

Pattern and Dynamics of Remnant Dry Afromontane Forests: A Case Study in Northwestern Ethiopia

By

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Dissertation presented for the degree of Doctor of Philosophy (Forest Science) in the Faculty of
AgriSciences at Stellenbosch University

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April 2019

Declaration

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Abstract

Often forest managers get confronted with the management of a new forest area for which no information is available. The concept of this dissertation is to use a combination of common analytical tools to develop a first approximation of the ecological status of Afromontane forests in northwest Ethiopia. This included analyses of the floristic-structural composition and species associations of these forests, their plant-plant and plant-site relationships, and their response to different disturbance factors. These aspects form the basis for developing a sustainable resource use management system. The floral composition, plant-plant and plant-environment interactions, spatial scales of disturbance affecting regeneration of species differently, and population status of species, were investigated in three Afromontane forests of northwest Ethiopia, to develop a first approximation of the ecological status of forests. A systematic sampling design in homogenous stands was employed to collect vegetation and environmental data. Data were collected from 150 nested circular plots, with 50 plots sampled in each of three Afromontane forests, namely Alem Saga, Gelawudiwos and Tara Gedam. Each plot consisted of a main plot of 100 m² and a sub-plot of 1 m², respectively for the woody and herbaceous species. Soil and litter were collected from the subplot. Topographical variables, including altitude, aspect and slope, were collected from each plot. Species were grouped into four propagule types, based on the type and size of the part of the fruit or seed or combination of the two, that gets dispersed by dispersal agents: fleshy large, fleshy small, dry large and dry small. Propagules considered as small when <5 mm diameter, and large with ≥5 mm diameter. Diversity and diversity profiles were analysed, using Shannon index and Renyi index, respectively. The floral similarity with other Afromontane forests in Ethiopia and Africa, and woodlands from Ethiopia, were analysed, using Sørensen similarity index. TWINSpan and DCA analyses (indirect gradient analysis) were used separately for woody and herbaceous species to identify plant communities. Direct gradient analysis (CCA) was used to investigate the relationship between the identified communities and various environmental variables. Spatial ordination analysis, using DCA, was used as an analytical approach to investigate the scales of disturbance (gap sizes), affecting the regeneration of canopy tree species. The population structure of selected tree species was analysed using stem diameter class distributions across different communities. A total of 209 vascular plant species, including 109 woody and 100 herbaceous species, were recorded. Seven of these species were known to be endemic to Ethiopia. The species presented 58% with dry and 42% with fleshy propagules, with 40% small, dry propagules. In herbaceous species, dry and small propagules were predominated with 64%. The area showed a Shannon-Weiner diversity and evenness value of 4.0 and 0.26, respectively; indicating that the study area has high floristic diversity despite uneven distribution of the individuals among the encountered species. The three most diverse Afromontane forests, with their shared number of species

and Sørensen similarity percentages between brackets, within the present study area, were Wondo Genet with 80 (35.6 %), Gendo with 70 (37.1%) and Denkoro with 68 (35.5%), but 23 species (6.6%) were shared with the Southern Cape in South Africa at the southern end of Africa. The Metema woodlands contributed a 20.6% similarity for herbaceous species. Such floral similarity of Afromontane forests maybe attributed to fragmentation of their historical landmass connectivity (vicariance) and dispersal between more local forests. Four main woody plant communities along with sixteen sub-communities and two main herbaceous plant communities along with eight sub-communities were identified. Different communities showed different affinities towards different gradients, despite some overlap occurring among communities. Radiation index (calculated from slope and aspect) and altitude were found to be the common highly significant environmental variables to explain the occurrence and composition of both herbaceous and woody communities. Various scales of disturbance affected regeneration of canopy tree species across forest communities, ranging from fine to coarse spatial scales. Some species, including *Prunus africana*, *Olea capensis* subsp. *macrocarpa*, *Olea europaea* subsp. *cuspidata* and *Schefflera abyssinica* showed critically poor regeneration, which need conservation attention. Plant communities were also characterized by different gradients and spatial scales of disturbance affecting their regeneration, indicating the need for different management interventions. The information obtained in this study, about floristic-structural composition, species associations, their plant-plant and plant-site relationships, and their response to different disturbance factors, provide the essential basis for guiding better resource use management of these forests.

Opsomming

Dikwels word woudbestuurders gekonfronteer met die bestuur van 'n nuwe woud waarvoor geen inligting beskikbaar is nie. Die konsep van hierdie tesis is om algemene analitiese tegnieke in kombinasie te gebruik om 'n eerste benadering te ontwikkel van die floristies-strukturele samestelling, species-assosiasies, hulle plant-plant and plant-groeiplek verhoudings, en hul reaksie op verskillende versteuringsfaktore, as basis vir die ontwikkeling van volhoubare hulpbrongebruiksbestuursisteme. Inligting oor die flora van 'n woud, die plantgemeenskappe en hul onderliggende omgewingsveranderlikes, en die versteuring-herstelprosesse, is basiese insette vir volhoubare bestuur van 'n woudekosistiem. Die aanwesige plantsoorte en hul samestelling in plantgemeenskappe, die plant-plant en plant-omgewing interaksies, ruimtelike skale van versteuring wat verjonging van kroondakboomsoorte verskillend beïnvloed, en die populasie-status van boomsoorte, is in drie Afromontane-woude van noordwestelike Ethiopië ondersoek. 'n Sistematiese opname in homogene boomsamestellings is gedoen om plantegroei- en omgewingsdata te versamel. Data is op 150 genestelde sirkelpersele versamel, met 50 persele in elk van drie Afromontane-woude, naamlik Alem Saga, Gelawudiwos and Tara Gedam. Elke perseel het bestaan uit 'n hoofperseel van 100 m² vir houtagtige en 'n sub-perseel van 1 m² vir kruidagtige soorte. Grond- en blaarvalmonsters is binne die sub-perseel versamel. Hoogte bo seevlak, aspek en helling, is vir elke perseel aangeteken. Plantsoort-diversiteit en diversiteitsprofiel is onderskeidelik met behulp van Shannon- en Renyi-indekse ontleed. Die plantsoort-ooreenkomste met ander Afromontane-woude in Ethiopië en in Afrika, en met boomveld in Ethiopië, is ontleed met die Sørensen ooreenkomsindeks. Afsonderlike ontledings vir houtagtige en kruidagtige soorte, met TWINSPAN- en DCA (indirekte gradientanalise), is gebruik om plantgemeenskappe te identifiseer. Die verwantskap tussen geïdentifiseerde gemeenskappe en verskeie omgewingsveranderlikes is met CCA (direkte gradientanalise) ontleed. 'n Ruimtelike-ordeningsontleding met DCA is gebruik om die invloed van die ruimtelike skaal van versteuring (kroondakopening-grootte) op die verjonging van kroondakboomsoorte te ondersoek. Die stamdeursneeklas-verdeling van geselekteerde boomsoorte is gebruik om hul populasiestruktuur oor plantgemeenskappe te ontleed. 'n Totaal van 209 plantsoorte bestaande uit 109 houtagtige en 100 kruidagtige soorte, is aangeteken. Sewe plantsoorte is endemies tot Ethiopië. Die Shannon-Weiner-diversiteit en gelykheidswaardes van onderskeidelik 4.0 en 0.26, wys dat die studiegebied 'n hoë floristiese diversiteit het, ongeag die ongelyke verspreiding van plante van die versamelde soorte. Die drie mees diverse Afromontane-woude in die studiegebied, met hul onderskeie gedeelde aantal plantsoorte, en hul Sørensen ooreenkomsindeks tussen hakies, is Wondo Genet met 80 (35.6 %), Gendo met 70 (37.1%) en Denkoro met 68 (35.5%), maar 22 spesies (6.6%) is gedeel met die Suid-Kaap in die suide van Afrika. Die Metema boomveld het 20.6% bygedra tot

die ooreenkomste met kruidagtige soorte. Sulke ooreenkomste in plantegroei van die Afromontane-woude kan toegeskryf word aan fragmentasie van hul historiese landmassa-konneksies (vikariansie-teorie) en saadverspreiding tussen meer naby-gelee woude. Die houtagtige samestelling het in vier hoof- en sestiën sub-plantgemeenskappe verdeel, en die kruidagtige samestelling in twee hoof- en agt sub-plantgemeenskappe. Die gemeenskappe verskil in terme van verskille in omgewingsgradiënte, afgesien van oorvleueling in samestelling tussen gemeenskappe. Radiasie-indeks (gebaseer op helling en aspek) en hoogte bo seevlak was die algemene en hoogsbeduidende omgewingsveranderlikes wat die voorkoms en samestelling van beide houtagtige en kruidagtige gemeenskappe bepaal. Verskeie skale van versteuring (fyn tot growwe grein) beïnvloed verjonging van kroondakboomsoorte oor verskillende gemeenskappe. Sekere boomsoorte, soos *Prunus africana*, *Olea capensis* subsp. *macrocarpa*, *Olea europaea* subsp. *cuspidata* en *Schefflera abyssinica*, het kritiese swak verjonging, wat bewaringsaandag benodig. Plantgemeenskappe is gekenmerk deur verskillende skale van versteuring in terme van hul verjonging, wat aandui dat verskillende tipes van bestuursingryping nodig is. Die inligting wat met hierdie studie verkry is, oor die floristies-strukturele samestelling, plantspesies assosiasies, hulle plant-plant en plant-groeiplek verhoudinge, en hul reaksie op verskillende versteuringsfaktore, sal leiding voorsien tot beter hulpbronbestuur.

Acknowledgments

I would like to express my sincere gratitude to my promoters, Professor Coert J. Geldenhuys and Prof. Pierre Ackerman, for their professional guidance throughout my study period. I thank Dr. Hannél Ham for her guidance during the earlier stages of my studies. I am thankful to Dr. Wessel J. Vermeulen, Professor Karen J. Esler and Professor Demel T. Fanta, for their valuable comments and inputs contributed as the examiners of this dissertation.

I am very thankful to my scholarship sponsor, Intra-ACP (AFIMEGQ Project), for funding me to further my study. I am thankful to the Department of Forest and Wood Science, and Merit Bursary of Stellenbosch University for the bursaries I received to pursue my studies. I extend my deepest gratitude to my wife, Lemlem Kebede Metaferia, for her willingness and the commitment she took so that I could use this opportunity to further my studies. I am thankful to all individuals and organizations in Ethiopia, for their kind cooperation during data collection. My gratitude also goes to my friends and colleagues for their encouragement throughout my study period.

Dedication

To my daughter, Eliana Haile Adamu.

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Chapter 1: General Introduction

1.1 Background of the study

Often forest managers get confronted with the management of a new forest area for which no information is available. What common analytical tools could be used in combination, to develop a first approximation of the floristic-structural composition, species associations, their plant-plant and plant-site relationships, and their response to different disturbance factors as basis for developing a sustainable resource use management system? Each stand of forest, and its place within a specific landscape complex of adjacent forest patches, presents the sum-total of a multitude of interactions that determine its floristic-structural composition and dynamics. Its species represent biogeographical links that span the local, regional and global landscapes, and geological time scales. It represents an association of species of different growth forms with different ecological characteristics and site relationships. It represents a history of adaptation to different disturbance-recovery processes that is reflected in the population demography of each component species. This patch of forest presents the potential for sustainable resource use if such a resource use system could be designed within the multitude of interactions represented in its floristic-structural composition and ecosystem dynamics. This study has addressed the challenge to unpack the multitude of interactions of a group of forests in northwestern Ethiopia.

1.1.1 Afromontane forests in Africa and Ethiopia

In Africa, the Afromontane region is an archipelago-like centre of endemism which extends from 11° West in Sierra Leone to 49° East in Somalia, and from 17° North in Sudan to 34° South in the Cape Peninsula in South Africa (White, 1983). In the tropics of Africa, most Afromontane communities are found only above 2000 m, but where the climate is more oceanic, as in the West Usambara Mountains in Tanzania, they occur as low as 1200 m. Further South, where latitude compensates for altitude, they descend progressively further, and in the Southern Cape area in the south of South Africa, exclaves of Afromontane forest (classified as Afrotemperate) are found at almost sea-level. Rainfall in Afromontane forest varies from 800 mm to considerably more than 2500 mm per year (White, 1983). Though these forest ecosystems are scattered in disjunct fragments, they are phytogeographically important areas harbouring high numbers of endemic species of fauna and flora, as well as ecologically and economically important tree species (Morgenthal and Cilliers, 2000; Craig *et al.*, 2002; Fjeldså *et al.*, 2010). Many of their species, such as some giant lobelias and senecios, are endemic to a single mountain or mountain system (Popp *et al.*, 2008). Apart from this, different

reports showed that such kinds of forest ecosystems in the continent are under pressure due to free grazing, agricultural expansion, and other anthropological pressures (Lejju *et al.*, 2000; Popoola *et al.*, 2002; Vieira and Scariot, 2006; Scutcliffe *et al.*, 2012; Kikoti and Mligo, 2015).

The Ethiopian Highlands are thought to have begun to rise some 75 million years ago. They are notably different from the rest of Africa by their vast extent of high plateaux with extensive farming. They harbour an estimated 5,200 vascular plant species, and of these, 555 species are endemics (Williams *et al.*, 2004). About 70% of the African landmass exceeding 1,500 m above mean sea level (a.s.l) is found in Ethiopia (Loader *et al.*, 2009). The Ethiopian highlands constitute more than 45% of the total area of the country and its highland forests are part of the Afromontane forest zone of Africa (White, 1983; Bekele, 2000). They are part of the Eastern Afromontane Hotspot, which is broadly described as the eastern portion of White's (1983) Afromontane Region of Africa. In this portion of the area, lower altitudinal limits are largely between 1,500 and 2,000 m a.s.l. (CEPF, 2012). The forest ecosystems of the Eastern Afromontane Hotspot have a wide but fragmented distribution, in a disparate geography, along the eastern edge of Africa and have remarkably similar floras. It is one of the world's 10 most threatened hotspot areas with only 11% remaining habitat (CI, 2005, 2011). The vegetation extent remaining in this area is 106,870 km² which is small compared to its original extent of 1,017,806 km² (CEPF, n.d.; Olson, 2010).

Natural forests of Bale and Semien mountains, and of the highlands at Menagesha Subba, Wof Washa, Borena-Sayint National Park, and Chilimo, are some examples of remnant Afromontane forests in Ethiopia (Bekele, 1993; Couralet *et al.*, 2007; Schürmann, 2008; Schmitt *et al.*, 2010; Tesfaye *et al.*, 2011; Chane and Yirga, 2014). Previous reports disclosed that these forests are experiencing ongoing deterioration due to free livestock grazing, farming practices, land-use change, settlement and other related anthropogenic pressures (Bishaw, 2001; Aerts *et al.*, 2006; Schmitt *et al.*, 2010; Daye and Healey, 2015; Guillozet *et al.*, 2015). These forests represent a highly fragmented vegetation type in the country and plant biodiversity of these forests are at potential risk of global warming (Kreyling *et al.*, 2010). Assisted colonization of plant species to the lower altitudinal ranges, particularly endemic and endangered species (such as *Hagenia abyssinica* and *Prunus africana*), has been suggested.

Two factors may have influenced the plant species present in these Afromontane forests of Ethiopia, their community associations (in addition to local site variation), and their links with other parts of the African Afromontane region: Biogeographical processes over geological time scales, and forest disturbance-recovery processes at landscape level.

1.1.2 Biogeographic processes over geological time scales

Most species, whether on continents or islands, have distributions that are patchy and located in discontinuous areas of suitable habitat. These species each exist as a metapopulation, that is, a population of distinct sub-populations that are separated geographically but potentially connected by propagule dispersal events (Heads, 2017). The distribution and evolution of species are not due to chance dispersal; instead, range expansion (dispersal) and geographic differentiation are both mediated by geomorphological and climate changes (Heads, 2012). Species can evolve and distribute from the dynamic interplay of vicariance, dispersal and extinction (Noben *et al.*, 2017). Ecological processes better explain distribution at smaller scales than do biogeographical and evolutionary processes (Heads, 2015).

Species on earth are not evenly distributed due to the influence of historical processes (Daniel and Vaz-de-Mello., 2016). Biogeography is a multidisciplinary science that involves the study of the geographical distribution of living organisms and their attributes in space and time. It can be divided into various sub-disciplines based on subjects, methods and aims (Morrone, 2014; Cox *et al.*, 2016; Fattorini, 2016).

Vicariance biogeography is about speciation resulting from a division or fragmentation within a group of organisms caused by a geographical barrier. Vicariance biogeography became more widely accepted through the 1970s and 1980s, but many biogeographers assumed that it could operate only on continents, as the result of continental breakup or the uplift of mountain ranges. Now, in the molecular era, most authors accept that vicariance occurs in many different geographical contexts and at a wide range of scales. However, vicariance is still not accepted as an explanation for the classic examples of evolution-endemic land organisms on young volcanic islands and archipelagos (Heads, 2017). This biogeography may explain the observed number of shared species between the studied forests, and Afromontane Forests in Ethiopia and other parts of Africa.

1.1.3 Forest disturbance-recovery processes shaping forest structure and function

Disturbances are a natural and integral part of forest ecosystems. The change in forest structure and function may be extreme, when disturbances exceed the natural tolerance ranges of the species. Disturbances are significant aspects of stand development (Dale *et al.*, 2000; Franklin *et al.*, 2002). They are ubiquitous, inherent and unavoidable that can affect all levels of biological organization (White and Jentsch, 2001). Disturbances disrupt the structure, composition and function of an ecosystem, community or population, and change resource availability or the physical environment.

In doing so, they create heterogeneity in the landscape, foster diversity across a wide range of guilds and species and initiate ecosystem renewal or reorganization. Disturbances are discrete events in time that reduce biomass and regulate material and energy flow through ecosystems; and thereby form characteristic regimes of typical disturbance frequencies, sizes and severities over extended spatial and temporal scales (Seidl *et al.* 2014, 2017; Morris *et al.*, 2015). The resulting landscape patterns, after disturbance, influence the rate and pattern of energy flow, nutrient cycling, wildlife and human responses, and susceptibility to subsequent disturbances (Foster *et al.*, 1998). There are three categories of intensity of disturbance: a non-event, if the frequency or intensity is too minor to elicit a response; an incorporated disturbance, if the entity is adapted to the scale of a disturbance event which then becomes necessary to maintain the entity in its present state; and a disaster, if the scale of the disturbance forces the entity into a new state. This varies depending on the scale of the entity, i.e. at the levels of an individual, population, community, ecosystem, landscape, etc (Hansen and Walker 1985; Geldenhuys, 2011).

The ‘disturbance/recovery’ paradigm has been gradually replacing the ‘stability/fragility’ paradigm in tropical forest ecology. Such a paradigm shift is about understanding the replacement of the notion of climax and stability, with a model of flux and dynamic change. Ecologists have long recognized that disturbances and recovery processes overlap in both spatial and temporal dimensions (Chazdon, 2003). Disturbances provide opportunities for colonization and establishment, and affect the competitive balance between early- and late-successional species at stand and landscape levels (Vanderwel and Purves, 2014). Understanding the probable consequences of a particular disturbance in a particular stand or landscape contributes to more informed decision-making, in relation to silvicultural management of forests (Peterson, 2007; Geldenhuys, 2010). However, though species can cope with optimum disturbance regimes (frequency, intensity, spatial scales, etc), they may be influenced by the intensification of other forms of external stresses, such as from drought, flooding, and in current context, climate change, air pollution and invasive plants (Trumbore *et al.*, 2015). The disturbance/recovery paradigm is relevant to understand the ongoing disturbance-recovery processes, observed in the studied forests. For example, it is important to understand what the optimum gap size would be for different tree species (for seedling establishment and growth), overall species diversity, structural heterogeneity and sustainability of the studied forests. Some tree species can regenerate well within small canopy openings (gaps), but others may need medium to large canopy gaps, depending on characteristics of tree species in relation to light conditions in gaps of different size (Poulson and Platt, 1989; Whitmore, 1989; Muscolo *et al.*, 2014; Sharma *et al.*, 2016).

Various factors cause disturbances in Afromontane forests. For example, Geldenhuys (2011) mentioned the occurrence of windfalls causing gaps of diverse size, lightning with or without fire,

fire spotting, flooding, and land slides, in other forest systems. However, there is no documentation on natural disturbance events that have been happening in the Afromontane forests within the Ethiopian biogeographical area. The forests of Ethiopia have been facing various anthropogenic pressures. Many churches have wooden structures and doors, made from relatively large-sized tree. The fact that the area was the center of power in the civilization process of the country, relatively high population presence and their pressures could have shaped the patterns of the natural forest ecosystems. Poles of various dimensions are being used in construction, and wood is used as energy source for cooking, as observed in various households.

