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Nature's contributions to people from church forests in a fragmented tropical landscape in southern Ethiopia

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ABSTRACT

Despite expanding interest in nature's contributions to people (NCP) studies, understanding of sacred natural sites' contributions to human society and the restoration of fragmented landscapes remains relatively limited. This study examines the diversity and extent of NCP by church forests in a fragmented tropical landscape in southern Ethiopia. We identify 339 church forests in the Gurage Zone and examine them using a combination of historical (1967) aerial photographs and recent (2017) orthophoto images, supplemented by vegetation sampling and in-depth interviews with key informants from 42 selected church communities. Church forests can be found in all agro-ecological zones and across the entire vegetation types in the Gurage socio-ecological landscape. In the last five decades, the extent of church forests has been remarkably persistent, and 67% of the forests have seen an increase in size even while surrounding state- and community-controlled forestland has been degraded over time. Interview findings suggest the church forests' persistence is in large part due to the church compound being seen as a sacred space and hence respected and protected by the community. This powerful social norm has allowed for multiple uses of the church forest to continue over time through sustained forest management. More than 15 distinct contributions of church forests to local communities were identified including material, nonmaterial, and regulating NCP categories, suggesting church forests deliver a wide range of NCP in addition to their well-established ecological and conservation value. Findings underscore the current contributions of church forests to local people in southern Ethiopia, as well as the potential for church forests to support the restoration of degraded landscapes through integration into regional landscape planning and management policies.

1. Introduction

Sacred natural sites can be found across Africa (Wassie et al., 2007; Alohou et al., 2017) and Asia (Omura, 2004; Anthwal et al., 2010; Rath et al., 2020), and have attracted attention from researchers across the natural and social sciences (Bhagwat and Rutte, 2006; Aerts et al., 2016; Reynolds et al., 2017a). In many cases, sacred groves or sacred forests are remaining fragments of survived forest habitats (Alohou et al., 2017). These residual forest patches preserve indigenous species and old-growth forest trees with cultural

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and/or religious significance for local people (Anthwal et al., 2010; Rath et al., 2020). In other cases, sacred forest patches have been planted – or small and degraded forest patches expanded and restored through enrichment planting – by communities seeking to enhance cultural, economic, and ecological benefits from forested areas (Wassie et al., 2005; Reynolds et al., 2017a). In either case, sacred forests can have significant contributions to local communities, including material, non-material, and regulating provisions. And even though many sacred forests' provisioning services have been reduced over time due to isolation and degradation (Ferraz et al., 2014; Cardelús et al., 2013), many scholars continue to see these forests as essential for biodiversity conservation goals, as well as other globally significant ecological services such as carbon sequestration (Wassie et al., 2007; Lowman and Palatty, 2017; Irvine et al., 2019).

The long-term protection of sacred forests by traditional conservation mechanisms has received some international recognition. Sacred forests are mentioned in the Convention on Biodiversity (CBD, 1992), highlighted by the United Nations Educational, Scientific and Cultural Organization (UNESCO, 2005), and appear in the Sacred Natural Site management guidelines (Wild and McLeod, 2008), and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Roué and Molnár, 2016; Karki et al., 2017). But despite the relevance of sacred forests for global biodiversity conservation goals and local-level benefits, many sacred forest systems have continued to be overlooked by state agencies, conservation institutions, and broader civil society (Schaaf and Lee, 2006). As a result, many sacred sites still have no legal protection and face threats from agricultural expansion and other land-use changes associated with population growth and economic development (Aerts et al., 2016; Reynolds et al., 2017a; Rath et al., 2020).

In the past two decades two related conceptual frameworks – ecosystem services, and nature's contributions to people – have been developed in an effort to better understand the relationships between people and nature, including in sacred natural site systems. The ecosystem services concept is widely known, particularly since the Millennium Ecosystem Assessment (MA) (Millennium Ecosystem Assessment MA, 2005). More recently, nature's contributions to people (NCP) conceptual framework has been developed by the IPBES (Díaz et al., 2015). NCP has been introduced as a broader concept to ecosystem services by planning to capture a broad range of worldviews, knowledge systems, and stakeholders (Andrew et al., 2019). NCP may be better suited to incorporate indigenous and local knowledge (ILK) in assessments of ecosystem benefits, an area in which the ecosystem services approach has often failed to engage (Braat, 2018). Namely, NCP includes a context-specific perspective – rather than a generalizing perspective based on a predetermined set of ecosystem services – which recognizes unique local or cultural worldviews that can apply to specific socio-ecological settings, and which acknowledges that ecosystem values may not transfer universally (Díaz et al., 2018; Peterson et al., 2018; Andrew et al., 2019). Identifying NCP values offers conservation biologists, ecologists, and economists a shared vocabulary for discussing the benefits of conserving and investing in the natural world (West, 2015). Although some past research has explored sacred forests' contributions to biodiversity and ecological benefits, their NCP provisioning potential has yet to be extensively studied (Dudley et al., 2010; Blicharska et al., 2013; Karki et al., 2017). An assessment of NCP provisions in sacred forests could enhance the understanding of land-use planners and decision-makers seeking to more effectively manage degraded agricultural landscapes (Roué and Molnár, 2016; Karki et al., 2017; Parthasarathy and Naveen, 2019).

This study examines NCP values associated with forest patches protected by followers of the Ethiopian Orthodox Tewahedo Church (EOTC) in the Ethiopian highlands. The EOTC has more than 35,000 Christian churches and monasteries in Ethiopia, some dating back to the 4th and 5th centuries, and most of them are within forest groves known as "church forests" (Wassie, 2002; Gobena, 2018). In some parts of Ethiopia, the church forests are virtually the only patches of Afromontane forest on the degraded agricultural landscape (Aerts et al., 2006; Wassie et al., 2010; Tura et al., 2017). Even though the forests themselves are not the subject of worship, the church forests are an integral component of the church, as they provide sites for religious ceremonies, social gatherings, and burial grounds (Reynolds et al., 2015; Klepeis et al., 2016). Often surrounded by cropland and degraded grazing land, the church forests can be quickly identified by travelers as either churches or monasteries (Aerts et al., 2016; Scull et al., 2017; Mekonen et al., 2019). Church communities manage their forests largely autonomously, and management varies from strict protection to weak protection with poorly controlled harvesting of trees (Amare et al., 2016; Klepeis et al., 2016; Orlowska and Klepeis, 2018). Recent research suggests the church forests have been threatened by many social changes, including the building of larger churches that take up a larger footprint within the forest, and the planting of cash crops such as Eucalyptus within or alongside church forest groves (Liang et al., 2016; Reynolds et al., 2017a; Cardelús et al., 2017). But Cardelús et al. (2019) note that even small, heavily used sacred forest patches in Ethiopia can offer a wealth of benefits to surrounding communities in the form of fuelwood, food, fodder, and shade, alongside broader conservation benefits.

Despite the widely acknowledged relevance of church forests for biodiversity conservation and other ecological benefits (Cardelus et al., 2019), no previous studies have conducted an assessment of NCP under the recommended categories of the IPBES. Moreover, although several past studies have evaluated the conservation value of church forests in central and northern Ethiopia (e.g., Aerts et al., 2006, Wassie et al., 2010, Tura et al., 2013; Cardelús et al., 2017), to date there is no information on the contributions of church forests in the southern Ethiopian highlands. This study considered church forests in the Gurage Administrative Zone in south-central Ethiopia with the aims of:

1) characterizing southern Ethiopian church forests in terms of spatial distribution, patch configuration, and forest management practices associated with long-term persistence and;
2) assessing nature's contributions to people by church forests in the southern highlands.

Our focus is on specific church forests in southern Ethiopia; however, the study could help to assess NCP values associated with similar sacred natural sites in other contexts, to better understand local management practices, and identify opportunities for local, national, and global policies and institutions to better support conservation goals.

2. Material and methods

2.1. Study area

The Gurage Zone is situated in south-central Ethiopia, with an area of 5932 km^2 and thirteen *woredas* (administrative districts). The landscape is semi-mountainous, with elevations spanning from 968 m to 3605 m above sea level. Based on the 2007 Census conducted by the Central Statistical Agency of Ethiopia (CSA), the Gurage Zone has a population of 1279,646 (622,078 men and 657,568 women), and an overwhelming majority of this population (92.4%) lives in rural areas and engages in agricultural production (Central Statistical Agency CSA, 2009). Settled agriculture has taken place in the area for at least a millennium (Zewede, 1972; Tadesse, 2009), with many Gurage settlements emerging around the cultivation of enset, a starchy root and tuber crop (also known as false banana) and a staple food among the Gurage people today (Shack, 1966; Sahle et al., 2018a). The enset farming system is traditionally a polyculture incorporating other crops such as pulses, cereals, coffee, and/or fruit trees – but nevertheless contributes to forest clearing in favor of agricultural production.

