Tree based ecosystem service potential of church forests and trees in their agricultural matrix near Lake Tana, Ethiopia

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List of abbreviations

IDF: Inverse Distribution Function

IUCN: International Union for Conservation of Nature

NCP: Nature Contribution to People

MEA: Millennium Ecosystem Services Assessment

SOC: Soil Organic carbon

SPSS: Statistical Package for Social Sciences

UNESCO: The United Nations Educational, Scientific and Cultural Organization

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Abstract

Church forest fragments have enormous importance for saving the last tracts of primary forest and biodiversity on earth. They are currently being threatened by natural and human-induced factors. The objective of this research was to study the diversity of tree species, their ecosystem services (ES), and ecosystem multifunctionality (ESMF) of church forest fragments and their adjoining agricultural matrices in the East of Lake Tana (Northwestern highlands) of Ethiopia. Ecosystem services were analyzed based on the Millennium Ecosystem Assessment (MEA) classification of ecosystem services. The data was analyzed by using Statistical Package for the Social Sciences (SPSS v.16) and Microsoft office excel. In particular, multiple regression analysis was undertaken to explain the factors affecting diversity, ES, and ES multifunctionality in both church forests and the agricultural matrices. The results show that there are higher tree diversity indices (average Shannon diversity index (H'=2), Simpson diversity indices (0.8), and Shannon evenness (0.76)), and a higher alpha diversity and gamma diversity in church forests than in agricultural matrices. The ecosystem services indicate a higher average ES in agricultural matrices, but this difference was not significant according to the performed t-tests. Based on the MEA division, there are higher cultural and regulating services in the agricultural services than in the church forest fragments. The multifunctionality metrics indicate that there are higher average multifunctionality levels in the agricultural matrices than in the church forests, and this indicates the deliberate plantings of multifunctional trees by farmers in the respective matrices. The multiple regression analysis indicates that factors affecting the church forests also affect the matrices and vice-versa. These major results indicate the role of the church and matrices as a separate component and the relationship between these two important ecosystems. Conservationists, foresters, and policy makers should take into account this interdependence and apply a holistic measure while conserving biodiversity in these areas.

Keywords: *Church forests, Ecosystem, Ecosystem services, Multifunctionality*

1. Introduction

Established as a result of religion, faith or belief system; SNS (Sacred Natural Sites) have cultural, historical and religious importance (Oviedo *et al.*, 2005). Some of the mainstream faiths like Christianity, Catholicism and other forms of spiritual revelations contributed for the existence and continuance of SNS around the world. Remains of old forests, rivers, caves, graveyards and ancestral worship sites are some of the types of SNS. SNS are well protected for many years and contain high biodiversity content with a deep cultural value intertwined into their protection. They preserve threatened species and maintain the local biodiversity thus playing a prominent role for in situ conservation (Dudley *et al.*, 2010; Mgumia and Oba, 2003; Verschuuren, 2018).

The cultural values of SNS is inherent in the moral values and traditions that is transferred for generations. These sites are important areas mirroring the historic identities of the ancestors from the past. e.g. in Central Italy, important moments in farming and pastoralism are coincided with the celebratory moments/rituals or 'fiestas' of the SNS. This shows their role in conservation of cultural identities in addition to their role in sheltering the various biological diversities (Verschuuren, 2018). For instance: in sacred forests of Central Italy better species richness and unique biotas are maintained compared to the neighboring national protected areas with non-sacred value (Verschuuren, 2018). SNS also serve by providing material benefits such as water, medicine and other provisions of ecosystem services like being a place for celebratory events (i.e. Pilgrimages) and tourist sites (IUCN,2010).

Ecosystem services in the Millennium Ecosystem Assessment (MEA, 2005); classifies nature to provide to mankind provisioning, regulating, supporting and cultural services (aesthetic, recreational and educational services). The value of aesthetic services and spiritual services are poorly represented by the 'materialistic' or 'Utilitarian' theories of most ecosystem service studies (Cooper *et al.*, 2016). In view of this, Bhagwat (2009) proposed a different kind of approach which reconciles the 'Utilitarian view' with the ancient elements of nature (Land, Air, Water, Fire and Ether), the basics of nature. This approach is able to classify the cultural service element into pieces to shed light on the undervalued spiritual service or the 'intangible services' provided by nature. Recent studies show the importance of this approach as it provides logical reasoning and moral

ground for people to conserve nature e.g. (Cooper *et al.*, 2016). SNS are great examples of this sort in which local people act as 'custodians of nature' in preserving the ecosystem.
Recently, a new paradigm is set by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) which depicts the context specific 'Nature's Contribution to People' in which SNS even sacred objects such as trees and animals are recognized and interlinked with the rest of the ecosystem services (material, non-material and regulating contributions). i.e. contributions instead of services (IPBES ES classification) (Díaz *et al.*, 2018). In order to assist this shift in paradigm more studies should focus not only on the ecosystem service potential of SNS but also on sacred trees and individual sacred objects having sacred value in the remaining matrices.

Internationally, SNS are recognized by the international bodies of IUCN (International Union for Conservation of Nature) and UNESCO (The United Nations Educational, Scientific and Cultural Organization) in which a guideline with best practices is devised for protected area managers and 'nature custodians' (indigenous people) in order to better manage SNS in and around protected areas across the globe (Verschuuren, 2018). The CBD (Convention on Biological Diversity), the UN permanent forum on indigenous issues, the UN declarations on the rights of indigenous peoples are also some of the international platforms which provided recognition to SNS worldwide (IUCN, 2010).

Church forests or sacred groves; the subsystem of SNS exist in many countries such as India (Anthwal *et al.*, 2010), Kenya (Metcalfe *et al.*, 2010), Zimbabwe (Byers *et al.*, 2001), China (Brandt *et al.*, 2013), Italy (Verschuuren, 2018). Forests preserved in this way serve as unofficial protected areas with local communities looking after them (Metcalfe *et al.*, 2010).

The last fragments of the natural forests in Ethiopia are found in churches around 35,000 which are spread across the country (Abbott, 2019). Forest fragments contained in the church Aerts et al.(2016); Aerts et al.(2006) and scattered trees in the matrix remain to be the last resorts of the natural vegetation. Material and non-material services are derived from these church forests (Klepeis *et al.*, 2016) including water retention, soil conservation, reservoir for local fauna, flora and also provision of fuel, fodder, timber, medicinal plants and holy water (Klepeis *et al.*, 2016; Endalew and Wondimagegnhu, 2019). The non-material services provided by church forests are burial grounds, funeral procession grounds, prayer, contemplation and ritual spaces, school grounds (Klepeis *et al.*, 2016). The use of these services is restricted to church rules and norms.

Apart from church forest fragments; the matrix habitat has a determinant effect on biodiversity (Prevedello, 2017). Vandermeer and Perfecto (2007) indicate the matrix is a corridor serving for the movement of plant and animal communities therefore is key for preventing extinction. It plays a major role in the functioning of the ecosystem due to large area coverage and connectivity (Levin *et al.*, 2008). Scattered trees in the matrix are also keystone structures for many species, and often contain similar species composition with the nearby forest habitat patches (Prevedello, 2017).

The type of the matrix, in addition to patch size and isolation determines biodiversity parameters in the patches such as species abundance and richness (Prevedello and Vieira, 2010). One of the factors determining the type of matrix depends on the scale of investigation i.e. at a finer scale the matrix could be 'mature forest' surrounding a forest fragment and at a broader scale the matrix could be agricultural land surrounding the mature forest fragments (Levin *et al.*, 2008). The agricultural matrix has also the capacity to affect individual abundance of species, species composition and assemblages of flora and fauna communities (Ferrante *et al.,* 2017).

Regardless of their role in maintaining biodiversity, the matrix is usually overlooked in most studies (Prevedello, 2017). Few studies have dealt with this issue in recent years highlighting the significance of the matrix and the need of the landscape approach dealing with restoration of church forests (Ricketts, 2001; Vasconcelos, 2006; Augusto and Marcus, 2009; Prevedello and Vieira, 2010; Ruffell *et al.,* 2017).

In view of this issue, this research tries to understand the potential of tree related ecosystem services in church forests in comparison to its agricultural matrix by: I. Comparing tree species diversity in church forests and in the agricultural matrix; II. Determining potential ecosystem services of trees in church forests and agricultural matrix and III. Comparing the ecosystem (tree) multi-functionality of church forests with agricultural matrix.

1.1 Problem statement

Several studies have dealt with church forest fragments in Ethiopia; so far, due attention is on the northern part of the country where there are significant number of churches under the mainstream faith ‘Orthodox Tewahido’. The focus of these studies range from ecological mainly biodiversity studies e.g. (Aerts *et al*., 2006; Wassie *et al.,* 2010a; Wassie *et al.,* 2010b) and qualitative assessment of ecosystem services of church forest fragments e.g. (Gokhale and Pala, 2011; Amare *et al.,* 2016). Despite of this, focusing only on fragments can do worse than good since the rest of the landscape referred to as the ‘matrix’ in this study and others are usually overlooked. Moreover, studies available on ecosystem services of church forests are rather qualitative assessments (Amare *et al.,* 2016). There is a need to quantify ecosystem services from both the church and the matrix to proper plan for conservation of biodiversity in the area.

What is in the matrix? Although, most of these studies lack to give due attention to individual scattered trees in the matrix spread across the landscape, these trees are said to shelter important microorganisms, fauna and flora communities of importance to local, regional and global biodiversity. For example, they are important landing areas for seasonal birds, arthropods and woody plants, e.g. (Prevedello, 2017). This study focuses not only on the ecosystem service potential but also the ecosystem multifunctionality of trees in the church forest and in the adjacent matrix with the aim of magnifying the role of trees in the matrix.

1.2 State of the art

1.2.1 Sacred groves: Importance and threats

1.2.1.1 Sacred groves as ‘ecological libraries’ for biodiversity conservation

Sacred groves are the spiritual living force for communities, biodiversity hotspots harboring many endemic fauna and flora of importance to the local and global diversity which are also repositories of the ancient religious and cultural links between people and nature. Generally speaking, the sizes of sacred groves range from <1 to >100 ha depending on factors such as location and management conditions (Ray and Ramachandra, 2010). Both large (>100ha) and small (<1ha) sacred groves in the middle of the landscape support diverse fauna and flora communities, provide important ecological services like pollination, seed dispersal, monetary services from restricted fuel wood or charcoal sell, medicinal plants and etc. (Wassie *et al.*, 2010b). indicate more than half of the tree species present in tropical north east Africa are also present in the sacred groves of the northern and central highlands of Ethiopia, more than two thirds of surveyed trees identified as native to Ethiopia (Aerts *et al.*, 2016a) (Lowman, 2011) identified insects with specimens representing 26 families of beetles.

The functional diversity of sacred groves reported in recent years also widens the trajectory of contributions of sacred groves from harboring biodiversity to sequestering carbon. The standing trees maintain a significant amount of SOC in the undisturbed soils. For instance, the biomass and carbon stock contribution of sacred groves of Kodagu district of Karnataka, India estimated to be 228-316 t ha^{-1} and 114-158 t ha^{-1} were either higher than some forests or in the same range as other types of forests in India. When this capacity is compared to the Amazonian forest with the maximum recorded accumulation of SOC 397.7t ha^{-1}; proves the significant contribution of the groves for climate change mitigation (Devakumar, 2018). Studies show that sacred groves can also serve adaptation to climate change through improved landscape connectivity and supporting local livelihoods through non-destructive resource use activities (Hailemariam, 2019). Sacred groves are also capable of stabilizing the micro and macro climatic conditions through interception of radiation, precipitation and increased water availability and moisture through infiltration, and stem flow often better work in the groves than the rest of the landscape (Ray and Ramachandra, 2010).

1.2.1.2 Institutional values of sacred groves

Sacred natural sites are the oldest form of environmental protection often more successfully kept compared to the official protected areas (Dudley *et al.*, 2009). Church forests are good examples of this form of nature protection since establishment of most of these churches dates back to thousands of years.

The Ethiopian Orthodox Tewahido Church (EOTC) as is the oldest religious institutions in Africa; it's institutional formation for the management of the church and the surrounding forest is a good model for modern schemes of habitat conservation. The robust social institution ruling church forests in Ethiopia has great archives for modern biodiversity conservation strategies across the globe (Reynolds *et al.*, 2015).

An example of this is of church forests in South Gondar zone. The highest authority; the church council ('Sebeka Gubaye') overlooks the church management such as timely payments of church priests, deliverance of mass services, facilitating church renovations with the available fund. The source of funding mainly comes from the community as a form of mandatory payments, external donations (philanthropy), grass and Eucalyptus sell from a land managed by the church (Orlowska and Klepeis, 2018).

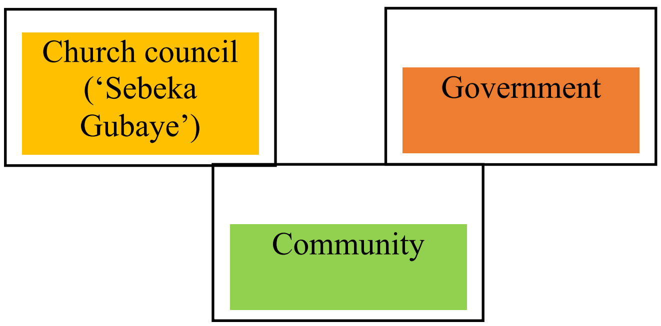

Figure 1. A hybrid model of conservation in Ethiopian church forests

Source: adapted from (Klepeis *et al.*, 2016)

'Sebeka Gubaye' is composed of the priests and 'lay members' (ordinary representatives) from the community. The council is responsible for the management of the church but not the forest surrounding the church (Orlowska and Klepeis, 2018). The respect for the protection of the forest encircling the church is instilled in the communities mainly because the forest is considered as the 'cloth of the church'(Lowman, 2011; Reynolds *et al.*, 2015) and anyone going against that will be punished by 'God'. In addition to this, communities protect the church forest because of the material (holy water, fresh water etc.) and non-material (funeral procession grounds 'Mahiber', burial ground, rituals, church schools) benefits from the spaces in the church (Reynolds *et al.*, 2015; Klepeis *et al.*, 2016). As land is owned by the state; the local government is entitled for ownership, but control is under the church and communities in the area. Although found in a fragile state; there is a lot to learn from this ancient church conservation model in order to make robust decisions for effective biodiversity conservation.

1.2.1.3 Threats to sacred groves

Deforestation and forest degradation are the biggest threats for tropical forests worldwide. More than half of these forests have been destroyed since the early 1960's and this is currently undergoing with more than a hectare of tropical forests are destroyed every second (IUCN, 2017). The global forest area is decreased by 3.3 million hectares between 2010 and 2015. Although the growing demand of land for agriculture is among the main drivers for deforestation; reasons are context specific and differ among countries (EFI, 2020). As a general theory indicated in (fig 2), human alterations of the land cause a decrease in biodiversity mainly because of loss of habitats and changing living conditions (slow changes in the local microclimate) of fauna and flora communities.

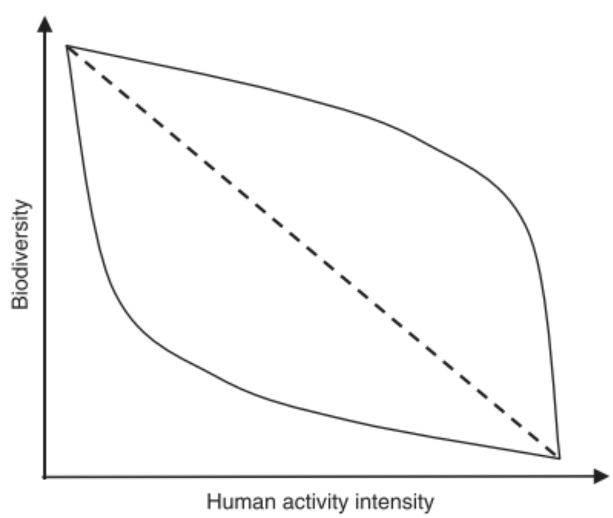

Figure 2. A hypothetical decay function between human activity intensity and biodiversity.