Disturbance-recovery processes and rates of change are the basis for silviculture and sustainable forest management. Species dominance changes from early regrowth stands towards mature forest and some species have their optimum development and growth in some of these development stages. The appropriate silvicultural system depends on the position of these key species within the vegetation development stages of the disturbance-recovery regimes (Geldenhuys, 2011). Grain analysis, i.e. the relationship between canopy species in the canopy and regeneration of the same stand, is a tool to gain better understanding of the scale of disturbance processes in the forest (Midgley et al. 1990; Everard et al. 1995; Geldenhuys 1996). A coarse grain represents larger-scale disturbances which favor the dominance of light-demanding species that need large gaps away from the current stand, with better light conditions, to regenerate and establish. A fine grain represents smaller scale disturbances which favor the dominance of shade-tolerant species that can regenerate and establish under the closed canopy. In addition to this, stem diameter distributions for important species over different communities provide useful information on the regeneration requirements of specific species. The inverse J-shaped stem diameter distribution is typical of the species that regenerate regularly under the specific conditions of the closed-canopy stands, while the Bell-shaped stem diameter distribution is typical of the species that require disturbed conditions with large gaps in the forest (Geldenhuys, 1993, 1996, 2010, 2011). The associated silvicultural system would be a single-tree selection system to favor small gaps for fine grain forest and species with the inverse J-shaped stem diameter distribution, and a group-felling system for the coarse-grained forest dominated by light-demanding species with Bell-shaped stem diameter distributions (Geldenhuys, 2010).

1.1.4 Forest Fires in Afromontane Forests of Ethiopia

Fire is one of the important disturbance factors that can shape the distribution and location pattern of natural evergreen forests within fire-prone vegetation (Geldenhuys, 1994). Frequent fires prevent the persistence of such forests within landscapes potentially suitable for forest growth. Wildfires may

have been playing an important role in the fragmentation and shaping of the distribution patterns of the highland forests in Ethiopia. For instance, presently many of the remaining Afromontane forests of Northwestern Ethiopia are located in the high elevation and hilly landscapes. The presence of many small fragmented patches of Afromontane forest in various ridges and folding lands of the present study area, might also reflect their persistence in such sites, sheltering them from fire-carrying winds that happened during the ancient times ([Wale, personal observation](#)), similar to observations of fire fragmentation of forests in South Africa ([Geldenhuys, 1994](#)).

There seems to be no recorded evidence of the history and occurrence of wildfires during ancient times and their role in the distribution of Afromontane forests of Ethiopia. However, it has been reported that human induced fires had devastated large areas of tree and shrub vegetation, including the Afromontane forests ([Wassie et al., 2005](#); [Belayneh et al., 2013](#)). One of the more devastating human-induced forest fires might have happened during the invasion of Imam Ahmad Ibn Ibrahim or Gagn (1528 –1543 A.D), who attempted to destroy the churches and monasteries of Ethiopian Orthodox Tewahido Church. During that time, the church owned about one third of Ethiopian lands; and most of the churches and monasteries were established in the central and northern parts of the country where remnant Afromontane forest patches are still existing today ([Eshete, 2007](#)). Moreover, fires set by the armies of Yodit/Gudit (849-897 A.D) had devastated large extent of Afromontane forests in this particular biogeographical area ([Lemessa and Perault, 2001](#)). Studies in this particular area, showed that a changing climate has negatively affected the ring growth and development of tree species, which in turn might affect trees' vulnerability or sensitivity to human induced fires ([Wils et al., 2011](#); [Mokria et al., 2015](#); [Belay, 2016](#)). During the last few decades, significant human-induced fires have occurred in this particular vegetation type ([Johansson, 2013](#)). Given the human factors and the influence of ongoing climate change, it is likely that there will be an increase in the occurrence of fires in the Afromontane forests in this biogeographical zone of Ethiopia ([van Breugel et al., 2016](#)).

Wildfires are still playing a significant role in shaping the distribution patterns of woodland vegetation in lowland Ethiopia ([Lemenih and Bongers, 2011](#); [Lemenih et al., 2014](#)). They also play significant roles in other parts of Africa and the world ([Ahlgren and Ahlgren, 1960](#); [Geldenhuys, 1994](#); [Adámek et al., 2015, 2016](#); [Hantson et al., 2016](#); [Kulakowski et al., 2017](#)).

The role of wildfires in shaping the distribution and location patterns of the Afromontane forests will not be addressed in this study. However, the history and role of wildfires in forests of this particular biogeographical area, need further study.

Wildfires are a key and integral part of the ecosystem processes in many ecosystems around the world ([Pausas and Keeley, 2014](#)). For example, fires can trigger regeneration of tree and shrub species by

inducing the germination of dormant soil-stored seed banks (Lipoma *et al.*, 2018). It can also initiate seedling recruitment by opening gaps in closed vegetation (Teketay, 2005).

1.1.5 Forest recovery processes through seed dispersal and regeneration

Nearly 75% of tropical tree species produce fruits presumably adapted for animal dispersal, and animals are estimated to move >95% of all seeds in tropical regions (Howe and Smallwood, 1982; Tsuji & Su, 2018). Seed size of a given plant species plays a significant role in the enhancement of dispersal and tolerance to seed damage by seed predators. Some seed predators inflict nonlethal damage, thereby allowing partially consumed fruits and seeds to survive and establish (Bartlow *et al.*, 2018). The presence of Lake Tana, and suitable wetlands and riverine ecosystems nearby the study area may play a significant role in harbouring many bird species and thereby enhancing seed dispersal, within this biogeographical area, in the country and Africa. Lake Tana and its surrounding wetlands, is considered to be one of 73 Important Bird Areas identified in the country (EWNHS, 1996). From riverine and wetland habitats of Lake Tana (in the southern tip of the lake), about 129 bird species were observed and reported including Intra-African Migrant bird species Abdim's Stork (*Ciconia abdimii*), African pygmy-Kingfisher (*Ispidina picta*) and Woodland Kingfisher (*Halcyon senegalensis*). Some of the other bird species observed in this area were African Citril (*Serinus citrinelloides*), African Collared-Dove (*Streptopelia roseogrisea*), African Fish-Eagle (*Haliaeetus vocifer*), African Jacana (*Actophilornis africana*), African Paradise Monarch (*Terpsiphone viridis*), African pygmy-goose (*Nettapus auritus*), African Rook (*Corvus capensis*), African Spoonbill (*Platalea alba*), African Water-Rail (*Rallus caerulescens*), African Wattled Lapwing (*Vanellus senegallus*), and Great white pelican (*Pelecanus onocrotalus*) (Aynalem and Bekele, 2008). Some frugivorous birds were observed in the Lake Tana area (Plate 1.1). Other fauna, such as baboons, bats, porcupines and colobus monkeys, may also contribute to seed dispersal.



Plate 1.1 Some birds observed in Tana Lake, in about 15 km to 50 km away from studied forests, that may contribute to dispersal of propagules of forest species.

1.1.6 The Plant Community

There are different views or paradigms on the meaning of a plant community. Some researchers consider plant communities to be parts of one organism (organismic concept) composed of various species, and therefore consider communities as recognizable and definable entities which repeat themselves over a given region of the earth's surface. The smallest unit of vegetation succession is a discrete plant association or community (Clements, 1916, 1936). In contrast, Gleason (1926) considered plant species distribution as a continuum, with no discrete units in the form of plant associations or communities, and that the phenomena of vegetation depend entirely upon the phenomena of the individual (individualistic concept). Clements (1916, 1936) considered that the vegetation unit (organism) exhibits a series of functions distinct from those of the individual and within which the individual plants play a part as subsidiary to the whole, similar to that of a single tracheid within a tree (Eliot, 2007).

Plant communities cannot be individualistic because the presence of one plant can increase the fitness of another species or the probability that another species may occur in the site. Positive interactions among plants occur when the presence of one plant enhances the growth, survival, or reproduction of a neighbouring plant (Callaway, 2010). Description of plant communities, however, needs to include information on how the individuals and species are grouped together, what determines their relative proportions, and their spatial and temporal relations to each other. Such information are paramount to fully understand and describe plant communities and their relationships, in both space and time.

There is high inherent variability within and among the natural plant communities, across space and time dimensions (Watt, 1947; Palmer *et al.*, 1997).

A study at plant community level is a useful approach towards forest management planning for conservation and resource use, for several reasons. Restoration efforts often involve a focus on multi-species assemblages (Palmer *et al.*, 1997). The plant community provides useful information on the underlying environmental drivers of species distribution, with plants that live together having similar environmental requirements for their existence (Berg *et al.*, 2014). However, species composition may vary in terms of response to disturbance-recovery processes (Geldenhuys, 2011). The plant community information helps to identify and locate vulnerable parts/patches of a given forest ecosystem, in relation to climate change, for effective priority conservation and management (Mokany *et al.*, 2014). Community-level spatial correlograms revealed a fixed pattern in time that is not apparent from species-level dynamics (Anand and Kadmon, 2016) which implies that the community is more stable than the sum of its parts, and that forest ecosystem research and management will be better and more reliable if research and conservation endeavours use community-level approaches, especially for data poor regions of the world (Arponen, 2009). The plant community concept and its application in vegetation management, conservation and environmental monitoring will be more practical and applicable, if it can integrate and consider multiple input data. The assembly rules that underlie structuring and functioning of plant communities, have to be found by integrating phytosociological, physiological, biochemical, morphological, genetical, historical, chronological, and ecological data (Biondi *et al.*, 2004; Berg *et al.*, 2014).

The two pioneering scholars with their contrasting views on the concept of the plant community, largely agreed on the principles of vegetation functioning but they differed in their methodologies and how to integrate recognized principles into general theory (Eliot, 2007). The understanding and application of both individualistic and organismic concepts, are both mandatory and supplementary to each other for better conservation and management planning of a given forest ecosystem (Wookey, 2008; Gonzalez and Loreau, 2009; Kahilainen *et al.*, 2014; Barracclough, 2015). Theoretically, neither individualistic nor organismic plant community theory provide a comprehensive modern view of plant communities, but we have yet to formalize and develop the current perspectives into an integrated plant community theory (Lortie *et al.*, 2004). In this study, the classification of the plot data into more homogenous plant associations will be compared with the results from indirect and direct gradient analyses where species will present as a continuum in ordination space in relation to species and site information.

1.1.7 Dry evergreen Afromontane forests and their sustainable Management in Ethiopia

Dry evergreen Afromontane forest is one of the main vegetation types found in Ethiopia, even though it is relatively limited and locally confined in its spatial distribution. The eleven other main vegetation types in the country include desert and semi-desert scrubland, *Acacia-Commiphora* woodland and bushland, wooded grassland of the western Gambela region, *Combretum-Terminalia* woodland and wooded grassland, moist evergreen Afromontane forest, transitional rain forest, ericaceous belt, Afro-alpine belt, riverine vegetation, freshwater (lakes, lake shores, marshes, swamps and floodplains) vegetation, and salt-water (lakes, lake shores, salt marshes and pan) vegetation types (Friis *et al.*, 2010). Floristically, Dry evergreen Afromontane forest is the second most rich vegetation type, after *Acacia-Commiphora* woodland and bushland. It occurs between altitudinal ranges of 1800 to 3000 m a.s.l, mainly in northern, northwestern, central and southeastern highlands of the country. The average annual temperature varies between 14 and 20°C and the annual rainfall between 700 and 1100 mm, with most of the rain recorded in mid-summer (July). It has a shared species similarity with the two adjacent vegetation types, i.e. riverine woodland and *Acacia-Commiphora* woodland and bushland (Teketay, 2005; Friis *et al.*, 2010). The two most direct threats in terms of deforestation and degradation are habitat conversion and unsustainable resource use, caused by the prevailing demographic change. The majority of Ethiopian people have been living, up to the present, in this biogeographic region because the central and north of the country was the center of power. Their pressures on the forests are still ongoing, due to poverty, a lack of awareness and of integrated resources management (IBC, 2005, 2014). This implies that there is a need for sustainable management and utilization of the dry evergreen Afromontane forests.

Ethiopia's rural population almost totally depends on biomass energy sources for cooking and other energy requirements. The biomass energy accounted for 89% of total national energy consumption, with fuel wood accounting for about 81% of these different biomass energy sources (Geissler *et al.*, 2013). This is happening despite that only 12.3% of the land area of Ethiopia is covered by tree and shrub vegetation, including Afromontane and transitional rainforests, woodlands, shrublands, afro-alpine, ericaceous belt, and riverine vegetation (World Bank, 2013). The economy of Ethiopia and the livelihoods of its people mostly depend on agriculture, and its expansion rate is high at the expense of tree and shrub vegetation (Hailu *et al.*, 2015). Sustainable forest management is a concept specifically designed to embrace and reconcile the different interests in forests, including the maintenance of biodiversity (Rametsteiner and Simula, 2003). It refers to the forest-related income and economic well-being sustained over time and without compromising the environmental and social pillars of sustainability (Brukas *et al.*, 2015). The attainment of sustainable forest management involves multi-faceted approaches by implementing integrated, multiple-use resource management.

Practices such as agroforestry, forest landscape restoration, use of timber and non-timber forest products, and preventing unsustainable, unregulated and unauthorized harvesting, are needed to achieve sustainable forest management. It also requires the need to consider the role of local communities, and their education and awareness creations (SCBD, 2009; Williamson and Edwards, 2014; Assuah *et al.*, 2016).

1.2 Problem Statement and conceptual framework for this study

The Afromontane forests of Northwestern Ethiopia have faced major resource use impacts and the perception is that large parts of these forests have been converted to agricultural land, except small fragments that are left in some inaccessible church, monastery and conservation areas (Wassie *et al.*, 2005). Previously, in this biogeographic area, various research activities had been carried out (Alelign *et al.*, 2007; Eshete, 2007; Zegeye *et al.*, 2011; Wale *et al.*, 2012a, b), but they focused only on woody species growing either in only church forests or lowland woodland ecosystems. Most of the studies were carried out without the consideration of other ecological parameters such as various environmental variables which are vital inputs to better explain the ecology of a given plant species or forest ecosystem.

There is still limited ecological information and knowledge on the floristic and structural composition of the Afromontane forests of Northwestern Ethiopia in relation to underlying biophysical factors, and the ecological drivers of their dynamics. Such information and knowledge are needed to develop necessary skills to conserve a given tree species or forest ecosystem, and to develop effective sustainable forest management systems and practices. Specific gaps exist in terms of the vascular plant species occurring in these forests and how they are associated with each other across forest ecosystems, how the composition of the species and forests relate to the underlying site variables, and what the conservation status of the species and forest communities area in relation to disturbance factors operating in this biogeographical area.

This study was designed to address the existing gaps in information and knowledge in the Afromontane forests of Northwestern Ethiopia. The conceptual framework for this study linked the different gaps in information and knowledge towards an understanding of the ecological processes (biophysical site factors, disturbance-recovery processes, including human resource use, population and community dynamics of key species) underlying the observed patterns in species assemblages across these forests (Figure 1.1).

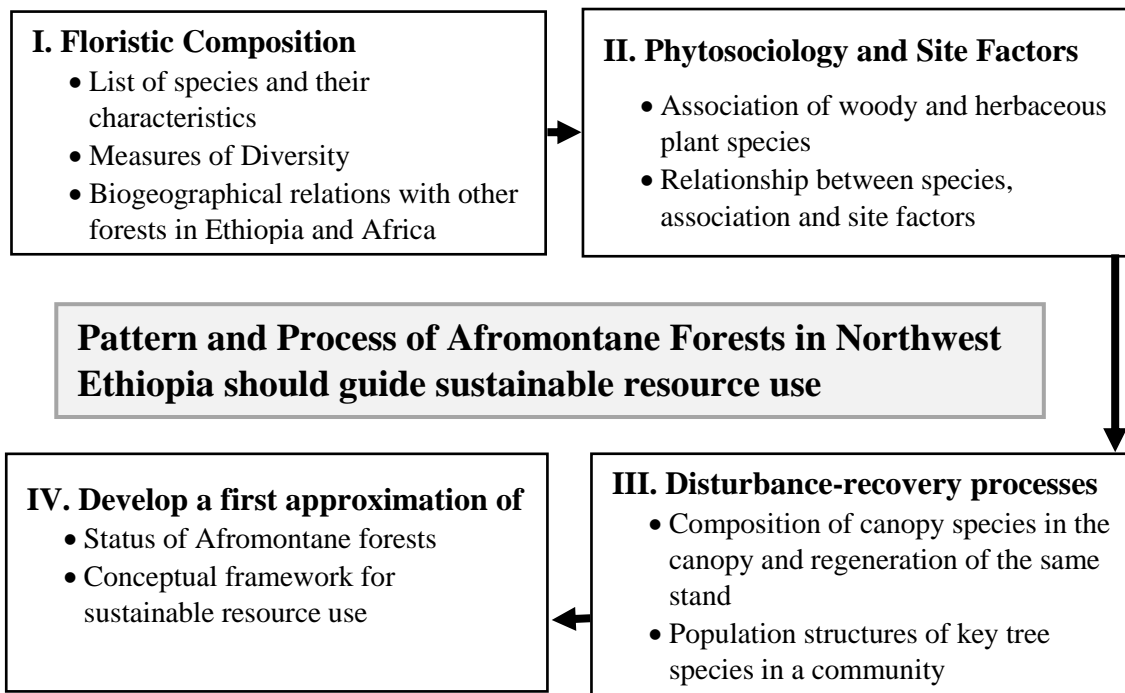


Figure 1.1 Conceptual framework for the study of the Afromontane Forests in Northwestern Ethiopia

1.3 Objectives and Key questions

The overall objective of the study was to use different analytical tools to assess and explain the causal ecological drivers of three remnant Afromontane forests in Northwestern Ethiopia at species, community and ecosystem level as basis for sustainable resource use management systems at different levels. This general objective of the dissertation was addressed through pursuing four specific objectives and related questions.

Objective 1: To assess the floristic composition of three Afromontane forests in Northwestern Ethiopia.

The following specific questions were addressed:

- 1.1. What species of different growth forms (trees, shrubs, climbers, ferns, graminoids, epiphytes, etc.) are present in these forests?
- 1.2 What is the diversity in species and growth forms of these forests?
- 1.3 How evenly and equitably were the plant species distributed within and between forests, and how would this inform the status of disturbance and environmental wellness of the forests?
- 1.4. What is the status of this forest area in terms of endemism?

1.5 What are the biogeographical relationships of the plants species of these Afromontane forests with other forests in Ethiopia and the African Afromontane forests?

Objective 2: To assess the floristic-structural composition of the associations of plants in the three Afromontane forests in Northwest Ethiopia, and their relationships with physical site factors.

Related questions addressed in this objective were:

2.1 What are the identifiable associations of the woody species in the three Afromontane forests?

2.2 What are the identifiable associations of the herbaceous species in the three Afromontane forests?

2.3. What is the relationship between the identified woody and herbaceous plant associations?

2.4. What is the relationship between the identified woody and herbaceous plant associations with physical environmental variables (soil chemical and physical properties, slope, altitude and radiation index)?

Objective 3: To assess the scale of ecological processes of disturbance and recovery and how these affect the population structure and regeneration status of canopy tree species across forest communities in the three Afromontane forests.

The related questions addressed in this objective were:

3.1 Which forest communities regularly disturbed (relatively early regrowth stage) and which are relatively stable (relatively mature forest) ?

3.2 Which species can regenerate under the forest canopy (relative shade-tolerant species), and which species typically require larger gaps, with more light, to regenerate (cannot regenerate under the canopy, i.e. shade-intolerant species)?

3.3 What are the typical stem diameter class distributions of the main canopy tree species in the studied forests, and how do they vary across the identified tree communities?

Objective 4: To recommend the possible management interventions based on the pattern and dynamics of the forests

To address this objective, the results and findings of specific Objectives 1 (Chapter 2), 2 (Chapter 3), and 3 (Chapter 4), were summarized in Chapter 5 (general conclusion). The focus of the synthesis will be the conservation status of these forests, and the development of a first approximation of a conceptual framework for sustainable resource use from these forests.

1.4 Thesis structure

The dissertation has a total of five chapters. Chapter 1 presents a review of relevant literature as basis for development of the overall and specific research objectives and the conceptual framework for the study. Chapters 2 to 4 address studies in relation to the specific objectives of the study. Chapter 5 provides a synthesis of the results from the different specific studies in relation to the stated overall objective of the study.