There have been no previous studies of church forests in Gurage Zone, but current figures show that EOTC followers make up about 41.9% of the population (Central Statistical Agency CSA, 2009), and in 2015, the number of churches in the landscape was over 400, of which 13 were monasteries. Many churches are located in Sodo and Mihurna Aklil woredas, and the number of churches is increasing in areas where churches are sparsely distributed.

2.2. Data

The study adopted a mixed-method approach consisting of geospatial data analysis, open-ended interviews of church leaders with field-guided walks, and church forest vegetation sampling. Spatial data draw from a combination of recent orthophoto images, declassified historical aerial photographs, Google Earth images, and publicly accessible land use land cover data. Orthophoto images were obtained from the regional rural land administration office and have a 0.15 m spatial resolution with three spectral bands. The images were captured and orthorectified for land administration and certification purposes in 2017, and are of sufficient quality to measure the current church forest coverage in the Gurage Zone (Ethiopian Mapping Agency EMA, 2017). Google Earth imagery is

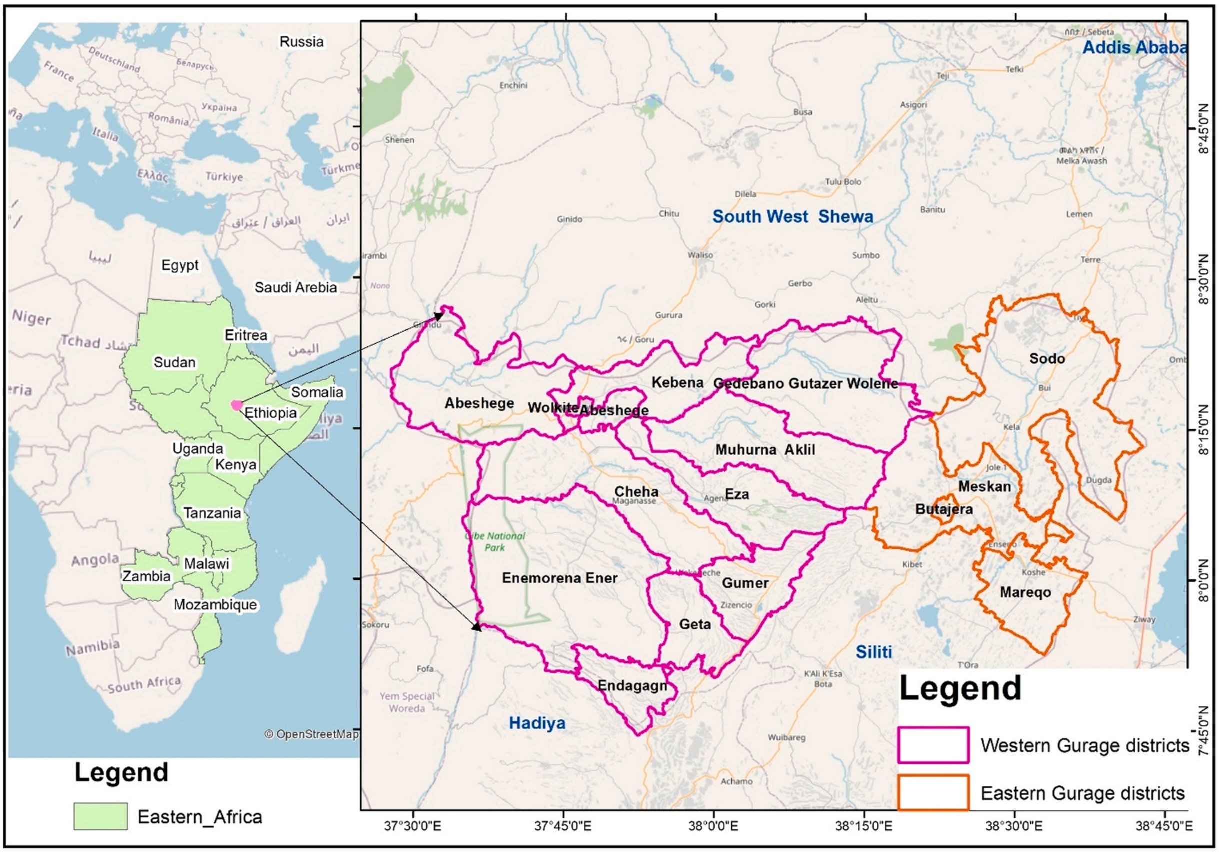

Fig. 1. Map of the Gurage socio-ecological landscape in southern Ethiopia. The polygon boundaries show administrative districts with the division of Western and Eastern Gurage Zone.

considered for estimating current church forest extent in areas not covered by orthophoto images. To estimate the past extent of church forests in the Gurage Zone historical aerial photographs taken in 1967 were used. The photographs are declassified from U.S. intelligence satellites and released by the National Archives and Records Administration (NARA) and the U.S. Geological Survey (USGS) under Executive Order 12951 on February 23, 1995 (Geological Survey U.S., 2008). The vertical photographs, which can be accessed through the Earth Explorer database, are black-and-white images with a ground resolution of 2.75 m, again allowing accurate estimation of the area and patch configuration of church forests in the study area. Additional geospatial analyses included an evaluation of the contribution of church forests to local temperature regulation, drawing on cloud-free Landsat 8 imagery from 2019. Finally, land use land cover maps produced by the Ethiopian Mapping Agency (Ethiopian Mapping Agency EMA, 2011) were used for estimation of the potential contributions of church forests to pollination for cereal crops.

To ground-truth remote sensing findings and collect further ecological samples and qualitative interview data, 42 church forests were selected based on a multi-stage cluster sampling method to represent diverse agroecological zones (AGZs), administrative boundaries, and dates of the church establishment. The first clustering was made by dividing the church forests into Western and Eastern sub-zones considering the Gurage Mountain chain as a natural boundary (Fig. 1). Forests were then clustered into three elevational groups with each sub-zone (Fig. 2). The date of church establishment among the 13 *woredas* in the landscape varies, with Mihurena Aklil, Sodo, and Enmohernena Ener administrative districts considered to represent older church forests, while Abesghe, Gumer, and Cheha represent newly established church forests (since the 1900 s). Larger samples were drawn from the Mihurena Aklil and Sodo *woredas* because of the relatively large number of church forests present.

In each of the selected church forests in-depth, open-ended interviews were conducted with priests, leaders, and elders as key informants. All key informants in their respective churches were selected by the church community based on their participation and extensive knowledge about historical trends and current church forest management. The interviews were conducted in 2015 at 30 church forests and in 2020 at 12 additional sites. Key informant interviews used structured questionnaires to explore the spatial patterns of the forest system, trends of change, existing challenges, management practices, and contributions of the church forests to the local community.

Finally, vegetation data obtained from three different field survey periods covering 42 church forests in 51 sample plots (Fig. 2), including 30 plots in 2015, 9 plots in 2016, and 12 plots in 2020 with sample sizes of 20 × 20 m. The selected church forests considered for vegetation data collection match the churches sampled for key informants. For 31 church forests, we took one representative