(A concave decay relationship (top curve) shows high biodiversity is maintained in medium or low human activity whereas low biodiversity is plausible when high human activity is involved (the convex curve). The linear dashed line represents the intermediate between the two conditions). Source: (Mendenhall *et al.*, 2013)

The main threats for sacred groves and SNS ranges from locally specific to global issues affecting many sacred sites around the world. A common denominator for most of these sites are encroachment, culture diffusion partly contributing to fading of cultural and religious values frequently linked with the younger generation, neglect from public officials and protected area managers about these sites. From researches done in Ethiopia; Reynolds et al.(2015) has compiled threats (table 1) to sacred groves in Ethiopia and their implication for biodiversity conservation and Cardelus et al. (2019) pointed out land conversion to agriculture increases forest fragmentation later magnified by human activities like the introduction of weedy species, native and exotic tree plantings, clearings for space and buildings in churches of Northern Ethiopia; as the main threat to sacred groves with significant negative effects on species richness, biomass and tree density.

Table 1. Threats to sacred groves and implication for biodiversity conservation in Ethiopia

Threats to sacred natural sites	Description and implications for biodiversity conservation
Economic drivers of forest degradation	Ancient church forests face threats from livestock grazing, but also from communities converting biodiverse forest patches to more economically rewarding *Eucalyptus* plantations.
Environmental drivers of forest degradation	Low species population densities and low natural regeneration, combined with climate change and associated threshold effects, threaten the long-term viability of indigenous groves.
Cultural/social shifts and changing demographics challenging forest "sacredness"	Institutions that have protected forests for centuries may be changing, shifting community norms away from conservation. Some church communities now prioritize economic rewards from planting exotic tree crops over traditional values from indigenous trees.

Source: (Reynolds *et al.*, 2015)

Some of the threats to the church forest conservation has come from the inside of the church in which the church favoring the construction of buildings and expansion of burial sites, additional spaces for church congregation sites by clearing the forest Reynolds et al.(2015); Cardelús et al. (2019) and disturbance by introduction of weedy species and the planting of exotic or native trees (Cardelús *et al.*, 2019). The planting of exotic tree species like *Eucalyptus globulus* in agricultural plots Matthies and Karimov (2014) and in and around the peripheries of the church at the expense of native tree species has been increasing in recent years (Liang *et al*., 2016).

Churches interests Klepeis et al.(2016) and farmers preference to this and other type of fast growing, financially rewarding trees brought the scare of forest degradation due to impacts on ecological health and loss of native plant species. The areas with Eucalyptus plantations exhibited higher acidic soils, lower soil organic matter and nutrient status (Liang *et al.*, 2016). Regardless of the effort to eradicate the widely planted Eucalyptus; it continues to be a threat to the remaining forest fragments (Aklilu *et al.*, 2019). Additionally, problems of forest encroachment due to livestock interference and reduced regenerative capacity due to low nutrient availability, increased soil compaction and severe edge effects in the smaller fragments are prevalent (Cardelus, 2012; Cardelús *et al.*, 2013, 2019). Cardelús et al. (2013) and Cardelús et al. (2019) explains, due to the small size, isolation from each other and increased edge effects compromising the survival of large canopy trees increases the vulnerability small fragments to be lost. Orlowska and Klepeis (2018) points out despite religious views remains strong in Ethiopia; relating the church to 'old and dense natural forest' composing of indigenous trees is slowly fading.

1.2.2 Biodiversity and ecosystem services of trees

The basic premise of existence and civilization of human beings are closely linked with forests and trees. Forests provide tangible and intangible services summarized in the recent NCP (Nature Contribution to People) as regulating, material and non-material NCP. Material NCP are objects, substances and materials that directly sustain the needs of people. Nonmaterial NCP enhances quality of life through its subjective and psychological effects. Regulating NCP are the functional and structural aspects of contributions that modify environmental conditions. The culture element of NCP spread throughout all the elements of NCP (Díaz *et al.*, 2018).

Nearly 1.6 billion people depend on forests for their livelihood, 300 million people live near forested landscapes and 30 percent of forests are used for the production of timber and non-timber forest products (UN,2011). A recent article by Gamfeldt et al. (2013) summarized ecosystem services potential of forests for biomass production, carbon storage, dead wood material, understory plant richness and other services; increase with increased species richness (better in five tree species than a single tree species). Although there are many exceptions related with factors of site and species limiting generalizations; several studies have proven the importance of species richness for improved ecosystem services.

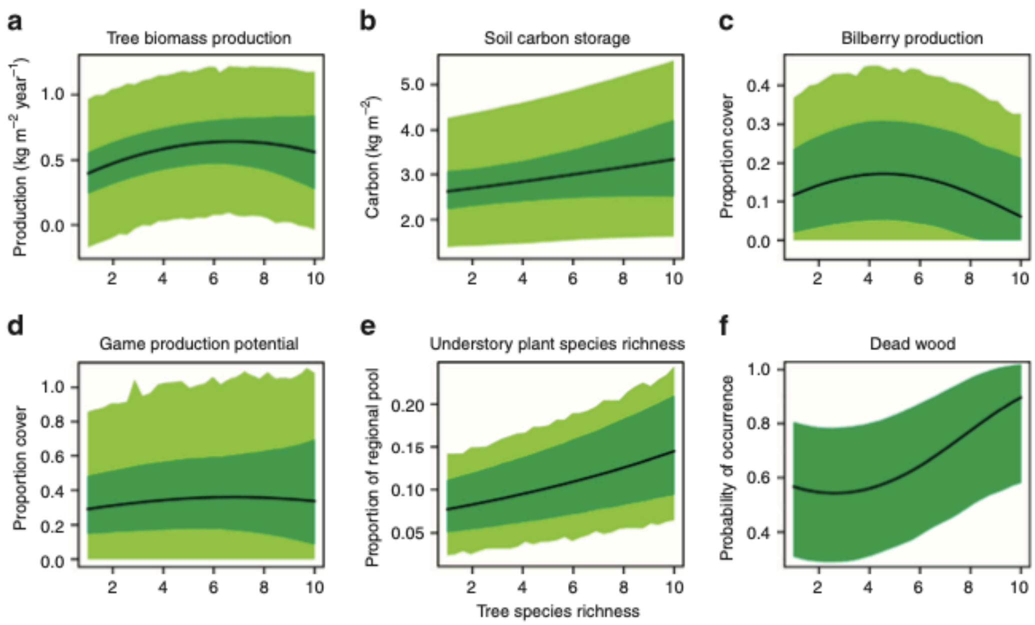

Figure 3. The relationship between plant species richness and ecosystem services

Source: (Gamfeldt *et al.*, 2013)

The theoretical premise between biodiversity and 'ecosystem function' interchangeably referred to as ecosystem services is described below in the fig (4). Type A relationship between biodiversity and ecosystem functions indicate that every species participates in the making of ecosystem functions including the rare species. There may be redundancy of services from same species in both A and B type of relationship. Type B curve indicates rather the opposite that not every species participates in making the ecosystem function or service. Presumably, with high biodiversity is expected a high return of ecosystem function depending on many factors. In this type of relationship the contribution of rare species to ecosystem function or service is low or the presence of similar species with no additional input explained by low level of biodiversity (Schwartz *et al.*, 2000).

Prevedello (2017) highlighted, single trees are also as important in maintaining the richness of other species like woody plants and animals (arthropods, vertebrates). Overall species richness for areas with scattered trees are 50 to 100% higher indicating the importance of trees for promoting high level of species richness.

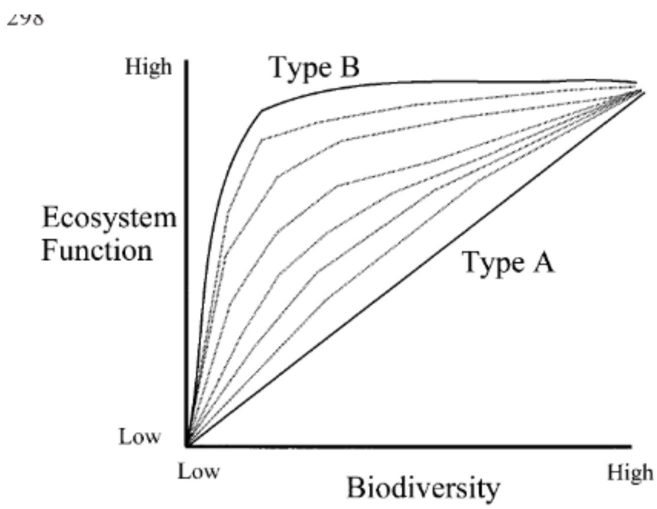

Figure 4. Relationship between biodiversity and ecosystem function

Source: (Schwartz *et al.*, 2000)

Studies show that, biodiversity plays an important role in providing many ecosystem services through ecosystem providers. Ecosystem service providers are ‘the component of populations, communities, functional groups, interaction networks or habitat types that provide ecosystem services’ (Luck *et al.*, 2009). The main ecosystem providers are vascular and non-vascular plants, terrestrial and aquatic invertebrates and microbes (Quijas and Balvanera, 2013). Additionally, genetic diversity, species diversity, functional diversity (traits affecting one or more aspects of the functioning of an ecosystem) Tilman (2001) and vertical diversity (the number of tropic levels) Zhao et al.(2019) are also identified as ecosystem providers (Quijas and Balvanera, 2013).

As a general overview; the decline of biodiversity has severe consequences from proportional to rapid and abrupt decline in ecosystem services and functions (fig 5) due to the loss of keystone species or the loss of the final member of a key functional group. Redundancy of plant species functions because of low species diversity results in a slow initial decrease but at later is accompanied by a rapid decline in services as indicated in fig (5). Apart from the theoretical premise; the outcome of biodiversity loss on the services varies depending on ecosystem service types, spatial and temporal factors (Quijas and Balvanera, 2013).

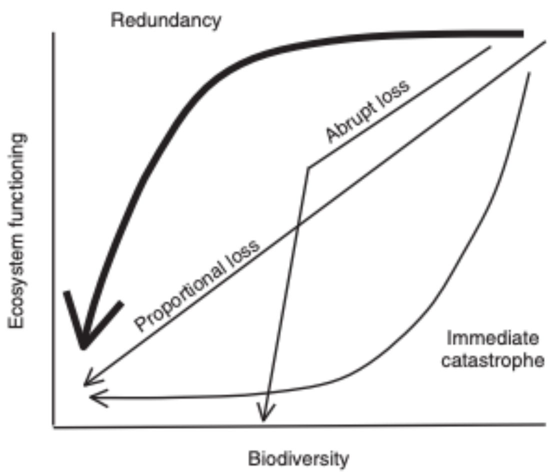

Figure 5. Ecological consequences of biodiversity loss

Source: (Quijas and Balvanera, 2013)

1.3 Aim, Hypothesis and Research questions

Sacred forests have reported to contribute immensely to biodiversity conservation majorly because they are the remnants of the natural vegetation which was once prevalent in an area. Their successful conservation model intertwines culture and nature which recently draw the international community interest to work for their conservation. Individual scientists like (Lowman, 2011) documented biodiversity of insects and mobilized funds for building conservation walls and a more organized effort by the IUCN and UNESCO prepared a guideline with best practices devised for protected area managers and 'nature custodians' (indigenous people) in order to better manage sacred forests in and around protected areas across the globe. This study aims to build on previous studies of church forests not only from the point of view of biodiversity but also ecosystem services and multifunctionality and highlighting their contribution by comparing their contributions with the adjoining agricultural matrix. Recent concerns of threats on church forests and similar small size fragments in a landscape can be addressed through a holistic approach were conservation efforts must include forest fragments and the rest of the matrix in the landscape. In general, a landscape approach to conservation is crucial to save the loss of forest fragments in an ecosystem.

The main objective of this study is therefore, to understand the potential of tree related ecosystem services in church forests in comparison to the agricultural matrix surrounding them. Accordingly, the following hypothesis and research questions are formulated:

H1. Church forests are the last remains of the natural forest thus contain high diversity of tree species compared to the rest of the landscape /agricultural matrix.

Q1. What is the diversity of tree species in church forests compared with the remaining agricultural landscape/matrix?

H2. Higher tree diversity in church forests contributes to higher potential ecosystem services than the agricultural matrix.

Q2. What are the potential ecosystem services provided by trees in church forests compared with the remaining agricultural matrix?

H3. Trees in the agricultural landscape matrix provide higher multi-functionality level of ecosystem services than church forests due to deliberate plantings to satisfy diverse community needs.

Q3. What is the ecosystem service multi-functionality of the agricultural matrix compared with church forests?

1.4 Overall approach of the thesis

The general approach of this study is indicated in the fig (6). Literature search on articles written about sacred groves were collected and read to identify studied and unstudied facts on the issue. After setting the objectives; the data was organized in a format suitable for analyzing each objective as presented in the first part of the study. Tasks for data analysis were enforced in a manner of answering each objective at a time. First, the diversity analysis was undertaken followed by ecosystem service and multifunctionality. Supporting literatures for each analytical procedure was also presented. Finally, results, discussions and recommendation were underway following the order set in the objectives in the first part of this study.

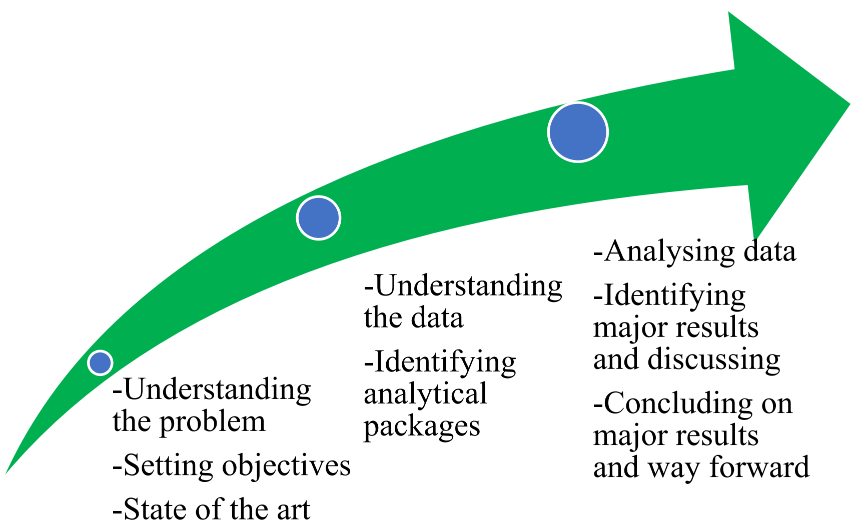

Figure 6. The general approach of the thesis

2. Materials and Methods

2.1 Study area and biophysical features

The Ethiopian highlands consists of plateaus and mountains with altitude of 1600 meter above sea level. Annual precipitation ranges between 600 mm in the North East to more than 2000m in the South West. Soil type varies with elevation and parent material mainly composed of Sandstone, Limestone and Volcanic rock. Major land uses in the highlands range from small holder farmland, scattered woodlot mostly for grazing of animals and small woodlots with Eucalyptus and Cupressus forming a mosaic of land uses in the landscape (Nyssen *et al.*, 2004, 2014; Teketay *et al.,* 2010).

