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Research paper

Ethiopian vegetation types, climate and topography

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A B S T R A C T

Ethiopia is land of geographical contrasts with elevations that range from 125 m below sea level in the Danakil Depression to 4533 m above sea level in the Semien Mountains, a world heritage site. The diverse climate of various ecological regions of the country has driven the establishment of diverse vegetation, which range from Afroalpine vegetation in the mountains to the arid and semi-arid vegetation type in the lowlands. The formation of Ethiopian vegetation is highly connected to the climate and geological history of the country. Highland uplift and rift formation due to volcanic forces formed novel habitats with different topography and climatic conditions that have ultimately become drivers for vegetation diversification. Due to Ethiopia's connection with the temperate biome in the north and the Arabian Peninsula during the dry glacial period, the biotic assemblage of Ethiopian highlands consists of both Afrotropical and palearctic biota. In general, eight distinct vegetation types have been identified in Ethiopia, based mainly on elevation and climate gradients. These vegetation types host their own unique species, but also share several common species. Some of the vegetation types are identified as centers of endemism and have subsequently been identified globally as the East African Afromontane hotspot. Ethiopia is biologically rich, with more than 6500 vascular plant species. Of these species, 12% are endemic mainly due to geographical isolation and unique climatic conditions. However, researchers have yet to extensively investigate the ecology, phenology, as well as the evolutionary, genetics, and conservation status of Ethiopian vegetations at community and species level over space and time. This lack of research is a barrier to achieving the goal of zero global plant extinctions. Taxa extinction risk assessment has not been extensively carried out for majority of Ethiopian species. Detailed research is needed to explore how vegetation and species respond to rapidly growing environmental change. Currently, human-induced climate change and habitat fragmentation are severely threatening the country's biodiversity, and the consequences of these effects have not been studied at large. Furthermore, we still lack scientific evidence on how micro- and macro-ecological and evolutionary processes have been shaping vegetation structures in this climatically, topographically, and geologically diverse country. These gaps in our knowledge represent an opportunity for ecologists, geneticists, evolutionary biologists, conservation biologists, and other experts to investigate the biodiversity status and the complex ecological processes involved in structuring vegetation dynamics so as to help take effective conservation actions.

1. Introduction

Ethiopia hosts the Eastern Afromontane and Horn of Africa biodiversity hotspots (Mittermeier et al., 2004). Located within the tropics (3° and 15°N latitude and 33° and 48°E longitude) (Fig. 1), Ethiopia is the center of the East African region that has eleven Afrotropical ecoregions and has been designated a Global 200, an ecoregion of global importance for biodiversity conservation (Olson

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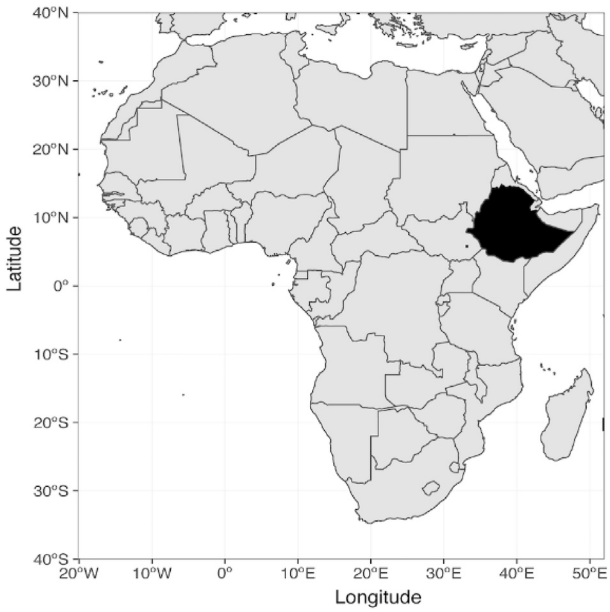

Fig. 1. Location map of Ethiopia (shown in black).

and Dinerstein, 2002). However, the endangered and critically threatened ecoregions of Ethiopia have been poorly studied.

Ethiopia has the fifth highest biodiversity in Africa (Anonymous, 1997). This biodiversity in flora and fauna is strongly associated with the geomorphological history of the region. The country is characterized by dramatic geological history and a broad range of elevations, from the Afar Depression (~125 m below sea level) in the east to the spectacular world heritage mountains of Ras Dashen (4533 m above sea level) in the north (IBC, 2005). This large elevational range has become the source for variation in topography and climate, and has resulted in a heterogenous landscape with high habitat diversity, species diversity, and centers of species endemism, particularly in the highlands. The Ethiopian highlands are divided by the Great East African Rift Valley into the northwestern and southeastern highlands. Consequently, these highlands have formed unique vegetation types.