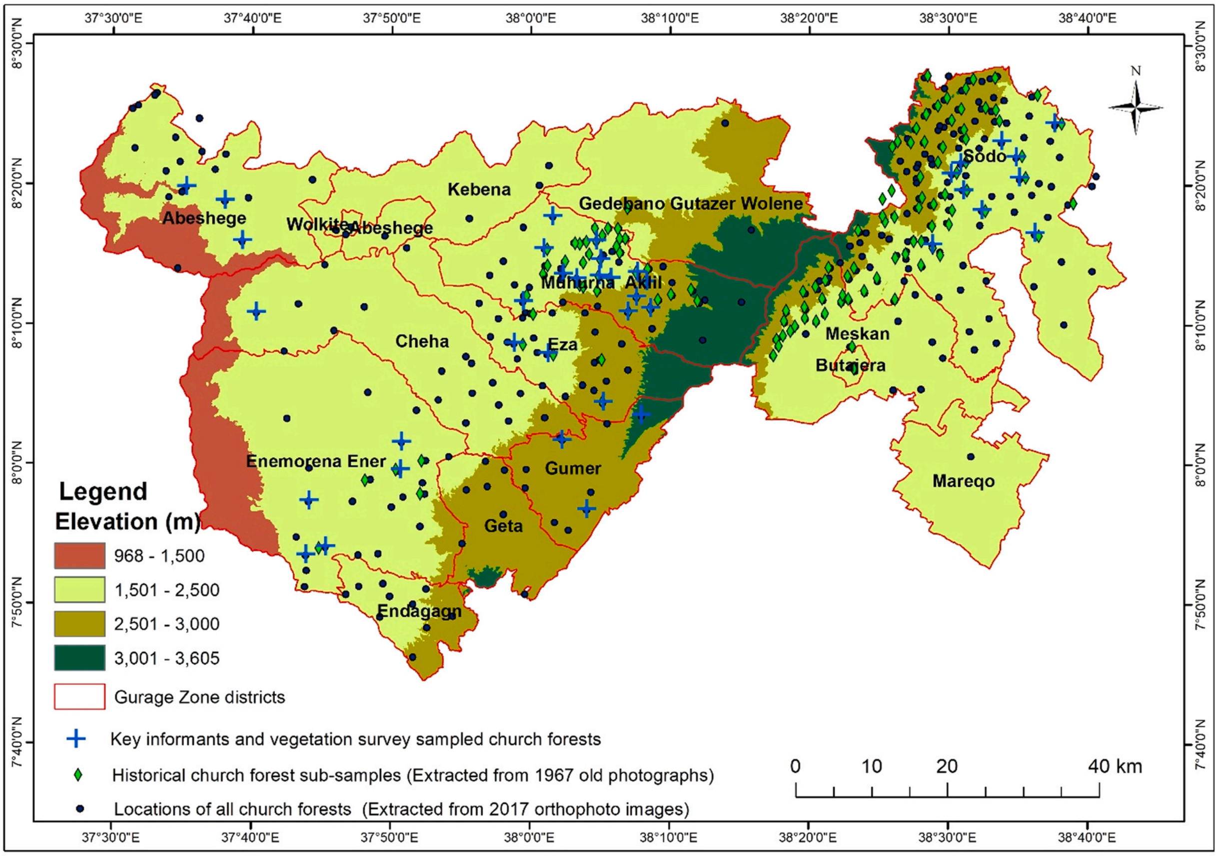

Fig. 2. The spatial distribution of church forests with historical and key informants and vegetation sample sites in Gurage Socio-ecological landscape.

sample plot. For the remaining church forests which relatively have larger extents, we sampled two plots. In each church forest, we selected representative sample plots within the forest patches to evaluate species types present and estimate forest vegetation density. These data were then used to estimate church forest contributions in the form of habitat creation, maintenance of plant communities, and carbon sequestration.

2.3. Characteristics of church forests

2.3.1. Spatial distribution and patch configuration

All the selected church forests were visited with the guidance of key informant's walks and sketched by using Google Earth (for 2015) and orthophoto images (for 2020)–which enabled to document of physical features of the church forest system. Some of the field works were conducted on Sunday and around important events, which allowed for observations of how congregations use church forests and validation of evidence gleaned from interviews. The researcher noted down each functional space and forest cover in the church compound with sketching on the printed images of the forests. The informants described each functional space and a comparison has been made and a shared functional space usage among the church forests was considered to describe the forest system.

As the church forests are distinct from other land-use types (primarily agricultural) in the study area, it is possible to identify them using high-resolution satellite imagery. Reports from the Gurage Diocese office of the EOTC name 417 churches in the Gurage Zone in 2015; on this study, 394 church forests were able to identify using satellite imagery (Fig. 2). Of these churches, 55 have been established in the last 20 years (i.e., were not visible in previous historical satellite imagery) and have limited forest coverage, and hence these newly established forests were not included in the analysis. For the remainder, the study used ArcGIS digitization tools to the present-day spatial dimensions of the forests.

To quantify church forest patch characteristics, the extracted spatial features from orthophoto and Google Earth images were analyzed using the Patch Analyst 3.1 extension to ArcGIS 10.7. For each forest, calculated patch properties include patch size (ha), perimeter (m), perimeter: area ratio (m ha^{-1}), pattern shape index, and edge density. To allow consistent estimates between high-resolution orthophoto images and Google Earth imagery (used where orthophotos were unavailable), the data extracted from Google Earth are georectified to the available orthophoto images. In all estimates of church forest's vegetation coverage, the land occupied by buildings (churches, monasteries, schools, other housing), and open areas were masked from each forest. Ground verification at selected church forests was conducted to check the accuracy of the remotely measured spatial extent through field observations (tracing forest perimeters by GPS and overlaying measurements on the features from orthophoto images to check their accuracy).

2.3.2. Trends in church forest cover over time

The historical extent of church forests was digitized based on 1967 black-and-white aerial photographs using standard procedures (Avery and Berlin, 1992), following a routine similar to Scull et al. (2017), Cardelús et al. (2017). The historical aerial photographs are without georeferencing, hence the study georeferenced all available photos with the more recent orthophoto images (2017), using the sampled church forests as ground control points (the transformation was performed in ArcMap 10.7 using third-order polynomials). Large parts of the 1967 imagery contain significant cloud cover and make it difficult to observe the full landscape. As a result, only a subset of church forests was considered for the analysis of church forest changes over time. In total the historical spatial extent of 125 church forests was extracted from 1967 photographs (Fig. 2), allowing estimation of changes in the extent of forest cover over the past 50 years (1967–2017).

2.4. NCP assessment in church forests

In this study, the diverse NCP of the church forests drew on key informant interviews which structured to facilitate the identification of NCP provisions of the church forests, including the type and time of uses, and restrictions surrounding access. A preliminary list of possible NCP provisions of the forests was developed based on previous literature. Then the study used the narrative method of NCP assessment to obtain key informants' qualitative perceptions of church forests' NCP, paired with quantitative analyses of specific selected NCP using a combination of field-based vegetation surveys and remote sensing-based geospatial analysis.

2.4.1. Qualitative assessment of church forest NCP

Qualitative assessments of NCP based on key informant interviews can offer a more comprehensive view of nature's contributions by incorporating broader aspects of NCP than quantitative evaluations alone. Semi-structured qualitative interviews, developed based on previous literature and the authors' experience in the study area, left substantial room for description of NCP according to the local context and individual perceptions of the interviewee (Busch, et al., 2012; Hausman, 2012). We used a deductive approach to code all qualitative interview data, allowing us to classify key informant responses based on established NCP themes. During field visits, the researchers also kept notes verifying the NCP identified by the participants, as well as noting some other NCP that respondents did not mention in their interviews. The final set of identified provisions were categorized into the NCP reporting categories of material, nonmaterial, and regulating NCP following indicators recommended by IPBES (Díaz et al., 2018). Material NCP included the production of timber, shelter, sacred utensils, and sources of energy (firewood). Spiritual and religious services, aesthetic values, social services, recreational and heritage values, and educational values were classified as non-material NCP following the reporting categories of NCP and their indicator for assessment (Díaz et al., 2018). Finally, regulating NCP was examined through a combination of qualitative and quantitative measures, as described in the following section.

2.4.2. Selected NCP quantification of church forests

In the established plots of selected church forests, the study recorded all woody species with the diameter at breast height (DBH) (1.3 m above ground) > 5 cm to quantify the contributions of church forests to the creation of habitat for woody tree species. For species that the researchers were unable to identify in the field, voucher specimens were collected and identified with a guide to the flora of Ethiopia and Eritrea (Hedberg, 1996). Based on the analysis, the most common species in all sampled forests were identified, and the relative woody species diversity within each forest was estimated using Simpson and Shannon diversity measures. Based on these metrics, we compared species diversity between more recently established churches (the 1900s and after) and relatively older churches (pre-1900). The study further used a map of Ethiopia's potential natural vegetation (Friis and Demissew, 2010) to compare church forest vegetation to potential natural vegetation zones.

In addition, we measured vascular tree species DBH in the 51 sample plots across 42 church forests to estimate carbon storage. To estimate the above-ground woody biomass (Y), the allometric equation developed by Brown (1989) was used (suitable for areas with annual rainfall < 1500 mm and vegetative stems with DBH measurements of >5 cm, corresponding to the characteristics of the study area):

$$Y = 38{\cdot}4908 - 11{\cdot}7883\,(DBH) + 1{\cdot}1926\,(DBH^2)$$

For estimating below-ground biomass, we used the root-to-shoot ratio (MacDicken, 1997), whereby the below-ground biomass is estimated by multiplying the above-ground biomass by a factor of 0.27, the recommended value for Afromontane forests (Intergovernmental Panel on Climate Change IPCC, 2006). Because the study area lies in tropical and sub-tropical regions, the sampling plots' biomass stock densities are converted to carbon stock densities after multiplying by an Intergovernmental Panel on Climate Change IPCC (2006) default carbon fraction of 0.5 as the dry biomass contained 50% organic carbon. The carbon stock in the biomass was converted into CO_2 equivalent by multiplying by 3.67.