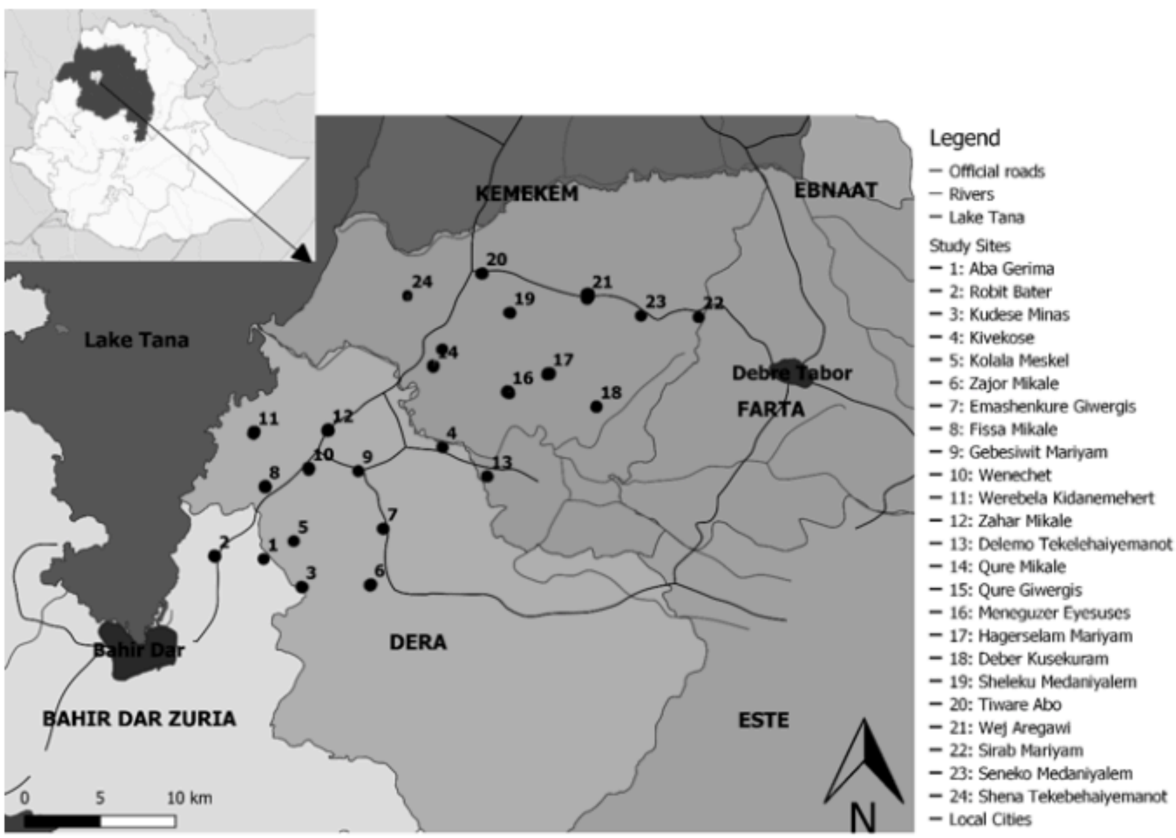

Figure 7. Map of the study area

Source: (Thirion, 2018 Unpublished)

The study area is situated in the East of Lake Tana (North western highlands) of Ethiopia. The 24 study sites selected for this study are located between the capital city Bahir Dar located in the South and Debre Tabor located in the North under three major districts (Bahir Dar Zuria, Dera and

Fogera) indicated in table (2). Under the Köppen climate classification system the area is classified under a subtropical highland climate (Cwb) with a yearly average rainfall of 1400mm (Thirion unpub, 2018). Major land use in the area is farming (52%), water bodies (20%), the forest cover including the plantations cover is around 5% (Aerts et al., 2006; Wassie, 2007; Demissie et al., 2017). Climatic conditions of the area vary with altitude and rainfall have a unimodal pattern (Thirion unpub, 2018). The main soil types are Leptosols, Luvisols, Cambisols, Rigosols, Arenosols, and wet Vertisols and Fluvisols (Wassie *et al.,* 2010b; Getahun and Selassie, 2017).

Figure 8. Church forests with stone walls

(February 25, 2020)

Some of the church forests are fenced with a stone wall; as a part of conservation effort to protect the forest under the church's vicinity (Fig 8). It is observed that Eucalyptus plantations are seen from the peripheries of the church forest all the way to the adjoining agricultural matrix. There are also small natural forest fragments scattered across the landscape similar with the Potential Natural Vegetation of the area (Thirion unpub, 2018).

Table 2. Study site (church) names and districts

Site names (code)	District	Age of church forest (years)
Aba Gerima (AGA)	Bahir Dar Zuriya	562
Kudese Minas (KMS)	Bahir Dar Zuriya	16
Robit Bater (RBR)	Bahir Dar Zuriya	659
Emashenkure Giwergis (EGS)	Dera	360
Fissa Mikale (FME)	Dera	483
Gebesiwit Mariyam (GMM)	Dera	770
Kivekose (KVE)	Dera	37
Kulala Mesekel (KML)	Dera	598
Wenechet (WET)	Dera	1680
Werebela Kidanemehert (WKT)	Dera	598
Zahar Mikale (ZIE)	Dera	1677
Zajor Mikale (ZME)	Dera	598
Deber Kusekuram (DKM)	Fogera	1012
Delemo Tekebehaiyemanot (DTT)	Fogera	338
Hagerselam mariyam (HMM)	Fogera	657
Meneguzer Eyesuses (MRE)	Fogera	338
Qure Giwergis (QGS)	Fogera	363
Qure Mikale (QME)	Fogera	338
Seneko Medaniyalem (SMM)	Fogera	338
Sheleku Medaniyalem (SMS)	Fogera	750
Shena Tekebehaiyemanot (STT)	Fogera	338
Sirab mariyam (SBM)	Fogera	457
Tiware abo (TEA)	Fogera	10
Wej Aregawi (WAI)	Fogera	137

2.2 Forest Inventory data collection

Sampling plots were systematically selected along the four cardinal directions (North, East, West, and South) in each of the church forests, but on different distances along the axis from the Church to edge. A total of four sampling plots with size of (20m x 20m) was employed to identify mature (i.e. diameter at breast height (DBH) $\geq$ 5 cm) and sapling (DBH<5 cm) trees. In each of the four sampling plots, all tree species were identified, counted (i.e. number of individuals present) and measured (i.e. height and DBH of each tree). DBH was measured at breast height (1.3m) when the height of the tree was >1.6m and at (10 cm) above the ground when the height is > 1 m and < 1.6 m. For buttress root trees and multiple stems, DBH was measured above the buttress and for multiple stems, all stems were counted and measured (Wassie *et al.*, 2010b).

Species identification was undertaken using 'identification keys', for those difficult to identify the 'Herbarium museum' located at the Addis Ababa University was used for identification.

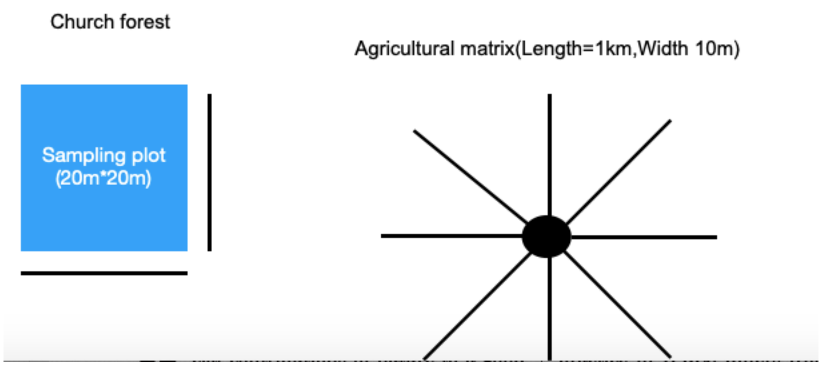

Figure 9. Determination of sample size for the Church forest and agricultural matrix

For the agricultural matrix in each of the 24 study sites, eight line transects (length=1km, width=10m) were set each starting at the boarder of the Church and sample was taken from the directions North, North-East, East, South-East, South, South-West, West, North-West (fig 1). The starting direction was selected randomly and continued in a clockwise direction (Fig 8). Tree height and Diameter at Breast Height (DBH) at 1.3m within the transect or overlapping crown cover was recorded.

The Height and DBH of species were measured using a 'Nikon Forestry Pro' rangefinder and diameter tape in both of the Church and the agricultural matrix. Garmin GPS 62s (a Nikon Forestry range finder, a compass) was used to delineate the transects and record the location of the data.

2.3 Data collection of Ecosystem services

For collecting ecosystem services in the agricultural matrix; 22 total respondents were chosen in which twelve respondents from Dera woreda, three respondents from Bahir Dar Zuriya woreda, three respondents from Fogera woreda and four respondents from Bahir Dar University. Interviews were conducted for the potential ecosystem services of each tree species in the agricultural matrices. These respondents were chosen purposely by selecting the most informed experts in the field (development agents, officers from the villages and agriculture office and plant protection officers). The list of ecosystem services included in the questionnaire was based on literature reviews and suggestions from local experts (Tekalign *et al.*, 2017). Similarly, for some of the tree species which are not recognized for their services by the experts a complementary analysis using literature search from Bekele (2007) and the Useful Tropical Plants database were used.

Later in the analysis these services were divided according to the classification of Millennium Ecosystem Service Assessment (MEA, 2005) for an overall view of church forests and agricultural matrix contribution in terms of provisioning, regulating and cultural services (Fig 10).
A separate sheet is established for potential ecosystem service of tree species in the Church forest. For this to be established literature search and inferring of species already identified for their services in the agricultural matrix was used as a reference. One was indicated for the species giving that specific service according to the literature and Zero was indicated for the service which is not offered.

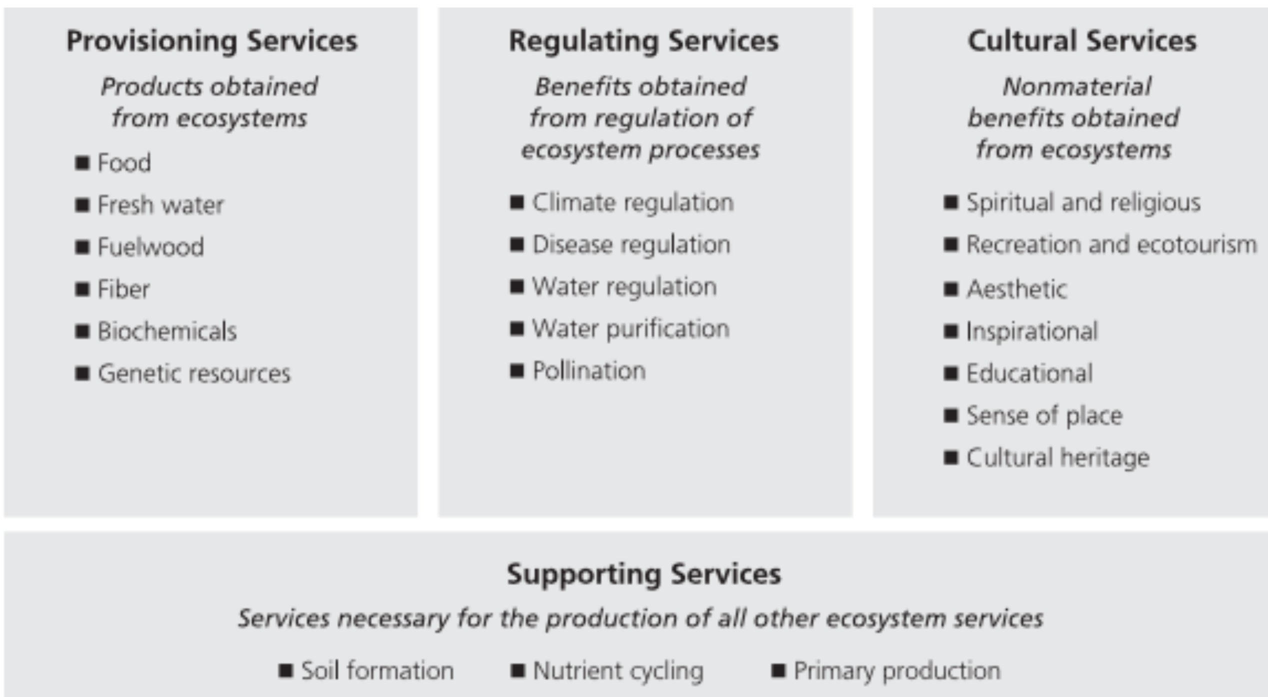

Figure 10. Millennium Ecosystem Service Assessment division of Ecosystem Services
Source: (MEA, 2005)

2.4 Data analysis

2.4.1 Diversity indices

For assessing diversity, Alpha (Species richness), Gamma, Shannon diversity, Simpson diversity and Shannon evenness were analyzed by using the species abundance data. The inventory data was transformed by the common logarithmic transformation (log10) to reduce skewedness of data due to differences in sample size (Aerts *et al.,* 2006). i.e. 0.16ha for the church and 8ha's for the agricultural matrix. This transformed data was used to calculate ecosystem service and the multifunctionality metrics of tree species.

Alpha diversity (α): regards to the count of species distinct to a certain area. It is the average species richness per site (Aerts *et al.,* 2006). Species richness is highly influenced by the sample size of an area. Therefore, statistical techniques such as logarithmic transformation indicated in Aerts *et al.*(2006) helps to reduce skewedness of data and make comparisons feasible. Gamma diversity (δ) is the total species richness (Whittaker, 1972; Aerts *et al.,* 2006).

Shannon- Wiener index (H'): takes both abundance and evenness into consideration. Depending on sample sizes used; the index value ranges between 0 to -4.6 but more commonly ranging between 1.5-3.5.

Formula:

$$H' = -\sum_{i=1}^{R} p_i \ln p_i$$

(Shannon and Weaver,1949)

Where: p_i= the proportion of individuals in the i^{th} species;

R=is the number of species in the sample

Simpson diversity index (D) is a dominance index which gives more weight to common species. Rare species in this case have no effect on the biodiversity of a certain area.

Formula:

$$D = 1 - \frac{\Sigma n(n-1)}{N(N-1)}$$ (Simpson, 1949)

Where: -

D= Simpson diversity index

n= the number of individuals of each different species

N= the total number of individuals of all species

Shannon Evenness Index (SEI): provides information on species composition and richness. The value of the evenness index varies in between 0 (no evenness) and 1(complete evenness).

Formula: SEI= (H')/ln (S), i.e. ln (S)= the natural logarithm of species richness.

$$H' = -\sum_{i=1}^{S} \frac{n_i}{N} \ln \frac{n_i}{N},$$

or

where ni is species abundance of species i and N is the number of all species/species richness (Chen and Zhou, 2015), 'S' is the species richness.

2.4.2 Ecosystem services calculations

From the church forest data on potential ecosystem services additional information was established, mainly per site data from the inventory of the church forest and its ecosystem service potential. This procedure is according to the methodology indicated by Tekalign et al. (2017) in which a cumulative weighted average calculation give rise to Ecosystem service of each tree species and each site (ES*Site matrix).

Last but not least, ecosystem services were analyzed not only per respective sites but also per respective services according to the classification of (MEA, 2005).

The Ecosystem Service Multifunctionality (ESM) metrics is analyzed using the 'averaging approach' indicated in Byrnes et al.(2014) computed based on species occurrence of each study sites and is compared with the its agricultural matrix done with similar procedure.

2.4.3 Statistical tests

The pairwise t test comparisons between respective means was undertaken by using Statistical Package for Social Sciences (SPSS v.16) in order to test significant differences between the diversity, ecosystem services and multifunctionality within and between the church and the agricultural matrix.

2.4.4 Regression analysis

Multiple Regression analysis was undertaken using SPSS. A number of independent variables were assessed in order to observe the relationship with the dependent variables and come up with a meaningful model predicting them. The dependent variables are Alpha diversity, Ecosystem services and multifunctionality of both the church and agricultural matrix and independent variables are age of the church, size of the church, altitude, latitude and longitude, distance from the capital city, distance from the river, presence or absence of stone wall around the church forest, number of households, type of land use (agriculture, agropastoral) in the adjoining agricultural matrix, the type of soil (haplic.luvisol, eutric.vertisol, chromic.luvisol) and distance from the nearest road. The independent variables were organized based on the available data collected, literature review and practical assumption on the presence of logical relationships given the conditions of the area of the church and the agricultural matrix.

After running each of the models, the data was checked if assumptions such as homoscedasticity, linearity and normality were met. In one instance, data transformation was applied in order to meet assumptions of normality using SPSS undertaking a two-step process involving fractional rank and Inverse Distribution Function (IDF) normal.

3. Results

3.1 Diversity of church forests and matrices

The highest alpha diversity is found in the church forest of Kudese Minas (KMS) with 23 tree species recorded, whereas the highest value for the matrix was recorded in Kivekose (KVE), with 15 tree species. The lowest alpha diversity in the church forest remains to be 8 at Qure Giwergis (QGS) whereas the lowest alpha diversity in the matrix is 3 species at Shena Tekebehaiyemanot (STT). Significant differences have been observed in the values of alpha diversity between the church forest and agricultural matrix (p-value= 0.00; t-value=-6.21). (I.e. alpha diversity indicates the presence of different kinds of species in an area) (Table 3). The average alpha diversity of the church is 14.3 (SE=0.71) and the matrix is 9.29 (SE=0.62).