Phytogeographically, Ethiopia comprises diverse vegetation types, including the tropical lowland rainforest in the southwest, arid and semi-arid dry woodlands in the East, and the Afroalpine forests in the north and southeast. Researchers have estimated the diverse Ethiopian topography harbors between 6500 and 7000 vascular plant species, of which, 12% are endemic (Tewolde, 1991).

Despite this biodiversity, the biological resources of Ethiopia are currently under critical threat mainly due to rapid population growth. The livelihood of the population mainly depends on natural products and lands, and the demand for these is consistently growing. This substantially drives the rapid decline of natural vegetation in Ethiopia (Tolessa et al., 2017). The south, southwest, southeastern and northwestern parts of Ethiopia are the main locations for some intact Afromontane rainforests for which habitat fragmentation and loss has been becoming the dominant threat, as it is also a threat for plant diversity at global level (Corlett, 2016). Ethiopia has been identified as one of the African regions containing large proportion of potentially threatened species with extinction (Stévart et al., 2019). A recent study on the global distribution of rare land plant species reported that Ethiopian highlands are hotspots for large number of rare species (Enquist et al., 2019). However, the ecological and evolutionary history of these vegetations and species have not been widely explored.

The elevational and climatic heterogeneity of Ethiopia provide natural conditions to test the response of biodiversity to global environmental change over space and time. However, the majority of studies have simply reported the species richness and floristic composition of different forests (Admassu et al., 2016; Feyera et al., 2007; Kebede et al., 2013; Kuma and Shibru, 2015; Masresha et al., 2015; Soromessa et al., 2004). Few studies have examined how the natural conditions separately and in concert affect species diversity, genetic diversity, vegetation formation, species growth, and carbon storage (Breugel et al., 2016; Chala et al., 2016; Derero et al., 2011; Friis et al., 2005; Kidane et al., 2019; Mokria et al., 2015; Siyum et al., 2019). However, to better understand the ecological dynamics of plants and animals of Ethiopia and develop effective conservation priorities, researchers should widely investigate the ecology and biology of plant populations, species, communities, and ecosystems across spatial and temporal scales. This is a great opportunity for ecologists, biologists, and conservationists to examine the responses of species, communities, and forests to the unprecedented disturbances, including environmental and climate changes. Furthermore, understanding the ecological dynamics of Ethiopia may help save some rare species that are critical for ecosystem to function.

Ethiopia provides an opportunity for a wide range of experts to investigate the ecological and evolutionary processes driving ecological communities and how the geological history of the region contributes for the biogeographical distribution of plants. Although the east African geological history, Great Rift Valley, diverse topography and climate are fascinating, few studies have examined how these factors act, separately and in concert, to affect species colonization, speciation, and extinction (Evans et al., 2011; Freilich et al., 2016; Friis et al., 2005; Smith et al., 2017). Furthermore, research is needed to describe the phenology, as well as the functional and evolutionary structure of plant taxa, assess the risk of extinction for taxa over time. The low percentage of known taxa for non-woody species and others have become barriers to designing effective conservation strategies and ultimately affects our ability to meet the goals of the zero global plant extinction project (Corlett, 2016).

The aim of this review is to introduce ecologists, geneticists, conservation experts, paleobotanists, and evolutionary biologists to the ecological dynamics of vegetations in Ethiopia. Specifically, we will provide an overview of the diversity of habitats, ecosystems and vegetation types in Ethiopia, and discuss research on the Ethiopian flora and its biogeographical implications. By integrating our understanding of these regional issues with global data, we anticipate that this review will contribute to global conservation efforts.

2. Geological history, climate and landscape features

The geological history of Ethiopia is characterized by periods of highland uplift and rift formation. The highlands are divided into northwestern and southeastern regions by the Great Rift Valley, which started to uplift because of volcanic forces 75 million year ago (Olson and Dinerstein, 1998). Generally, highland uplift forms new habitats with hydrological, elevational, and topographical heterogeneity, and has been shown to drive diversification of taxa (Smith et al., 2017).

The biotic assemblage of Ethiopian highlands consists of Afrotropical and palearctic biota. During dry glacial periods, a range of escarpments and jebels along the Red Sea permits connectivity with the temperate biomes in the north and Arabian Peninsula, which has provided a route for various palearctic species to colonize the highlands. The Kenyan desert in the south and the great Nile River floodplains in the west restrict immigration of new plant and animal species. Therefore, over the last one million years, the highlands have recruited species from the surrounding dry lowlands.

The post-volcanic and post-glacial history of Ethiopia are reflected in the distributions of plant diversity. Specifically, plant diversity is lower in the Ethiopian highlands than in the lowlands. However, the highlands are centers of endemism, largely due to their geographical isolation and unique climatic conditions (Berit and Linder, 2014; Friis et al., 2005; Noroozi et al., 2018). The Great Rift Valley also acts as a geological barrier, extending more than 900 km between the border with Djibouti in the northeast to the border with Kenya in the southwest (Billi, 2015) and with a width between 50 and 60 km. The Rift Valley restricts immigration of many taxa, including plants, birds, amphibians, reptiles, and insects (Freilich et al., 2014; Gottelli et al., 2004) and has novel habitats (e.g., rift valley lakes) that provide homes for large numbers of taxa.

