisioning and benefiting areas to evaluate the spill over effect of each ecosystem service flows. The spatial spill over effects of ecosystem service flows for benefits can be calculated using geostatistical analysis based on the size of the benefiting areas located within and outside the spill over area. Based on the literature (Fisher *et al.*, 2009; Walz *et al.*, 2017), the spatial relationships between *service provisioning areas and benefiting areas* for selected ecosystem services in the area are summarized in Table 3. According to Costanza (2008), the service flows of raw material and pasture for livestock grazing are considered as in-situ whereas in this study their spill over effects are assumed to follow Omni-directional flow.

Table 3. Spatial spill over characteristics of selected ecosystem service flows based on the relationship between service provisioning areas and benefiting areas

Ecosystem service	Directional spill over	What?
Raw materials	Omni-directional	Areas benefiting from conservation areas of reed plants
Pasture for livestock grazing	Omni-directional	Settlement areas benefiting from communal wetland grazing land
Carbon sequestration	Omni-directional (Costanza, 2008; Fisher *et al.*, 2009)	Changes in local surface temperature
Pollination	Local proximal (depends on proximity) (Costanza, 2008)	Pollinator dependent agricultural areas crop areas outside the service providing areas
Soil erosion control service	Directional (slope) (Costanza, 2008)	In-situ erosion control by vegetation cover
Tourism	User movement related (Costanza, 2008)	Flow of people to unique natural features

For the purpose of validating the model, a transect direction from church forests and wetlands to benefiting areas will be established. Interviews with households will be carried out to assess ecosystem service benefits provided from the conservation areas to the well-being of the rural people. Clustered random sampling will be used to select respondents who live within 1 km of the church forests and wetlands of the study sites. Therefore, 120 households will be randomly selected from seven church forest sites and five wetlands. A cross-sectional interview with the respondents will be conducted to discuss the benefits of ecosystem services for local people at different distances from the study sites. This will used to validate the spill over effects of the study ecosystems on the benefiting areas.

Methodology for objective 3: To assess the spatiotemporal ecosystem condition changes and ecosystem services for the last 40 years to evaluate the protection and management effectiveness

Human actions result in the loss and fragmentation of natural ecosystems with negative consequences on the natural capital for the provision of ecosystem services (Foley *et al.*, 2011). Globally, the conversion of native forests, wetlands and grasslands into human-dominated landscapes increases the production of food, timber, housing, and other commodities but at the cost of reductions in many ecosystem services (MEA, 2005). Remote sensing data are valuable for the assessments of ecosystem condition, including mapping of land cover change, fragmentation, vegetation change, alien species and measurements of ecosystem attributes as input to ecosystem models (DeFries *et al.*, 2005).

Spatiotemporal ecosystem condition changes for the last 40 years will be quantified and mapped to evaluate protection and management effectiveness. Spatiotemporal ecosystem condition changes in terms of its capacity to continue to provide ecosystem services to rural people to evaluate the conservation status is not yet explored. In this research, Landsat and Sentinel-2 satellite images will be used to assess spatiotemporal ecosystem condition changes as a proxy of changes in ecosystem services in the last 40 years in Lake Tana Basin. This research will trace the effectiveness of management practices and conservation area status to evaluate the ecosystem condition of the church forests and wetlands to indicate the corresponding ecosystem services and their linkage with human well-being.

In the study area, quantitative information about the different patterns of ecosystem condition changes that affect the supply of ecosystem services will be assessed for the years 1980, 2000 and 2020. The starting year (1980) is selected based on historical records of rapid population and land redistribution in the study area. The change in indicators of ecosystem condition will be used to assess the change in ecosystem services of raw materials, pasture for livestock grazing, carbon sequestration, pollination, soil erosion control and tourism. In addition, socioeconomic survey data will be collected to triangulate the linkages between ecosystem conditions and rural people's well-being over time. For this purpose, in-depth interview will be done for 60 randomly selected key informants. Archival data (land holding size) about the human dependence on church forest and wetland ecosystems related to the selected ecosystem services can also be consulted to triangulate the changes in different time periods.

Methodology for objective 4: To develop scenarios for policy and ecosystem condition changes for the next 30 years to model the impact on ecosystem services

Globally, human actions have significantly transformed the ecosystems of the Earth. The degradation and fragmentation of ecosystems has led to significant increases in the production of food, timber, housing and other commodities, but at the cost of reducing many ecosystem services and biodiversity (MEA, 2005).The capacity of ecosystems to provide these services has declined significantly. Scenarios for policy and ecosystem condition changes for the next 30 years will be developed to model the impact on ecosystem services. Spatial assessments of the supply of ecosystem services from current and future ecosystems are valuable for policy and decision-making processes regarding the conservation and use of natural resources. These ecosystem condition change scenarios will be based on biomass degradation, population growth, land cover fragmentation, alien species expansion, infrastructure development and climate change.

For this purpose, Cellular Automata (CA) model will be used since the ecosystem change dynamics can be simulated its ability to give equal weight to the importance of space, time and system attributes (Vázquez-Quintero *et al.*, 2016). The remote sensing data and ecosystem type outputs produced in objective three will be used for the ecosystem condition change simulation. A 3x3 Moore neighborhood can be used in the simulation process to determine the transformation matrix for the years 2000 and 2020 to predict for 2020. Based on the transformation matrix, the long-term scenarios for ecosystem changes to supply of ecosystem services will be modelled for the 30 years' time period. This result will help to recognize the future ecosystem condition of the Lake Tana Biosphere Reserve and to formulate appropriate management practices in future.

3. Proposed timeline

No	Activities	2018		2019				2020				2021				2022	
		3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
1	PhD proposal preparation and qualifier																
2	Preparation of data collection tools																
3	Field data collection																
4	Data analysis and first two objectives paper write-up																
5	Coursework and training																
6	Second round data collection satellite imageries, reference data, policy documents, secondary data																
7	Present findings of the first two papers, sending papers for comments and editing's, and for journals																
8	Data analysis and third objective paper write-up																
9	Data Analysis and final objective papers write-up																
10	Present findings of the 3rd and 4th objective paper, sending papers for comments and editing's, and as well for journals																
11	Incorporate comments and suggestions																
12	Thesis Finalization																

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