A

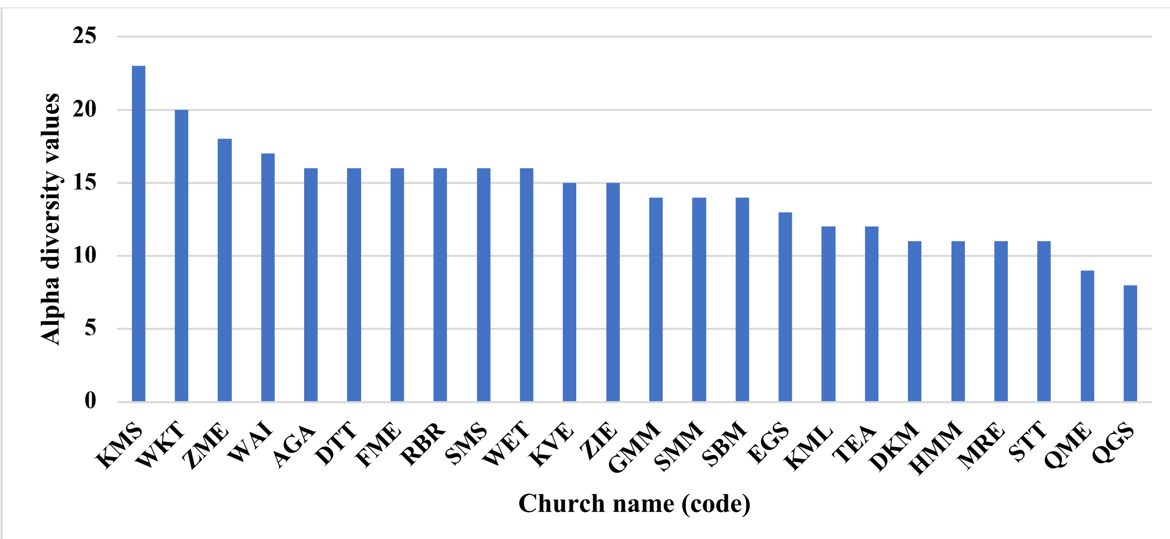

Figure 11. Alpha diversity (species richness) of church forests based on tree species abundance

B

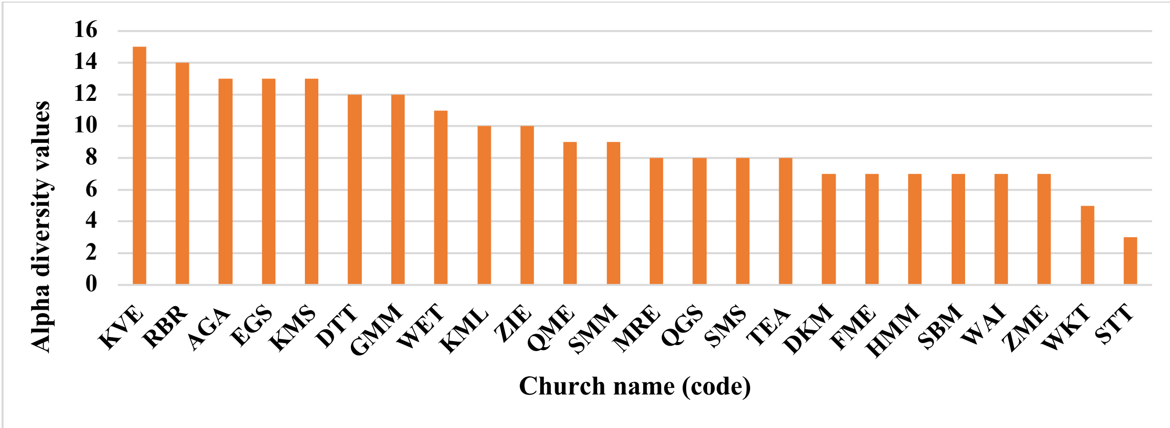

Figure 12. Alpha diversity (species richness) of agricultural matrices based on tree species abundance

Figure 13. Alpha diversity (local species richness) of the 24 church forests and adjoining agricultural matrices.

Church names: KVE (Kivekose), RBR (Robit Bater), AGA (Aba Gerima), EGS (Emashenkure Giwergis), KMS (Kudese Minas), DTT (Delemo Tekebehaiyemanot), GMM (Gebesiwit Mariyam), WET (Wenechet), KML (Kulala Mesekel), ZIE (Zahar Mikale), QME (Qure Mikale), SMM (Seneko Medaniyalem), MRE (Meneguzer Eyesuses), QGS (Qure Giwergis), SMS (Sheleku Medaniyalem), TEA (Tiware abo), DKM (Deber Kusekuram), FME (Fissa Mikale), HMM (Hagerselam mariyam), SBM (Sirab mariyam), WAI (Wej Aregawi), ZME (Zajor Mikale), WKT (Werebela Kidanemehert), STT (Shena Tekebehaiyemanot).

A

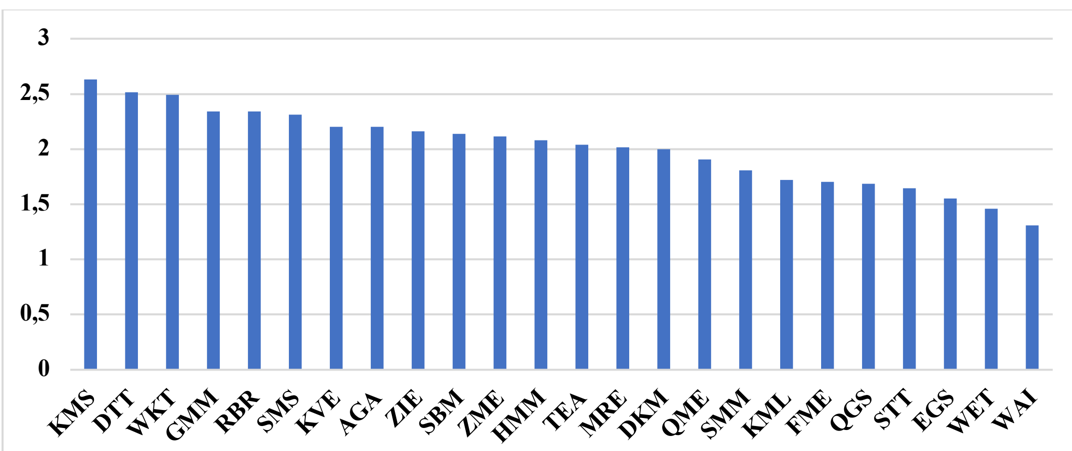

Figure 14. Shannon diversity index of church forests based on tree species abundance

B

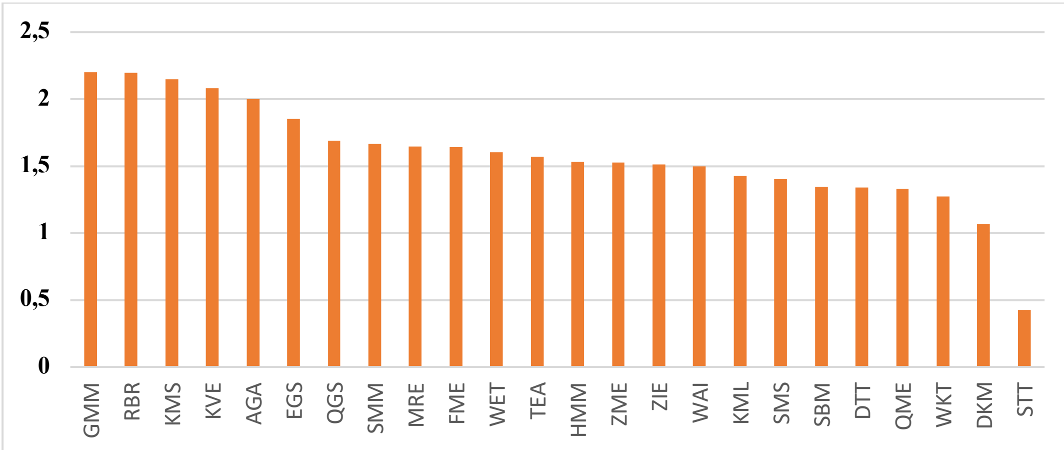

Figure 15. Shannon diversity index of agricultural matrices based on tree species abundance

Figure 16. Shannon diversity index of the church forest and agricultural matrix

Church names: KVE (Kivekose), RBR (Robit Bater), AGA (Aba Gerima), EGS (Emashenkure Giwergis), KMS (Kudese Minas), DTT (Delemo Tekebehaiyemanot), GMM (Gebesiwit Mariyam), WET (Wenechet), KML (Kulala Mesekel), ZIE (Zahar Mikale), QME (Qure Mikale), SMM (Seneko Medaniyalem), MRE (Meneguzer Eyesuses), QGS (Qure Giwergis), SMS (Sheleku Medaniyalem), TEA (Tiware abo), DKM (Deber Kusekuram), FME (Fissa Mikale), HMM (Hagerselam mariyam), SBM (Sirab mariyam), WAI (Wej Aregawi), ZME (Zajor Mikale),WKT (Werebela Kidanemehert), STT (Shena Tekebehaiyemanot). Shannon diversity index (H') value ranges between (0 -4.6) but more commonly ranging between (1.5-3.5).

The highest and lowest Shannon diversity index for the church forest sites were observed at Kudese Minas (KMS) 2.63 and at Wej Aregawi (WAI) 1.31 respectively. In the agricultural matrix, the highest Shannon diversity index was 2.19 at Emashenkure Giwergis (EGS) and the lowest was 0.42 at Wej Aregawi (WAI) sites. There are significant differences of Shannon diversity index values (p-value=0.00; t-value=4.78) between the church forest and agricultural matrix indicating differences in the diversity of the church and agricultural matrix. The average Shannon diversity index for the church is 2 (SE=0.07) and for the matrix is 1.5 (SE=0.08) indicating that there is high diversity in the church than the agricultural matrix. (I.e. high Shannon diversity indicates high species richness and evenness).

A

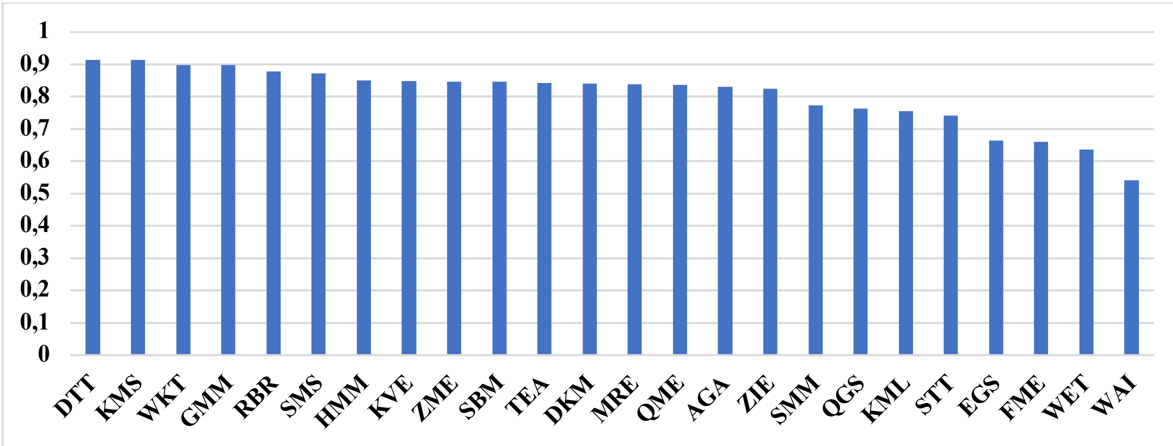

Figure 17. Simpson diversity index of church forests based on tree species abundance

B

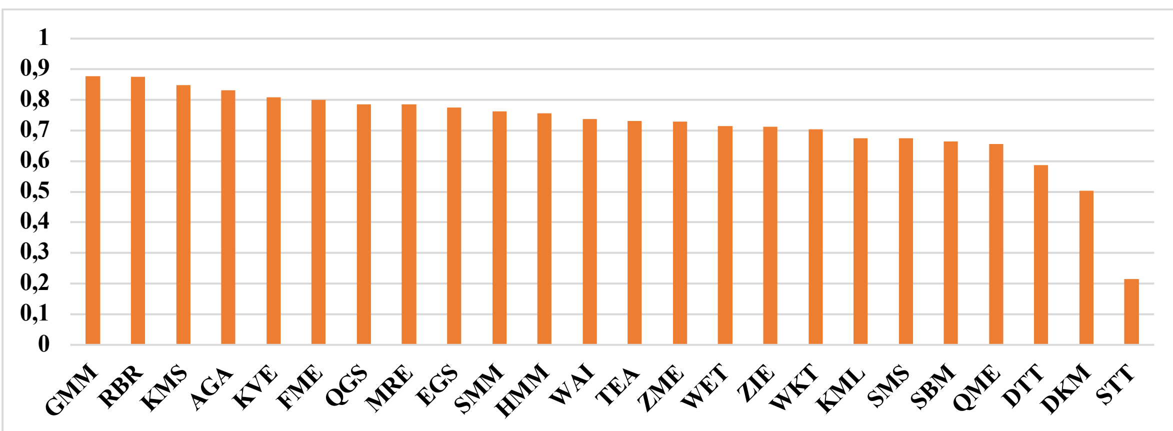

Figure 18. Simpson diversity index of agricultural matrices based on tree species abundance

Figure 19. Simpson diversity index of the church forest and agricultural matrix

Church names: KVE (Kivekose), RBR (Robit Bater), AGA (Aba Gerima), EGS (Emashenkure Giwergis), KMS (Kudese Minas), DTT (Delemo Tekebehaiyemanot), GMM (Gebesiwit Mariyam),WET (Wenechet), KML (Kulala Mesekel), ZIE (Zahar Mikale), QME (Qure Mikale), SMM (Seneko Medaniyalem), MRE (Meneguzer Eyesuses), QGS (Qure Giwergis), SMS (Sheleku Medaniyalem), TEA (Tiware abo), DKM (Deber Kusekuram), FME (Fissa Mikale), HMM (Hagerselam mariyam), SBM (Sirab mariyam), WAI (Wej Aregawi), ZME (Zajor Mikale), WKT (Werebela Kidanemehert), STT (Shena Tekebehaiyemanot). Simpson diversity index (D) value ranges between (0 -1).

The highest Simpson diversity index in the church forest is 0.91 at (Delemo Tekebehaiyemanot DTT) and the lowest is 0.54 at Wej Aregawi (WAI) church forest sites. For the matrix, the highest observed is 0.87 at Gebesiwit Mariyam (GMM) and the lowest is 0.21 at Shena Tekebehaiyemanot (STT). Taking into account per site comparisons of the church and the matrix; pairwise t tests of

Simpson diversity indices indicate that there are significant differences (p-value=0.01; t-value=2.67) between the diversity of the church and the agricultural matrix.

The average Simpson diversity index for the church forest is 0.8 (SE=0.02) and for the matrix is 0.7 (SE=0.02) indicating that there is high diversity of tree species in the church forest than the agricultural matrix. I.e. This index takes into account both richness and evenness.