References

- Adámek, M. Bobek, P. Hadincová, V. Jan Wild, J. and Kopecký, M. (2015). Forest fires within a temperate landscape: A decadal and millennial perspective from a sandstone region in Central Europe. *Forest Ecology and Management*, 336, 81-90.
- Adámek, M. Hadincová, V. and Wild, J. (2016). Long-term effect of wildfires on temperate *Pinus sylvestris* forests: Vegetation dynamics and ecosystem resilience. *Forest Ecology and Management*, 380, 285-295.
- Aerts, R., Maes, W., November E., Negussie, A., Hermy, M. and Muys, B. (2006). Restoring dry Afromontane forest using bird and nurse plant effects: direct sowing of *Olea europaea* ssp. *cuspidata* seeds. *Forest Ecology and Management*, 230, 23-31.
- Ahlgren, I. F. and Ahlgren, C. E. (1960). Ecological effects of forest fires. *The Botanical Review*, 26 (4), 483-533.
- Alelign, A., Teketay, D. Yemishaw, Y. and Edwards, S. (2007). Diversity and status of regeneration of woody plants on the peninsula of Zegie, Northwestern Ethiopia. *Tropical Ecology*, 48(1), 37-49.
- Anand, M. and Kadmon, R. (2016). Community-level analysis of Spatiotemporal plant dynamics. *Écoscience*, 7(1), 101-110.
- Arponen, A. (2009). Species-based and community-level approach to conservation. Academic Dissertation, University of Helsinki, Faculty of Biosciences, Department of Biological and Environmental Sciences, Finland.
- Assuah, A. Sinclair, A. J. and Reed, M. G. (2016). Action on sustainable management through community forestry: the case of the Wetzin'kwa community forest corporation. *The Forestry Chronicle*, 92(2), 232-244.
- Aynalem, S. and Bekele, A. (2008). Species composition, relative abundance and distribution of bird fauna of riverine and wetland habitats of Infranz and Yiganda at southern tip of Lake Tana, Ethiopia. *Tropical Ecology*, 49(2), 199-209.
- Barracclough, T. G. (2015). How interactions affect evolutionary dynamics across whole communities? *Annual Review of Ecology, Evolution and Systematics*, 46, 25-48.

- Bartlow, A. W. Agosta, S. J. Curtis, R. Yi, X. and Steele, M. A. (2018). Acorn size and tolerance to seed predators: the multiple roles of acorns as food for seed predators, fruit for dispersal and fuel for growth. *Integrative Zoology*, 13, 251-266.
- Bekele, T. (1993). Vegetation ecology of remnant Afromontane forests on the Central plateau of Shewa, Ethiopia. *Acta Phytogeographica Suecica*, 79, 1-59.
- Bekele, T (2000). Plant Population Dynamics of *Dodonaea angustifolia* and *Olea europaea* ssp. *cuspidata* in Dry Afromontane Forests of Ethiopia. PhD Dissertations. Faculty of Science and Technology, Acta Universitatis Upsaliensis, Uppsala.
- Belay, T. T. (2016). Climate-growth relationship of *Pinus patula* Schldl. et Cham. in Wondo Genet, South Central Ethiopia. *Journal of Climatology and Weather Forecast*, 4, 181. DOI: 10.4172/2332-2594.1000181.
- Belayneh, A. Yohannes, T. and Worku, A. (2013). Recurrent and extensive forest fire incidence in the Bale Mountains National Park (BMNP), Ethiopia: Extent, Cause and Consequences. *International Journal of Environmental Science*, 2(1), 29-39.
- Berg, C. Abdank, A. Isermann, M. Jansen, F. Timmermann, T. and Dengler, J. (2014). Red Lists and conservation prioritization of plant communities—a methodological framework. *Applied Vegetation Science*, 17, 504-515.
- Biondi, E., Feoli, E. and Zuccarello, V. (2004). Modelling Environmental Responses of Plant Associations: A Review of Some Critical Concepts in Vegetation Study. *Critical Review in Plant Science*, 23(2), 149-156. DOI: 10.1080/0735268049043327.
- Bishaw, B. (2001). Deforestation and Land Degradation in the Ethiopian Highlands: A Strategy for Physical Recovery. *Northeast African Studies*, 8(1), 7-26.
- Brukas, V. Mizaras, S. and Mizaraite, D. (2015). Economic Forest Sustainability: Comparison between Lithuania and Sweden. *Forests*, 6, 47-64. DOI: 10.3390/f6010047.
- Callaway, R.M. (2010). Do Positive Interactions among Plants Matter? In: Pugnaire, F.I. (ed.). *Positive Plant Interactions and Community Dynamics*. CRC Press/ Taylor and Francis Group, Boca Raton.
- CEPF (Critical Ecosystem Partnership Fund). (2012). Ecosystem Profile. Eastern Afromontane Biodiversity Hotspot. Arlington, Virginia. 1-267.
- CEPF (Critical Ecosystem Partnership Fund). (n.d.). Eastern Afromontane. <http://www.cepf.net/resources/hotspots/africa>. Date Visited: 04/04/2016.

- Chane, M. and Yirga, S. (2014). Diversity of Medium and Large-sized Mammals in Borena-Sayint National Park, South Wollo, Ethiopia. *International Journal of Sciences: Basic and Applied Research*, 15(1), 95-106.
- Chazdon, R.L. (2003). Tropical forest recovery: legacies of human impact and natural disturbances. *Perspectives in Plant Ecology. Evolution and Systematics*, 6 (1, 2), 51-71.
- CI (Conservation International). (2005). Biodiversity Hotspots. Conservation International Facts, Washington DC, 1-2.
- CI (Conservation International). (2011). World's 10 most threatened forest hotspots. <http://www.conservation.org/NewsRoom/pressreleases>. Date Visited: 04/04/2016.
- Clements, F. E. (1916). Plant succession: An analysis of the development of vegetation. Carnegie Institute of Washington Publication, Washington.
- Clements, F. E. (1936). Nature and Structure of Climax. *The Journal of Ecology*, 24(1):252-284.
- Couralet, C. Sass-Klaassen, U. Sahle, Y. Sterck, F. Bekele, T. and Bongers, F. (2007). Dendrochronological investigations on *Juniperus procera* from Ethiopian Dry Afromontane forests. In: Haneca K, Verheyden A, Beekmann H, Gärtner H, Helle G, Schleser G (eds.) TRACE -Tree Rings in Archaeology, Climatology and Ecology, Vol. 5: Proceedings of the DENDROSYMPOSIUM 2006, April 20th - 22nd 2006, Tervuren, Belgium, Schriften des Forschungszentrums Jülich, Reihe Umwelt, 74, 73-79.
- Cox, C. B. Moore, P. D. and Ladle, R. J. (2016). Biogeography: An Ecological and Evolutionary Approach. 9th edition. UK, John Wiley and Sons.
- Craig T. Symes, J. Olaf Wirminghaus, Colleen T. Downs and M. Louette. (2002). Species richness and seasonality of forest avifauna in three South African Afromontane forests. *Ostrich*, 73(3 & 4), 106-113. DOI: 10.1080/00306525.2002.11446738.
- Crisci, J. V. (2001). The voice of historical biogeography. *Journal of Biogeography*, 28, 157-168.
- Dale, V. H. Linda, U. Joyce, A. McNulty, S. and Neilson, R. P. (2000). The interplay between climate change, forests, and disturbances. *The Science of the Total Environment*, 262, 201-204.
- Daniel, G. M. and Vaz-de-Mello, F. Z. (2016). Biotic components of dung beetles (Insecta: Coleoptera: Scarabaeidae: Scarabaeinae) from Pantanal - Cerrado Border and its implications for Chaco regionalization. *Journal of natural history*, 50(17-18), 1159-1173.

- Daye, D. D. and Healey, J. R. (2015). Impacts of land-use change on sacred forests at the landscape scale. *Global Ecology and Conservation*, 3, 349 - 358.
- Eliot, C. (2007). Method and metaphysics in Clements's and Gleason's ecological explanations. *Studies in History and Philosophy of Biological and Biomedical Sciences*, 38(1), 85-109.
- Eshete, A. W. (2007). Ethiopian Church Forests: opportunities and challenges for restoration. PhD thesis, Wageningen University, Wageningen, The Netherlands.
- EWNHS (Ethiopian Wildlife and Natural History Society) (1996). Important Bird Areas of Ethiopia: A First Inventory. Ethiopian Wildlife and Natural History Society, Addis Ababa, Ethiopia.
- Everard, D. A. Midgley, J. J. and Van Wyk, G. F. (1995). Dynamics of some forests in KwaZulu-Natal, South Africa, based on ordinations and stem-diameter distributions. *South African Journal of Botany*, 61, 283-292.
- Fattorini, S. (2016). A history of chorological categories. *History and Philosophy of the Life Sciences*, 38(3), 1-21.
- Fjeldså, J. Kiure, J. Doggart, N. Hansen, L. A. and Perkin, A. (2010). Distribution of highland forest birds across a potential dispersal barrier in the Eastern Arc Mountains of Tanzania. *Steenstrupia*, 32 (1), 1-43.
- Foster, D. R. Knight, D. H. and Franklin, J. F. (1998). Landscape Patterns and Legacies Resulting from Large, Infrequent Forest Disturbances. *Ecosystems*, 1,497-510.
- Franklin, J. F. Spies, T. A. Van Pelt, R. Carey, A. B. Thornburgh, D. A. Berg, D. R. Lindenmayer, D. B. Harmon, M. E. Keeton, W.S. Shaw, D. C. Bible, K. and Chen, J. (2002). Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *Forest Ecology and Management*, 155, 399-423.
- Friis, I. Demissew, S. Breugel, P. (2010). Atlas of the Potential Vegetation of Ethiopia. The Royal Danish Academy of Sciences and Letters. Denmark.
- Geissler, S. Hagauer, D. Horst, A. Krause, M. and Sutcliffe, P. (2013). Biomass Energy Strategy Ethiopia. Environment for Development. Addis Ababa, Ethiopia.
- Geldenhuis C. J. (1993). The use of diameter distributions in sustained use management of forests: examples from southern Africa. In: Pearce GD, Gumbo DJ. (eds). The ecology and management of indigenous forests in southern Africa. Proceedings of an International Symposium, Victoria Falls, Zimbabwe, 27-29 July 1992, Zimbabwe Forestry Commission & SAREC. 154-167.

- Geldenhuys, C. J. (1994). Bergwind fires and the location pattern of forest patches in the southern Cape landscape, South Africa. *Journal of Biogeography*, 21, 49-62.
- Geldenhuys C. J. (1996). Forest management systems to sustain resource use and biodiversity: examples from the southern Cape, South Africa. In: Van der Maesen LJG, Van der Burgt XM, Van Medenbach de Rooy JM. (eds). *The Biodiversity of African Plants. Proceedings of XIVth AETFAT Congress, Wageningen, The Netherlands. Kluwer Academic Publishers, Dordrecht.* 317-322.
- Geldenhuys, C. J. (2010). Managing forest complexity through application of disturbance-recovery knowledge in development of silvicultural systems and ecological rehabilitation in natural forest systems in Africa. *Journal of Forest Research*, 15, 3-13. Doi: 10.1007/s10310-009-0159-z.
- Geldenhuys, C. J. (2011). Disturbance and recovery in natural forests and woodlands in Africa: Some concepts for the design of sustainable forest management and rehabilitation practices. In: Geldenhuys C. J, Ham, C and Ham, H (eds.). *Sustainable Forest Management in Africa: Some Solutions to Natural Forest Management Problems in Africa. Proceedings of the Sustainable Forest Management in Africa Symposium. Stellenbosch, 3 - 7 November 2008, 61-70.*
- Gleason, H. A. (1926). The Individualistic Concept of Plant Association. *Bulletin of the Torrey Botanical Club*, 53, 7-26.
- Gonzalez, A. and Loreau, M. (2009). The Causes and Consequences of Compensatory Dynamics in Ecological Communities. *Annual Review of Ecology, Evolution and Systematics*, 40, 393-414.
- Guillozet, K. Bliss, J. C. and Kelecha, T. S. (2015). Degradation in an Afromontane Forest in Highland Ethiopia, 1969 - 2010. *Small-scale Forestry*, 14, 121-137.
- Hailu, B. T. Maeda, E. E. Heiskanen, J. and Pellikka, P. (2015). Reconstruction pre-agricultural expansion vegetation cover of Ethiopia. *Applied Geography*, 62, 357-365.
- Hansen, A. J and Walker, B. H. 1985. The dynamic landscape: perturbation, biotic response, biotic patterns. *SAIE Bulletin*, 4(2), 5-14.
- Hantson, S. Arneeth, A. Harrison, S. P. Kelley, D. I. Prentice, I. C. Rabin, S. S. Archibald, S. Mouillot, F. Arnold, S. R. Artaxo, P. Bachelet, D. Ciais, P. Forrest, M. Friedlingstein, P. Hickler, T. Kaplan, J. O. Kloster, S. Knorr, W. Lasslop, G. Li, F. Mangeon, S. Melton, J. R. Meyn, A. Sitch, S. Spessa, A. van der Werf, G. R. Voulgarakis, A. and Yue, C. (2016). The status and challenge of global fire modelling. *Biogeosciences*, 13, 3359-3375.

- Heads, M. (2015). The relationship between biogeography and ecology: envelopes, models, predictions. *Biological Journal of the Linnean Society*, 115, 456-468.
- Heads, M. (2017). Metapopulation vicariance explains old endemics on young volcanic islands. *Cladistics*, 1- 20.
- Heads, M. J. (2012). *Molecular Panbiogeography of the Tropics*. University of California Press, Berkley and Los Angeles, California.
- Howe, H. F. and Smallwood, J. (1982). Ecology of seed dispersal. *Annual Review of Ecology and Systematics*, 13, 201-228.
- IBC (Institute of Biodiversity Conservation). (2005). National Biodiversity Strategy and Action Plan. Addis Ababa, Ethiopia.
- IBC (Institute of Biodiversity Conservation). (2014). Ethiopia's Fifth National Report to the Convention on Biological Diversity. Addis Ababa, Ethiopia.
- Johansson, M. (2013). Fire and grazing in subalpine heathlands and forests of Bale Mountains, Ethiopia: Fire ecology and traditional use of fire. Doctoral Thesis, Department of Forest Ecology and Management, Swedish University of Agricultural Sciences, Umeå, Sweden.
- Kahilainen, A. Puurtinen, M. and Kotiaho, J. S. (2014). Conservation implications of species-genetic diversity correlations. *Global Ecology and Conservation*, 2, 315-323.
- Kikoti, I. A. and Mligo, C. (2015). Impacts of grazing on plant species composition in montane forests on the northern slope of Mount Kilimanjaro, Tanzania. *International Journal of Biodiversity Science, Ecosystem Services and Management*, 11(2), 114-127.
- Kreyling, J. Wana, D. and Beierkuhnlein, C. (2010). Potential consequences of climate warming for tropical plant species in high mountains of southern Ethiopia. *Diversity and Distributions*, 16, 593-605.
- Kulakowski, D. Seidl, R. Holeksa, J. Kuuluvainen, T. Nagel, T. A. Panayotov. M. Svoboda, M. Thorn, S. Vacchiano, G. Whitlock, C. Wohlgemuth, T. and Bebi, P. (2017). A walk on the wild side: Disturbance dynamics and the conservation and management of European mountain forest ecosystems. *Forest Ecology and Management*, 388, 120-131.
- Lejju, J. B. Oryem-Origa, H. and Kasenene, J. M. (2000). Regeneration of Afromontane forest following agricultural encroachment in Southwest Uganda. *Israel Journal of Plant Sciences*, 48(4), 281-288.

- Lemenih, M. and Bongers, F. (2011). Dry Forests of Ethiopia and Their Silviculture. In: Günter, S. Weber, M. Stimm, B. Mosandl, R. (eds.) *Silviculture in the Tropics. Tropical Forestry*, vol 8. Springer, Berlin, Heidelberg.
- Lemenih, M. Kassa, H. Kassie, G. T. Abebaw, D. and Teka, W. (2014). Resettlement and woodland management problems and options: a case study from north-western Ethiopia. *Land degradation & development*, 25, 305-318.
- Lemessa, D. and Perault, M. (2001). Forest fires in Ethiopia: Reflections on socio-economic and environmental effects of the fires in 2000. UNDP Emergencies Unit for Ethiopia, Addis Ababa, Ethiopia.
- Lipoma, M.L. Funes, G. and Diaz, S. (2018). Fire effects on the soil seed bank and post-fire resilience of a semi-arid shrubland in central Argentina. *Austral Ecology*, 43, 46-55.
- Loader, S. Mengistu, A. Schwaller, S. Gower, D. Nagel, P. Getahun, A., Saber, S. and Kassahun, R. (2009). Are Ethiopian Highlands Changing? Amphibians as Ecosystem Indicators. *Mountain Forum Bulletin*, 6(2), 1-6.
- Lortie, C. J. Brooker, R. W. Choler, P. Kikvidze, Z. Michalet, R. Pugnaire, F. I. and Callaway, R. M. (2004). Rethinking Plant community theory. *OIKOS*, 107(2), 443-448.
- Midgley, J. J. Seydack, A. Reynell, D. and McKelly, D. (1990). Fine-grain pattern in southern Cape plateau forests. *Journal of Vegetation Science* 1: 539-546
- Morgenthal, T. L., and Cilliers, S. S. (2000). Species composition and phytogeographical significance of Afromontane forest fragment in Mpumalanga Province, South Africa. *The South African Forestry Journal*, 189 (1), 81-102. DOI: 10.1080/10295925.2000.9631283.
- Mokany, K. Westcott, D. A. P. Prasad, S. Ford, A. J. and Metcalfe, D. J. (2014). Identifying Priority Areas for Conservation and Management in Diverse Tropical Forests. *PLoS ONE*, 9(2), 1-10. DOI: 10.1371/journal.phone.0089084.
- Mokria, M. Gebrekirstos, A. Aynekulu, E. and Bräuning, A. (2015). Tree dieback affects climate change mitigation potential of a dry Afromontane forest in northern Ethiopia. *Forest Ecology and Management*, 344, 73-83.
- Morris, J. L. McLauchlan, K. K. and Higuera, P. E. (2015). Sensitivity and complacency of sedimentary biogeochemical records to climate-mediated forest disturbances. *Earth-Science Reviews*, 148, 121-133.

- Morrone, J. J. (2014). Perspective On biotas and their names. *Systematics and Biodiversity*, 12(4), 386-392.
- Muscolo, A. Bagnato, S. Sidari, M. and Mercurio, R. (2014). A review of the roles of forest canopy gaps. *Journal of Forestry Research*, 25(4), 725-736.
- Noben, S., Kessler, M. Quandt, D. Weigand, A. Wicke, S. Krug, M. and Lehnert, M. (2017). Biogeography of the Gondwanan tree fern family Dicksoniaceae-A tale of vicariance, dispersal and extinction. *Journal of Biogeography*, 1-12.
- Olson, D. (2010). A decade of conservation by the Critical Ecosystem Partnership Fund 2001-2010: An independent evaluation of CEPF's global impact. Conservation Earth for the Critical Ecosystem Partnership Fund, Arlington, Virginia. 1-100.
- Palmer, M. A. Ambrose, R. E. and LeRoy Poff, N. (1997). Ecological theory and community restoration ecology. *Restoration Ecology*, 5(4), 291-300.
- Pausas, J. G. and Keeley, J. E. (2014). Abrupt climate-independent fire regime changes. *Ecosystems*, 17, 1109-1120.
- Peterson, C. J. (2007). Consistent influence of tree diameter and species on damage in nine eastern North America tornado blowdowns. *Forest Ecology and Management*, 250, 96-108.
- Popoola, L., Tangwa, G. W. and Adedire, M. O. (2002). Commercial Exploitation and Conservation of *Prunus africana* in Cameroon's Afromontane Forests. *Arboricultural Journal*, 26(1), 65-76. DOI: 10.1080/03071375.2002.9747319.
- Popp, M. Gizaw, A. Nemomissa, S. Suda, J. and Brochmann, C. (2008). Colonization and diversification in the African 'sky islands' by Eurasian *Lychnis* L. (Caryophyllaceae). *Journal of Biogeography*, 35, 1016-1029.
- Poulson, T.L. and Platt, W.J. (1989). Gap light regimes influence canopy tree diversity. *Ecology*, 70 (3), 553-555.
- Rametsteiner, E. and Simula, M. (2003). Forest certification - an instrument to promote sustainable forest management? *Journal of Environmental Managements*, 67, 87-98.
- Schmitt, C. B., Denich, M., Demissew, S., Friis, I. B. and Boehmer, H. J. (2010). Floristic diversity in fragmented Afromontane rainforests: Altitudinal variation and conservation importance. *Applied Vegetation Science*, 13, 291-304. DOI: 10.1111/j.1654-109X.2009.01067. x.