Next, to make a comparison between the Land Surface Temperature (LST) within church forests and the surrounding environments, remote-sensing based LST values were extracted from the dense forest center and on the buffer zones of 0–100 m, 100–200 m, and 200–300 m. The Landsat series of satellites allow for estimates of LST at a relatively high spatial resolution (30 m), which is appropriate for local or small-scale studies (Ermida et al., 2020). Numerous studies have proposed LST retrieval algorithms for the Landsat series, and some datasets are available online. This study considered the Google Earth Engine (GEE) repository which provides publicly accessible LST estimates (http://rslab.gr/downloads_LandsatLST.html) with coverage in the study area (Parastatidis et al., 2017).

Finally, recognizing that forest fragments provide forage for pollinators in agricultural landscapes (Proesmans et al., 2019), we examined the potential of honeybees to provide pollination services from church forests to the surrounding croplands. The honeybee (*Apis mellifera litorea*) is an indicator pollinating agent (Ricketts et al., 2008), and honeybees are ubiquitous in Ethiopia, found both in the wild and around farmers' gardens as domestic hives managed using traditional and modern beekeeping methods (Pauly and Hora, 2013). To measure potential pollination benefits from church forests, the study used proximity analysis tools in ArcGIS 10.7, considering all croplands within 1543 m of church forests following Steffan-Dewenter and Kuhn (2003) and Massey (2015) who suggest this as the distance honey bees would travel to find forages. Pollination buffer zones are overlaid with estimated cereal croplands extracted from the land use land cover map produced by the Ethiopian Mapping Agency (Ethiopian Mapping Agency EMA, 2011). The area of the buffer zones that fall within the croplands was calculated to estimate the pollination contributions of the church forests in the Gurage Zone.

3. Results

3.1. Spatial characteristics of church forests in the Gurage Zone

3.1.1. Spatial distribution and patch configuration

The church forest is considered a holy place, and the land uses within the hundreds of forest patches in the Gurage Zone have similar patterns. There is a building at the center of each church forest; this building is the central holy place. Proximate to the main building, there is an open space that traditionally extends to 40 arm lengths of radius to a surrounding wall or fence. Most often, the intervening space is clear (sometimes scattered trees are retained), forming a smaller compound around the church. This inner circle is a place for attending the mass every Sunday, or for celebrating annual rituals. Previously, it was common to bury priests and monks within this physical space. Surrounding the inner circle, traditional churches have a wall or structured wooden fence that makes a partition between the main church compound and the surrounding forest. Along the perimeter of the inner circle, buildings such as Bethlehem (house of Holy Communion preparation and site for the beginning mass celebration), church treasures, and graveyards can be found in most churches.

In the immediate periphery surrounding the inner circle, large trees are usually present, and the burial grounds for almost all church community members are typically in this part of the forest under the tree canopy. Sometimes, families of the dead build houses or tombs with wood or concrete in the graveyards. More rarely, nuns and monks may live in these graveyard houses. Along the left and right sides of the main gate outside the inner fence, spaces including *Deje Selam* (a space used by priests for resting and eating food), as well as Sunday school, houses for nuns and monks are often situated beneath large canopy trees. The density of vegetation is often low in these parts of the forest due to human use of the space including prayer spaces, graveyards, and house construction (Fig. 3).

Except where church forests connect with other community-managed forests or riverine forest areas, the vegetation density of church forests typically decreases with proximity to the edge. In some cases, *Eucalyptus* ssp. trees are planted within or along the forest's edge as a source of fuelwood and cash for the church; such resources may also reduce pressures on the old-growth forests (Fig. 3). Some interview respondents also reported that burial of church leaders and community members in the inner parts of the forest is becoming less common and that recent burials have been limited to the periphery of the forests in an effort to reduce forest clearing and allow more space within the church forests for hosting annual festivals. Most churches have exterior perimeter fences, either made from soil bund, stone walls, wood, or concrete, to protect the church and its forest, including from livestock grazing and potential land clearing by neighboring farms.

The analysis of present-day orthophoto and Google Earth imagery suggests that about 74% of the land area within church forests' perimeter is covered with vegetation, on average. The remaining 26% of the church forest area consists of church buildings, open spaces for public gatherings, cemeteries, and clearings for other church activities. The mean total size of church forests in the landscape is 3.8 ± 4.2 ha (Table 1). In comparison, the mean patch size of the forest vegetation within the church forest perimeter is 2.8 ± 3 ha. The forests are consistently small, with a similar surface area across elevations and agroecological zones. The total church forests' estimated area in the Gurage landscape is about 1384 ha.

At the landscape scale, church forests can be found along a wide elevational gradient ranging from 1083 m to 3323 m above sea level (Fig. 2). Of the nearly 400 identified church forests in the Gurage Zone, only eight are in an elevation below 1500 m (lowland areas). Many forests (212) are in the midland/warm and humid climatic zones. In the highlands (elevation between 2500 and 3300 m), 115 church forests are found. Only one church forest is in a cold climatic zone above 3300 m. The vast majority of church forests in the Gurage Zone (90%) are found in the Dry Evergreen Afro-Montane Forest and Grassland complex vegetation type (1800–3000 m, annual precipitation < 1700 mm yr^{-1}). Twelve forests are in higher elevation zones – ten in the Ericaceous Belt (3000–3200 m) and two in the Afro-Alpine belt (> 3200 m). And 23 forests are in the lower limit of the landscape in the Combretum-Terminalia woodland and wooded grassland zone. The mean patch size is somewhat higher in the Dry Evergreen Afro-Montane Forest and Grassland complex vegetation type (3.9 ± 4.4 ha) than in other vegetation types. In Combretum-Terminalia woodland and wooded grassland zones, for example, the average size of church forests is 3.2 ± 2.2 ha. The sizes of the forest located in the Afro-Alpine belt and Ericaceous Belt are even smaller, although sample sizes for these vegetation types are small (Table 2). Similarly, the edge density is highest in Dry Evergreen Afro-Montane Forest and Grassland complex vegetation type forests compared to the other vegetation types. The mean shape index is higher in the Combretum-Terminalia woodland and wooded grassland zones than in the other vegetation types, but overall, the forests located in Dry Evergreen Afro-Montane Forest and Grassland complex vegetation types have much higher