A

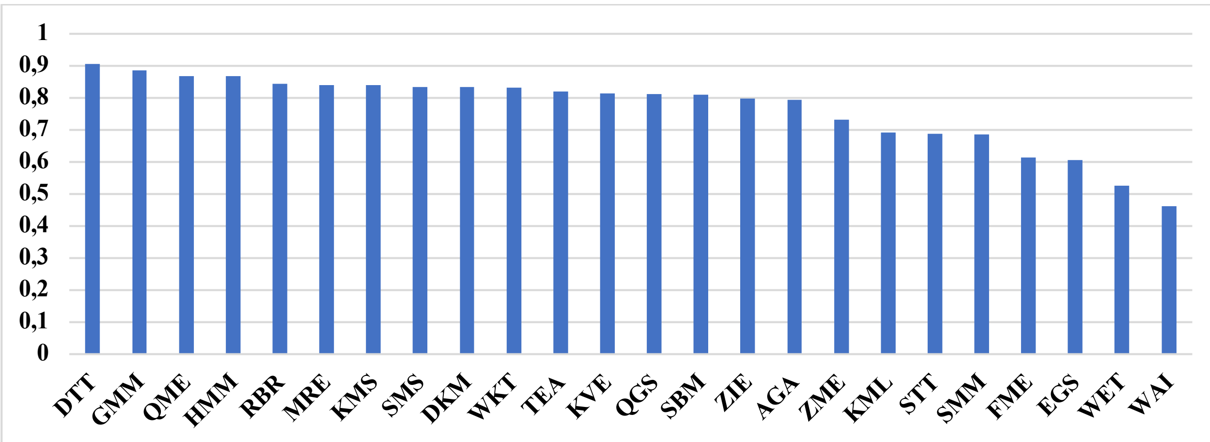

Figure 20. Shannon evenness index of church forests based on tree species abundance

B

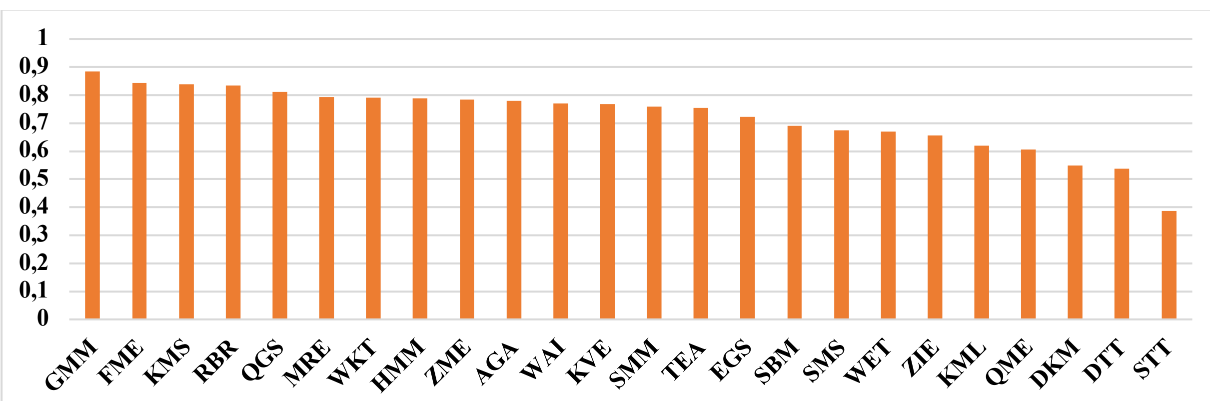

Figure 21. Shannon evenness index of agricultural matrices based on tree species abundance

Figure 22. Shannon evenness index based on species abundance of the church forest and agricultural matrix

Church names: KVE (Kivekose), RBR (Robit Bater), AGA (Aba Gerima), EGS (Emashenkure Giwergis), KMS (Kudese Minas), DTT (Delemo Tekebehaiyemanot), GMM (Gebesiwit Mariyam), WET (Wenechet), KML (Kulala Mesekel), ZIE (Zahar Mikale), QME (Qure Mikale), SMM (Seneko Medaniyalem), MRE (Meneguzer Eyesuses), QGS (Qure Giwergis), SMS (Sheleku Medaniyalem), TEA (Tiware abo), DKM

(Deber Kusekuram), FME (Fissa Mikale), HMM (Hagerselam mariyam), SBM (Sirab mariyam), WAI (Wej Aregawi), ZME (Zajor Mikale), WKT (Werebela Kidanemehert), STT (Shena Tekebehaiyemanot). Shannon eveness index value ranges between 0 (no evenness) and 1 (complete evenness).

The highest value for Shannon evenness index in the church forests is 0.9 at Delemo Tekebehaiyemanot (DTT) and the lowest value is 0.46 at Wej Aregawi (WAI). Similarly, for the matrix, the highest Shannon evenness index is observed at Gebesiwit Mariyam (GMM) 0.88 and the lowest is at Shena Tekebehaiyemanot (STT) 0.38. The average value for Shannon evenness index of the church forest is 0.76 (SE= 0.02) whereas for the matrix 0.72 (SE=0.02) indicating no significant differences of species evenness between the church and agricultural matrix (p-value=0.17; t-value=1.39) (table 3). I.e. Shannon evenness provides information on area composition and species richness.

Out of all the sites of the church and agricultural matrices; Wej Aregawi (WAI) and Shena Tekebehaiyemanot (STT) holds the lowest Alpha diversity (except for the church forest), Shannon diversity, Simpson diversity and Shannon evenness values indicating that there may be is a single species dominating these sites.

Table 3. Pair wise t-test comparison of the diversity indices of church forest and agricultural matrix

	Variables	Mean	Stan.dev	Std.error mean	t-value	p-value	Sig.
Church	**Species abundance**	94.87	54.92	11.21	8.39	.000	**
Matrix		0.84	0.38	0.07			
Church	**Species basal area**	2.08	1.31	0.26	7.26	.000	**
Matrix		0.14	0.07	0.01			
Church	**Alpha diversity**	14.3	3.43	0.7	-6.21	.000	**
Matrix		9.29	3.02	0.61			
Church	**Shannon diversity**	2.02	0.34	0.07	4.78	.000	**
Matrix	**index**	1.58	0.39	0.08			
Church	**Simpson diversity**	.08	0.09	0.02	2.67	.014	**
Matrix	**index**	0.72	0.14	0.02			

Church	Shannon evenness	0.76	0.12	0.02	1.39	0.17	ns
Matrix	index	0.72	0.12	0.02			

i.e. ((**) indicate p-value<0.05); ns indicate non significance)

Significant differences in species abundance alpha diversity, Shannon and Simpson diversity indicate differences in the diversity of tree species present in the church and agricultural matrix. Regarding gamma diversity, average values indicates higher overall diversity within the church forests 14.3 (SE=0.7) than the agricultural matrices 9.29 (SE=0.62).

3.2 Ecosystem Service and Ecosystem service multifunctionality of church forests and matrices

Unlike the results from species diversity for site WAI indicating low diversity; the highest ES is delivered from Wej Aregawi (WAI) for the church forest site. This may be because of single species (common or dominant) fulfilling the ecosystem service needs in this site. The lowest ES is from Aba Gerima (AGA) and Gebesiwit Mariyam (GMM) church forest sites (fig 23).

A

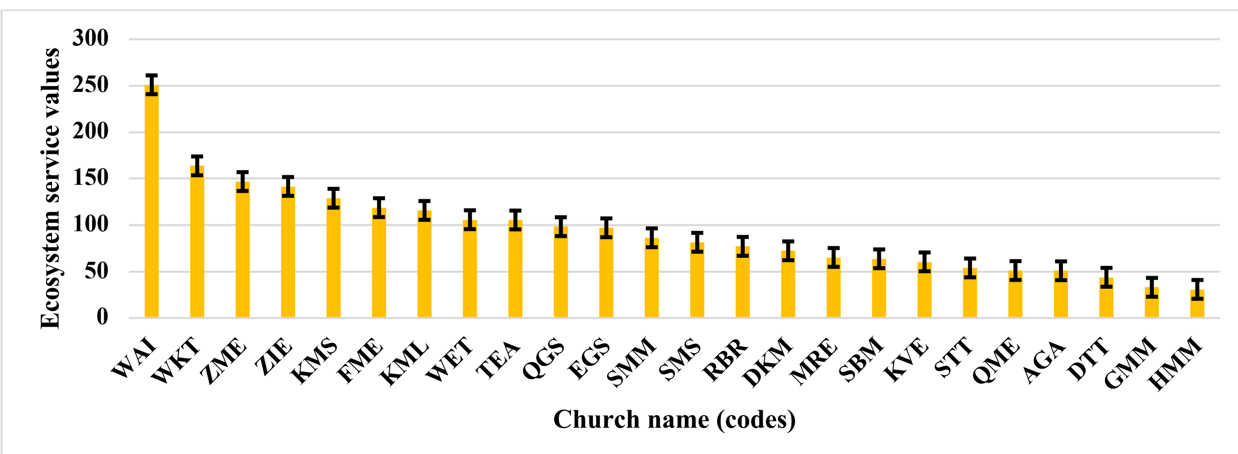

Figure 23. Potential Ecosystem services of tree species in church forests

B

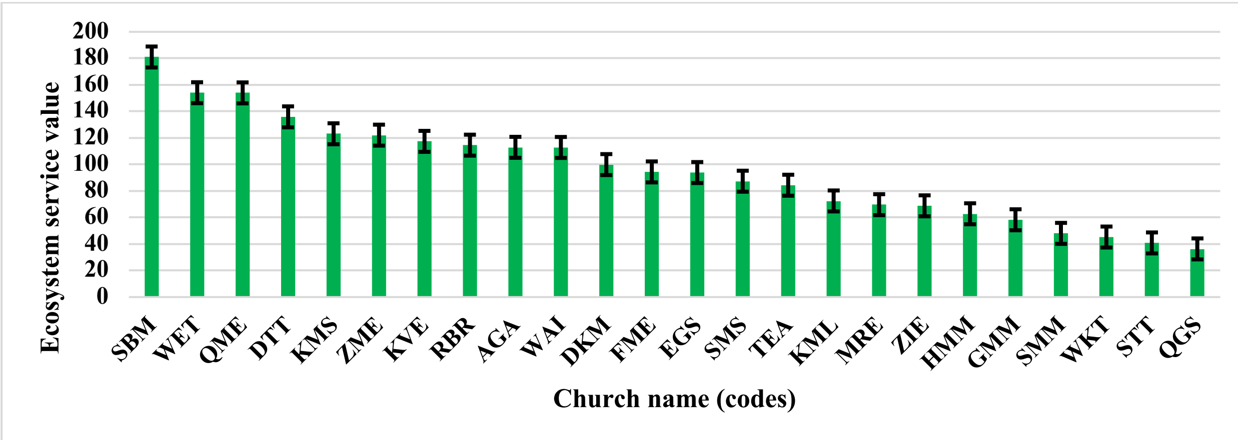

Figure 24. Potential Ecosystem services of tree species in the agricultural matrix

Figure 25. Potential Ecosystem services of tree species in church forests and agricultural matrix

Church names: KVE (Kivekose), RBR (Robit Bater), AGA (Aba Gerima), EGS (Emashenkure Giwergis), KMS (Kudese Minas), DTT (Delemo Tekebehaiyemanot), GMM (Gebesiwit Mariyam), WET (Wenechet), KML (Kulala Mesekel), ZIE (Zahar Mikale), QME (Qure Mikale), SMM (Seneko Medaniyalem), MRE (Meneguzer Eyesuses), QGS (Qure Giwergis), SMS (Sheleku Medaniyalem), TEA (Tiware abo), DKM (Deber Kusekuram), FME (Fissa Mikale), HMM (Hagerselam mariyam), SBM (Sirab mariyam), WAI (Wej Aregawi), ZME (Zajor Mikale), WKT (Werebela Kidanemehert), STT (Shena Tekebehaiyemanot).

For the agricultural matrices found adjacent to the church forests, the highest average potential ecosystem services are offered by Sirab mariyam (SBM) and the least of these services are provided by Shena Tekebehaiyemanot (STT) (fig 24); the p-values indicating no significant differences of ES provided within the different sites of agricultural matrices (p-value= 0.25; t-value= -1.2) (Table 4).

The average ES of the church is 2711.32 (SE=10.12) and agricultural matrix is 2767.45 (SE=7.91). Although the difference in the average ES of the church and the matrix is not significant (table 4). Contrary to this, per site comparisons of church forests shows significant differences in ES indicating there is indeed differences in the ecosystem services provided within church forests.

Table 4. Pair wise t-test comparison of ES of the church forest and agricultural matrix

	Variables	Mean	Std. dev	Std.error mean	t-value	p-value	Sig.
Church	ES	93.4	49.5	10.1	-0.14	0.88	ns
Matrix		95.4	38.7	7.91			
Church	**ES within church**	**76.2**	**34.4**	**9.95**	**-2.44**	**0.03**	**
		110.6	**57.4**	**16.5**			
Matrix	ES within matrix	87.9	35.8	10.3	-1.2	.255	ns
		102.8	41.6	12.0			
Church	**ES provisioning**	**63.6**	**33.5**	**6.85**	**-2.45**	**.022**	**
Matrix		**88.7**	**36.1**	**7.38**			
Church	**ES regulating**	**6.75**	**1.33**	**0.27**	**-11.36**	**.000**	**
Matrix		**1.04**	**42.2**	**8.63**			
Church	ES cultural	1.07	52.1	10.6	-0.7	0.48	ns
Matrix		1.17	46.7	9.54			
Church	**ESMF**	**0.5**	**0.12**	**0.02**	**-11.88**	**0.00**	**
Matrix		**0.76**	**0.16**	**0.00**			
Church	**ESMF within church**	**0.58**	**0.05**	**0.01**	**6.23**	**0.00**	**
		0.41	**0.11**	**0.03**			
Matrix	**ESMF within matrices**	**0.77**	**0.00**	**0.00**	**15.65**	**.038**	**
		0.74	**0.01**	**0.00**			

i.e. ((**) indicate p-value<0.05); ns indicate non significance)

Following the ecosystem services classification after the Millennium Ecosystem Assessment (MEA); both church forests and respective agricultural matrices provide provisioning services, and this is significantly higher in church forests (p-value= 0.02; t-value= -2.45). Contrary to the assumption that church forests provide higher regulating services; it was found that agricultural matrices provide much higher regulating services. The average of the regulating services; church forests provide is 40.5 (SE= 1.62) and agricultural matrix is 729.6 (SE= 60.4) and this difference is found to be significant (p-value= 0.00; t-value=-11.36).

Contrary to the assumption that cultural ecosystem services are higher in the church forest than the agricultural matrix; both of the areas provide cultural Ecosystem services and the difference is found to be not significant (Table 4).

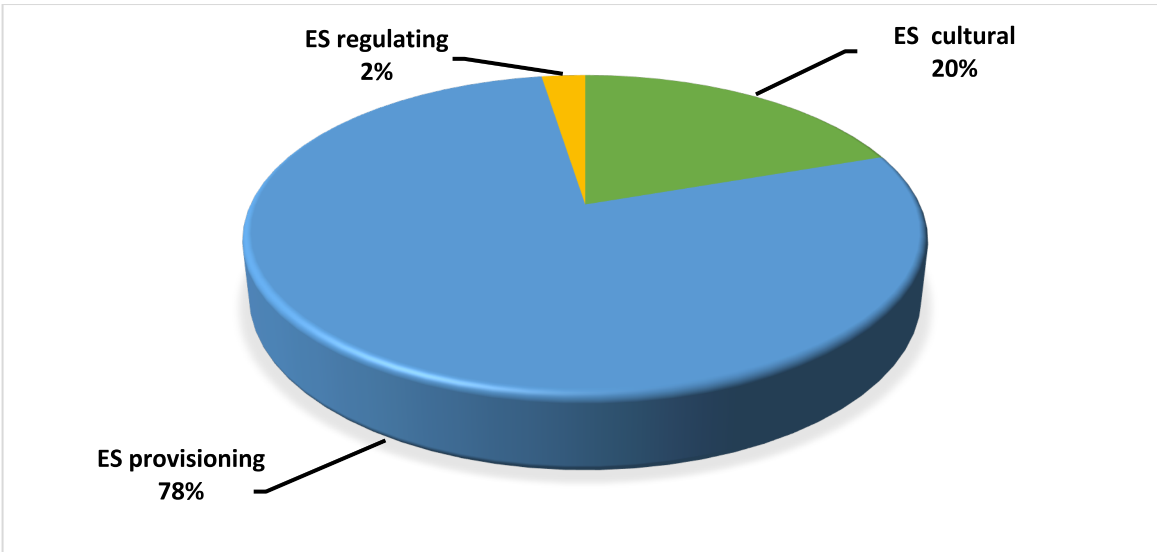

Figure 26. Ecosystem services in church forests (MEA classification)