- Schürmann, V. (2008). Dynamics of a forest at the Eastern Escarpment of the Ethiopian Highlands. Diploma Thesis at the Department of Geography, University of Zurich, Zurich.
- Scutcliffe, J. P., Wood, A. and Meaton, J. (2012). Competitive forests sustainable in south-west Ethiopia. *International Journal of Sustainable Development and World Ecology*, 19(6), 471-481. DOI: 10.1080/13504509.2012.740510.
- SCBD (Secretariat of the Convention on Biological Diversity). (2009). Sustainable Forest Management, Biodiversity and Livelihoods: A Good Practice Guide. Montreal, Canada.
- Seidl, R. Rammer, W. and Spies, T.A. (2014). Disturbance legacies increase the resilience of forest ecosystem structure, composition, and functioning. *Ecological Applications*, 24(8), 2063-2077.
- Seidl, R. Thom, D. Kautz, M. Martin-Benito, D. Peltoniemi, M. Vacchiano, G. Wild, J. Ascoli, D. Petr, M. Honkaniemi, J. Lexer, M. J. Trotsiuk, V. Mairota, P. Svoboda, M. Fabrika, M. Nagel, T. A. and Reyer, C. P. O. (2017). Forest disturbances under climate change. *Nature climate change*, 7, 395-402.
- Sharma, L.N. Grytnes, J-A. Maren, I.E. and Vetaas, O.R. (2016). Do composition and richness of woody plants vary between gaps and close canopy patches in subtropical forests? *Journal of Vegetation Science*, 27, 1129-1139.
- Teketay, D. (2005). Seed and regeneration ecology in Dry Afromontane Forests of Ethiopia: seed production-population structures. *International Society for Tropical Ecology*, 46(1), 29-44.
- Tesfaye, G. Teketay, D. Fetene, M and Beck, E. (2011). Phenology of seven indigenous tree species in a dry Afromontane forest, southern Ethiopia. *Tropical Ecology*, 52(3), 229-241.
- Trumbore, S. Brando, P. and Hartmann, H. (2015). Forest health and global change. *Forest Health*, 349(6250), 814-818.
- Tsuji, Y. and Su, H-H (2018). Macaques as Seed Dispersal Agents in Asian Forests: A Review. *International Journal of Primatology*, 39, 356-376.
- van Breugel, P. Friis, I. Demissew, S. Lillesø, J-P. B. Kindt, R. (2016). Current and Future Fire Regimes and Their Influence on Natural Vegetation in Ethiopia. *Ecosystems*, 19, 369-386.
- Vanderwel, M. C. and Purves, D. W. (2014). How do disturbances and environmental heterogeneity affect the pace of forest distribution shifts under climate change. *Ecography*, 37, 10-20.
- Vieira, D. and Scariot, A. (2006). Principles of Natural Regeneration of Tropical Dry Forests for Restoration. *Restoration Ecology*, 14(1), 11-20.

- Wale, H. A. Bekele, T. and Dalle, G. (2012a). Floristic Diversity, Regeneration Status and Vegetation Structure of the Woodland Vegetation in Metema Area, Amhara National Regional State, Northwestern Ethiopia. *Journal of Forestry Research*, 23(3), 391-398.
- Wale, H. A. Bekele, T. and Dalle, G. (2012b). Plant Community and Ecological Analysis of the Woodland Vegetation in Metema Area, Amhara National Regional State, Northwestern Ethiopia. *Journal of Forestry Research*, 23(4), 599-607. DOI: 10.1007/s11676-012-0300-2.
- Wassie, A., Teketay, D. and Powell, N. (2005). Church forests in North Gonder administrative zone, Northern Ethiopia. *Forests, Trees Livelihoods*, 15 (4), 349-373.
- Watt, A. S. (1947). Pattern and Process in the plant community. *Journal of Ecology*, 35(1/2), 1-22.
- White, F. (1983). The vegetation of Africa. A descriptive memoir to accompany the UNESCO/AETFAT/UNSO Vegetation map of Africa, Paris, UNESCO.
- White, P. S. and Jentsch, A. (2001). The search for generality in studies of disturbance and ecosystem dynamics. *Progress in Botany*, 62, 399-450.
- Whitmore, T.C. (1989). Canopy gaps and the two major groups of forest trees. *Ecology*, 70(3), 536-538.
- Williams, S. D. Vivero, J. L. Spawls, S. Anteneh, S. and Ensermu, K. (2004). Ethiopian Highlands. In: Mittermeier, R.A. Robles-Gil, P. M. Hoffmann, J.D. Pilgrim, T.M. Brooks, C.G. Mittermeier A. and Fonseca, G. (eds.), Hotspots Revisited: Earth's Biologically Richest and Most Endangered Ecoregions. CEMEX, Mexico City, 262-273.
- Williamson, T. B. and Edwards, J. E. 2014. Adapting sustainable forest management to climate change: criteria and indicators in a changing climate. Canadian Council of Forest Ministers, Ottawa, Canada.
- Wils, T. H. G. Robertson, I. Eshetu, Z. Touchan, R. Sass-Klaassen, U. and Koprowski, M. (2011). Crossdating *Juniperus procera* from North Gondar, Ethiopia. *Trees*, 25, 71-82.
- Wookey, P. A. (2008). Experimental approaches to predicting the future of tundra plant communities. *Plant Ecology and Diversity*, 1(2), 299-307. DOI: 10.1080/1755802338354.
- World Bank (2013). Africa Development Indicators 2012/2013. Washington DC, USA. DOI: 10.1596/978-0-8213-9616-2.

Zegeye, H., Teketay, D. and Kelbessa, E. (2011). Diversity and regeneration status of woody species in Tara Gedam and Abebaye forests, Northeastern Ethiopia. *Journal of Forestry Research*, 22(3), 5 - 328.

Chapter 2: Floristic composition of three Afromontane Forests in Northwest Ethiopia

Abstract

Each plant species in the flora of an area represents the sum total of its adaptations to survive environmental conditions, community interactions and disturbance-recovery processes during a long period of its development. The species characteristics determine its function under different environmental conditions, its position within the dynamics of such vegetation, its contribution to the patterns observed in the plant communities in an area, and how it should be managed. The flora of three remnant and fragmented Afromontane forest patches in Northwest Ethiopia, i.e. Alem Saga, Gelawudiwos and Tara Gedam, was investigated to understand their contribution to the differentiation into different forest communities in the area. Plant species data were collected during a systematic sampling design in homogenous stands to collect vegetation data, from a total of 150 nested circular plots, with 50 plots per forest. A nested plot consisted of a main plot of 100 m² and a sub-plot of 1 m², respectively for the woody and herbaceous species. The flora from the three studied forests was compared with the flora of 13 previously reported Afromontane forests and woodlands from Ethiopia and other parts of Africa. Diversity and diversity profiles of the three studied forests were analysed using Shannon index and Renyi index, respectively. The floral similarity between the present study area and other previously reported Afromontane forests and woodlands from Ethiopia and parts of Africa, were analysed using Sørensen similarity index. A total of 209 vascular plant species, including 109 woody and 100 herbaceous species, were recorded. The seven species known to be endemic to Ethiopia, were: a subshrub *Acanthus sennii*, a shrub *Lippia adoensis* and five forbs namely *Aeollanthus abyssinicus*, *Bidens ghedoensis*, *Impatiens rothii*, *Mikaniopsis clematoides* and *Solanecio gigas*. The three most dominant families, with their total species counts and percentage of all recorded species in brackets, were Asteraceae with 22 species (10.5%), Fabaceae with 22 species (10.5%), and Poaceae with 15 species (7.2%). They contributed about 28.2% to the total species pool. The area showed a Shannon-Weiner diversity and evenness value of 4.0 and 0.26, respectively; indicating that the study area has high floristic diversity despite the fact that there is uneven distribution of the individuals of species. The three most similar Afromontane forests, with their shared number of species with the present study area and Sørensen similarity percentages between brackets, were Wondo Genet with 80 (35.6%), Gendo with 70 (37.1%) and Denkoro with 68 (35.5%), but 22 species (6.6%) were shared with the Southern Cape in the south Africa. From woodlands, with a value of 20.6%, the highest similarity percentage for herbaceous species was observed with Metema

woodland. Having a low evenness implied that the environmental wellness of studied forests was low. Consequently, it is recommended that these forests need a strong stewardship effort towards their conservation. The ranking of the forests based on their diversity profiles, showed that Tara Gedam had the highest evenness value, followed by Gelawudiwos and Alem Saga. This further suggests that the highest conservation priority should be given to Gelawudiwos, followed by Alem Saga and Tara Gedam.

Keywords: Afromontane; fragment, floristic; diversity; evenness; endemism; biogeography; Alem Saga; Gelawudiwos; Tara Gedam; Northwest Ethiopia.

2.1 Introduction

Each plant species in the flora of an area represents the sum total of its adaptations to survive environmental conditions, community interactions and disturbance-recovery processes during a long period of its development. Species characteristics determine vegetation function under different environmental conditions, its position within the dynamics of such vegetation, and its contribution to the patterns observed in the plant communities in an area, and how it should be managed. Investigating the floral composition is one of the fundamental ways of understanding the biodiversity and biological productivity of forest ecosystems. The highland forests of Northwest Ethiopia represent disjunctly remnant Afromontane forest complexes in the country.

The flora of the Afromontane forests of Ethiopia has to be assessed in the context of the long period of vegetation change in relation to continental uplift in Africa since the break-up of Gondwanaland (Kadu *et al.*, 2013). During the Early Mesozoic time period (245 Ma or million years ago), Gondwanaland had a low relief (King, 1963), composed of broad plains and basins, and scattered Precambrian (4 Ga) highs. The topography was flat with a high sea level. Most of the existing rift basins experienced marine incursions during late Cretaceous (100–65 Ma) at the end of Mesozoic. Lowland rainforest was formed in all of the northern part of Africa (Axelrod and Raven, 2012), until Late Cretaceous-Paleocene (75–55 Ma). Sea level began to subside during the Paleocene (from 65 Ma) (Haq *et al.*, 1987). The tectonic deformations through swell uplift and local rift-flank uplift in East Africa modified the surface. Two phases of uplift involved 150–300 m elevation during the early Miocene (soon after 22.5 Ma), with an additional lift of 900 m since ca. 5 Ma. The interior plateaux were raised more than 1,800 m above the Miocene level. The great rift valleys developed in phases. The continental movements during the middle Miocene (16–14 Ma) brought northeast Afro-Arabia against south-central Asia, closed the Tethys Sea and ended the long-persistent latitudinal circulation system (Shevenell *et al.*, 2004; Holbourn *et al.*, 2013). The warm moist climate progressively became drier over northern Africa, and changed the rainforest into savanna and woodland (Burke and Gunnell, 2008). During the Paleogene (66–23.03 Ma), the swells in East and Southeast Africa, probably were sufficiently high and cool to enable certain subtropical rainforest taxa, present until late Paleocene, to radiate upward into a temperate montane zone, and presumably also for north temperate and south temperate plants to extend their ranges towards the equator. All Tertiary-Neogene (23.03–2.58 Ma) vegetation types are more diverse in composition and differed importantly from those of the present. The modern communities arose as climates gradually changed, and especially rapidly in the later Pliocene and Pleistocene (5–1.5 Ma). The African landscape was flexed into a number of broad warps and basins during the middle Tertiary under the great rift system and volcanism (Burke and Gunnell, 2008). Late Tertiary (7–5 Ma) woodland, grassland and thorn scrub

vegetation in northern Africa, commenced to spread in their areas previously being occupied by rainforest. Semi desert taxa have in large measure been derived by adaptation of taxa in woodland, savanna and thorn scrub vegetation to the somewhat drier conditions (<250 mm) that developed over the areas of their former occurrence (Axelrod and Raven, 1978), flanking the rainforest over the interior with spreading dry climate. The Neogene (23.03–2.58 Ma) trend towards drier climates, brought on by the general uplift of the continent, changes in circulation, and the resultant decrease in moisture, caused closed forests to retreat as savannas and woodlands replaced them. In the Sudanian Region, savannas attained a progressively wider area as the trend towards aridity increased during the Neogene. Many trees and shrubs of the East African montane forests must have disappeared as precipitation was lowered following the Miocene (23.03–5.33 Ma). This is the scenario in which the current flora of the Afromontane forests of Northwest Ethiopia developed.

Within-continental disjunctions in species distribution are often attributed to large-scale climatic events, such as global climate cooling or aridification that would have eradicated a once continuous biota from part of its area of distribution, leaving relict taxa in refugia or ‘continental islands’ (Coleman *et al.*, 2003; Pelsler *et al.*, 2012; Mairal *et al.*, 2015). The Afromontane archipelago-like regional centre of endemism (White, 1983) extends from Sierra Leone in West Africa, to Somalia in the Horn of Africa, and from the Red Sea Hills in former Sudan Republic in the north to the Cape Peninsula in the south of Africa. The archipelago-like isolated ‘island’ mountains of this region vary in geological history, from basalt outcrops of the Ethiopian Highlands, to volcanic origin to crystalline basement rock formation (White, 1983). Its forests are highly fragmented within a matrix of surrounding fire-adapted vegetation. The Afromontane Region of Africa is considered to be one of floristically rich forest ecosystems, harbouring unique and threatened flora and fauna. It comprises about 4000 species, 3000 of which are endemic to this particular region (White, 1983; Lawes *et al.*, 2006; Ramdhani *et al.*, 2008; Taylor, 2015), with high species numbers per land area (Bussmann, 2001). The floristic differences between extremes on a single mountain are usually greater than the differences between the Afromontane assemblage as a whole on that mountain, and the assemblage found on nearby and even distant mountains. The collective flora of the archipelago shows a remarkable continuity and uniformity (White, 1983). These forests provide a vital role as water catchments and erosion barriers (Bussmann, 2001). The landscape physiography associated with these forests also influences dynamic changes in forest ecological conditions and associated species distributions (Kadu *et al.*, 2013).

Ethiopia is a country with part of its flora related to Afromontane vegetation in the central and northern parts of the country, tropical rainforest in the southwest, and lowland arid vegetation in the eastern part of the country. The country was recently recognized as one of Like-minded Megadiverse

Countries (LMMCs), in cognizance of its richness in biological resources and associated traditional knowledge. The country has more than 7000 plant species, of which 12% are considered to be endemic (LMMC, 2017). Despite the presence of ongoing deterioration and fragmentation due to high population pressures and related factors, the Ethiopian highlands are one of the biogeographically distinct regions of Africa, harbouring a unique flora (Linder *et al.*, 2012).

Poor land-use planning, lack of strong forest policy and its firm implementation are some of the main causal factors for the ongoing deforestation of tree and shrub vegetation, including Afromontane forests (Ayana *et al.*, 2013; Tadesse *et al.*, 2014). Owing to its high level of endemism and loss of biodiversity, this particular ecoregion is considered to be one of the world's biodiversity hotspot areas (CI, 2005; Kebede *et al.*, 2013). Furthermore, Afromontane forests of Northwest Ethiopia is part of this ecoregion (Ethiopian highlands) that experienced severe historical land use pressures, which resulted in a widespread deforestation and land degradation. The consequence of this is that only small fragments of Afromontane forest are left in some church yards, and conservation areas (Wassie *et al.*, 2010; Aerts *et al.*, 2016).

Species diversity and biodiversity are widely used terms in ecological studies. Biodiversity refers to the variety and variability of life on earth and explains the diversity at all levels: genes, phenotypes, species, populations, communities and ecosystems (Gatson and Spicer, 2004; Mouchet *et al.*, 2010). Species diversity refers to two parameters: species richness, which indicates the number of species in a given forest, and species evenness, which is the relative abundance of the different species making up the richness of a forest (Odat *et al.*, 2015). It is the most commonly used representation of ecological diversity, though it is not the only measure. Niche width and habitat diversity are also key components of ecological diversity (Hamilton, 2005). A given forest ecosystem can be said to have a high species diversity, if many equally or nearly equally abundant species are present. By contrast, the forest ecosystem can have low species diversity, if it has a few species, or if only few species are abundant and the rest of many others are rare (Magurran, 2004; Goswami *et al.*, 2017).

Information from a floristic study can help to understand the status of the forests and thereby to set priorities for conservation (Kier *et al.*, 2005; Jayakumar *et al.*, 2011; Geri *et al.*, 2016). Moreover, the species diversity of a given forest is important to understand ecological and evolutionary processes such as speciation, disturbance, succession, extinction, competition, and biological productivity (Gatson, 2000; Yong *et al.*, 2012; Yeboah and Chen, 2016). It can also give insights into the ecological resilience of a given forest ecosystem. A forest ecosystem with high species diversity is considered to have better ecological stability and resilience; towards interferences such as disease, invasive alien species, and disturbances (Elmqvist *et al.*, 2003; Downing *et al.*, 2012; Dymond *et al.*, 2015; Chambers *et al.*, 2017).

The present study was motivated by the limited information on the general vascular plant species composition, and their ecological relationships, in Afromontane forests of Northwest Ethiopia. The objective of this study was therefore to assess the floristic composition of three Afromontane forests in Northwestern Ethiopia, to understand the ecological information of all vascular plant species growing in the forest ecosystem as an entity, as a basis for strengthening the ongoing conservation endeavours. This descriptive study addressed the following key questions:

1. How many plant species by growth form and fruit/seed type/size occur in the studied forests, i.e. what is the diversity in species, growth form and dispersal strategies of these forests?
2. How evenly and equitably were the plant species distributed within and between forests, and how would this inform the status of disturbance and environmental wellness of the forests?
3. What is the status of this forest area in terms of endemism?
4. What are the biogeographical relationships between the studied forests and other Afromontane forest and woodland systems in Ethiopia and other parts of Africa?

2.2 Materials and Methods

2.2.1 Study Area

The study was carried out in three selected Afromontane forests, Alem Saga, Gelawudiwos and Tara Gedam, in the South Gonder zone of Northwestern Ethiopia (Figure 2.1 and Table 2.1). South Gonder zone is located at 600 km north of Addis Ababa and 50 km east of Lake Tana ([Wassie *et al.*, 2010](#)), with geographic coordinates 11°50'59.87"N, 37°00'59.55"E, and altitude masl. Alem Saga forest is 35 km away from both Gelawudiwos and Tara Gedam, the distance between Gelawudiwos and Tera Gedam is 70 km. Afromontane forests of Semien Mountains National Park and Lasta-Lalibela Afromontane forest complexes such as Mount Abune Yoseph, Nakuto Leab, Yimrhane Kirstos, and Ayna Eyesus forests, occur about 300 to 350 km North and Northeast of these study forests ([Wale, 2006](#)). Afromontane forest complexes of Mount Chokie and Borena Sayint National Park occur about 200 to 250 km to the South and Southeast of the study forests.