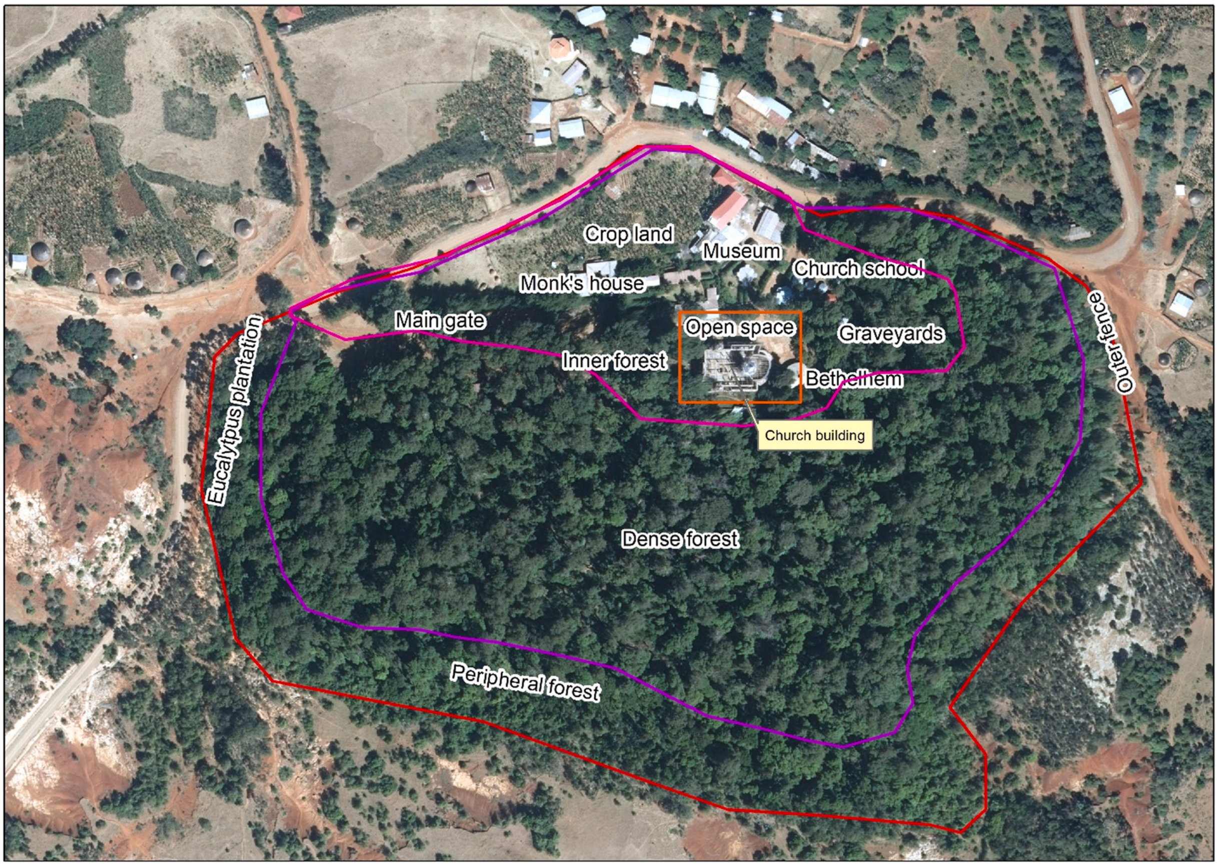

Fig. 3. Illustrative land use management in church forests in Gurage Zone over orthophoto imagery (Mihur Eyesus Monastery in Mihurena Aklil district, Gurage Zone).

Table 1
Patch characteristics of church forests in the Gurage Zone socio-ecological landscape.

Patch characteristics	Total area including church compound	Area of forest cover
Number of patches	339	339
Mean patch size	3.8	2.8
Patch size standard deviation	4.2	3
Mean shape index	1.2	2.2
Area weighted mean shape index	1.2	2.1
Mean perimeter-area ratio	266	697.6
Total edge	260,126	392,332
Edge density	203.5	416.6
Mean patch edge	769.6	1157

Table 2
Patch characteristics of church forests by vegetation type in the Gurage Zone.

Vegetation type/ Patch characteristics	Number of patches	Mean patch size	Patch size standard deviation	Mean shape index	Mean perimeter-area ratio	Edge density	Area
Dry Evergreen Afro-Montane Forest and Grassland complex vegetation type	304	3.9	4.4	1.2	264.4	184.0	1174.6
Afro-Alpine Belt	2	2.7	0.0	1.2	253.8	1.1	5.4
Ericaceous Belt	10	2.4	1.1	1.1	283.8	4.8	23.9
Combretum-Terminalia woodland and wooded grassland zone	23	3.2	2.2	1.3	281.4	13.7	74.1

total edge density and area coverage than forests found in the remaining vegetation types.

In terms of the current administrative boundaries, the majority of church forests in the Gurage Zone are found in the Mihurna Aklil and Sodo districts (Fig. 4). Of the total, 124 church forests are located in the Sodo district with a mean patch size of 4.2 ± 5.9 ha. In

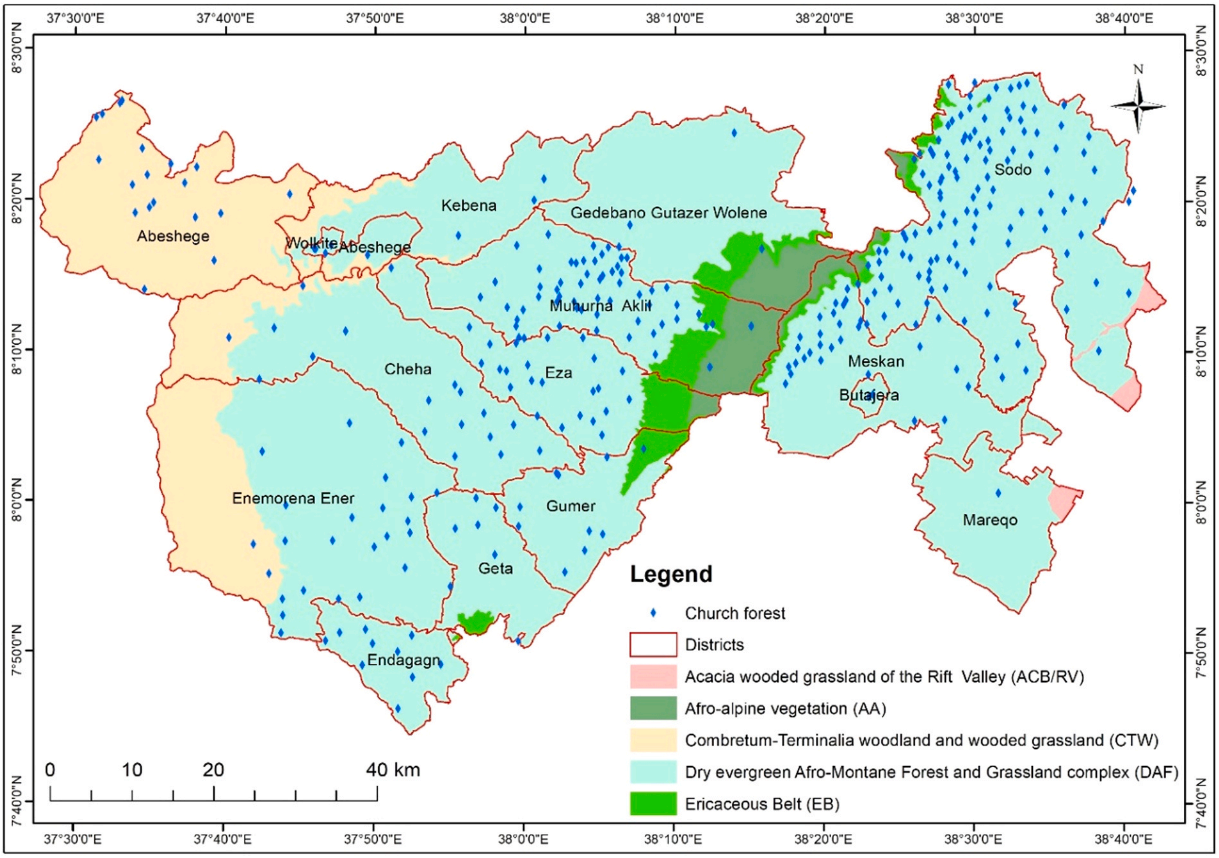

Fig. 4. Location of church forests by vegetation type in the Gurage Zone.

Mihurna Aklil district, 58 church forests are found, and the mean patch size is 3.4 ± 1.2 ha. The Meskan (31), Enemoherna Ener (24), Ezha, and Abseghe (21) districts have the next largest number of church forests in the landscape. In the remaining districts, this study examined a smaller number of church forests, associated with fewer EOTC followers.

3.1.2. The persistence of church forests over time

A comparison between 1967 aerial photographs and 2017 orthophoto images shows relatively few changes to the extent of church forests in the study area during the last five decades. While some forests appear to suffer degradation over time, the majority of church forests in the study area actually increased in size between 1967 and the present (Fig. 5). About 27% of the 125 forests for which 1967 and present-day imagery are available stayed the same size over the past 50 years, while 67% increased in size, and only 6% saw reduced area over time. The extent of increased forest areas ranges from 0.1 to 51 ha. In contrast, any losses in the forest area were relatively small - ranging between 0.1 and 1.3 ha in the last 50 years.

Key informant interviews suggest the persistence of the church forests in the Gurage Zone is largely attributable to religious commitment. The church compound is seen as sacred and hence is respected – and as the church forest area is part of the holy place, every EOTC follower is expected to respect the rules. Cutting a tree in the church forest is allowed only by particular people (e.g., church leaders) and only for specific church purposes. In many cases, the communities surrounding the churches do not even remove dead branches from the church forest, and cutting live trees within a church for personal use is beyond imagination. Multiple key informants emphasized that since the church forests are believed to be God's house or a symbol of heaven, everyone in the church community wants to protect them – this widely shared commitment has allowed the forests to persist and even regenerate or expand. In some churches with more extensive open spaces, and in some of the relatively newly established churches with limited native vegetation cover, church followers are voluntarily planting trees in the church compound and in neighboring areas.