The Ethiopian highlands are extremely heterogenous, with steep escarpments and deep valleys (Fig. 2). The highlands are known as “the roof of Africa” (in Africa the majority of land over 3000 m is found in Ethiopia) and reach 4533 m at the summit of Ras Dashen in the scenic world heritage Simien Mountains (Roberts et al., 2012). Most of the sub-Saharan Africa's Afroalpine ecosystem above 3200 m is found in Ethiopia (Williams et al., 2004). Ethiopian highlands have been designated hotspots for large number of rare land plant species (Enquist et al., 2019). The highlands are also rich in endemics species of birds (Redman et al., 2011), mammals (Melaku, 2011; Yalden and Largen, 2008) and frogs (Largen and Spawls, 2010).

The highlands can be categorized into the lower elevations (800–1500 m), higher elevations (1500–3000 m) and peaks (above 3000 m). The lower elevations of Ethiopian highlands support woodland vegetations such as *Acacia* and *Terminalia* species. The higher elevations support conifers such as *podocarpus* and *Juniperus* species. The peaks (Afroalpine ecosystem) support *Erica* species, grasslands, and herb layer and are mainly characterized by giant *Lobelia* species. Details on these vegetation types are given in the following sections.

Several factors are known to regulate Ethiopia's climate. Generally, the climate is controlled by the Intertropical Convergence Zone (ITCZ) and has a clear bimodal rainfall pattern: the rainy season is from June to September, and the dry season is from October to April. Rainfall generally increases from north to south and east to west, with an average annual rainfall of 600 mm in the northeast and 2000 mm in the southwest (Aerts et al., 2016). This huge climate variability is responsible for the wide range of vegetation types across the country, which includes arid and semi-arid Acacia woodland and Afroalpine vegetations.

Ethiopia's proximity to the equator and the complexity of the country's topography also play a role in regulating Ethiopia's climate, especially the temperature. Slight seasonal variation on the average monthly temperature has been reported at a given elevation with about 2 °C in the southern and 6 °C in the northern part of the country. Importantly, Ethiopia's climate varies with elevation (Fig. 3). Elevation is the most important determinant of the average annual temperature of the country with a reduction of 0.5–0.7 °C per 100 m increase in altitude (Liljequist, 1986).

3. Ethiopian vegetation types and distribution

Four studies have classified Ethiopian vegetation into different types (Table 1). Pichi Sermolli (1957) and White (1983) tried to classify Ethiopian vegetation based on topography. However, these studies produced vegetation maps that differed in terms of the geographical extent of vegetation types. Specifically, the geographical extent of similar vegetation types on these two maps is inconsistent. In addition, the vegetation types on these maps, which were mainly associated with elevation, do not match the complex topography of the country (Friis et al., 2010). Inconsistent vegetation maps pose a clear challenge for stakeholders trying to plan and implement various development and conservation objectives. In response, the Ethiopian Flora Project was established in 1980 and ended in 2009 with the publication of eight volumes of the *Flora of Ethiopia* and *Eritrea*. These books extensively describe