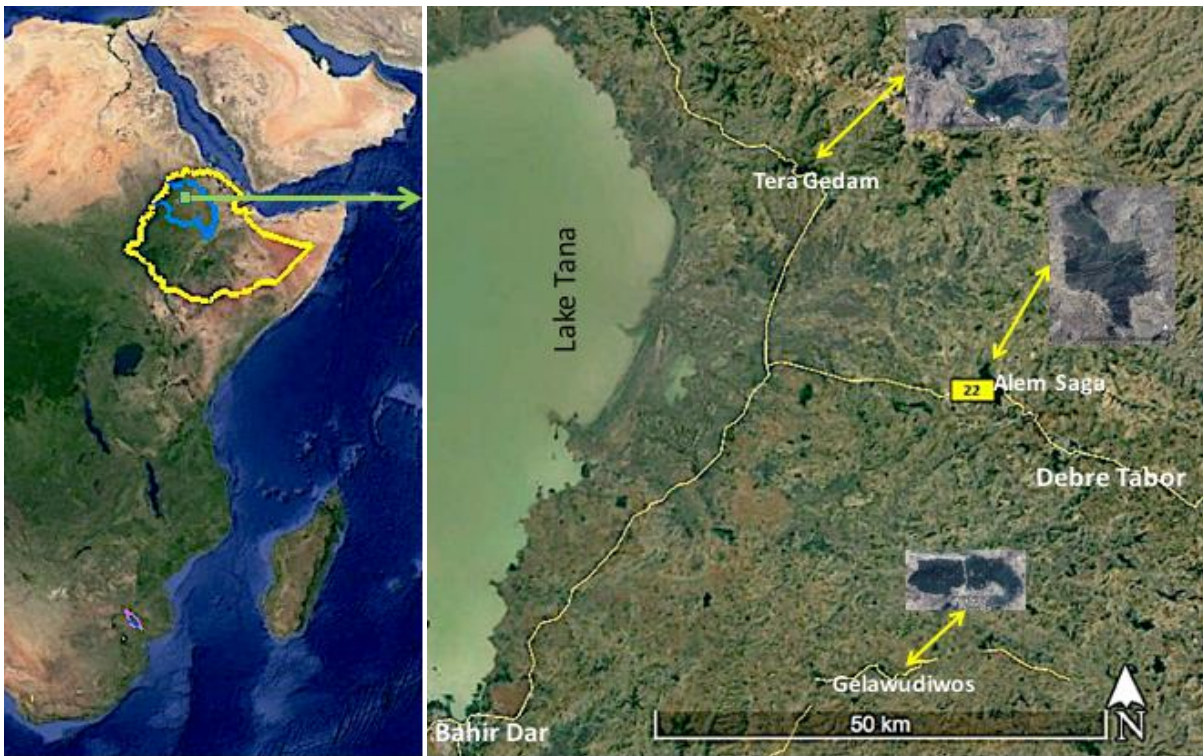


Figure 2.1 Location of the Alem Saga, Gelawudiwos and Tara Gedam Afromontane Forests in Northwest Ethiopia, with the inserts showing the shape and orientation of each forest.

Table 2.1 Location and environmental characteristics of the three selected forests in Northwestern Ethiopia.

See also Plates 1, 2 and 3, along with their Google Earth images, respectively for Tara Gedam, Alem Saga and Gelawudiwos.

Forest	Gelawudiwos	Alem Saga	Tara Gedam
Administrative District	Dera	Farta	Kemkem
Coordinates	11°38'26.19"N, 37°48'49.27"E	11°55'14.40"N, 37°56'19.06"E	12°08'55.85"N, 37°44'37.92"E
Forest size, ha (Eshete, 2007; Zegeye <i>et al.</i> , 2011)	100	820	975
Altitudinal range, m asl	2380 to 2511	2115 to 2541	2115 to 2441
Aspect	W to N to NE	S to SW to NW; N	W to NE; some S
Soils	Vertisol, Cambisol, Rigosol, Liptosol, Flovisol and Arenosol	Vertisol, Cambisol, Rigosol, Liptosol, Flovisol and Arenosol	Vertisol, Cambisol, Rigosol, Liptosol, Flovisol and Arenosol
Landscape physiography	Near ridge top, undulating, gentle slopes, shallow valleys	Along relatively steeper slopes below scarp	Undulating with gentle to steep slopes
Forest physiognomy	Tall forest	Scrub forest with some taller forest	Scrub forest with some taller forest, with parts deciduous

Mean annual rainfall is 1476 mm, ranging between 1097 mm and 1646 mm over the 13 years between 1999 and 2011, with a unimodal distribution pattern and with maximum rainfall in summer between July and August (Figure 2.2; Debre Tabor meteorological station, Amhara Regional Meteorological Agency). The mean monthly temperature is 16°C.

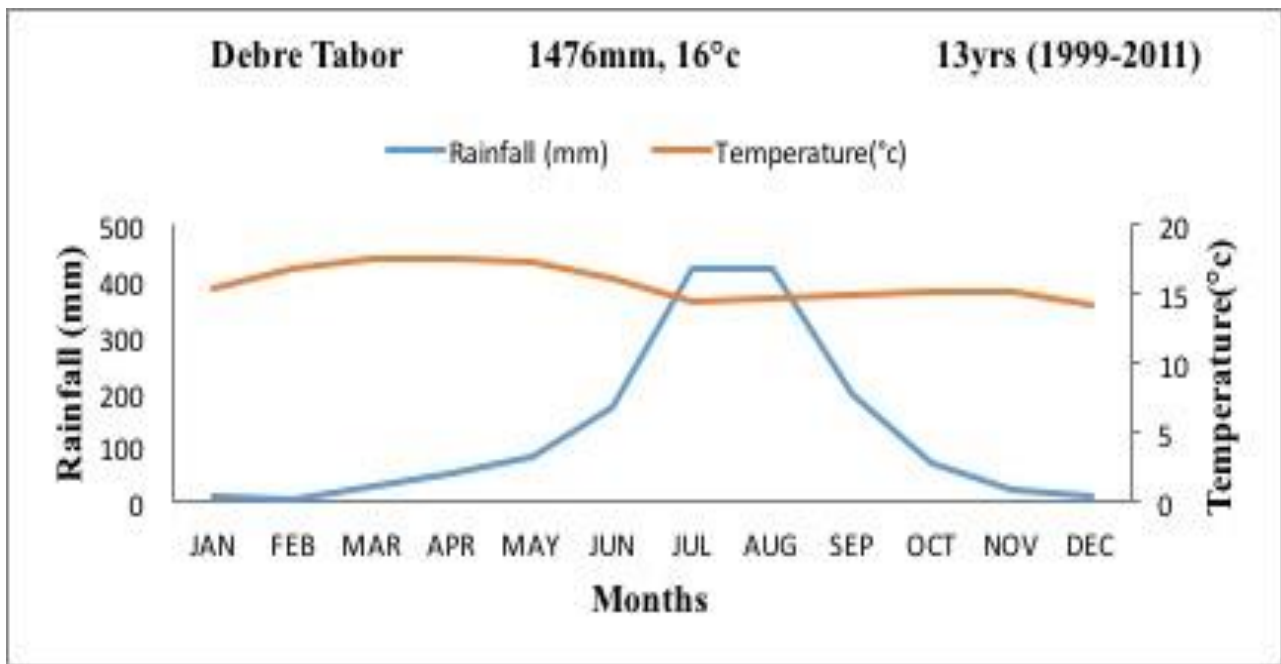


Figure 2.2 Climatic Graph of the areas of Afromontane Forests of Northwest Ethiopia.

Thirteen years meteorological data was taken from the meteorological station situated in Debre Tabor (11°50'59.87"N, 37°00'59.55"E, 2690 masl).



Plate 2.1 Location in the landscape and physiognomy of Tara Gedam Forest, shown for November 2013 and March 2016: Scrub forest with some taller forest, with parts deciduous



Plate 2.2 Location in the landscape and physiognomy of Alem Saga Forest: Scrub forest with some taller forest



Plate 2.3 Location in the landscape and physiognomy of Gelawudiwos Forest: Tall forest

2.2.2 Plant species data collection

Plant species were recorded during collection of stand composition on a total of 150 nested circular plots, with 50 plots per forest along transect lines, using a systematic sampling design in homogenous stands. A nested plot consisted of a main plot of 100 m² to record trees ≥ 2 cm DBH, i.e. stem diameter at 1.3 m above ground level, of woody species by species and DBH, and a sub-plot of 1 m² for herbaceous species, recorded by cover-abundance values per species.

The flora from the three studied forests was compared with the floras of 13 previously reported Afromontane forests and woodlands from Ethiopia and other parts of Africa (Table 2.2).

Table 2.2 Plant species lists were compiled from 13 previously reported Afromontane forests and woodlands from Ethiopia and other parts of Africa

Name of Forest/woodland & geographic coordinates	Forest size, ha	Altitude range, m	Geology	Rainfall, mm/annum	Reference
Denkoro, N Ethiopia, 10°35'N; 38°30'E	4375	1500-3500	Basalt and trachyte rocks (Cambisols, Arenosols, Lithosols and Vertisols soils)	933	Ayalew (2003)
Bale Mountains National Park, SE Ethiopia; 06°33'N; 39°37'E	215000	3010-3410	Trachyte and Basalt rocks (with loam soils)	1218	Yineger <i>et al.</i> (2008)
Bibita, SW Ethiopia; 6°45'N; 35°15'E	256500	900-2200	Metamorphic rocks	1888	Denu (2006)
Gendo, W Ethiopia, 9°49'N; 36°40'E	16	2183-2300	Rhyolites, tuffs, ignimbrites, agglomerates rocks (Clay-loam (60%), clay (20%) and sandy (20%) soils)	1487-2119	Gemechu <i>et al.</i> (2015)
Kimphe Lafa, SE Ethiopia, 7°20'N; 38°4'E	450	1557-1650	Andosols (52%) and Nitosols (48%) soils	500-1000	Aliyi <i>et al.</i> (2015)
Mana Angetu, SE Ethiopia, 6°27'N; 39°30'E	90000	1533-2431	Dystric nitosols, Chromic and Pellic vertisols, orthic Acrisols, and Chromic, Eutric and Calcic cambisols	702	Lulekal <i>et al.</i> (2008)
Wondo Genet, S Ethiopia, 7°5'N; 38°36'E	6500	1800-2500	Loam or sandy loam soils (volcanic origin)	1200	Kebede <i>et al.</i> (2013)
Kilimanjaro, Tanzania, 2°45'S; 37°43'E	6000	2000-5780	Phonolitic volcanic rocks	1714	Kikoti and Mligo (2015)
Metema, NW Ethiopia *, 12°39'N; 36°17'E	23360	550-1608	Haplic Luvisols and Vertisols	924	Wale <i>et al.</i> (2012a,b)
Delo Mena, SE Ethiopia *, 5°53'N; 40°38'E	90000	800-2000	Nitosols	986	Didita <i>et al.</i> (2010)
Miombo, S Tanzania *, 7°35'S; 35°35'E	6,065	850-1300	Metamorphosed schists and gneisses	617	Mwakalukwa <i>et al.</i> (2014)
Southern Cape, South Africa, 34°00'S; 23°12'E	60.500	5-1220	Quartzite, Shale and Dune sand	700-788	Geldenhuis (1992a)
Wof Washa, Central Ethiopia +, 9°35'N; 39°45'E	3600	2100-3600	ferric basalts, fine grained basalts, zeolitised basalts, phonolites, alkali-trachytes, trachyphonolites, and subordinate alkaline and peralkaline rhyolites	2750	Bekele (1993) and Teketay and Bekele (1995)

* Indicate woodland ecosystems; + Areas for which herbaceous species were not included.

2.2.3 Data Analysis

2.2.3.1 Species identification

Specimens were collected, pressed, dried and transported to the National Herbarium, Addis Ababa University. Species identification with author names of species was done using different published books and articles on the flora of Ethiopia (Hedberg and Edwards, 1989; Edwards *et al.*, 1995, 1997, 2000; Kyalangalilwa *et al.*, 2013; Moffett, 2007; Phillips, 1995; Hedberg *et al.*, 2003, 2006, 2009; Tadesse, 2004). Listing of endemic species was based on these relevant reports on the flora of Ethiopia.

2.2.3.2 Diversity and Diversity Profiles

The Shannon-Weiner Index was used to analyse diversity. It is one of the most widely used measures of diversity and is based on both species richness and evenness. An advantage of using this index is that its distributional properties have been examined. If the index is calculated for a number of samples, the indices themselves will be normally distributed and can be compared using parametric statistics (Kent and Coker, 1992; Magurran, 2004). The Shannon-Weiner Index analysis was done using the analysis package in PAST version 2.17c (Hammer *et al.*, 2001). The Shannon-Weiner diversity index normally varies between 1.5 and 3.5 and rarely exceeds 4.5; and low Shannon evenness is an indication of the existence of unbalanced distribution of the individuals of species encountered (Kent and Coker, 1992; Strong, 2016; Gatti *et al.*, 2017). Evenness is a scale ranging from 0 to 1; indicating lowest evenness or high single-species dominance at 0 and maximum evenness or equal abundance of all species at 1 (Stirling and Wilsey, 2001). In addition, the package was used to analyse the diversity profiles. Diversity profiles allow for a simultaneous direct graphical comparison and interpretation of the most applied diversity indices in ecology. It is a graphical presentation of the family of indices, including Simpson's dominance index, Shannon's index, and the total number of species, in a single continuous parameter (Tóthmérész, 1995; Patil, 2013).

For graphical presentation of diversity profiles, the package PAST uses the exponential of the Renyi index, which depends upon a scale parameter alpha (Hammer, 2016). For $\alpha = 0$, this function gives the total species number. $\alpha = 1$ gives an index proportional to the Shannon index, $\alpha = 2$ gives an index which behaves like the Simpson index, and where alpha equals ∞ , the profile equals the Berger-Parker index. Renyi diversity index can be calculated as follows:

$$H\alpha = \frac{\ln(\sum p_i^\alpha)}{1 - \alpha}$$

Where p_i is the proportional abundance of each species. α is a scale parameter that must be ≥ 0 and $\neq 1$. Profiles are calculated by changing the value of alpha from 0 to ∞ (Dickson, 2009; Hammer, 2016).

Sørensen similarity index was employed to explain the biogeographical relationships of Afromontane forests of the present study area in Northwest Ethiopia with other previously reported Afromontane forests from different geographical areas of Ethiopia and Africa, and with woodland vegetation in Ethiopia and Africa (Sørensen, 1948). The index provides simple and intuitive overlap measures to compare two species lists of two sites, regardless of the species abundance data. It gives more weight to the species that are common to the sites rather than to those that only occur in either sites (Chao *et al.*, 2006; Schmera and Podani, 2018). Sørensen similarity coefficient was calculated using the formula:

$$S_s = \frac{2a}{2a + b + c}$$

Where S_s = Sørensen similarity coefficient, a = number of species common to both sites, b = number of species observed only in site 1, and c = number of species observed only in site 2.

The type and size of the fruit and seed of the collected species were recorded as fleshy or dry, and small (<5 mm diameter) or large (≥ 5 mm diameter), based on Geldenhuys (1993a). In terms of the ecology of dispersal strategies, a propagule, in this study, was defined as the part of the reproductive structures that is dispersed by different agents (birds, mammals, wind, water, ballistics, or other mechanisms). In the analyses, the species were grouped into four propagule types, based on the type and size of the part of the fruit or seed or combination of the two, that gets dispersed by dispersal agents. For example, if a fruit is a capsule or pod, and the seed is exposed to dispersal agents, then the size and type of the seed was considered the propagule. If the fruit is fleshy with many small seeds, but the whole fruit is eaten by a bird, then the fruit is considered the propagule.

2.3 Results

2.3.1 Floristic Composition

In total, 209 species, belonging to 170 genera and 75 families were recorded from the 150 plots (Appendix 2.1 and 2.2), with the top 13 families listed in Table 2.3. Author name(s) for each species

are indicated in Appendices 2.1 and 2.2. The three most dominant families (with total counts and the percentage of all species between brackets were: Asteraceae with 22 species (10.5%), Fabaceae, with 22 species (10.5%), and Poaceae, with 15 species (7.2%). They presented 28% of all species. A total of 151, 143 and 82 plant species were recorded from the three Afromontane forests of Tara Gedam, Alem Saga and Gelawudiwos, respectively. There were 57 species (27%) common to all three studied forests. The families Celastraceae and Solanaceae showed the highest species : genus ratios, as compared to the other families. There were two woody and five herbaceous endemic plant species of Ethiopia. The observed endemic species, with their families between brackets, were *Acanthus sennii* (Acanthaceae), a subshrub, *Lippia adoensis* (Verbenaceae), a shrub, and herbaceous species *Aeollanthus abyssinicus* (Lamiaceae), *Bidens ghedoensis* (Asteraceae), *Mikaniopsis clematoides* (Asteraceae), *Solanecio gigas* (Asteraceae), and *Impatiens rothii* (Balsaminaceae).

Table 2.3 List of top 13 families with their respective numbers of species, numbers of genera and species: family ratios in Afromontane Forests of Northwest Ethiopia

Families	No. of		Ratio of
	Species	Genera	Species: genus
Asteraceae	22	11	2.0
Fabaceae	22	15	1.5
Poaceae	15	13	1.2
Lamiaceae	12	10	1.2
Malvaceae	8	6	1.3
Euphorbiaceae	6	5	1.2
Oleaceae	6	4	1.5
Rosaceae	6	4	1.5
Acanthaceae	5	4	1.3
Celastraceae	4	1	4.0
Rhamenaceae	4	3	1.3
Solanaceae	4	1	4.0
Urticaceae	4	4	1.0

The Afromontane forests of the study area showed a variety of growth forms. Growth form of woody species included canopy trees (height >10 m); sub-canopy trees (height 6 to 10 m), shrubs (height 2 to 6 m), subshrubs (height <2 m) and lianas (woody climbers). Growth forms of herbaceous species included ferns, graminoids, forbs and vines. Forbs (37% of all species) and sub-canopy tree species (18% of all species) were the most dominant growth forms in these forests (Table 2.4).

The understory growth forms of graminoids, followed by forbs and vines, showed the highest species to family ratios (Table 2.4). The growth forms of canopy and sub-canopy trees, showed similar species to family ratios. Ferns showed the lowest species to family ratio. This indicates higher species

differentiation in the understory growth forms (the herbaceous graminoids, forbs and vines) than the growth forms of canopy and sub-canopy trees (Table 2.4).

Table 2.4 Numbers of species, genera and families in each growth form, and species: family ratios, and genera: family ratios in Afromontane Forests of Northwest Ethiopia

Growth Form	Contributions in %	Number of			Ratio of	
		Species	Genera	Families	Genera: Family	Species: Family
Canopy Trees	15	32	25	21	1.2	1.5
Sub-canopy Trees	18	38	33	25	1.3	1.5
Shrubs	12	24	21	19	1.1	1.3
Subshrubs	2	4	4	4	1.0	1.0
Lianas	5	11	10	8	1.3	1.4
Ferns	2	4	3	3	1.0	1.3
Graminoids	9	18	15	2	7.5	9.0
Forbs	34	71	57	30	1.9	2.4
Vines	3	7	7	4	1.8	1.8

Fruit and seed types

In the studied forests, about 58% and 42% of species were respectively with dry and fleshy propagules (Table 2.5, Appendix 2.1 and 2.2). The study area was predominated by dry and small propagules, accounting 40% of the total propagules. Growth forms of forbs and graminoids predominated by dry and small propagules, while canopy and sub-canopy by large-sized propagules. In herbaceous species, dry and small propagules were predominated with 64% (Table 2.9).

Diversity

The 209 vascular plant species gave a Shannon-Weiner Index value of 4.0 with evenness value of 0.26. The Shannon-Weiner Index and evenness values for the three forests were 4.0 and 0.38 for Tara Gedam, 3.8 and 0.34 for Alem Saga, and 2.8 and 0.21 for Gelawudiwos.

The Renyi Diversity Profiles for all vascular plant species rank Tara Gedam first, with the highest diversity profile, followed by Alem Saga (relatively similar to the Tara Gedam profile) and Gelawudiwos (Figure 2.3).

The separate Renyi Diversity Profiles for woody (Figure 2.4) and herbaceous (Figure 2.5) species showed different variations between the three forest ecosystems. Tara Gedam showed the highest

ranking in terms of both total number of woody species (85, at $\alpha = 0$) and evenness (equitability) (at $\alpha \geq 0$) (Figure 2.4). In the case of diversity profiles for herbaceous species, Tara Gedam also showed the highest total number of species (66, at $\alpha = 0$), but was similar to Alem Saga in terms of other diversity indices ($\alpha \geq 0$) (Figure 2.5). For both the woody and herbaceous diversity profiles, Tara Gedam and Alem Saga forests ranked higher than Gelawudiwos forest.

Table 2.5 Number of species in the flora of three Afromontane forests in Northwest Ethiopia by fruit and seed types and size across plant growth forms.

See Appendix 2.1 and 2.2 for more details.