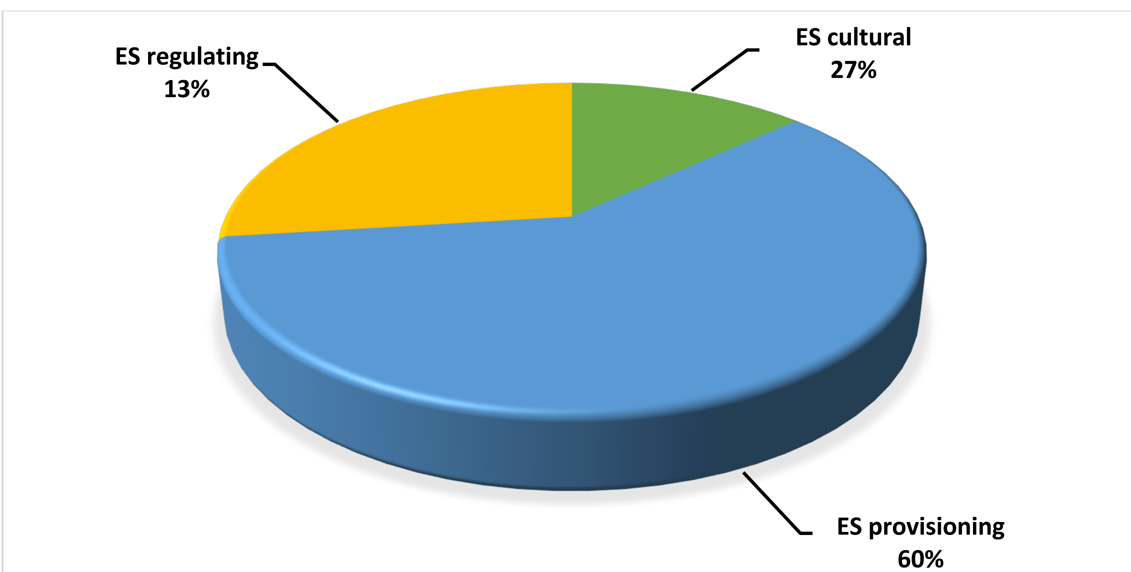

Figure 27. Ecosystem services in agricultural matrix (MEA classification)

A

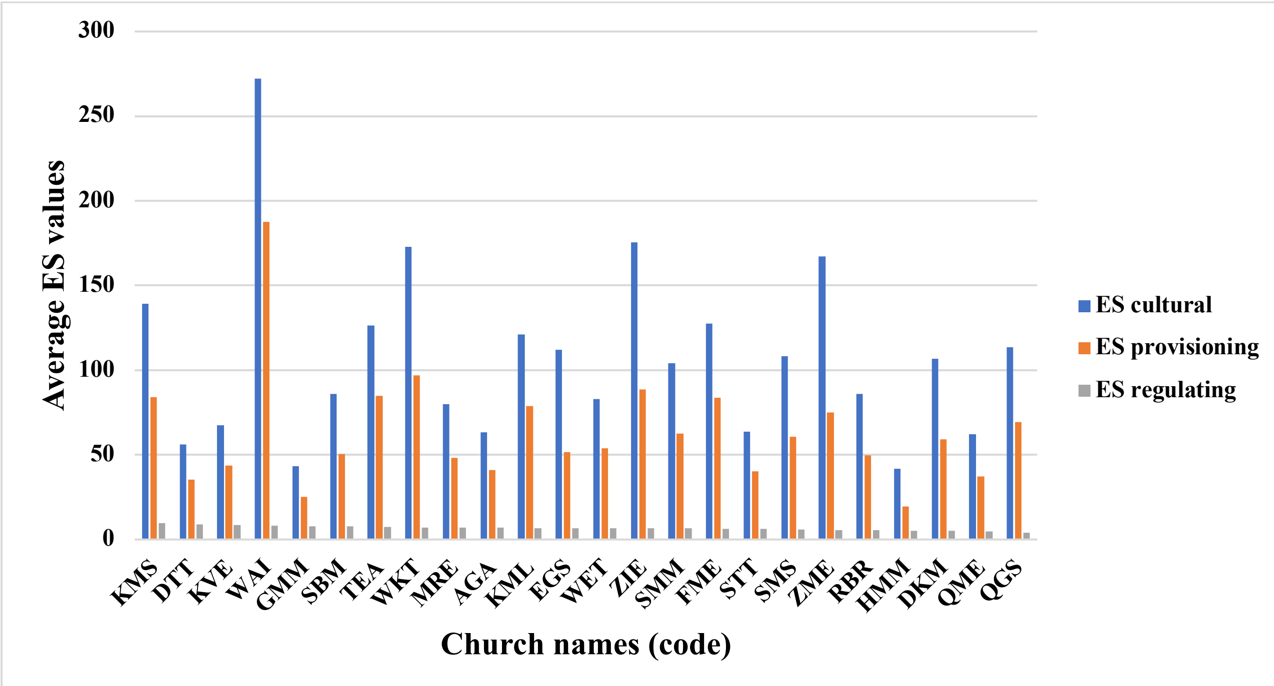

Figure 28. Potential ecosystem services of the church forest based on MEA classification.

For church forest sites; out of the 24 churches included in the study; Wej Aregawi (WAI) provide the highest provisioning and cultural services than any other study site. Following are Werebela Kidanemehert (WKT) and Zahar Mikale (ZIE) with second, third highest on provisioning services. For cultural services; Zahar Mikale (ZIE), Werebela Kidanemehert (WKT), Zajor Mikale (ZME) provide the highest cultural services from the rest of the study sites. Kudese Minas (KMS) is the highest and Qure Giwergis (QGS) is the lowest on provision of regulating services. Compared with the provisioning and cultural services; regulating services were found to be relatively small in all church forests. However, Kudese Minas (KMS), Delemo Tekebehaiyemanot (DTT), Kivekose (KVE) provided the highest regulating services compared to the remaining church forests. In all of the church forest sites ES cultural services are the biggest followed with ES provisioning and regulating services. It is also observed that for church forest sites with increased cultural services there is also increased provisioning services and vice versa (fig 28).

B

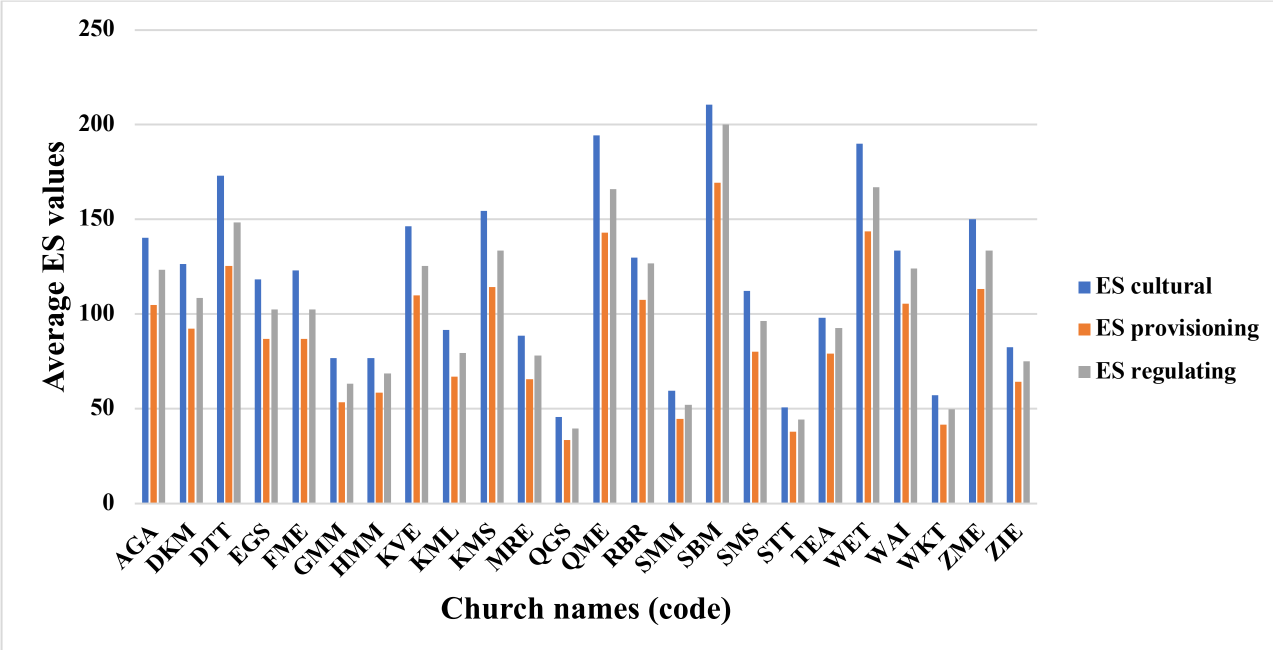

Figure 29. Potential ecosystem services of the agricultural matrix based on MEA classification

Figure 30. Potential ecosystem services of church forests and agricultural matrix based on MEA classification

Church names: KVE (Kivekose), RBR (Robit Bater), AGA (Aba Gerima), EGS (Emashenkure Giwergis), KMS (Kudese Minas), DTT (Delemo Tekebehaiyemanot), GMM (Gebesiwit Mariyam), WET (Wenechet), KML (Kulala Mesekel), ZIE (Zahar Mikale), QME (Qure Mikale), SMM (Seneko Medaniyalem), MRE (Meneguzer Eyesuses), QGS (Qure Giwergis), SMS (Sheleku Medaniyalem), TEA (Tiware abo), DKM (Deber Kusekuram), FME (Fissa Mikale), HMM (Hagerselam mariyam), SBM (Sirab mariyam), WAI (Wej Aregawi), ZME (Zajor Mikale), WKT (Werebela Kidanemehert), STT (Shena Tekebehaiyemanot).

In the matrix, ES cultural, provisioning and regulating services seem to increase and decrease together. i.e. from the fig (29), for sites with increase of ES cultural service, there seems to be an increase in regulating and provisioning services and vice versa. It is also observed that, ES cultural services are the highest from the rest of the services following with regulating and provisioning services. The highest cultural ES provision is derived from SBM and the lowest is from QGS. For provisioning services, the highest is from SBM and the lowest is from QGS. For regulating services, the highest is from SBM and the lowest is from QGS. Although, the differences in different ES within the study sites of the matrices is found to be non-significant (p-value= 15.65; t-value= 0.00) (Table 4).

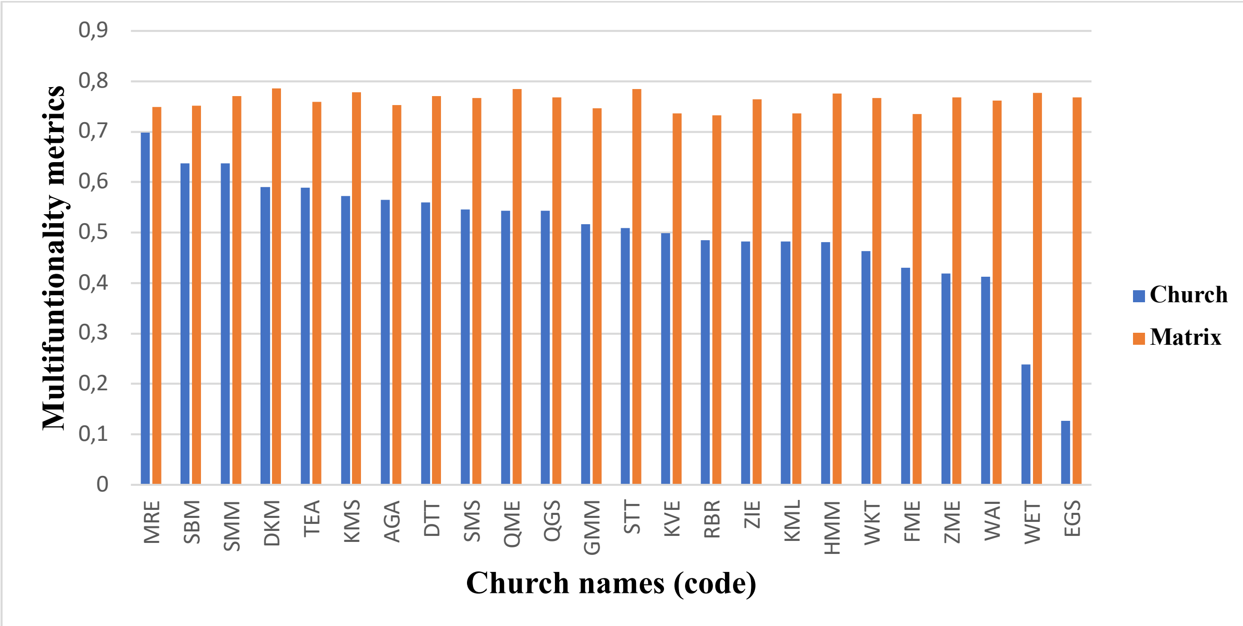

Figure 31. ES multifunctionality scores of church forests and agricultural matrix

Church names: KVE (Kivekose), RBR (Robit Bater), AGA (Aba Gerima), EGS (Emashenkure Giwergis), KMS (Kudese Minas), DTT (Delemo Tekebehaiyemanot), GMM (Gebesiwit Mariyam), WET (Wenechet), KML (Kulala Mesekel), ZIE (Zahar Mikale), QME (Qure Mikale), SMM (Seneko Medaniyalem), MRE (Meneguzer Eyesuses), QGS (Qure Giwergis), SMS (Sheleku Medaniyalem), TEA (Tiware abo), DKM (Deber Kusekuram), FME (Fissa Mikale), HMM (Hagerselam mariyam), SBM (Sirab mariyam), WAI (Wej Aregawi), ZME (Zajor Mikale), WKT (Werebela Kidanemehert), STT (Shena Tekebehaiyemanot).

For ES multifunctionality, (fig 31) indicates nearly all sites in the matrix scored high ES multifunctionality values compared with the church forest sites and this difference is found to be significant.

Significant differences were also observed between ES multifunctionality within church forests and within their agricultural matrices (p-value= 0.00; t-value= -11.8) (Table 4).

3.3 Factors explaining diversity, Ecosystem services and Ecosystem service multifunctionality

Multiple regression analysis was undertaken to explain further the factors affecting the diversity, ES and ESMF. With regards to the church forest variables best determining local species richness are listed in (table 5). Results show that the size of the church is correlated positively with alpha diversity of species in the church. The model best explaining the dependent variable local species richness or alpha diversity is with an R^2 of 0.85 explaining 85% of existing variability within the dependent variable and this is significant with a p-value of 0.01 (Table 5).

Table 5. Multiple regression analysis of Alpha diversity of the church forest

	R^2 0.85	B-weight	Std.error	t-value	F-value 4.35	p-value 0.01**
Indep varia.						
Altitude		0.003	0.006	0.51		0.61
Distbd		-8.740E-5	0.00	-1.13		0.28
Age		-0.001	0.00	-0.85		0.41
Size		**0.87**	**0.23**	**3.69**		**0.00****
Stone wall		-0.91	1.27	-0.71		0.49
Soil type		0.41	0.75	0.55		0.59
Land use		0.23	1.68	0.14		0.89
Distriver		6.93E-5	0.00	0.33		0.74
Distnr		0.000	0.00	1.46		0.17
Household		-0.001	0.00	-0.98		0.34
Natural forest		3.79	1.95	1.94		0.08
Latdeci		12,83	12.69	1.01		0.33
Longdeci		-	-	-		-
Alphadiv mat		0.09	0.21	0.41		0.69

(Dependent variable: Alpha diversity in the church; (**) indicate p value <0.05)

For local species richness in the agricultural matrix (alpha diversity matrix), the model selected is with an R^2 of 0.86 explaining 86% of the variability. Distance from the main city Bahir Dar and the number of households are negatively and positively correlated with alpha diversity in the agricultural matrices (Table 6).

Table 6. Multiple regression analysis of Alpha diversity of the agricultural matrix

	R^2 0.86	B weight	Std.error	t-value	F-value 4.42	p-value 0.01
Indep.vari						
Alphadiv chur		68	38.8	1.75		0.17
Altitude		0.99	0.68	1.45		0.27
Distbd		**-0.03**	**0.01**	**-3.75**		**0.01****
Age		-0.07	0.14	-0.48		0.5

Size	-94.7	42.5	-2.22	0.41
Stonewall	-276.2	134.5	-2.05	0.15
Soil type	126.3	79.1	1.59	0.15
Land use	-486.5	214.5	-2.26	0.2
Dstriver	0.1	0.02	3.60	0.31
Distnr	-0.03	0.03	-1.07	0.14
Household	**0.68**	**0.15**	**4.34**	**0.00****
Natural forest	-1048.9	371.5		0.38
Latdeci	-	-	-	0.54
Longdeci	2289.9	6678.7	-2.82	0.54

(Dependent variable: Alpha diversity in the matrix; (**) indicate p value <0.05)

For church forest ES, the size of the church and distance from a river both positively correlate with the dependent variable. The model best explaining the variability in the dependent variable is with an R^2 of 0.87; thus 87% of the variability present is explained by this model (Table 7).