3.2. Nature's contribution to people by church forests in Gurage Zone

Reports from semi-structured key informant interviews suggest church forests provide a wide range of NCP. The following sub-sections outline some of the contributions identified by key informants under the three main categories of NCP based on IPBES categories: material provisions, non-material provisions, and regulating provisions.

3.2.1. Material NCP of church forests in Gurage Zone

According to key informants, material NCP of church forests in the Gurage Zone summarily include (i) timber for construction of church buildings, (ii) shade and protection for graveyards as well as for church ceremonies, (iii) fuelwood for monks and nuns who live within the church compound, and (iv) other utensils, oils, incense and fruit associated with church sacraments.

Provision of construction materials – including harvesting of large trees – is only permitted for church buildings; trees are only permitted to be cut when used to build churches or associated structures that serve the church. In the past, large trees such as *Podocarpus falcatus* and *Juniperus procera* were cut from within the church forest perimeter to construct and maintain the church's main

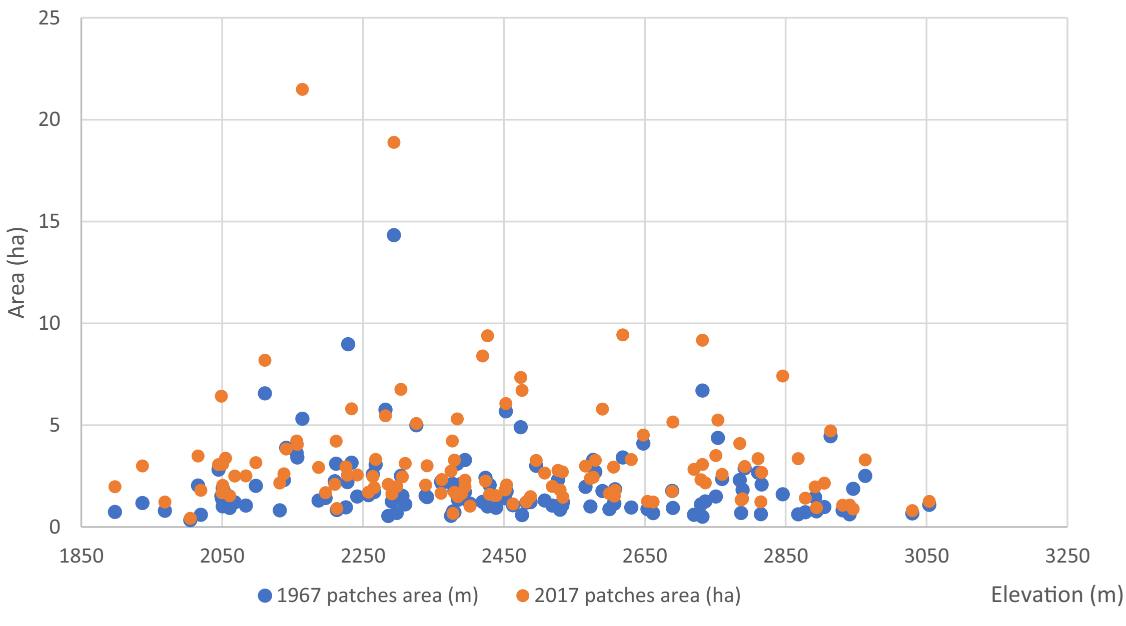

Fig. 5. Church forests' extent in 1967 (blue) and 2017 (orange) along elevational gradients, based on orthophoto and declassified aerial photograph imagery. One outlier is omitted, one church forest was 9.0 ha in 1967, and 60.2 ha in 2017 (+51 ha). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

buildings. Today, in many cases the main church buildings are renovated using concrete and stone construction, reducing the use of large trees. However, in some churches, small indigenous trees, as well as exotic plantings of *Eucalyptus* trees, continue to be harvested from the forest and are used to construct buildings such as Sunday schools, as well as housing for nuns and church guests. It has become increasingly common over the past 2–3 decades for churches to plant eucalyptus in open areas; when mature the trees are either used for church building construction/maintenance or cut down as timber and sold for cash.

As previously mentioned, the church forests also serve as shelters for graveyards, and for the nuns and monks who in many forests live in small houses under the shade of church forest trees. Although clearing church forest trees for burial sites and housing is a key driver of forest loss in some church forests, key informants also note that tree planting to mark a tomb is actually a very ancient and widely practiced tradition in church grounds for remembrance, with the planted trees later serving as a shelter for the graveyards. The priests, monks, nuns, and other church followers also often benefit from the shade provided by church forest trees, allowing them to pray in isolation or attend mass celebrations for their church communities. The church forest trees have a significant role in providing shelter in both the hot, dry season for shade and in the rainy season for protection from heavy rains.

Other key informants noted that although removing firewood from church forests is typically forbidden, the principal source of energy for cooking *within* many churches is fuelwood. The people who live in the church, such as nuns, and the community members who prepare foods during monthly or annual events, use deadwood from within the church as fuelwood. In particular during August, which is the coldest season in Ethiopia and coincides with the fasting period called *Feleseta,* a large amount of biomass from the church forest – sometimes supplemented by purchased fuelwood or by Eucalyptus from church plantations – is used for cookfires.

Finally, key informants noted several cases where vegetation in church forests provides essential sacramental products and sacred utensils such as *Tsilat* (a consecrated wooden altar slab that symbolizes the Ark of the Covenant), oil, incense, drums, crosses, plates, beads, and prayer stick for church services. According to key informants, for example, in some churches during Holy Friday the priests use branches from the *Olea africana* tree, harvested from the church compound, as whips in a ceremony commemorating the flagellation of Christ before the crucifixion. The widespread planting of *Olea africana*, as well as other religiously important species such as *Juniperus procera* (used in church building construction), is in part driven by such ceremonial use-values.

Fig. 6. Illustrative church forests showing aesthetic qualities at various locations in Gurage Zone (a) Ener Amanuel Monastery at Enemoherena Ener district (Field survey, 2015), b) Fato Baleweld church at Sodo district (Field survey, 2015) c) Mihur Eyesus and Elias Monastery at Mihurena Aklil district (Field survey, 2020), and d) Medre Kebed Abo Monastery at Sodo district (Field Survey, 2017)).

3.2.2. Nonmaterial NCP of church forests in Gurage Zone

Respondents reported that the church forests also enhance the aesthetic and scenic beauty of churches. Forests provide a green and pleasant area for prayer and contemplation. A repeated remark was that a church without trees "looks like a person without clothes" – losing its grace and beauty (Fig. 6).

Even though most religious ceremonies are undertaken within church buildings and in the inner clearing, the church forests still provide many other spiritual and religious benefits. All churches have weekly, monthly and annual celebrations depending on the adorned saints of each church community. However, not all community members are permitted entry into the main church building for all ceremonies; in some cases, most community members attend services outside, within the open spaces maintained within the church forests. The church's trees provide a shaded enclave allowing attendees to stand for hours-long ceremonies while attending mass, and the trees provide privacy for personal prayer. Several informants emphasized that the church's garden-like seclusion allowed them to anchor their spirit and connect with God in prayer.

Key informants further reported that church forests serve as places for eating food after mass celebrations called *Senbetie* (derived from the word Sabbath, particular church members gathered together every Sunday) and social gatherings such as *Tsiwa Mahabber* (an association to commemorate a particular saint's day monthly). Various groups of church followers – e.g., those dedicated to different patron saints – regularly gather in specific spaces within the church forest, usually in small clearings under the shade of large trees. Similarly, after mass celebrations, the church elders often sit under the shade of particular trees (outside the gate) to discuss issues raised by local communities related to crime, community support, and religious matters.

According to key informants the church forests also serve to attract pilgrimage from other regions during local festivals. Though the travelers' prime motives are related to obtaining blessings from holy places for particular patron saints, the church forests themselves were described as creating additional attractions such as the especially dense, biodiverse, and extensive forests in Mihur Eyesus, Ener Amanuel, and Kote Gedera monasteries.

Finally, in churches or monasteries where traditional church schools are present, the shade of trees was often cited as beneficial for open-air classrooms. Most church forests contain an area devoted to some form of church school located along the forest edge. The teacher typically provides instruction under the trees. The quiet of the forest and the natural surroundings were described by key informants as supporting memorization of church texts and songs, helping students develop their *Qene* poems, and contributing to the study and interpretation of the bible and other spiritual texts.