Growth forms	Propagule type				Total
	Fleshy fruits/seeds		Dry fruits/seeds		
	Large	Small	Large	Small	
Canopy Trees	12	8	9	3	32
Sub-canopy Trees	11	16	6	5	38
Shrubs	5	2	4	7	18
Shrubs, scandent	3	3			6
Subshrubs	2			2	4
Lianas	2	2	4	3	11
Vines	1	2	3	1	7
Ferns				4	4
Graminoids		3		15	18
Forbs	5	12	10	44	71
Total	41	47	36	84	209

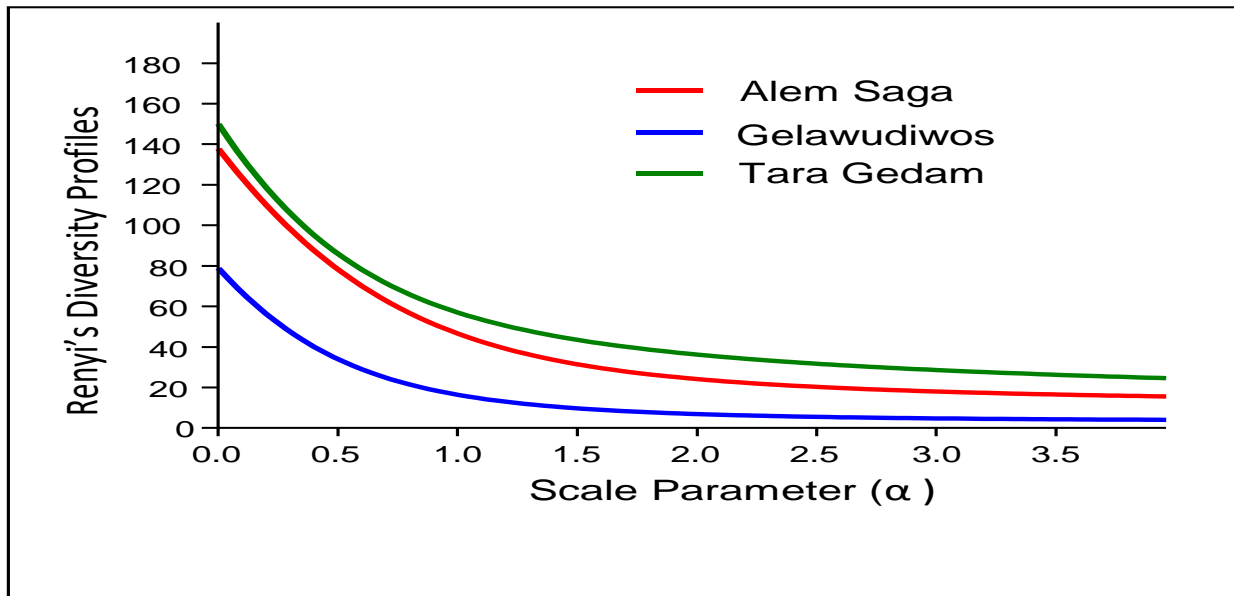


Figure 2.3 Renyi Plant Diversity Profiles for all vascular plant species across the three studied forest areas (Alem Saga, Gelawudiwos and Tara Gedam).

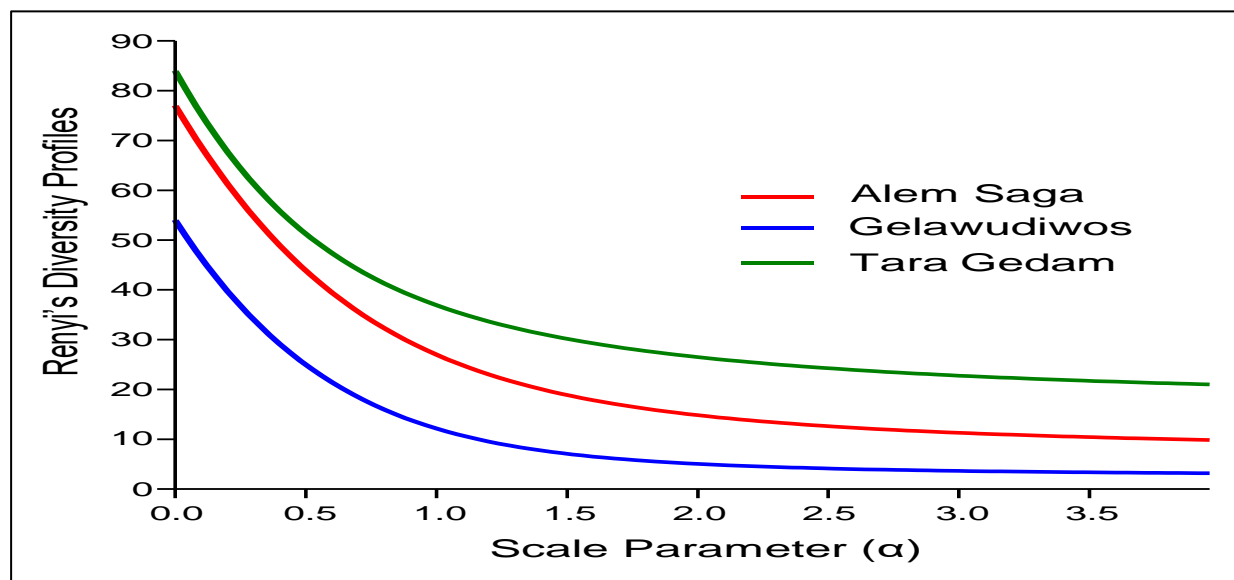


Figure 2.4 Renyi Plant Diversity Profiles for all woody plants across the studied forests (Alem Saga, Gelawudiwos and Tara Gedam).

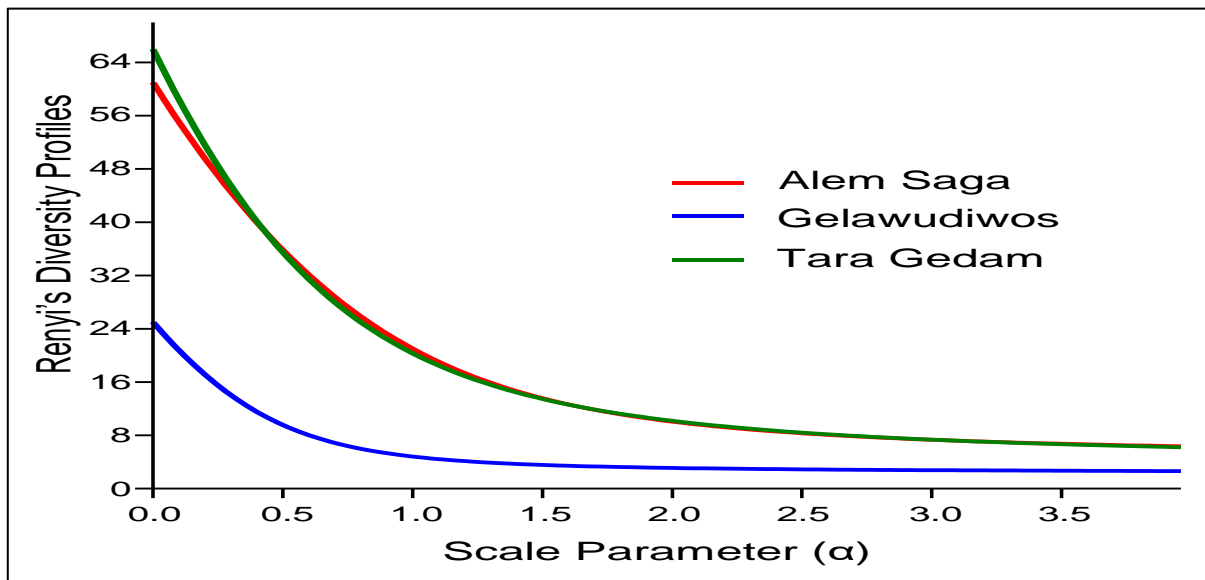


Figure 2.5 Renyi Plant Diversity Profiles for herbaceous plants across the studied forests (Alem Saga, Gelawudiwos and Tara Gedam).

2.3.2 Shared Plant Species, Floral Similarity and Biogeographical Relationships

The number of shared species and their Sørensen Similarity Index (%) were compared between the three Afromontane forests of Northwest Ethiopia of the current study, and with other previously studied Afromontane forests and woodlands from Ethiopia and parts of Africa (Tables 2.3, 2.6 to 2.8). This was based on what species were present in all the forests, as presented in Appendix 2.1 for all woody species and Appendix 2.2 for all herbaceous species. The most frequently observed species in various Afromontane forests and woodlands of Ethiopia and Africa are presented in Table 2.9. In total, 156 (75%) of vascular plant species of the three studied forests in Northwest Ethiopia, were shared with the other previously reported Afromontane forests and woodlands from Ethiopia and Africa. Of these shared species, 38 (18%) were observed in the woodland systems, apart from their presence in various observed Afromontane forests. Several plant species (53 or (25%) of the present study area were not observed in any of the other forests and woodlands.

The highest number of shared species and Sørensen similarity percentage of Northwest Afromontane forest was observed with Afromontane forest of Wondo Genet from Southcentral Ethiopia with 80 species, followed by Afromontane forests of Gendo from West Ethiopia with 70 species and Denkoro from Northcentral Ethiopia with 68 species (Table 2.6). The three studied forests shared 21 woody species with the woodland vegetation of Delo Mena from Southeast Ethiopia, 10 species with Metema

in Northwest Ethiopia, and 5 species with Miombo in Tanzania (based on data presented in Appendices 2.1 and 2.2).

Table 2.6 Number of shared species and Sørensen similarity index (%) of Afromontane forests of Northwest Ethiopia with the other previously reported Afromontane forests and woodlands from Ethiopia and parts of Africa

Other Afromontane forests and woodlands (indicated with +) (* = herbaceous species were not included)	All species		Woody		Herbaceous	
	No. of shared species	Sørensen Similarity (%)	No. of shared species	Sørensen Similarity (%)	No. of shared species	Sørensen Similarity (%)
Denkoro	68	35.5	40	45.7	28	26.9
Bale Mountains National Park	31	14.7	6	8.5	25	17.9
Bibita	47	23.4	34	29.3	13	15.3
Gendo	70	37.1	46	46.5	24	26.8
Kimphe Lafa	44	26.6	36	36.5	8	11.9
Mana Angetu	60	28.6	43	33.2	17	21.1
Wondo Genet	80	35.6	57	47.7	24	22.9
Kilimanjaro	26	16.0	14	16.1	12	16.0
Metema ⁺	19	12.8	10	13.0	9	12.7
Delo Mena ⁺	28	14.7	21	19.0	7	8.8
Miombo ⁺⁺	5	5.1	5	5.1	-	-
Southern Cape	23	6.6	14	9.7	8	4.2
Wof Washa [*]	12	17.7	12	17.7	-	-

The highest number of shared woody species and Sørensen similarity between Afromontane forests in Northwest Ethiopia was between Alem Saga and Tara Gedam (Table 2.7). The second highest number of shared woody species, but with the least similarity percentage, was observed between Tara Gedam and Gelawudiwos. Denkoro forest, of all the other previously observed and reported Afromontane forests from Ethiopia and Africa, showed the highest Sørensen similarity percentage with the three studied Afromontane forests in Northwest Ethiopia, as follows (with their similarity percentages between brackets: Gelawudiwos (45.9%), Tara Gedam (43.7%) and Alem Saga (44.1%). Alem Saga shared the lowest similarity percentage with Southern Cape forests (6.9 %) and Bale Mountains National Park (BMNP) (8.9%). For Gelawudiwos forest the lowest similarity values were

with the Southern Cape (7.6%) and BMNP (9.0%), and for Tara Gedam the lowest similarity values were with BMNP (6.8%) and the Southern Cape forests (8.2%).

Table 2.7 Number of shared woody species and Sørensen similarity index (%) between the three studied Afromontane forests of Northwest Ethiopia and other previously studied Afromontane forests and woodlands from Ethiopia and parts of Africa (see Table 2.2 for details)

All Afromontane forests and woodlands (indicated with +) (* = Afromontane forests of current study)	Afromontane forests of Northwest Ethiopia					
	Alem Saga		Gelawudiwos		Tara Gedam	
	No. of shared Species	Sørensen similarity (%)	No. of shared Species	Sørensen similarity (%)	No. of shared Species	Sørensen similarity (%)
Alem Saga*	-	-	46	68.1	63	76.8
Gelawudiwos*	46	68.1	-	-	47	63.9
Tara Gedam*	63	76.8	47	63.9	-	-
Denkoro	32	44.1	28	45.9	33	43.7
Bale Mountains National Park	5	8.9	4	9.0	4	6.8
Bibita	26	25.7	20	22.3	26	23.6
Gendo	34	40.5	26	19.1	38	31.3
Kimphe Lafa	24	28.7	16	22.2	30	34.7
Mana Angetu	29	25.3	28	26.9	34	28.9
Wondo Genet	36	34.4	31	33.3	47	43.7
Mount Kilimanjaro	10	14.1	8	13.2	11	14.7
Metema	6	9.7	3	5.9	4	3.8
Delo Mena	17	17.8	9	10.7	16	16.2
Miombo	4	4.8	2	2.8	3	3.5
Southern Cape	9	6.9	9	7.6	11	8.2
Wof Washa	9	15.7	7	15.6	11	17.9

The highest shared number of herbaceous species and Sørensen similarity for the studied forests were observed between Alem Saga and Tara Gedam, and the lowest values were between Tara Gedam and Gelawudiwos (Table 2.8). The highest Sørensen similarity percentage with forests outside the study area was observed between Tara Gedam and Denkoro Afromontane forest of Northcentral Ethiopia (26.4%). The Southern Cape forests showed the least similarity with all of the three Afromontane forests in Northwest Ethiopia, with 2.3% with Alem Saga, 2.6% with Gelawudiwos and 2.9% with Tara Gedam. Metema woodland showed 20.6% similarity of herbaceous species with Gelawudiwos. This is a high value, not even observed in any of the other Afromontane forests of Ethiopia and Africa.

Table 2.8 Number of shared herbaceous species and Sørensen similarity index (%) between the three studied Afromontane forests of Northwest Ethiopia and other previously studied Afromontane forests and woodlands from Ethiopia and parts of Africa (see Table 2.2 for details; no herbaceous species were recorded for Miombo and Wof Washa)

All Afromontane forests and woodlands (indicated with +) (* = Afromontane forests of current study)	Afromontane forests of Northwest Ethiopia					
	Alem Saga		Gelawudiwos		Tara Gedam	
	No. of shared Species	Sørensen similarity (%)	No. of shared Species	Sørensen similarity (%)	No. of shared Species	Sørensen similarity (%)
Alem Saga*	-	-	15	33.3	38	58.5
Gelawudiwos*	15	33.3	-	-	15	32.6
Tara Gedam*	38	58.5	15	32.6	-	-
Denkoro	14	17.1	8	10.6	23	26.4
Bale Mountains National Park	15	12.3	6	5.8	16	13.0
Bibita	6	9.0	6	12.5	8	11.8
Gendo	13	18.2	8	15.2	16	22.1
Kimphe Lafa	5	10.2	1	3.3	6	12.0
Mana Angetu	7	11.2	7	16.1	12	18.9
Wondo Genet	16	18.4	4	5.9	16	19.3
Mount Kilimanjaro	8	14.0	3	7.9	8	13.1
Metema ⁺	4	7.5	7	20.6	8	14.8
Delo Mena ⁺	5	8.1	0	0.0	4	6.4
Southern Cape	4	2.3	4	2.6	5	2.9

The tree species *Afrocarpus falcatus*, *Celtis africana*, *Croton macrostachyus*, *Ficus sur*, *Ficus thonningii*, *Prunus africana*, and *Syzygium guineense* were observed in most of the previously studied Afromontane forests of Ethiopia and Africa. *Achyranthes aspera* (also in Southern Cape forests as observed by Baard, 1994, but listed as an invasive weed species) and *Commelina africana* were also the two herbaceous species observed in most of the forests and woodlands. Most of these species have small (10 species) and large (8 species) fleshy propagules (Table 2.9). A total of 53 (25%) plant species, 15 woody and 38 herbaceous species, were absent from reports on the other Afromontane forests and woodlands from Ethiopia and parts of Africa (as listed in Table 2.2). They were observed only in Northwest biogeography, i.e. the studied Afromontane forests of Alem Saga, Gelawudiwos and Tara Gedam. Some of such species included the woody *Euphorbia abyssinica*, *Flacourtia indica*, *Helinus mystacinus*, *Pittosporum abyssinicum*, *Stephania cyanantha*, *Terminalia schimperiana*, and *Triumfetta tomentosa*, and the herbaceous *Orobancha minor*, *Pennisetum unisetum*, and *Vigna schimperi*.

Table 2.9 Woody and herbaceous plant species observed in most other previously reported Afromontane forests and woodlands from Ethiopia and parts of Africa, by their botanical names, family, growth form, propagule type and presence in each study forest (indicated as x). See details for woody and herbaceous species in Appendix 2.1 and 2.2, respectively.

Botanical Name	Family Name	Growth Forms+	Propagule type \$	Alem Saga	Gelawudiwos	Tara Gedam	Other previously reported Afromontane forests and woodlands++
<i>Achyranthes aspera</i>	Amaranthaceae	Fo	2			x	1,2,3,4,5,8,9 & 10
<i>Afrocarpus falcatus</i>	Podocarpaceae	T	1		x	x	1,4,5,6, 7 & 12
<i>Asparagus africanus</i>	Asparagaceae	Scs	2	x	x	x	1,2,4,7,8 & 9
<i>Bersama abyssinica</i>	Melanthaceae	Ts	1	x	x	x	1,3,4,5,7 , 8 & 13
<i>Carissa spinarum</i>	Apocynaceae	S	1	x	x	x	3,4,5,6,7,8 & 10
<i>Celtis africana</i>	Ulmaceae	T	2	x			1,3,4,5,7,8 & 12
<i>Commelina africana</i>	Commelainaceae	Fo	2	x		x	1,2,5,6,7,8,10 & 12
<i>Croton macrostachyus</i>	Euphorbiaceae	T	3	x	x	x	1,3,4,5,6,7 & 10
<i>Ficus sur</i>	Moraceae	T	2	x	x	x	1,3,4,5,6,7 & 12
<i>Ficus thonningii</i>	Moraceae	T	2	x			3,4,5,6,7,8,9 & 10
<i>Grewia ferruginea</i>	Tiliaceae	Ts	1	x		x	3,4,5,6,7 & 10
<i>Hypoestes forskoolii</i>	Acanthaceae	Fo	4	x	x	x	4,5,6,8,9 & 12
<i>Maesa lanceolata</i>	Myrsinaceae	Ts	2	x	x	x	1,3,4,6, 7 & 13
<i>Maytenus undata</i>	Celastraceae	Ts	2			x	5,7,8,9, 12 & 13
<i>Prunus africana</i>	Rosaceae	T	1		x		1,3,6,7,8 & 12
<i>Rubus steudneri</i>	Rosaceae	Scs	1	x			1,2,3,4,6 & 7
<i>Syzygium guineense</i>	Myrtaceae	T	1	x		x	2,4,5,6,7 & 10
<i>Teclea nobilis</i>	Rutaceae	Ts	1	x	x	x	1,3,4,6,7 & 10
<i>Thalictrum rhynchocarpum</i>	Ranunculaceae	Fo	2	x	x	x	1,2,3,4,6 & 7
<i>Zehneria scabra</i>	Cucurbitaceae	Fo	2	x		x	2,3,5,7,9 & 12

+Growth form symbols: T = canopy tree, Ts = Sub-canopy tree, S = shrub, L = Liana, Scs = Scandent shrub and Fo = Forb.

\$ Propagule types: 1 = Fleshy large, 2 = Fleshy small, 3 = Dry large and 4 = Dry small

++Other previously reported Afromontane forests and woodlands from Ethiopia and parts of Africa: 1 = Denkoro; 2 = Bale Mountains National Park; 3 = Bibita; 4 = Gendo; 5 = Kimphe Lafa; 6 = Mana Angetu; 7 = Wondo Genet; 8 = Mount Kilimanjaro (Northern Slope, Tanzania); 9 = Metema; 10 = Delo Mena; 11 = Miombo (Tanzania), 12 = Southern Cape (South Africa), and 13 = Wof Washa.

Only two Afromontane forests outside of Ethiopia were included in the comparison of their floras with the three studied forests in Ethiopia (with direct distance from the studied forests, and the number of shared species between brackets): Mount Kilimanjaro forests (1600 km; 23 species) and Southern Cape forests (5200 km; 23 shared species, including *Achyranthus aspera*). These two outlier Afromontane forests shared only six species: two canopy tree species (*Celtis africana* and *Prunus africana*) and one subcanopy tree species (*Maytenus undata*) all with fleshy propagules, and three forb species (*Achyranthus aspera*, *Commelina africana* and *Hypoestes forskalii*) all with small propagules. The other species shared between the Mount Kilimanjaro forests and forests of this Ethiopian study are mainly understory species (4 forb, 3 grass and 6 shrub species) with mainly drier small propagules, with one canopy and three subcanopy tree species, with small to larger fleshy propagules. The other species shared between the Southern Cape forests and forests of this Ethiopian study were 11 woody species (5 canopy tree, 4 subcanopy tree and 2 shrub species), with mostly small to large fleshy propagules, and six herbaceous species (3 forb, 1 fern and 2 vine species), with small fleshy (or soft) propagules.