Table 7. Multiple regression analysis of church ecosystem services

	R^2 0.87	**B-weight**	**Std.error**	**t-value**	**F-value 4.32**	**p-value 0.01**
Indep varia.						
Alphadiv chur		-0.47	4.46	-0.11		0.91
Altitude		-0.08	0.09	-0.94		0.37
Distbd		0.00	0.00	0.24		0.81
Age		-0.02	0.02	-1.00		0.34
Size		**11.41**	**5.14**	**2.21**		**0.05****
Stone wall		8.26	18.48	0.44		0.66
Soil type		-11.03	10.82	-1.02		0.33
Land use		32.3	23.79	1.35		0.21
Distriver		**0.00**	**0.00**	**2.67**		**0.03****
Distnr		0.00	0.00	0.29		0.78
Household		-0.00	0.02	-0.23		0.82
Natural forest		-6.5	32.36	-0.2		0.85
Latdeci		402.3	188.2	2.13		0.06
Longdeci		-	-	-		-
Alphadiv mat		-3.57	3.12	-1.14		0.28

(Dependent variable: Ecosystem services in the church; (**) indicate p value <0.05)

For agricultural matrix ES, alpha diversity in the matrix, presence of stone wall surrounding the church, altitudinal location and the size of the church correlate with the dependent variable. Out of these variables only stone wall is negatively correlated with the ecosystem service provision in the matrix. The model best explaining the dependent variable is with an R^2 of 0.54 in which 54% of the variability present in the dependent variable is best explained by this model (Table 8).

Table 8. Multiple regression analysis of agricultural matrix ecosystem services

	R^2 0.54	B weight	Std.error	t-value	F-value 3.23	p-value 0.02
Indep.vari						
Alphadiv mat		**4.73**	**2.18**	**2.17**		**0.04****
Stone wall		**-43.7**	**14.89**	**-2.93**		**0.00****
Altitude		**0.17**	**0.06**	**2.57**		**0.02****
Age		0.03	0.02	1.55		0.14
Size		5.33	2.81	1.90		0.07**
Land use		30.5	19.33	1.58		0.13

(Dependent variable: Ecosystem services in the matrix; (**) indicate p value <0.05)

For church forest multifunctionality, size of the church, stonewall, distance from the river, the number of households in the area all negatively correlate with the dependent variable. This model has an R^2 of 0.94 hence, it significantly explains 94% of the existing variability in ESMF of the church (Table 9).

Table 9. Multiple regression analysis of church forest ecosystem multifunctionality

	R^2 0.94	B-weight	Std.error	t-value	F-value 10.45	p-value 0.00
Indep varia.						
Alphadiv chur		0.00	0.00	0.05		0.96
Altitude		6.78E-5	0.00	0.98		0.35
Distbd		3.882E-7	0.00	0.46		0.65
Age		1.34E-5	0.00	0.79		0.45
Size		**-0.01**	**0.00**	**-2.27**		**0.05****
Stone wall		**-0.05**	**0.00**	**-3.35**		**0.01****

Soil type	0.01	0.01	1.72	0.12
Land use	0.01	0.02	0.77	0.46
Distriver	**7.95E-6**	**0.00**	**3.33**	**0.01****
Distnr	-6.75E-7	0.00	-0.22	0.83
Household	**-3.51E-5**	**0.00**	**-2.24**	**0.05****
Natural forest	-0.03	0.03	-1.38	0.21
Latdeci	-0.02	0.15	-0.1	0.92
Longdeci	-	-	-	-
Alphadiv mat	0.00	0.00	1.22	0.25

(Dependent variable: Ecosystem, service multifunctionality in the church; (**) indicate p value <0.05)

For ecosystem service multifunctionality of the matrix, the selected model has an R^2 of 0.63, significantly explaining 63% of the variability in the response variable (matrix multifunctionality). For the variables, only the size of the church is correlated with ESMF of the agricultural matrices (Table 10).

Table 10. Multiple regression analysis of the agricultural matrix ecosystem multifunctionality

	R^2 0.63	B weight	Std.error	t-value	F-value 3.9	p-value 0.01**
Indep.vari						
Alphadiv mat		0.00	0.00	1.58		0.13
Age		-4.51E-6	0.00	-0.61		0.55
Land use		-0.00	0.00	-1.07		0.30
Size		**-0.00**	**0.00**	**-2.13**		**0.04****
Stonewall		-0.00	0.00	-1.05		0.31
Soil type		-0.00	0.00	-1.75		0.09
Distriver		-1.06E-6	0.00	-1.37		0.18

(Dependent variable: Ecosystem service multifuntionality in the matrix; (**) indicate p value <0.05)

4. Discussion

4.1 Diversity of church forests and matrices

Proving the assumption made on the first hypothesis, by all diversity index levels church forests contain higher diversity of tree species than the agricultural matrices. Similar findings by Devakumar (2018) from scared groves in Central Western Ghats indicate that the sacred groves consist as high Shannon diversity index as 4.15, which is considerably large. Our findings for church forests indicate an average Shannon diversity index of 2. In line with this, higher tree diversity and 85% of the tree species found in the area were contained in culturally protected sites like community forests, ancestral temple forests and cemetery forests in the south east China (Gao *et al.*, 2013). However, Tekalign et al.(2017) indicated higher tree species diversity in human modified landscapes such as agricultural lands, rangelands and exotic forests than indigenous forest and agro forest explaining that the deliberate plantings by local communities in the former land use types which increases the tree diversities in these sites.

The distance to the nearest road positively correlates with alpha diversity of the church forest while the presence of stone wall, age of the church affected alpha diversity of the church in a negative manner. The latitudinal location of the church has the biggest correlation with alpha diversity of the church. This is maybe related with increased precipitation in the Northern part of the church forest attributing for increased local species richness. This is in line with Aerts et al.(2016b) who indicated mean annual precipitation contributing to increased alpha diversity of church forest patches. As size and isolation of the forest patch is one of the factors affecting realities of church forest conditions, this study indicated that increased sizes of church forest patches contribute to increased alpha diversity, whereas the presence of stone wall was found to decrease alpha diversity of the church forest patch. The interpretation given for this correlation could be the establishment of stone walls in already degraded areas with low local species richness gives the impression that there is a decreased alpha diversity where stone walls are built. This finding supports studies which are pledging for the contribution to build structures around church forest boundaries for conservation (Lowman, 2011; Woods *et al.*, 2017).

Wassie et al.(2010b) indicated that ease of access to sacred groves influences the structural composition of these fragments. Distance from the main city and the number of households near the church seem to affect alpha diversity in a negative manner as this clearly increases the level of disturbances by people and livestock. Contrary to this finding, with increased distance from the nearest road increased alpha diversity levels is reported indicating accessibility is also an important factor in increasing and/or maintaining biodiversity e.g. ease of access for enrichment planting by the communities. Proximity to a river correlated positively with species richness of the church and this coincided with a study by Aerts et al.(2006) and this along with topographical gradient associated with amount of soil phosphorous, soil depth and stoniness affects species composition and diversity in the Afromontane highlands of church forests in Ethiopia. Additionally, species richness of the adjacent matrix correlated positively with species richness of the church which may indicate that these areas contain similar species remaining from the original vegetation which according to Aerts et al. (2006) and Prevedello (2017) remnants of Afromontane vegetation is largely present in church groves and other parts in a matrix e.g. cropland or savannah. Although not significant, the diversity within the church varies quietly with as high as 23 species to the lowest species richness of 8. Taking into consideration of the age of the church forest, it was observed that younger church forest ageing 16 and 10 for instance had considerably higher species richness (e.g. 16 years of age has the highest species richness with 23 species). Based on the regression analysis results, it was possible to observe age was a factor determining local species richness but in a negative manner. The reason why younger church forests have equally or in some cases larger species richness may have to do with several factors related with old growth forests with increased human perturbations leading to less species richness because of limited regeneration status and gradual loss of forest quality indicated in Ferraz et al.(2014); Santos et al.(2008); Tabarelli et al.(2008) and also relatively larger canopy spaces in younger forests increases inputs for regeneration such as sunlight thereby increasing diversity of tree species. It was also observed that; majority of the conditions of the matrix depend on the adjoining church forest conditions. This was indicated in this finding that, instances such as the presence of stone wall in the church boundaries seem to decrease the alpha diversity of the matrix. One way to explain this is the establishment of stone wall in already degraded sites of the churches and with similar conditions of the adjoining agricultural matrix. Determining both the matrix and the church forest diversity was the land use where in both cases an agro-pastoral system seem to increase their alpha diversity. This may be is related with a land use system which helps to increase the number of trees through plantings by farmers and/or maintain existing trees in the landscape as mentioned by (Tekalign *et al.*, 2017; DeClerck,2010; Burkhard *et al.*, 2012).

In addition to this, Alpha diversity of the church and longitudinal location affected positively while the rest of the variables like the size of the church, nearness to a natural forest patch and soil type affected Alpha diversity of the matrix in a negative manner. Several analyses could be given as to why for instance a bigger church forest patch decreases the diversity in the matrix which could be because farmer's needs are better satisfied with the bigger patch reducing their interest to plant or keep trees in their agricultural lands. Similar analysis could also be given to why nearness to natural forests decrease Alpha diversity of the matrix.

The matrix proven in many studies to support significant plant and animal diversity in addition to being a place for interpatch movements, a place of reproduction and survival of plant and animal communities (Renjifo, 2001; Berggren *et al.*, 2002; Raman, 2006). This study showed that there were significant differences of the local species richness within the agricultural matrices. Several factors have been indicated in the regression analysis but one of the factors indicated was the type of land use in the matrix which is agriculture correlating negatively with species richness in the matrix. A study by Tefera et al.(2014) in the agriculture dominated landscape of northern Ethiopia studies show that, low Shannon diversity index level (H'=0.58) dominated by a woodlot of *Eucalyptus globulus* trees planted by farmers with a limited presence of native tree species such as *Olea europea* and *Juniperus procera*. Similarly, in our study site; the lowest recorded Shannon diversity index for the agricultural matrix was (H'=0.42). Similar explanations could be given as Tefera et al.(2014) for low diversity levels encountered in the surveyed areas of agricultural matrices; given high farmers interests for Eucalyptus stands which is visibly seen in the entire landscape. It is also important to point out that; apart from the single values; the overall average Shannon diversity index for the matrix in the study area showed an index of (H'=1.52) indicating a considerable level of diversity is still present in these matrices and that the cumulative impact of tree species in these landscapes is enormous.

4.2 ES and ES multifunctionality of church forests and matrices

There was a difference in the average ES potential between the church forest and agricultural matrix but this difference was found not to be significant disproved the assumption provided in this thesis work that due to high diversity of tree species there is a higher ecosystem services in church forests than the agricultural matrix. This indicates that trees in the agricultural matrices provide important ecosystem services as church forests. Tekalign et al.(2017) compared different land use systems and found more services to be provided by indigenous forest and agro forest than cropland, rangeland and exotic forest. Farmland without agroforestry and rangeland provided ES of soil conservation and animal forage compared to the countless services provided by the former land use types like milk flavoring, toothbrush, edible fruits, bee forage, beehives, farm implements etc.

Higher regulating services were pronounced in the agricultural matrices than the church forest; the reason for this may be farmers decision to plant multipurpose trees in their farmland and/or their decision to retain remnant trees already existing in the landscape usually aimed by farmers to increase services like nitrogen fixation, soil conservation, pest control, climate regulation (Burkhard *et al.*, 2012; Tekalign *et al.*, 2017). In line with this finding is that in all the church forests studied regulating services was found to be consistently small and compared to the provisioning and cultural services. In the same token, the multifunctionality metrics of the agricultural matrices was found to be higher than the church forests. An important finding supporting our hypothesis that the deliberate plantings of trees by farmers in the agricultural matrices aiming to maintain multipurpose benefits; a backing evidence was seen for sites with increased cultural ES there was also increased provisioning ES and similarly increased regulating ES in the matrices. This higher multifunctionality in the matrices was not due to higher levels of biodiversity since it was reported that alpha diversity and other diversity indices measures indicated a significantly higher diversity in church forests than the matrices. This finding was in line with Zavaleta et al.*(*2010) that in some occasions the tradeoffs between different ecosystem functions/services bring diverse ecosystems in providing less multifunctionality levels compared to areas with fewer diversity levels and this was further proved by Gamfeldt et al.(2013) which studied the relationship between the different ecosystem services which are not always positive (e.g. deadwood occurrence and game production potential).

For the agricultural matrices, the deliberate plantings by farmers is either indigenous and exotic tree species commonly the latter being preferred as is seen in many parts of the country Matthies and Karimov (2014) in order to achieve multipurpose benefits from trees. Part of the reason is also that seedlings for plantings are more readily available in tree nurseries for fast growing exotic tree species than for native tree species, and supply of seedlings is derived from government owned nurseries than private ones, which narrows farmer's choice on the type of seedlings to grow. For supporting ecosystem services like water and nutrient cycling Ferraz et al.(2014) reports that native trees play a critical role in maintaining such services which the agricultural landscape seem to be dominated by exotic tree species like Eucalyptus in the study site.

According to the ES classification proposed by the MEA assessment, the difference in the provision of cultural ecosystem services in the agricultural matrices and church forests was found to be not significant. Cultural ES service provision by church forest was about 20% and 27% for agricultural matrices. This was an interesting finding given the preliminary assumption that cultural services were stronger in the church forest than in the agricultural matrices. The fundamental principles for protection of sacred forests is incorporated in the cultural and spiritual element more than areas with non-sacred values Gao et al.(2013) and the reason that agricultural matrices offer equally higher cultural services could be due to the religious and cultural values attached to individual trees in the agricultural landscapes and also for the reasons that religious practices other than the mainstream religion (Christianity) is exercised in which trees serve for these purposes. For church forest ES, size, stone wall, Alpha diversity of the matrix and latitudinal location was found to correlate positively while soil type, nearness to natural forest and Alpha diversity of the matrix seem to affect in a negative manner. A question may be raised why the stone wall built in already low Alpha diversity of the church indicates high ES supply from the church? Does more diversity always mean more ES? Does more diversity always mean more ES multifunctionality? As stated previously the presence of tradeoffs between different ES functions and services could contribute to less Ecosystem services and multifunctionality levels as stated by Zavaleta et al.(2010) and Gamfeldt et al.(2013) even with higher levels of diversity. For the agricultural matrix ES it was interesting to observe that agriculture increases ES provision of the matrix while an agro-pastoral system increases the alpha diversity of the agricultural landscape. Similarly, stone wall surrounding the church decreased the ES of the adjoining agricultural matrix. This matched with the finding that stonewall being negatively correlated with alpha diversity of the matrix due to already lower diversity levels in areas where stone walls are built. The result of the ES could be due to a direct effect of decreased local diversity levels of the matrix or an indirect effect of decreased local diversity levels in the church.

5. Conclusions

This study was able to look at the diversity, Ecosystem Services (ES) and Ecosystem Service Multifunctionality (ESMF) comparing two land uses (the church forest and the agricultural matrix). The ES was further studied based on the MEA classification (provisioning, regulating and cultural) services. The factors explaining the differences in these variables within each of the respective land use types (within the church forest and within the matrix) was also analyzed.

Generally, according to the alpha diversity (local species richness) and other diversity indices, higher diversity levels were observed in the church forest than in the agricultural matrix. Many other studies also proved that church forest fragments have a high diversity level.

Considering the ES, and specifically considering the MEA ES division; cultural services in the agricultural matrices very high, as well as in the church forest. As indicated in various studies the church is fundamentally crucial in serving the cultural ES needs in the community and these cultural elements are important for keeping the church forest safe from disturbance; similarly the agricultural matrices adjoining the church forest in the study sites are believed to possess remnants with trees similar as in church forest patches and that this landscape contain sacred individual trees of importance to local communities in the area given that cultural services were as high as in the surveyed church forests. Another aspect to this is unlike church forests trees in the agricultural matrices serve for cultural and religious revelations other than Christianity. However, there were consistently smaller regulating services in all the surveyed church forests and these values were relatively higher in the agricultural matrices. Considering provisioning services, they were relatively higher in church forests than in the agricultural matrices. It is important to mention that native tree species recorded in the agricultural matrices were also present in the church forests and that these species are understood to offer similar ES by the local communities that participated in the interviews. It is concluded that the differences in the services between forest fragments and matrix trees is related to both abundance and diversity of tree species in the two land use types.