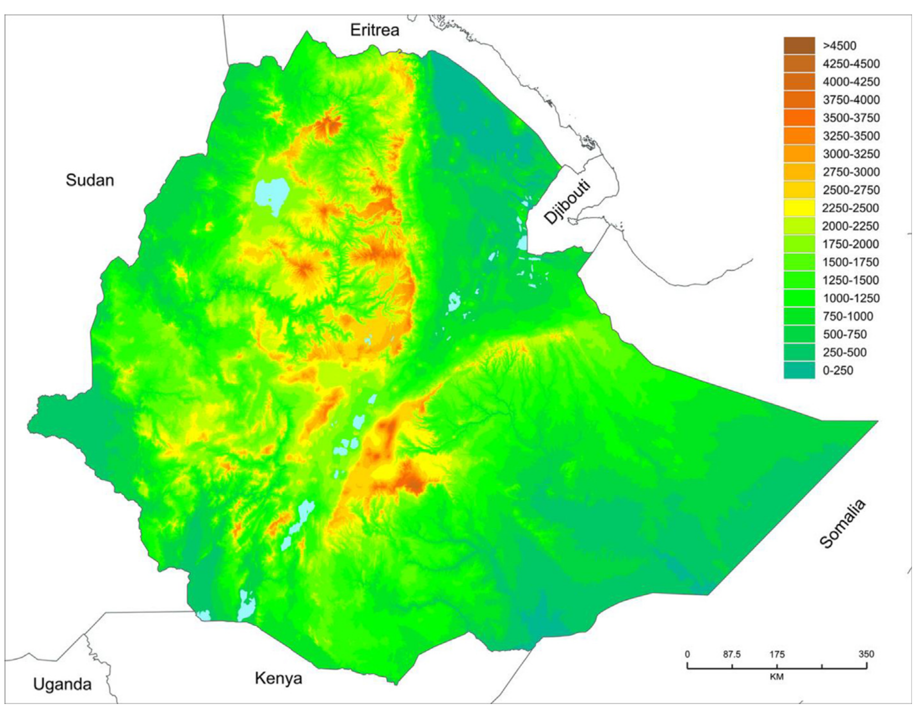

Fig. 2. Distribution of altitudes in Ethiopia. The small area below sea level at the Afar Depression is shown as the 0–250 m interval. With permission, this map is reproduced from Friis et al. (2010) (Used under Creative Commons licenses).

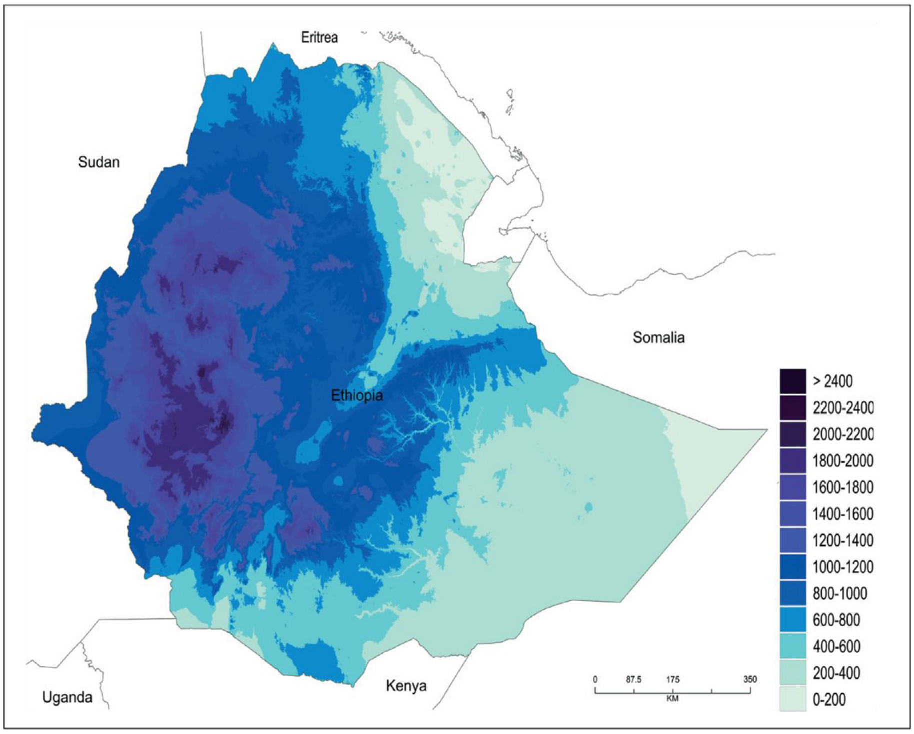

Fig. 3. Distribution of mean annual rainfall (mm) in Ethiopia. With permission, this map is reproduced from Friis et al. (2010) (Used under Creative Commons licenses).

Table 1
The four classification systems for Ethiopian vegetation types.

Classification system	# of vegetation types	Criteria	Note
Pichi Sermolli (1957)	24	altitude	includes Ethiopia, Eritrea & Somalia
White (1983)	13	altitude	
Sebsibe et al. (2004)	8	altitude & climate	
Friis et al. (2010)	12	altitude & climate	

the geographical distribution of each woody vascular plant species. The project has also produced an insightful book with the new potential vegetation types of Ethiopia showing the location map of each vegetation type (Friis et al., 2010).

Here we present the 8 vegetation types of Ethiopia based on elevation and climate (Sebsebe et al., 2004). These are the same vegetation types officially used by the Institute of Biodiversity of Ethiopia (IBC, 2005). These vegetation types have been re-classified into 12 major types, including sub-vegetation types based on elevation and rainfall pattern (Friis et al., 2010). In this new classification system, the 'aquatic vegetation type' has been re-classified into three more detailed vegetation types. Moreover, one vegetation type called 'Ericaceous belt' has been added. Ericaceous belt vegetation is dominated by *Erica* species in the highlands with a narrow range of elevations between 3000 and 3200 m. The upper and lower limit of this Ericaceous belt is bordered by Afroalpine and Afromontane vegetation types respectively. The other 8 vegetation types of this new classification system (Friis et al., 2010) are mostly similar to the officially recognized 8 vegetation types. Therefore, here we present 8 vegetation types: Afroalpine and sub-afroalpine vegetation, Dry evergreen Afromontane forest and grassland complex, Moist evergreen Afromontane forest vegetation, Acacia-Comiphora woodland vegetation, Combretum-Terminalia woodland vegetation, Lowland semi-evergreen forest vegetation, Desert and semi-desert scrubland vegetation, and Aquatic vegetation. We provide the elevational range and number of recorded species in each vegetation type in Table 2.