2.4 Discussion

2.4.1 Species Richness

The total of 209 species recorded in the study area was lower than the 653 plant species recorded in forests in Southwestern Ethiopia (Senbeta *et al.*, 2014), but more than the 27 woody species in the Wof-Washa forest and 70 woody species from the central plateau of Shewa in the central Ethiopian Afromontane forests (Bekele, 1993), 168 and 142 vascular plant species respectively in the Gendo forest (Gemechu *et al.*, 2015) and Menagesha forest (Aramde *et al.*, 2010). The Southeastern Ethiopian forests included 211 vascular plant species (Lulekal *et al.*, 2008), i.e. similar to the number of species of the present study area.

Afromontane forests in other African countries included 115 Afromontane plant species in the Mount Kilimanjaro forests of Tanzania (Kikoti and Mligo, 2015), 465 species in the Southern Cape forests in South Africa (Geldenhuys, 1992a, 1993), and 245 species in the Mpumalanga forests in South Africa (Morgenthal and Cilliers, 2000). Mount Oku, a tropical montane forest located in the high plateau of Cameroon (>3,000 m.a.s.l), has about 218 vascular plant species (Neba, 2006), which is a similar amount than the number of species of the present study.

The number of recorded species increased with the size of the three studied forests, with size in ha and species/ha shown between brackets: Gelawudiewos (100 ha; 0.82 species/ha); Alem Saga (820

ha; 0.17 species/ha); Tara Gedam (975 ha; 0.15 species/ha). Geldenhuys (1992a) showed that the a significant log species - log area relationship for both woody and herbaceous species explained, respectively, only 30% to 38% of the variation in the size of the floras of 14 forest complexes in South Africa. Proximity to other forests, the number of dispersal corridors and mean altitude explained >81% of the variation in number of woody species. In the three studied forests the variation in site conditions (steepness and orientation of slopes, and moisture conditions), and forest physiognomy, as shown in Plates 2.1 to 2.3, may have an influence on the number of species present.

2.4.2 Diversity

Species Diversity is one of the most important ecological attributes which can determine stability of a given forest ecosystem. An ecosystem containing several species is more productive and stable than a forest with a lower variety of species (Cardinale *et al.*, 2011; Zhang *et al.*, 2012). The present study showed that the study area has a high Shannon-Weiner Index value of 4.0 and low evenness value of 0.26. This indicates that the study area has high species richness despite the fact that there is uneven distribution of the individuals of species. The three studied forests showed variation in their diversity and evenness: Tara Gedam with 4.0, followed by Alem Saga (3.8) and Gelawudiwos (2.8). The Shannon evenness values are highest in Tara Gedam forest, followed in decreasing values at Alem Saga and Gelawudiwos; despite the fact that they all show low values. This indicated that Tara Gedam forest had the highest plant species diversity, but that all three forests had a relatively poor equitability of species. There was some variation in both values between the highest value at Tara Gedam and lowest value at Gelawudiwos. In conformity with Shannon values, the Renyi Diversity Profiles for all vascular plant species also ranked Tara Gedam at the topmost in diversity profile ranking orders, followed by Alem Saga (relatively similar to Tara Gedam profile) and Gelawudiwos. Though Tara Gedam and Alem Saga showed differences in woody species diversity and evenness, they were similar and incomparable in terms of herbaceous diversity and evenness. This maybe attributed to the relative small sized propagules of herbaceous species, as compared to woody species, thereby enhancing propagule exchange between the two forests. About 67% of herbaceous propagules were dry and small in sizes, which has a direct implication for easy dispersal by wind.

2.4.3 Endemism

The seven recorded endemic plant species (to Ethiopia) from the Afromontane forests of Northwestern Ethiopia represents a low endemism as compared to endemism reports of other Afromontane forests in Ethiopia: 29 species in Wof-Washa in central Ethiopia (Teketay and Bekele, 1995); 18 species Gendo forest (Gemechu *et al.*, 2015); 31 species in Afromontane forests of Southwest Ethiopia (Senbeta *et al.*, 2014); and seven species in Wondo Genet Afromontane forest in South Central Ethiopia (Kebede *et al.*, 2013). Such observed variation of plant endemism in sub-Saharan tropical Africa is considered to be due to palaeoclimatic fluctuations (Linder, 2001), i.e. a climate prevalent at a particular geological time of the past. Two of the seven endemic plant species recorded in this study, were considered as red-listed endemic plant species of Ethiopia: *Acanthus sennii* and *Lippia adoensis* (Kelbessa *et al.*, 1992; Vivero *et al.*, 2005).

2.4.4 Taxonomic ratio and its implication on resource competition among growth forms

The overall taxonomic (species: family) ratios for this study were 2.8 for all vascular species (209 species and 75 families), 2.6 for herbaceous species, and 1.4 for woody species. The ratio for the top 13 families (in terms of number of species), was 9.1 species/family (Table 2.3). The ratios for the different growth forms ranged from 9.0 for graminoids, 2.4 for forbs, 1.8 for vines, and 1.0 to 1.5 for the other growth forms (Table 2.4).

The overall taxonomic ratio for the three studied Afromontane forests of Northwest Ethiopia is low, but with similar ranges to other Afromontane forests in Ethiopia: a ratio of 2.3 (162 species and 70 families) for vascular plant species in Southwest Ethiopia (Addi *et al.* 2016); 1.4 (70 species and 49 families) for woody species in Afromontane forests of central Ethiopia (Bekele 1993); 2.6 (168 species and 65 families) (Gemechu *et al.* 2015) and 2.5 (142 species and 26 families) (Aramde *et al.* 2010) for all vascular plants in Northwest Ethiopia; 3.0 (211 species and 75 families) in Southeast Ethiopia (Lulekal *et al.*, 2008); and 2.6 (240 species and 94 families) in South Central Ethiopia (Kebede *et al.*, 2013).

The ratios were similar to the reported floras for other African Afromontane forests: 3.0 (115 species and 39 families) from Tanzania (Kikoti and Mligo 2015); and 2.9 (218 species and 75 families) from Cameroon (Neba 2006); 2.6 (245 species and 95 families) in Mpumalanga, South Africa (Morgenthal and Cilliers 2000); and a higher ratio of 4.4 (470 species and 106 families) in the Southern Cape Afrotemperate forests (Geldenhuys, 1993a). In the Southern Cape forests, the ratio values of 3.1 for woody and 4.5 for herbaceous plants (Geldenhuys 1993a) were relatively higher when compared to

respectively 1.4 and 2.6 for this study. The ratio values in the tropical moist forests in the Congo Basin of 4.2 (160 species and 38 families) for tree species in the Congo-Brazzaville area ([Koubouana et al. 2015](#)) and of 5.7 (195 species and 34 families) for liana species in the Democratic Republic of Congo ([Ewango et al. 2015](#)) were much higher than for the reported studies in Afromontane forests, and particularly this study.

The taxonomic ratios of forests may indicate how species adapt to survive disturbance and other ecological processes related to site differentiation and resource competition amongst different growth forms in a given forest ecosystem or biogeographic region ([Geldenhuys, 1993a](#); [Grytnes et al., 2000](#); [Beaman, 2005](#)). In the Southern Cape forest flora ([Geldenhuys, 1993a](#)), the species : family ratios within the shared families were low in the forests compared to the very high ratios in the surrounding fire-adapted Fynbos shrublands. Similarly, endemism was very low with very few endemic species confined to the forest, whereas endemism was very high in the Fynbos vegetation. These results may suggest that speciation in the Ethiopian forests, and particularly the studied forests in Northwest Ethiopia, may have occurred on the ecotones and outside of these forests in fire-adapted vegetation and drier landscapes. Such developing species in this biogeographic region may have been lost during the periods of land occupation and land conversion to agriculture.

2.4.5 Floral similarity and biogeographical relationships

Various factors may have influenced the variation in shared species across the observed forests and woodlands, such as fragmentation over wide biogeographical distances due to changes in landscapes from rifting and uplift over geological times scales, increase in fire prevalence along with changing climate and aridification, variation in local climatic regimes, absence/presence of dispersal corridors connecting fragmented forests, and changes in local site conditions due to environmental and anthropogenic influences.

Vicariance biogeographical factors ([Mairal et al., 2015](#)), related to the uplift and rifting along East Africa until the Late Tertiary period, and development of the Ethiopian Highlands, caused the first level of fragmentation of forests and declining sharing of species across the Afromontane Archipelago ([White, 1983](#); [Burke and Gunnell, 2008](#)). This may have contributed to the low level of sharing of species of all growth forms between the study area and the forests of Mount Kilimanjaro and the Southern Cape, respectively 1600 km and 5200 km away (see section 2.3.2). The distances of separation, with unsuitable landscapes between the remnant islands of suitable montane landscapes, make connections through long-distance dispersal of species of all growth forms very unlikely. Most

of the shared species are either forest understory plants with fleshy and/or soft propagules that would not survive long-distance dispersal. This concept is supported by the reduction of species from north to south in southern Africa (Geldenhuys, 1993a), grouping of species of different growth forms and propagule types in disjunct locations in the Southern Cape forests (Geldenhuys, 1992b), and major differences in performance (genetic pools) of *Afrocarpus falcatus* provenances in South Africa (Geldenhuys and Von dem Bussche, 1997).

Afromontane forests of Northwest Ethiopia, in general, showed high numbers of shared species and Sørensen similarity percentages with Afromontane forests of Wondo Genet (South Central Ethiopia), Gendo (West Ethiopia) and Denkoro (North Central Ethiopia). It also observed a highest herbaceous species similarity percentage (i.e. 20.6%) with nearest woodland vegetation, specifically between Gelawudiwos and Metema woodland in Northwest Ethiopia (Table 2.5). The number of shared species (both woody and herbaceous) and similarity percentages in brackets respectively for Wondo Genet, Gendo and Denkoro were 80 (35.6 %), 70 (37.1%) and 68 (35.5%) (Table 2.5). About 122 (58%) plant species of the present study were observed either in one or two or all of these three Afromontane forests (Appendix 2.1 and 2.2).

All of these forests and woodland with high similarity percentages, except Wondo Genet forest, are located within a radius of 400 km from the present study area, with both Metema to the Northwest and Denkoro to the Southeast, 300 km away, and Gendo at 400 km to the Southwest. Two factors may contribute to the this relatively high sharing and similarity of plant species. Their geographical proximity can play a significant role in terms of seed dispersal among forest ecosystems, regardless of the type of ecosystem, i.e. whether evergreen forest or woodland. About 98 (47%) plant species were shared with either one or both of the nearest Afromontane forests, i.e. Denkoro and Gendo. A second factor could be that these Ethiopian Afromontane forests were being fragmented and isolated during relatively recent periods. Wondo Genet, with the highest shared number of species, is located at 800 km distance to the Southeast from the present study area, which may limit connections via long-distance seed dispersal. Though Wondo Genet located at a relatively far distance from this study area, such similarity can possibly be explained by vicariance biogeography (Mairal *et al.*, 2015). In the formation of the East African Rift System (EARS), land masses of this particular region disconnected and moved towards the Eastern and Western flanks of EARS (Sepulchre *et al.*, 2006; Ring 2014; de Gouveia *et al.*, 2018). This study area and Wondo Genet are currently located in the Western and Eastern flanks of EARS, respectively. In EARS evolution, Chorowicz (2005) reported that the plume that first formed at around 30 Million years (Ma), was likely in Lake Tana Region, where the current study area is located. This may possibly indicate the point of historical disconnection between this study area and other remnant Afromontane forests in the Eastern flank of

the rift, including Wondo Genet, Bale Mountains National Park, Kimphe Lafa, Mana Angetu and Delo Mena.

The observation of high similarity in herbaceous species between Metema woodland and Gelawudiwos forest, may be attributed to their relative close geographical proximity. It may also possibly indicate the development of the woodland towards forest, in Metema area. Control of fire for the protection of agricultural and forestry practices, such as for Sesame and gum and resin production in the area, might change the natural fire regimes and thereby enabling the woodland development towards forest. Similar observations and its possible interpretation was reported from South Africa ([Geldenhuis 1994](#); [Geldenhuis 1997](#); [Geldenhuis and Venter, 2002](#)).

The observation of the two *Ficus* species, namely *Ficus sur* and *Ficus thonningii*, in most of the observed forests, possibly shows their broad ecological breadth (Table 2.9). *Ficus thonningii* was observed in a woodland vegetation, in addition to its presence in most of the Afromontane forests. It was observed in Metema woodland, the nearby woodland vegetation of Northwest Ethiopia. Such a wide presence of the two *Ficus* species, might indicate their capability in long-distance seed dispersal, through various seed dispersal agents such as fruit-eating birds and bats. The fruits of these tree species often observed, attracting many fruit-eating birds. These tree species have been considered as keystone resources for fruit-eating animals in many tropical forests ([Kirika et al., 2008](#); [Daru et al., 2015](#); [Chaves et al., 2018](#)).

Seed size is one of the important traits in tree biology as it is vital for dispersal, establishment and survival of seedlings ([Leslie et al. 2017](#)). Owing to their seed and cone sizes, and other characteristics such as seed palatability by animals, the other most observed tree species listed in Table 2.9, might also have high chances of long-distance dispersal and showed such a wide range of presence in various geographical locations. Seeds palatability of *Celtis africana*, and *Croton macrostachyus* by birds and mammals, was observed in the evergreen forests of Malawi ([Dowsett-Lemaire, 1988](#)). *Prunus africana* and *Syzygium guineense*, despite having large seeds, can also attract fruit-eating birds and mammals ([Gross-Camp et al., 2009](#)). The fruit bat (*Rousettus aegyptiacus*) was reported as the main disperser of the seed of *Afrocarpus falcatus* (previously known as *Podocarpus falcatus*) in southern Cape forests ([Geldenhuis, 1993b](#)). Having large seed sizes, however, is a potential limitation for distance-dispersal of Afromontane tree species ([Lemenih and Teketay, 2006](#)). Besides, some characteristic Afromontane tree species, such as *Afrocarpus falcatus*, *Juniperus procera*, and *Olea europaea*, have problems in their seed viability ([Teketay and Granstrom, 1997](#); [Teketay, 2005](#); [Wassie and Teketay, 2006](#)). The protective tissue (stony shell) of *Afrocarpus falcatus* delays germination for about one year and thereby causes the exposure of the seed to high post-dispersal predation, by rodents and bushpig ([Geldenhuis, 1993b](#)). Such impairments suggest to be potential

area of research interventions, to conserve and sustain the utilization of Afromontane tree species. The herbaceous *Commelina africana* is present in most forests, including the Southern Cape forests, but is a forest understory species that survived in the stable forest understory of surviving forest patches over millenia. *Achyranthes aspera*, the other herbaceous species observed in most of the forests and woodlands, is generally considered a weedy introduced species from Asia, and locally abundant in disturbed sites. It has burr-like inflorescences that stick to animal hairs (di Vincenzo *et al.*, 2018), and it is likely that it was dispersed through the higher-rainfall areas, including forests, through livestock grazing in forests in many areas.

2.4.6 Species distribution ranges and implications for their conservation

The observation of a particular species only limited in a forest, might indicate its limited ecological breadth. One woody species, *Stephania cyanantha*, and 13 herbaceous species (*Bartsia trixago*, *Bidens ghedoensis*, *Crotalaria glauca*, *Digitaria abyssinica*, *Echinochloa pyramidalis*, *Galinsoga quadriradiata*, *Indigofera atriceps*, *Justicia ladanoides*, *Leonotis ocymifolia*, *Persicaria nepalensis*, *Rhynchosia elegans*, *Selaginella abyssinica*, and *Trifolium steudneri*) were observed to be limited to Alem Saga forest; (See Appendix 2.1 and 2.2). These species were not observed in any of the other two Afromontane forests of Northwest Ethiopia (Gelawudiwos and Tara Gedam). This might indicate the narrow range of their ecological amplitudes, and the need for conservation of these species. Gelawudiwos forest harboured some species which were not observed in any other of the studied forests in Northwest Ethiopia (woody species *Discopodium penninervium*, *Pittosporum abyssinicum*, *Rhynchosia resinosa* and *Terminalia schimperiana*, and herbaceous species *Chlorophytum tetraphyllum*, *Plectranthus lactiflorus*, and *Plectranthus longipes*). A total of 16 species were only found in Tara Gedam forest (woody species *Flacourtia indica*, *Rhamnus staddo*, *Triumfetta tomentosa*, *Albizia sp.* and *Vernonia sp.* and herbaceous species *Australina flasscida*, *Canarina abyssinica*, *Chrysopogon aucheri*, *Cyphostemma adenocaula*, *Kosteletzkya adoensis*, *Lactuca inermis*, *Lactuca sp.*, *Pavonia sp.*, *Pentas sp.*, *Pilea tetraphyla*, *Tacca leontopetaloides* and *Vernonia purpurea*). Nevertheless, this limited observation of the species does not mean that the particular species do not occur somewhere in the studied forests. It would be useful to assess a potential wider distribution of these species in the studied forests.

Despite their presence in most of the other observed forests and woodlands (Table 2.9), *Celtis africana*, *Ficus thonningii*, and *Rubus steudneri*, were observed only in Alem Saga forest. Such a limited range of distribution in this particular biogeographical area suggests the need for further investigation and formulation of conservation measures. The present study, however, observed that

some species were present in all three Afromontane forests of Northwest Ethiopia, and also in most of the other listed Afromontane forests and woodlands in Ethiopia and parts of Africa. These species included the woody *Asparagus africanus*, *Bersama abyssinica*, *Carissa spinarum*, *Croton macrostachyus*, *Ficus sur* and *Teclea nobilis*, and the herbaceous *Commelina africana* and *Thalictrum rynchocarpum*.

2.5 Conclusion

The Afromontane forests of Northwest Ethiopia, despite their fragmentation and threats of high population pressure, still maintain high plant species richness as high as other Afromontane forests of the country. The variation in diversity values and diversity profile rank ordering across the three Afromontane forests, indicated that there were differences in the extent of disturbances and environmental wellness among the forests. On the basis of the study results, and observations made during the field work, the study recommends that due attention should be given in terms of conservation measures, to Gelawudiwos forest. The low values of Shannon evenness for all forests suggest that they are dominated by a few species. This might indicate that all of the studied forests are in an earlier stage of development, recovering from probably diverse natural/anthropogenic disturbances. Such development stages may need appropriate silvicultural interventions along with local resource use, to facilitate the ongoing disturbance-recovery processes happening in all of the studied forests. The encountering of the two red-listed endemic plant species, *Acanthus sennii* (Acanthaceae) and *Lippia adoensis* (Verbenaceae), suggests also the need for strong conservation efforts.

The observation of some species limited only in either of the three studied Afromontane forests of Ethiopia, might indicate either their limited ecological breadth or the particular species may not naturally occur in the particular forest site conditions; the forest may be too dense (early regrowth stage) or disturbed or too closed for the particular species. However, it may be worthwhile to have a more in-depth assessment of the species in parts of those forests that were not adequately sampled during this study, and to include the various small-sized fragments of highland forest patches, still left over here and there in this biogeographical area. Some of such woody species are *Cadia purpurea*, *Flacourtia indica*, *Pittosporum abyssinicum*, *Rhamnus staddo* and *Stephania cyanantha*, and the herbaceous *Australina flascida*, *Bartsia trixago* and *Bidens ghedoensis*. The observation of 53 (25%) vascular plant species limited only in the biogeography of Northwest Ethiopia, also suggests the need and the importance of conserving all of the Afromontane forests located in this particular geographical area, regardless of the size of the particular forest patches. The observation of high

number of shared plant species with disjunctly located Afromontanes forests in Ethiopia and Africa, reflects the ongoing inter-connectivity of Afromontane forest species as mega-populations in the continent, through the dynamic interplay of dispersal, vicariance and extinction.