3.2.3. Regulating NCP of church forests in Gurage Zone

Regulating NCP of church forests was estimated based on field measurements of woody species prevalence and diversity. Assessments of selected regulating NCP from 42 ground-surveyed church forests revealed 16 different species per 400 m^2 plot on average. From the recorded plants, 89 species belonging to 41 families were identified. Out of the 823 total woody plants sampled with DBH > 5 cm, the most frequently recorded species include *Juniperus procera* (150 plants), *Podocarpus falcatus* (74 plants), *Eucalyptus globulus* (49 plants), and *Olea europaea* (46 plants). The *Eucalyptus* spp. species is most frequently present in more recently established churches – this exotic species is planted in the periphery of church forests, surrounding indigenous and old-growth trees as protection and as a source of materials, fuelwood, and income. The native tree species present in church forests varies depending on the agro-ecological

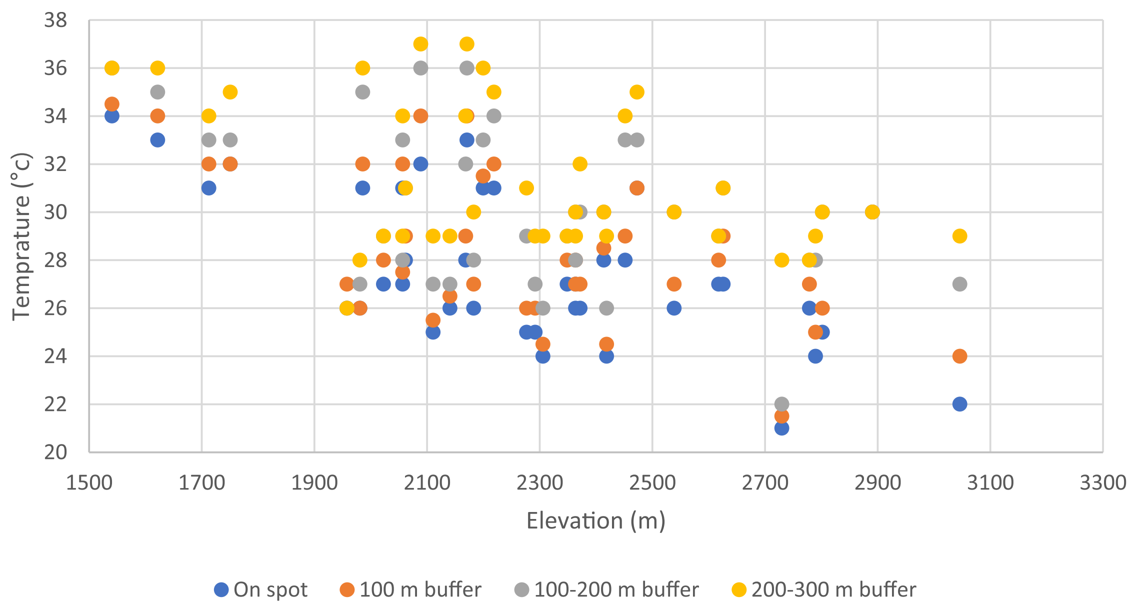

Fig. 7. An average satellite-based surface temperature during the month of January on the dense area of the sample church forest and in the buffer zone of 0–100 m, 101–200 m, and 200–300 m.

zone – church forests located in Dry Evergreen Afro-Montane Forest and Grassland complex vegetation type areas are largely dominated by *Juniperus procera*, *Podocarpus falcatus*, and *Olea europaea*. In the Combretum-Terminalia woodland and wooded grassland zone vegetation type areas of the landscape *Celtis africana*, *Acacia senegal*, and *Ficus vasta* are the most dominant species.

DBH measurement of the 823 sampled trees shows a diversity of tree sizes and ages, with 15% of trees falling in the lowest DBH class, less than 10 cm. About 24% of sampled trees have a DBH between 10 and 20 cm, and samples with DBH between 20 and 50 cm cover 42% of the recorded individual trees and shrubs. About 15% of sampled trees have a DBH between 50 and 100 cm, and only 4% had a DBH greater than 100 cm. The average size of tree stems varies by age of church forests themselves – church forests founded before the 1950 s are more likely to contain old-growth trees, while the more recently established churches are characterized by plantation forests with smaller stems on average. Larger trees and a high woody plant diversity including indigenous and rare species are defining characteristics of older and larger churches such as Mihur Eyesus, Ener Amanuel, and Kondelati Bealewold monasteries. Based on these inventory data, the mean above and below-ground biomass of the church forests (in terms of carbon stock) is 94.7 tons ha^{-1}. The minimum is 22.4 tons ha^{-1} in the Geharad Mariam church, and the maximum is 211 tons ha^{-1} in Mihur Eyesus Monastery. In total, the 339 identified churches with forest cover could have a potential of 131,065 tons of carbon storage, without counting dead organic matter, herbs and grasses, and soil organic carbon sinks.

In addition to carbon sequestration potential, consistent with key informant reports that church forests provide shade and shelter from extreme temperatures and weather conditions, analyses based on satellite images show the land surface temperature is significantly lower within and near church forests than in the surrounding area. On average, temperatures during the hot season within 0–100 m of church forests are higher by 1 °C than within church forests groves, while more distant land at 101–200 m is 3 °C higher on average, and at 200–300 m distance land is 4 °C higher (Fig. 7). These remotely-sensed findings are consistent with key informant reports that church forests provide shade for the clergy and other church followers during mass and religious festivals.

Finally, in terms of potential pollination services, considering all croplands within 1543 m of church forests (Steffan-Dewenter and Kuhn, 2003; Massey, 2015), church forests could support pollination service delivery by honeybees on as much as 40% of the Gurage Zone's current cropland. Pollination zone coverage is higher in the eastern zone as compared with the western Gurage landscape (Fig. 8), but overall, much of the Gurage Zone's cropland potentially benefits from the presence of church forests on the landscape. It is difficult to estimate the precise amount of honeybee forage obtained from the church forests as opposed to other potential sources, but at least the church forests have the potential to contribute to the production of honey and the broader pollination services honeybee populations provide.

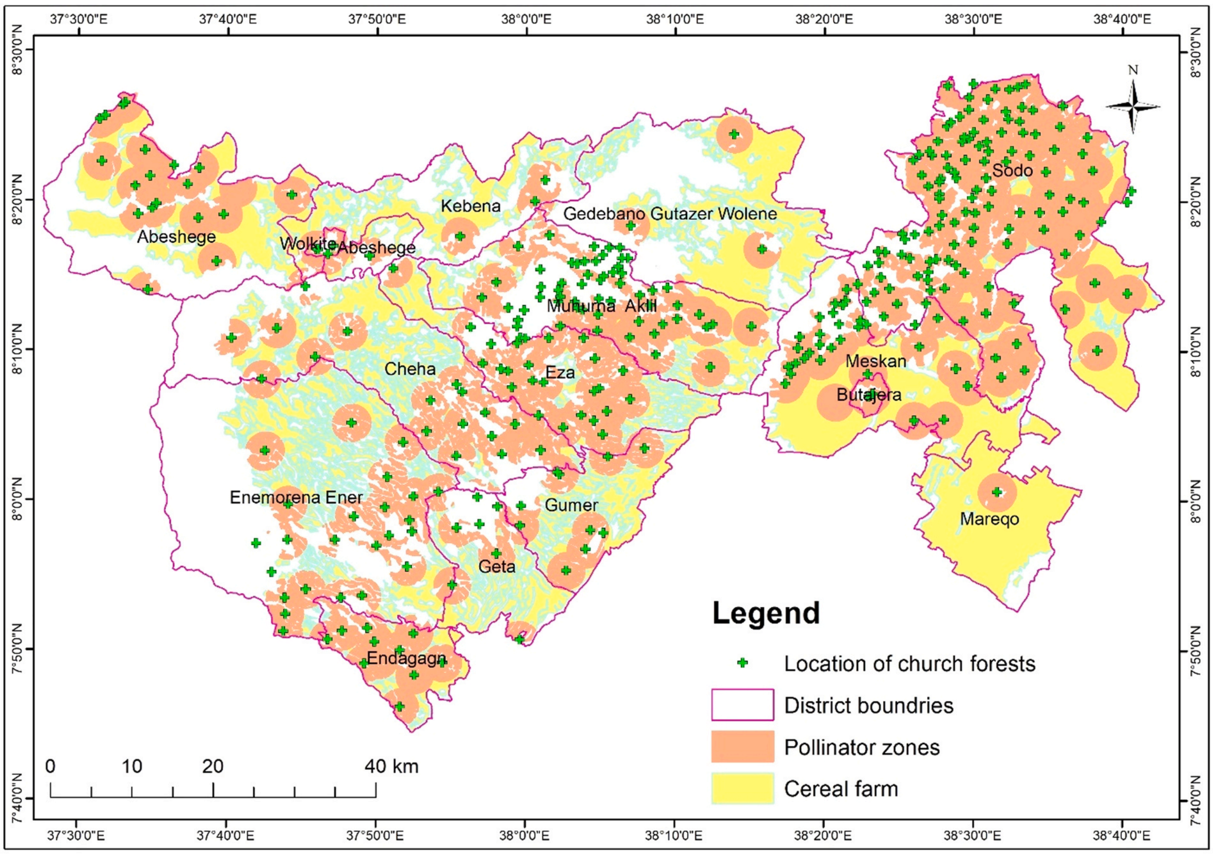

Fig. 8. Pollinator zones within a 1543 m radius of church forests over cereal cropland in Gurage Zone.