3.1. *Afroalpine and sub-afroalpine vegetation*

Afroalpine and sub-afroalpine vegetation types are widely distributed in Ethiopia, unlike in other African habitats (IBC, 2005). These vegetation types have widely been designated as the national protected areas due to the presence of several endemic plant and animal species. The vegetation is highly restricted to the highlands with elevations ranging from 3200 to 4533 m asl (the peak of Ras Dashen). Despite diurnal temperature fluctuations in which the days are summer-like and the nights are winter-like, seasonal temperature variation is not a characteristic of this vegetation type (Hedberg, 1995). For the past 10,000 years the Ethiopian highlands were largely covered with Afroalpine moorland and grasslands (Fig. 4). The current highland Afroalpine and sub-afroalpine vegetation represents remnants of these patches. Clearly, the remnants of these habitats in the complex highlands of Ethiopia demonstrate the effects of unprecedented and massive anthropogenic activity in the last 19th and 20th centuries (Nyssen et al., 2014).

Afroalpine and sub-afroalpine vegetation types in the Ethiopian highlands have not been widely studied even though they are inhabited by endemic plant and animal species (for example, the giant *Lobelia rhynchopetalum*). Studies have yet to investigate the adaptive mechanisms, phenology, species interactions, genetic

Table 2
Ethiopian vegetation types, number of recorded species obtained from Friis et al. (2010) and major threats.

	Vegetation types	Altitude	# of species	Threats
1	Afroalpine & sub-afroalpine	3200–4533 m	22	Agriculture, climate change
2	Dry evergreen montane & grassland complex	1800–3000 m	460	Agriculture, grazing, fuel wood
3	Moist evergreen montane forest	500–2600 m	135	Agriculture, tea & coffee plantations
4	Acacia-Commiphora woodland	900–1900 m	542	Fuel wood, charcoal, agriculture
5	Combretum-Terminalia woodland	500–1900 m	199	Fire, settlement
6	Lowland semi-evergreen forest	450–650 m	101	Fire, infrastructure
7	Desert & semi-desert scrubland	<400 m	131	Invasive species, grazing
8	Aquatic vegetation	Lowlands to highlands	251	Sedimentation, invasive species, change to farmlands

Fig. 4. Partial view of Afroalpine and sub-afroalpine vegetation.

diversity, species growth dynamics, and distribution patterns of species in these vegetation types.

3.2. Dry evergreen montane forest and grassland complex

Dry evergreen montane forest is usually found between 1800 and 3000 m asl, where human settlements and activity dominate (Friis et al., 2010). Dry evergreen montane forest is characterized by a complex set of successions with wide-ranging grasslands rich in legumes, shrubs, and small to large-sized trees to closed forest with vertical canopy stratification (Fig. 5). These forests cover most of the mountainous topography of the Ethiopian highlands.

The flora of Dry evergreen montane forest is, except for that of Acacia-Commiphora woodland, the largest of Ethiopian vegetation types, containing many unique species. Some of the most common species in this vegetation type are *Juniperus procera, Podocarpus falcatus, Olea europaea subsp. Cuspidata*, and *Eucalyptus* (Friis et al., 2010; IBC, 2005). *Eucalyptus* has rarely becomes naturalized as its presence in this vegetation is due to direct human interference (Friis, 1995).

One of the dominant ecological drivers of the vegetation structure in this ecosystem is grazing. The cattle population in Ethiopia is the largest in Africa, and 10th largest in the world, which has considerable implications for ecological and biological conservation (IBC, 2014). Thus, future studies should examine how grazing patterns shape the phenology, functional strategy, evolutionary history, and plant–animal interaction of the community in combination with other potential drivers.

3.3. Moist evergreen montane forest vegetation

The Ethiopian montane forests are part of the global biodiversity conservation priority areas as well as centers for plant diversity and endemic bird areas primarily because of exceptionally high endemism of species and habitat degradation (ICBP, 1992; WWF and IUCN, 1994). Moist evergreen montane forest is mainly distributed to the southwest escarpment of Ethiopia. It consists of the Afromontane rainforest between elevations of 1500 and 2600 m and the transitional rainforest, which is distributed from 500 to 1500 m in elevation (Sebsebe et al., 2004). The transitional rainforest is composed of species from both the Afromontane rainforest and the lowland forests (Friis, 1992; Gole et al., 2008), suggesting that it links the forest from highlands with lowlands. This forest is the location of the famous wild population of *coffee arabica* (Senbeta and Denich, 2006). However, Moist evergreen montane forest is threatened by tea and coffee plantations, human settlement, and agriculture (Gole et al., 2008).