Another important finding related to ES was that within the surveyed areas of agricultural matrices, the three services (provisioning, regulating and cultural) increase and decrease uniformly altogether. This indicates that the deliberate plantings of trees by farmers are able in providing these services simultaneously therefore increasing the level of ESMF in the agricultural matrices.

As a result, we were able to prove our hypothesis that the ESMF of the agricultural matrix was higher than the church forest.
Several factors come in to play in affecting the diversity, ES and ESMF but an important conclusion from this study is that several of the church forest conditions determine conditions within the matrices and vice versa.
To mention one of the factors affecting conditions in both church forest and agricultural matrix is the presence of stone walls built around the church forest boundaries. As was stated in the previous section, it is important to recognize stone wall as a solution for conservation and is important to see the interrelated aspects of the different habitats in the landscape. In addition, it may also be crucial to build a second larger wall around the remaining matrix.
Regarding the Ecosystem Service multifunctionality levels; the agricultural matrices are higher than the church forest given the deliberate plantings and decision to keep the remaining trees in the landscape.

6. Recommendations

Several studies have indicated the church forest's role in biodiversity conservation majorly because it contains the remnants from the original vegetation. Apart from this general truth, and based on the results of this study, the following recommendations were provided:

- The overall ES from both the church and the matrices were considerably high; but the MEA division on ecosystem services gave diverging results. Provisioning services were higher in the church forest while regulating and cultural services were higher in the matrices.

-Agricultural matrices are as important as church forests in serving cultural ES of communities mainly because of the cultural and spiritual elements attached to individual trees in the matrices; therefore, further activities should take in to account this fact while designing actions for conservation.

-Agricultural matrices have higher ES multifunctionality than church forests in a sense that they are the result of deliberate plantings by farmers with well-chosen multifunctional trees. Conservation actions should work toward conditions in order to change farmer's decision to plant multipurpose native trees, using seeds from local church forest provenances.

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Appendices

Appendix 1. Pair wise t-test comparison of the diversity indices of church forest and agricultural matrix

Variables	**Mean**	**Stan.dev**	**Std.error mean**	**t-value**	p-value	Sig.
Species abundance within church	13.1	8.44	2.43	-1.19	0.26	ns
	17.3	8.98	2.59			
Species abundance within matrix	5.93	2.88	0.83	-1.07	0.3	ns
	7.45	3.14	0.91			
Alpha diversity within church	13.8	3.83	1.11	-0.79	0.44	ns
	14.8	3.06	0.88			
Alpha diversity within matrix	**11.7**	**1.95**	**0.56**	**13.73**	**0.00**	**
	6.83	**1.46**	**0.42**			
Shannon diversity within church	2.05	0.34	0.09	0.52	0.61	ns
	1.97	0.36	0.1			
Shannon diversity within matrix	1.71	0.34	0.1	1.34	0.2	ns
	1.44	0.4	0.11			
Simpson diversity within church	0.81	0.08	0.03	0.5	0.62	ns
	0.79	0.11	0.03			
Simpson diversity within matrix	0.75	0.11	0.03	1.02	0.33	ns
	0.68	0.15	0.04			
Shannon evenness within church	0.84	0.03	0.01	6.22	0.00	ns
	0.68	0.11	0.03			
Shannon evenness within matrix	0.74	0.12	0.03	0.78	0.45	ns
	0.69	0.12	0.03			

ES provisioning within churches	**53.2**	**22.0**	**6.35**	**-2.01**	**0.06**	**ns**
	73.9	**40.5**	**11.7**			
ES regulating within churches	6.95	1.61	0.46	0.77	0.45	ns
	6.55	1.01	0.29			
ES cultural within churches	**89.3**	**34.5**	**9.97**	**-2.35**	**0.04**	**

	125.5	**61.4**	**17.7**			
ES provisioning within matrices	83.2	27.8	8.04	-0.79	0.44	ns
	94.2	43.5	12.5			
ES regulating within matrices	97.8	32.4	9.37	-0.78	0.45	ns
	110.6	50.9	14.7			
ES cultural within matrices	113.4	37.8	10.9	-0.5	0.62	ns
	122.4	55.6	16.1			

Appendix 2. Assumptions for Multiple regression

Alpha diversity church

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	9.4216	23.0050	14.3333	3.16629	24
Residual	-2.31679	2.95434	.00000	1.33106	24
Std. Predicted Value	-1.551	2.739	.000	1.000	24
Std. Residual	-1.148	1.464	.000	.659	24

a. Dependent Variable: alphadivchurch

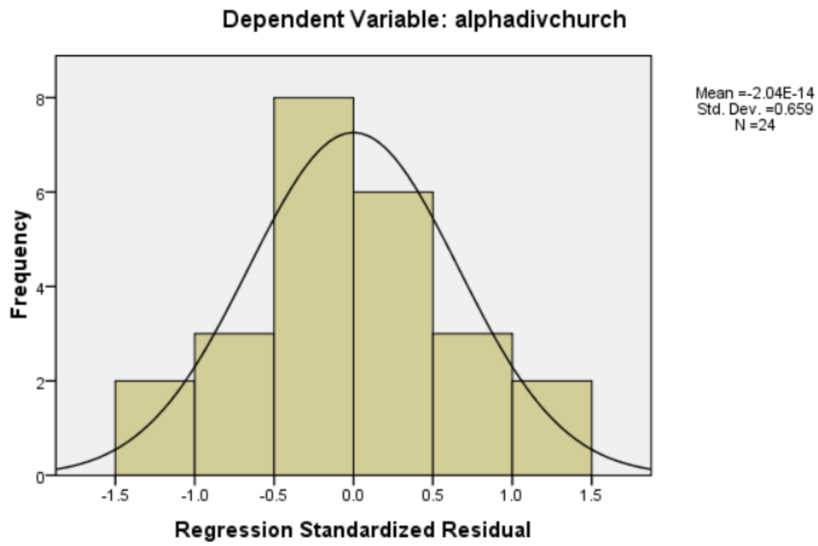
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Unstandardized Residual	.069	24	.200*	.981	24	.920
Standardized Residual	.069	24	.200*	.981	24	.920

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.

Histogram



Alpha diversity matrix

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-1.8558E2	1.5188E3	1.2929E2	338.40085	23
Residual	-3.2371E2	2.35333E2	.00000	133.93124	23
Std. Predicted Value	-.930	4.106	.000	1.000	23
Std. Residual	-1.546	1.124	.000	.640	23

a. Dependent Variable: transalphadivmatrix

Tests of Normality

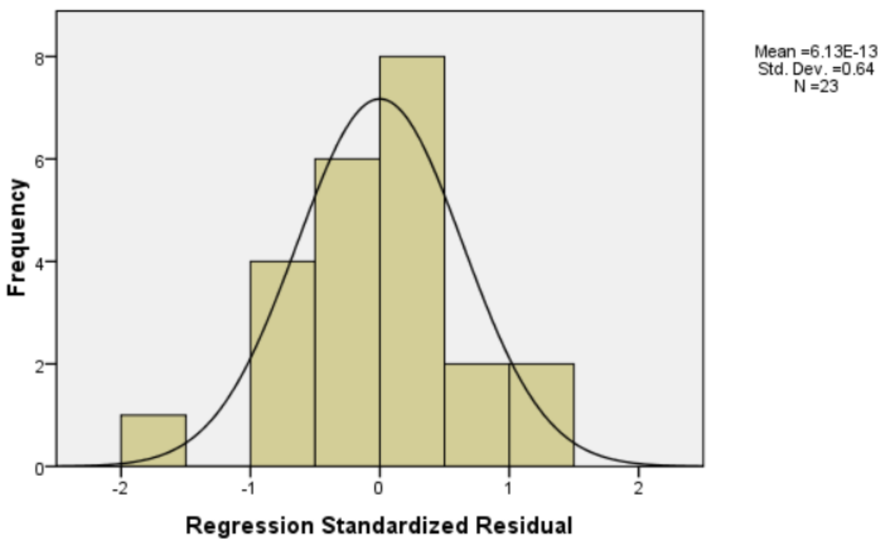
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Unstandardized Residual	.122	23	.200*	.963	23	.527
Standardized Residual	.122	23	.200*	.963	23	.527

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.

Histogram

Dependent Variable: transalphadivmatrix



Church ecosystem services

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	42.5215	248.4031	93.4941	46.26014	24
Residual	-3.9995E1	28.41290	.00000	17.83515	24
Std. Predicted Value	-1.102	3.349	.000	1.000	24
Std. Residual	-1.403	.997	.000	.626	24

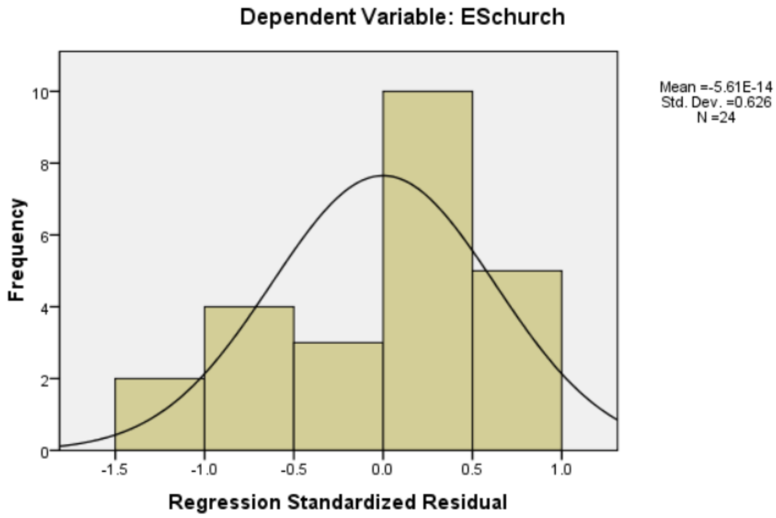
a. Dependent Variable: eschurch

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Unstandardized Residual	.154	24	.148	.973	24	.750
Standardized Residual	.154	24	.148	.973	24	.750

a. Lilliefors Significance Correction

Histogram



Matrix ecosystem services

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	40.4652	146.8753	95.4296	28.37408	24
Residual	-5.5819E1	60.81536	.00000	26.41654	24
Std. Predicted Value	-1.937	1.813	.000	1.000	24
Std. Residual	-1.817	1.979	.000	.860	24

a. Dependent Variable: esmatrix

Tests of Normality

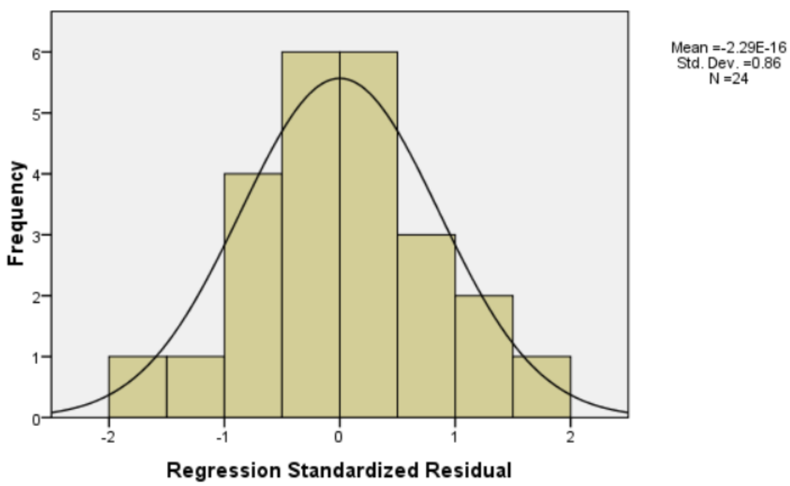
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Unstandardized Residual	.104	24	.200*	.983	24	.939
Standardized Residual	.104	24	.200*	.983	24	.939

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.

Histogram

Dependent Variable: esmatrix



ESMF church

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	.4285	.6157	.5028	.05296	23
Residual	-.02716	.02654	.00000	.01238	23
Std. Predicted Value	-1.402	2.131	.000	1.000	23
Std. Residual	-1.323	1.292	.000	.603	23

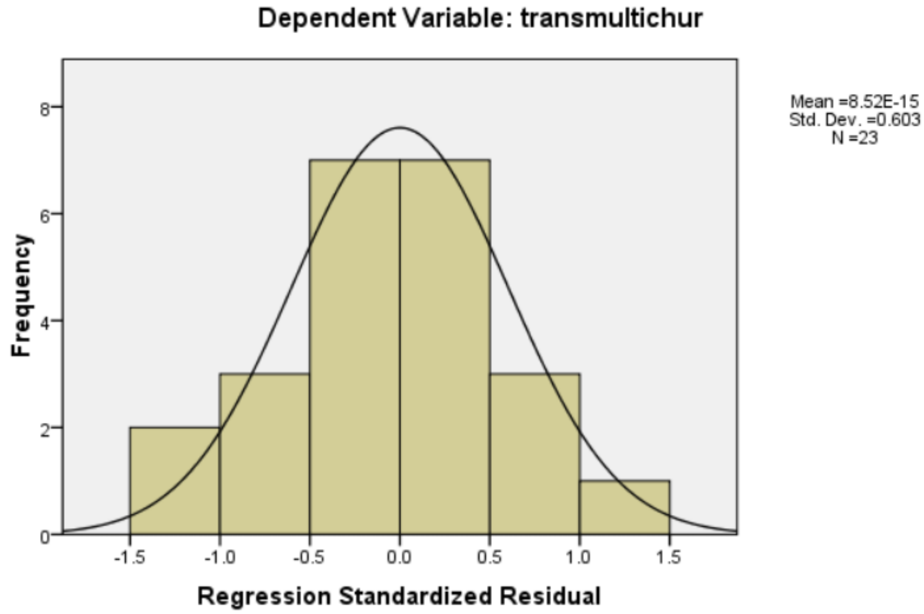
a. Dependent Variable: transmultichur

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Unstandardized Residual	.127	23	.200*	.975	23	.813
Standardized Residual	.127	23	.200*	.975	23	.813

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.



ESMF matrix

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	.7308	.7840	.7623	.01292	24
Residual	-.02253	.01842	.00000	.00984	24
Std. Predicted Value	-2.441	1.677	.000	1.000	24
Std. Residual	-1.910	1.561	.000	.834	24

a. Dependent Variable: multifunmatrix

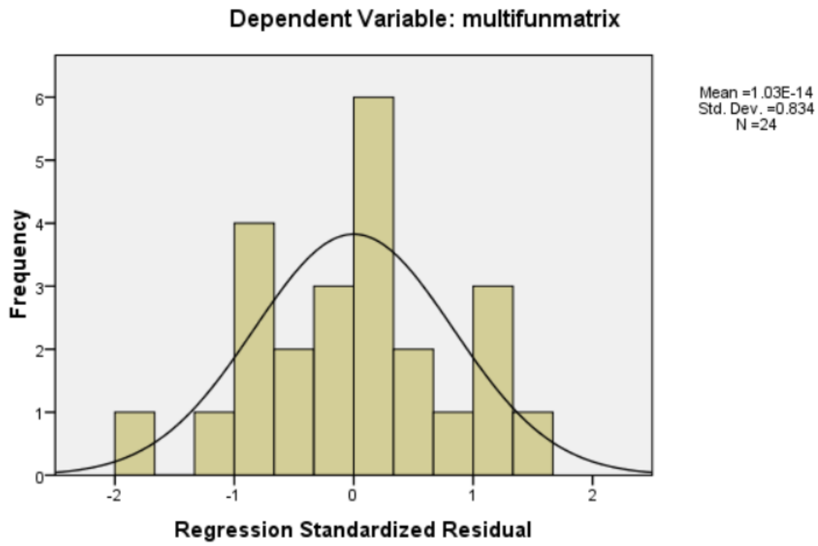
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Unstandardized Residual	.096	24	.200*	.979	24	.871
Standardized Residual	.096	24	.200*	.979	24	.871

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.

Histogram


Dependent Variable: multifunmatrix
Mean =1.03E-14
Std. Dev. =0.834
N =24
Frequency
0
1
2
3
4
5
6
-2
-1
0
1
2
Regression Standardized Residual