4. Discussion

4.1. Church forest characteristics and their contributions in southern Ethiopia

Church forests constitute some of the only remaining Afromontane forests in Ethiopia (Wassie et al., 2007), and they have persisted despite decades of dramatic land-use change all over the country (Nyssen et al., 2009). The church forests in Ethiopia represent a form of community-based conservation, rooted in the social norm that the church should look like heaven on earth and that natural forest is like clothing for the church – with thriving indigenous trees indicating the presence of angels guarding the church (Gobena et al., 2018; Wassie, 2002). This study's findings suggest that church forests have proven to be remarkably persistent in the fragmented landscapes of southern Ethiopia, consistent with previous findings by Scull et al. (2017) in northern Ethiopia. The forests' patch sizes in southern Ethiopia are somewhat larger than previously studied church forests in northern Ethiopia (2.48 ± 0.24 ha) (Aerts et al., 2016), though the total church forests' estimated area in the Gurage landscape overall is small. But even though church forests comprise only a tiny fraction of the Ethiopian landscape, they are ecologically critical. The finding that church forests in Gurage Zone are sanctuaries of many woody species that have almost disappeared in other parts of the landscape is similar to the past findings from central and northern Ethiopia (Wassie et al., 2007; Tura et al., 2013; Alerts et al., 2016). Some species, such as *Juniperus procera* and *Prunus africana*, are listed in the IUCN red list and are mostly found in Ethiopia's church forests (Vivero et al., 2005).

Church forests give grace and esteem to churches and they are important spaces for prayer and contemplation (Wassie, 2007; Mosissa and Abraha, 2018). According to Lacy and Shackleton (2017), trees are essential for praying and help for connection with God. And even from a strictly economic perspective, eco-tourists are attracted to forest destinations for reasons including the hospitable climate, clean air, wildlife, scenic beauty, and cultural heritage forests can provide (Nega et al., 2019). As the result, church forests are important tourist attractions in Ethiopia, like sacred forests in Asia (Rots, 2015; Worku, 2017).

The church forests also contribute directly to regional conservation in Ethiopia, not necessarily by conserving a large amount of habitat, but rather by conserving a large number of patches and covering a broad range of environmental conditions. The average carbon stock in church forests (94.7 tons ha^{-1}) in this study is much larger than that reported by Sahle et al. (2018b) in mixed forests in the Wabe River catchment (16 ± 20.8 tons ha^{-1}), and near the upper bound of the biomass carbon stock in tropical dry forests estimated by Murphy and Lugo (1986) which ranged between 13 and 123 tons ha^{-1}. Even though the church forests are small, they remain vital for mitigating GHG emissions from agricultural landscapes (Sahle et al., 2018b).

The results of this study further suggest church forests support reducing the high temperature during the hot season. Tura et al. (2016) recorded temperature differences from 23.2 ± 0.3 °C adjacent church forests to 24.7 ± 1.3 °C 200–500 m from the church boundary based on measurements from a church forest in Addis Ababa – findings which are consistent with estimates for Gurage Zone church forests from this study.

4.2. Implications of NCP assessment for restoration of fragmented landscapes

Landscape fragmentation has been occurring in southern Ethiopia due to a range of factors including human population growth, climate change, and more immediate drivers such as deforestation, agricultural expansion, and infrastructure development (Sahle and Yeshitela, 2018). Forest fragmentation may reduce NCP provision; however, some studies suggest landscape fragmentation can either enhance or degrade NCP provision depending on the local context (Mitchell et al., 2015). Namely, in some circumstances, forest fragmentation can increase flows of NCP to more beneficiaries through easier accessibility (Decocq et al., 2016). The church forests in southern Ethiopia have immense contributions to preserving biodiversity and also provide a diverse set of NCP, in part due to active management of the forests by church leaders and community members.

Wassie et al. (2007) stated that the future existence of the woody flora and vegetation characteristic of dry Afromontane areas in Ethiopia depends on effective conservation and sustainable utilization of the remnant natural forest patches. Maintaining viable populations in the forests and providing connections between forests is pivotal in this respect. Interconnecting these remnant forests by vegetation corridors following natural terrain or streamlines, or reducing the distance between them by creating buffer areas and plantations around them, and developing more patches in the landscapes are possible approaches to sustain and enhance NCP (Bennett and Mulongoy, 2006).

4.3. Opportunities to seek international recognition for church forests

Both the UNESCO-MAB biosphere reserve concept and the World Heritage Convention recognize the relevance of sacred forests as a component of sustainable development (Schaaf and Cathy, 2005). Many religious centers are considered heritage sites in different regions of the world. In northern Ethiopia, most churches and monasteries with their forests are considered heritage sites by the local government, and church forests surrounding Lake Tana were recently recognized through the establishment of a UNESCO MAB biosphere reserve in 2014 (Henry et al., 2017). Similarly, many churches and monasteries including the Mihur Eyesus, Ener Amanuel, Koter Gedera Kidane Miheret, and Medre Kebde Abune Gebre Menefes Kidus monasteries have been nominated as heritage sites by the Gurage Zone Office of Tourism and Culture based on their ecological and cultural significance.

Sacred groves provide the inextricable link between present society to the past in terms of biodiversity, culture, religion, and ethnic heritage (Khan et al., 2008). They provide various NCP beyond cultural services (Parthasarathy and Naveen, 2019) and have prominent roles in the restoration of fragmented landscapes (Reynolds et al., 2017b). The results of this study support previous authors' findings that respect, recognition, and learning from cultural traditions could greatly benefit efforts to conserve nature and biodiversity, and suggest that contextually rooted efforts may be more effective and sustainable than those based solely on government legislations or regulations. Regarding church forests in Ethiopia, improving policy to conserve forests more efficiently, managing forests to improve quality and stakeholder benefits, and seeking international recognition such as UNESCO's World Heritage List for Ethiopia's church forests have the potential to support the continued and expanded sustainable provision of NCP (Aerts et al., 2016).

5. Conclusions

Despite their small size, church forests in Ethiopia – like other sacred natural sites regionally and globally – are an essential component of natural landscapes that can contribute a variety of benefits to local communities and beyond. Church forests in the Gurage Zone, as elsewhere in Ethiopia, are mainly preserved for spiritual values, but they have significant roles in the provision of material, non-material, and regulating NCP as well. Church forests in Ethiopia are a powerful example of the myriad benefits sacred natural sites can provide to enhance the quality of life, particularly in the fragmented landscapes of the tropics. They are an essential hotspot for woody plant species, in addition to providing a regulating capacity vis à vis climate and pollination. The material NCP of the forests is in the production of energy, timber, sacred utensils, and shelter. But the non-material NCP of church forests in Ethiopia is worth a great deal as well and serves as supporting spirituality, cultural identity, and learning and inspiration. The results of this study provide further evidence that the NCP by small forest patches has the potential to mitigate the disservices provided by land degradation. But such potential benefits are not well documented, and the spatial and temporal contributions of sacred forests to agricultural productivity and human well-being remain poorly understood. An explicit and detailed assessment of NCP in groves such as church forests in Ethiopia could support planners' and decision-makers' understanding that the conservation value of sacred natural sites is not only for spiritual purposes but also has a significant role in supporting the livelihoods of the local community and the global society.

One of the key conclusions reached in the global assessment of nature and biodiversity of IPBES 7 plenary sessions is that indigenous peoples and local communities are critical to finding solutions to the worldwide degradation of natural resources at an alarming rate. Sacred groves are natural communally-protected forest fragments, conserved in large part through religious norms that promote biodiversity conservation and ensure the provision of nature's contribution to people. Thus, understanding, supporting, and promoting the institutions that maintain forest patches and sacred forests via integrated strategies including traditional, scientific, and cultural approaches are crucial for the sustainability of sacred natural sites in the years to come.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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