3.4. Acacia-Commiphora woodland vegetation

Acacia-Commiphora woodland vegetation occurs in the north, east, central and south parts of Ethiopia between 900 and 1900 m, including the rift valley, and consists of drought-resistant trees and shrubs of evergreen or deciduous leaves mainly in the sandy dominated soil type (Friis et al., 2010). Acacia-Commiphora woodland is a complex vegetation type and the most diverse forest type. It forms a complete set of stratum and has unique species with the ability to tolerate limited soil moisture (IBC, 2005). The most characteristic species of Acacia-Commiphora woodland vegetation are *Acacia* and *Commiphora* genera. The most common of these species include *Acacia prasinata* (endemic), *Acacia bussei, Commiphora alaticaulis*, *Commiphora boranensis,* and *Commiphora obovata*. Additional common species in this ecosystem include Fabaceae, Burseraceae, Balanitaceae, Combretaceae, and other families. Acacia-Commiphora woodland is also known for endemic

Fig. 5. Dry Evergreen Montane Forest and Grassland complex.

succulent species such as *Euphorbia awashensis, Euphorbia omariana,* and *Euphorbia burger* (Friis et al., 2010).

3.5. Combretum-Terminalia woodland

Combretum-Terminalia woodland vegetation is found in the western escarpment of Ethiopia where the Gambela and Alatish national parks are located. It consists of widely distributed small to moderate size trees that are adapted to fire (IBC, 2005). Commonly observed species include *Boswellia papyrifera, Anogeissus leiocarpa*, and other species in the genera *Terminalia* and *Combretum*. The grass stratum of Combretum-Terminalia woodland is well developed and frequently burned during the dry season. Thus, this vegetation type is especially vulnerable to fire during the dry season (Friis et al., 2010) (Fig. 6).

3.6. Lowland, semi-evergreen forest

Lowland, semi-evergreen forest is mainly found in the lowland eastern Gambela region at elevations between 450 and 650 m. Trees are semi-deciduous with a height ranging from 15 to 20 m tall with continuous canopy of *Baphia abyssinica*. The characteristic species of lowland semi-evergreen forest are *Alstonia boonei, Morus mesozygia, Pouteria altissima,* and *Trilepisium madagascariense* (Friis et al., 2010). Other species that build this forest type include *Celtis toka, Diospyros abyssinica,* and *Malacantha alnifolia*. This forest is prone to fire and human activities for agricultural purpose.

3.7. Desert and semi-desert scrubland

This scrubland is mainly restricted to the eastern part of Ethiopia below elevations of 400 m. It consists of drought-tolerant small trees, shrubs, and herbs. Characteristic species of Desert and semi-desert scrubland are *Acacia ehrenbergiana* (Fabaceae), *Boswellia ogadensis* (Burseraceae), *Kissenia arabica* (Loasaceae), and *Ziziphus hamur* (Rhamnaceae) (Friis et al., 2010). This vegetation has the highest endemism richness in Ethiopia, and includes species such as the succulent *Euphorbia doloensis*. However, scrubland is threatened by overgrazing and habitat degradation. In addition,

Fig. 6. Partial view of Combretum-Terminalia woodland obtained with permission from Friis and Sebsebe (2008) (Used under Creative Commons licenses).

invasive alien species such as *Prosopis juliflora* also threaten native and endemic species (Kelbessa et al., 1992).

3.8. Aquatic vegetation

Globally, aquatic ecosystems provide major support to flora and fauna. Ethiopia, where the headwaters of the Blue Nile originate, is one of the world centers of aquatic resources. Aquatic vegetation includes plants found in rivers, reservoirs, lakes, floodplains, and wetlands (Fig. 7).

Freshwater lakes, shores and floodplains represent a transition zone between aquatic and terrestrial habitats and are primarily characterized by highly diverse biological communities and centers of biogeochemical activity (Strayer and Findlay, 2010). This vegetation type is geographically restricted to lakes, lake shores, marshes and floodplains. Several freshwater lakes are distributed throughout Ethiopia, including Lake Tana in the northern highlands, and lakes Abaya and Chamo in the south.

The species composition, structure and density in aquatic ecosystems vary greatly and depend on the elevation and geographical location. Aquatic vegetation is characterized by poor floristic composition in relation to woody species. Species in aquatic ecosystems are not unique, but rather shared by other adjacent vegetation types. According to Friis et al. (2010), eight species have been recorded in this vegetation type. *Lemna aequinoctalis, Wolfia arrhizal* and *Pistia stratiotes* are the characteristic species particularly for freshwater lakes. On other hand, *Phoenix reclinata, Lannea edulis*, species in the genera *Aeschynomene* and *Sesbania* from woody species; *Cyperus digitatus, Cyperus denudatus, Cyperus dichroostachys, Cyperus elegantulus*, and *Cyperus latifolius* from the sedges are found to be the characteristic species for freshwater swamp, lake shores and floodplains. 36 plant species were recorded just from two wetland sites in the southwesten part of Ethiopia (Woldemariam et al., 2018), suggesting that wetlands are rich in species diversity.

Riverine vegetation commonly includes *Celtis africana* (Ulmaceae), *Ficus sycomorus* (Moraceae), *Mimusops kummel* (Sapotaceae), and *Tamarindus indica*. Below elevations of 1800 m, species composition of riverine vegetation differs greatly from the surrounding forest in lowland dry environments. Interestingly, however, this dissimilarity in species composition decreases as elevation increases (Friis et al., 2010). Well-framed ecological questions should be examined to understand the mechanisms responsible for the spatial variation in species composition, richness and diversity of different vegetations at a wide range of spatial and temporal scales.

Ethiopian aquatic ecosystems have been estimated to support more than 200 species of phytoplankton (IBC, 2005), and are centers of breeding, feeding, and roosting for several resident and migratory bird species. These aquatic ecosystems are also habitats for several native and endemic species of fish. Currently, however, these ecosystems are seriously threatened by climate change and human activities. Furthermore, the aquatic biodiversity of Ethiopia, particularly in Lake Tana, is threatened by invasive water hyacinth. Although Ethiopia is rich in aquatic resources, the biodiversity of this ecosystem has been poorly investigated. Moreover, many ecological questions remain to be explored, including those regarding diversity, distribution patterns, and the impacts of climate change and invasive alien species.

Table 2 shows the number of woody species recorded in each vegetation type. The composition of species in each vegetation type raises several broad and specific ecological, evolutionary, and conservation questions. What factors lead to the presence of unique species in these vegetation types? Why are some species confined to narrow ecological ranges? What are the adaptations that allow unique species to tolerate environmental stress? How do these unique species interact with other neighboring non-unique species? What do unique species contribute to ecosystem functioning? How does evolutionary history of species shape their current spatial distribution? What are the values of these species for biodiversity conservation?

The vegetation map of Ethiopia is derived from work by Friis et al. (2010) and is based on topography (elevation) and climatic conditions (Fig. 8).

4. Plant diversity and endemism in Ethiopia

Ethiopia is located at the center of two of the world's 36 biodiversity hotspots, the Eastern Afro-Montane and Horn of Africa biodiversity hotspots (CEPF, 2016; Mittermeier et al., 2004). For both of these biodiversity hotspots researchers have identified significant threats and levels of endemism. The number of endemic plant species and near-endemic species in Ethiopia is high (Friis et al., 2005). Specifically, 12% of the total woody species in Ethiopia has been found to be endemic to different vegetation types (Tewolde, 1991). High species diversity and endemism in Ethiopia is most likely associated with its diverse topography and climatic conditions. Levels of endemism can be predicted using various environmental gradients such as climate, temperature, and microhabitat. These predictions help identify centers of endemism and improve efforts to conserve biodiversity. In tropical and temperate regions, endemism increases along an elevational

Fig. 7. Vegetation of freshwater lakes and marsh.

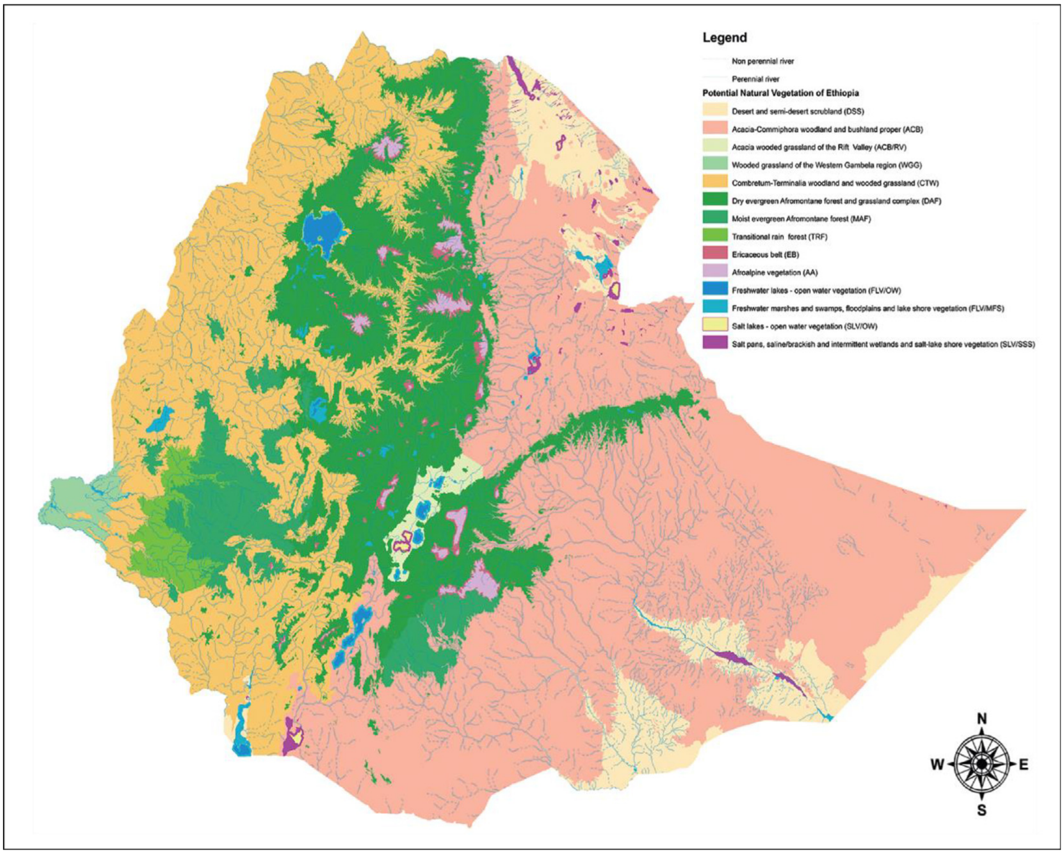

Fig. 8. Map of the vegetation types of Ethiopia obtained with permission from Friis et al. (2010) (Used under.Creative Commons licenses). This map contains additional potential vegetation types which are not explained in the article.

gradient, suggesting that mountains are rich in endemic plant species (Matthews et al., 1993).

In Ethiopia, centers of endemism include the highlands and southern part of the country (Ogaden). In southern Ethiopia, near-endemic species include taxa that have narrow geographical ranges shared between the horn of Africa and north Kenya. Endemic species are also linked to the environmental heterogeneity of Ethiopia's complex topography, which creates diverse local habitats that provide micro-refugia for species during extreme environmental changes (Steinbauer et al., 2013). Furthermore, complex topography is also expected to limit gene flow between isolated populations, thus promoting genetic differentiation that may lead to speciation (Gillespie and Roderick, 2014). Friis et al. (2005) found that high species diversity in Ethiopia is correlated with high elevations. This is consistent with previous studies that have reported that endemic plant and animal species increase as elevation increases (Ghimire, 2005; Noroozi et al., 2018), likely because isolated high mountain regions promote population divergence (Heaney, 2001). However, research is still needed to explore the population status, and the ecological and evolutionary drivers that underlie the distribution of endemic species in space and time, especially in response to rapidly changing environments.

In total, there are 476 endemic species in Ethiopia belonging to 69 families and 224 genera (Edwards et al., 2000, 1997; 1995; Hedberg et al., 2006, 2003; Hedberg and Edwards, 1989; Phillips, 1995; Tadesse, 2004). Five genera but no families are wholly endemic to Ethiopia. Based on the studies cited above, a list of endemic species has been compiled by Awas in the Institute of Biodiversity Conservation (http://www.ebi.gov.et/wp-content/uploads/downloads/Endemic_plants_of_Ethiopia-Reported.pdf). To prioritize conservation efforts, the distribution of these endemic species should be matched to the eight identified vegetation types. Furthermore, the population demography of most of the endemic species has not been well characterized.

5. Conclusion

Ethiopia is rich in biodiversity, topographical complexity and climate variability which jointly results in different vegetation types. The geological history and climate of the country are mainly responsible for the formation of different vegetation types ranging from drought-tolerant vegetation in the lowlands to cold-tolerant species at the peak of the mountain in the highlands. Ethiopia represents the Afrotropical and palearctic species due to the connection established in the dry glacial period. Most previous studies have focused assessing the floristic composition of forests. Studies remain needed to quantify and predict the effect of disturbance, environment, climate change, geology and topography on the ecology and biology of species. To understand the response of species and vegetation to climate and environmental changes at a global level, researchers are currently able to generate data on a global scale. This ultimately helps identify biodiversity hotspots and ecoregions, and thus design comprehensive conservation strategies that save threatened species. Ethiopian vegetation types provide an opportunity for ecologists, biologists, conservationists and other researchers to investigate how complex biotic interactions, physical environment, ecological, and evolutionary processes determine vegetation dynamics at regional scales and beyond.

Author contributions

MA and YJ wrote the manuscript, and all authors provided comments.

Declaration of Competing Interest

Authors declare no conflict of interests.

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