References

- Addi, A. Soromessa, T. Kelbessa, E. Dibaba, A. and Kefalew, A. (2016). Floristic composition and plant community types of Agama Forest, an “Afromontane Forest” in Southwest Ethiopia. *Journal of Ecology and the Natural Environment*, 8(5), 55-69.
- Aerts, R. Van Overtveld, K. November, E. Wassie, A. Abiyu, A. Demissew, S. Daye, D. D. Giday, K. Haile, M. TewoldeBerhan, S. Teketay, D. Teklehaimanot, Z. Binggeli, P. Deckers, J. Friis, I. Gratzer, G. Hermy, M. Heyn, M. Honnay, O. Paris, M. Sterck, F. J. Muys, B. Bongers, F. and Healey, J. R. (2016). Conservation of the Ethiopian church forests: threats, opportunities and implications for their management. *Science of the Total Environment*, 551-552, 404-414.
- Aliyi, K. Hundera, K. and Dalle, G. (2015). Floristic Composition, Vegetation Structure and Regeneration Status of Kimphe Lafa Natural Forest, Oromia Regional State, West Arsi, Ethiopia. *Research & Reviews: A Journal of Life Sciences*, 5(1), 19-32.
- Aramde, F. Bekele, T. and Lemenih, M. (2010). Diversity of non-timber forest products (ntfps) and their source species in menagesha suba forest. *Ethiopian Journal of Biology*, 9(1): 11-34.
- Axelrod, D. and Raven, P., (1978). Late Cretaceous and Tertiary vegetation history of Africa. *Biogeography and ecology of Southern Africa*, 77-130.
- Axelrod, D. and Raven, P. (2012). Late Cretaceous and Tertiary vegetation history. *Biogeography and Ecology of Southern Africa*, 31, 77.
- Ayalew, A. (2003). A floristic composition and structural analysis of Denkoro Forest, South Wello. MSc Thesis, Addis Ababa Univesity, Addis Ababa, Ethiopia.
- Ayana, A. N. Arts, B. and Wiersum, K. F. (2013). Historical development of forest policy in Ethiopia: Trends of Institutionalization and deinstitutionalization. *Land Use Policy*, 32, 186-196.
- Aynalem, S. and Bekele, A. (2008). Species composition, relative abundance and distribution of bird fauna of riverine and wetland habitats of Infranz and Yiganda at southern tip of Lake Tana, Ethiopia. *Tropical Ecology*, 49(2), 199-209.
- Baard, J. (1994). Description and analysis of the ground flora of the Southern Cape forests. Unpublished M.Tech Diploma, Saasveld Campus, Port Elizabeth Technikon. 192 pp.
- Beaman, J. H. (2005). Mount Kinabalu: Hotspot of plant diversity in Borneo. *Biologiske Skrifter*, 55, 103:127.
- Bekele, T. (1993). Vegetation ecology of remnant Afromontane forests on the Central plateau of Shewa, Ethiopia. *Acta Phytogeographica Suecica*, 79, 1-59.

- Burke, K. and Gunnell, Y. (2008). The African erosion surface: a continental-scale synthesis of geomorphology, tectonics, and environmental change over the past 180 million years. Geological Society of America, Boulder, USA.
- Bussmann, R. W. (2001). Regeneration and succession patterns in African, Andean and Pacific Tropical Mountain Forests: The role of natural and anthropogenic disturbance. *Lyonia*, 6, 93-111.
- Cardinale, B. J. Matulich, K. L. Hooper, D. U. Byrnes, J. E. Duffy, E. Gamfeldt, L. Balvanera, P. O'Connor, M. I. and Gonzalez, A. (2011). The functional role of producer diversity in ecosystems. *American Journal of Botany*, 98 (3), 572-592. DOI:10.3732/ajb.1000364
- Chambers, J. C. Maestas, J. D. Pyke, D. A. Boyd, C. S. Pellant, M. and Wuenschel, A. (2017). Using Resilience and Resistance Concepts to Manage Persistent Threats to Sagebrush Ecosystems and Greater Sage-grouse. *Rangeland Ecology & Management*, 70, 149-164.
- Chao, A. Chazdon, R. L. Colwell, R. K. and Shen, T-J. (2006). Abundance-based similarity indices and their estimation when there are unseen species in samples. *Biometrics*, 62, 361-371.
- Chaves, O. M. Bicca-Marques, J. C. and Chapman, C. A. (2018). Quantity and quality of seed dispersal by a large arboreal frugivore in small and large Atlantic forest fragments. *PloS ONE*, 13 (3): e0193660.
- Chorowicz, J. (2005). The East African rift system. *Journal of African Earth Sciences*, 43, 379-410.
- CI (Conservation International). (2005). Biodiversity Hotspots. Conservation International Facts, Washington DC, 1-2.
- Coleman, M. Liston, A. Kadereit, J. W. and Abbott, R. J. (2003). Repeat intercontinental dispersal and Pleistocene speciation in disjunct Mediterranean and desert Senecio (Asteraceae). *American Journal of Botany*, 90, 1446-1454
- Daru, B. H. Yessoufou, K. Nuttman, C. and Abalaka, J. (2015). A preliminary study of bird use of fig *Ficus* species in Amurum Forest Reserve, Nigeria. *Malimbus*, 37, 1-15.
- de Gouveia, S. V. Besse, J. de Lamotte, D. F. Greff-Lefftz, M. Lescanne, M. Gueydan, F. and Leparmentier, F. (2018). Evidence of hotspot paths below Arabia and the Horn of Africa and consequences on the Red Sea opening. *Earth and Planetary Science Letters*, 487, 210-220.
- Denu, D. (2006). Floristic composition and ecological study of Bibita Forest (Gura Ferda), Southwest Ethiopia. MSc Thesis, Addis Ababa University, Addis Ababa, Ethiopia.
- Dickson, R. P. (2009). Secondary Diversity: Ecological and Spectral dimensions of secondary succession following smallholder cultivation in the southern Yucatan. A Dissertation. Submitted to the faculty of Clark University, Worcester, Massachusetts, in partial fulfilment of the requirements for the degree of Doctor of Philosophy in the Department of Geography. 1-96p.

- Didita, M. Nemomissa, S. and Gole, T. W. (2010). Floristic and structural analysis of the woodland vegetation around Dello Menna, Southeast Ethiopia. *Journal of Forestry Research*, 21(4), 395-408.
- di Vincenzo, V. Gruenstaeudl, M. Nauheimer, L. Wondafrash, M. Kamau, P. Demissew, S and Borsch, T. (2018). Evolutionary diversification of the African achyranthoid clade (Amaranthaceae) in the context of sterile flower evolution and epizoochory. *Annals of Botany*, 122, 69-85.
- Downing, A. S. van Nes, E. H. Mooij, W. M. and Scheffer, M. (2012). The Resilience and Resistance of an Ecosystem to a Collapse of Diversity. *PLoS ONE*, 7(9): e46135.
- Dowsett-Lemaire, F. (1988). Fruit choice and seed dissemination by birds and mammals in the evergreen forests of upland Malawi. *Review of Ecology (Terre et Vie)*, 43, 251-285.
- Dymond, C. C. Spittlehouse, D. L. Tedder, S. Hopkins, K. McCallion, K and Sandland, J. (2015). Applying Resilience Concepts in Forest Management: A Retrospective Simulation Approach. *Forests*, 6, 442-4438.DOI:10.3390/f6124377.
- Edwards, S. Demissew, S. and Hedberg, I. (eds.). (1997). Flora of Ethiopia and Eritrea, Vol. 6, Hydrocharitaceae to Arecaceae. The National Herbarium, Addis Ababa University, Addis Ababa & Uppsala.
- Edwards, S. Tadesse, M. and Hedberg, I. (eds.) (1995) Flora of Ethiopia and Eritrea, Vol. 2 (2), Canellaceae to Euphorbiaceae. The National Herbarium, Addis Ababa University, Addis Ababa & Uppsala.
- Edwards, S. Tadesse, M. Demissew, S and Hedberg, I. (eds.) (2000) Flora of Ethiopia and Eritrea, Vol. 2 (1), Magnoliaceae to Flacourtiaceae. The National Herbarium, Addis Ababa University, Addis Ababa & Uppsala.
- Elmqvist, T. Folke, C. Nyström, M. Peterson, G. Bengtsson, J. Walker, B. and Norberg, J. (2003). Response diversity, ecosystem change, and resilience. *Frontiers in Ecology and in Environment*, 1(9), 488-494.
- Eshete, A. W. (2007). Ethiopian Church Forests: opportunities and challenges for restoration. PhD thesis, Wageningen University, Wageningen, The Netherlands.
- Ewango, C. E. N. Bongers, F. Makana, J. R. Poorter, L. and Sosef, M. S M. (2015). Structure and composition of the liana assemblage of a mixed rain forest in the Congo Basin. *Plant Ecology and Evolution*, 148 (1), 29-42.
- Gatson, K. J. (2000). Global Patterns in biodiversity. *NATURE*, 405, 220-227.
- Gatson, K. J. and Spicer, J. I. (2004). Biodiversity: An Introduction.2nd ed. Blackwell Science, UK.

- Gatti, R. C. Laurin, G. V. and Valentini, R. (2017). Tree species diversity of three Ghanaian reserves. *iForest*, 10, 362-368. DOI: 10.3832/ifor2056-010.
- Geldenhuys, C. J. (1992a). Richness, Composition, and relationships of the floras of selected forests in southern Africa. *Bothalia*, 22(2), 205-233.
- Geldenhuys, C.J. (1992b). Disjunctions and distribution limits of forest species in the southern Cape. *South African Forestry Journal* 161, 1-13.
- Geldenhuys, C. J. (1993a). Floristic Composition of the southern Cape forests with annotated checklist. *South African Journal of Botany*, 59(1), 26-44.
- Geldenhuys, C. J. (1993b). Reproductive biology and population structures of *Podocarpus falcatus* and *P. latifolius* in southern Cape forests. *Botanical Journal of the Linnean Society*, 112, 59-74.
- Geldenhuys, C. J. (1994). Bergwind fires and the location pattern of forest patches in the southern Cape landscape, South Africa. *Journal of Biogeography*, 21, 49-62.
- Geldenhuys, C. J. (1997). Native forest regeneration in pine and eucalypt plantations in Northern Province, South Africa. *Forest Ecology and Management*, 99, 101-115.
- Geldenhuys, C. J. and Venter, S. (2002). Plant communities and biodiversity of the Limpopo Province forests: relevance and management options. In: Seydack, A. H. W., Vorster, T., Vermeulen, W. J. and Van der Merwe, I.J. (eds.). Multiple use management of natural forests and savanna woodlands: Policy refinements and scientific progress. Proceedings of Natural Forests & Savanna Woodlands Symposium III, 6-9 May 2002, Berg-en-Dal, Kruger National Park, 23-37.
- Geldenhuys, C.J. and Von dem Bussche, G.H. (1997). Performance of *Podocarpus falcatus* provenances in South Africa. *Southern African Forestry Journal* 178, 15-24.
- Gemechu, T. Kelbessa, E. and Soromessa, T. (2015). Floristic Composition and Community analysis of Gendo Moist Montane Forest of East Wellega, Western Ethiopia. *Journal of Natural Sciences Research*, 5(15), 153-170.
- Geri, F. La Porta, N. Zottele, F. and Ciolli, M. (2016). Mapping Historical Data: Recovering a Forgotten Floristic and Vegetation Database for Biodiversity Monitoring. *International Journal of Geo-Information*, 5, 100.
- Goswami, M. Bhattacharyya, P. Mukherjee, I. and Tribedi, P. (2017). Functional Diversity: An Important Measure of Ecosystem Functioning. *Advances in Microbiology*, 7, 82-93.
- Gross-Camp, N.D. Mulindahabi, F. and Kaplin, B.A. (2009). Comparing the Dispersal of Large-seeded Tree Species by Frugivore Assemblages in Tropical Montane Forest in Africa. *BIOTROPICA*, 41(4), 442-451.
- Grytnes, J. A. Birks, H. J. B., Heegaard, E and Peglar, S.M. (2000). Geographical trends in the species-to-family ratio of vascular plants in Fennoscandia, *Norsk Geografisk Tidsskrift. Norwegian Journal of Geography*, 54(2), 60-64. DOI: 10.1080/002919500423780.

- Hamilton, A. J. (2005). Species diversity or biodiversity? *Journal of Environmental Management*, 75, 89-92.
- Hammer, Ø. (2016). PAST (Paleontological Statistics) Version 3.14. Reference manual, Natural History Museum, University of Oslo, Oslo.
- Hammer, Ø. Harper, D. A. T. and Ryan, P. D. (2001). PAST. Palaeontological Statistics software package for education and data analysis. *Palaeontological Electronica*, 4(1), 9.
- Haq, B.U., Hardenbol, J. and Vail, P.R. (1987). Chronology of fluctuating sea levels since the Triassic. *Science*, 235, 1156-1167.
- Hedberg, I. and Edwards, S. (eds.). (1989). Flora of Ethiopia, Vol. 3, Pittosporaceae to Araliaceae. The National Herbarium, Addis Ababa University, Addis Ababa & Uppsala.
- Hedberg, I. Edwards, S. and Nemomissa, S. (eds.) (2003). Flora of Ethiopia and Eritrea. Vol 4 (2), Apiaceae to Dipsaceae. The National Herbarium, Addis Ababa University, Addis Ababa & Uppsala.
- Hedberg, I. Friis, I. and Persson, E. (eds.) (2009). Flora of Ethiopia and Eritrea, Vol. 1, Lycopodiaceae to Pinaceae Appendix-Additions and Amendments to Vol. 2-7. The National Herbarium, Addis Ababa University, Addis Ababa & Uppsala.
- Hedberg, I. Kelbessa, E. Edwards, S. Demissew, S. and Persson, E. (eds.) (2006). Flora of Ethiopia and Eritrea. Vol 5, Gentianaceae to Cyclocheilaceae. The National Herbarium, Addis Ababa University, Addis Ababa and Uppsala.
- Holbourn, A. Kuhnt, W. Clemens, S. Prell, W. and Andersen, N. (2013). Middle to late Miocene stepwise climate cooling: Evidence from a high-resolution deep water isotope curve spanning 8 million years. *Paleoceanography*, 28, 688-699.
- Jayakumar, S. Kim, S. S. and Heo, J. (2011). Floristic inventory and diversity assessment- a critical review. *Proceedings of the International Academy of Ecology and Environmental Sciences*, 1(3-4), 151-168.
- Kadu, C. A. C. Konrad, H. Schueler, S. Muluvi, G. M. Eyog-Matig, O. Muchugi, A. Williams, V. L. Ramamonjisoa, L. Kapinga, C. Foahom, B. Katsvanga, C. Hafashimana, D. Obama, C. and Geburek, T. (2013). Divergent pattern of nuclear genetic diversity across the range of the Afromontane *Prunus africana* mirrors variable climate of African highlands. *Annals of Botany*, 111, 47-60.
- Kebede, M. Yirdaw, E. Luukkanen, O. and Lemenih, M. (2013). Plant community analysis and effect of environmental factors on the diversity of woody species in the moist Afromontane forest of Wondo Genet, South Central Ethiopia. *Biodiversity Research and Conservation*, 29: 63-80. DOI: 10.2478/biorc-2013-0003.

- Kelbessa, E. Demissew, S. Woldu, Z. and Edwards, S. (1992). Some threatened Endemic plants of Ethiopia. NAPRECA Monograph, Series 2, 35-55.
- Kent, M. and Coker, P. (1992). Vegetation Description and Analysis: A practical approach. Belhaven Press, London.
- Kier, G. Mutke, J. Dinerstein, E. Ricketts, T. H. Kuper, W. Kreft, H. and Barthlott, W. (2005). Global patterns of plant diversity and floristic knowledge. *Journal of Biogeography*, 32, 1-10.
- Kikoti, A and Mligo, C. (2015). Impacts of livestock grazing on plant species composition in montane forests on the northern slope of Mount Kilimanjaro, Tanzania. *International Journal of Biodiversity Science, Ecosystem Services & Management*, 11(2), 114-127.
- King, L. (1963). South African Scenery, Oliver and Boyd, Edinburgh.
- Kirika, J. M. Bleher, B. Bohning-Gaese, Chira, R. and Farwig, N. (2008). Fragmentation and local disturbance of forests reduce frugivore diversity and fruit removal in *Ficus thonningii* trees. *Basic and Applied Ecology*, 9, 663 - 672.
- Koubouana, F. Ifo, S. A. Moutsambote, J.M. Banzouzi, R. R. F. Akobe, A. Ikama, C. O. Mantota, A. B. Saint, D. and Mbemba, M. (2015). Structure and Flora Tree Biodiversity in Congo Basin: Case of a Secondary Tropical Forest in Southwest of Congo-Brazzaville. *Research in Plant Sciences*, 3(3), 49-60. DOI: 10.12691/plant-3-3-2.
- Kyalangalilwa, B. Boatwright, J. S. Daru, B. H. Maurin, O. and van der Bank, M. (2013). Phylogenetic position and revised classification of *Acacia* s.l. (Fabaceae: Mimosoideae) in Africa, including new combinations in *Vachellia* and *Senegalia*. *Botanical Journal of Linnean Society*, 172, 500-523.
- Lawes, M. J. Fly, S. and Piper, S. E. (2006). Gamebird vulnerability to forest fragmentation: patch occupancy of the crested guineafowl (*Guttera edouardi*) in Afromontane forests. *Animal Conservation*, 9, 67-74.
- Lemenih, M. and Teketay, D. (2006). Changes in soil seed bank composition and density following deforestation and subsequent cultivation of a tropical dry Afromontane forest in Ethiopia. *Tropical Ecology*, 47(1) 1-12.
- Leslie, A. B. Beaulieu, J. M. and Mathews, S. (2017). Variation in seed size is structured by dispersal syndrome and cone morphology in conifers and other nonflowering seed plants. *New Phytologist*, 216, 429-437.
- Linder, H. P. (2001). Plant diversity and endemism in Sub-Sahara tropical Africa. *Journal of Biogeography*, 28, 169-182.
- Linder, H. P. de Klerk, H. M. Born, J. Burgess, N. D. Fjeldsa, J. and Rahbek, C. (2012). The partitioning of Africa: statistically defined biogeographical regions in sub-Saharan Africa. *Journal of Biogeography*, 39, 1189-1205.

- LMMC (Like-Minded Megadiverse Countries). (2017). Biodiversity of Ethiopia. New Megadiverse Country. <http://paisesmegadiversos.org/en/etiopia/>. Date Visited 14/06/2017.
- Lulekal, E., Kelbessa, E., Bekele, T., and Yineger, H. (2008). Plant Species Composition and Structure of the Mana Angetu Moist Montane Forest, South-Eastern Ethiopia. *Journal of East African Natural History*, 97(2), 165-185. DOI: <http://dx.doi.org/10.2982/0012-8317-97.2.165>.
- Magurran, A. E. (2004). *Measuring Biological Diversity*. Blackwell Science Ltd, USA.
- Mairal, M. Pokorny, L. Aldasoro, J. J. Alarcon, M. and Sanmartin, I. (2015). Ancient vicariance and climate driven extinction explain continental-wide disjunctions in Africa: the case of the Randa Flora genus *Canarina* (Campanulaceae). *Molecular Ecology*, 24, 1335-1354.
- Moffett, R.O. (2007). Name changes in the Old World *Rhus* and recognition of *Searsia* (Anacardiaceae). *Bothalia*, 37, 2, 165-175.
- Morgenthal, T. L. and Cilliers, S. S. (2000). Species composition and phytogeographical significance of an Afromontane forest fragment in the Mpumalanga province, South Africa. *The Southern African Forestry Journal*, 189(1), 81-102.
- Mouchet, M. A. Villéger, S. Mason, N. W. H and Mouillot, D. (2010). Functional diversity measures: an overview of their redundancy and their ability to discriminate community assembly rules. *Functional Ecology*, 24, 867-876.
- Mwakalukwa, E. E. Meilby, H. and Treue, T. (2014). Floristic Composition, Structure, and Species Associations of Dry Miombo Woodland in Tanzania. *ISRN Biodiversity*, Article ID 153278, 1-15. DOI: <http://dx.doi.org/10.1155/2014/153278>
- Neba, N. E. (2006). Degradation of useful plants in Oku tropical montane cloud forest, Cameroon. *International Journal of Biodiversity Science & Management*, 2, 73-86.
- Odat, N. Hasan, H. S. Obeidat, M. and Aladaileh, S. (2015). Relationships between species diversity and evenness of necrophagous Diptera and environmental conditions in three habitats of Jordan. *Journal of Entomology and Zoology Studies*, 3(5), 89-94.
- Patil, G.P. (2013). Diversity Profiles. *Encyclopedia of Environmetrics*, 2.
- Pelster, P. B. Abbott, R. J. Comes, H. P. Milton, J. J. Moller, M. Looseley, M. E. Cron, G. V. Barcelona, J. F. Kennedy, A. H. Watson, L. E. Barone, R. Hernandez, F. and Kadereit, J. W. (2012). The genetic ghost of an invasion past: colonization and extinction revealed by historical hybridization in *Senecio*. *Molecular Ecology*, 21, 369-387.
- Phillips, S. (1995). Poaceae (Gramineae). In: Hedberg I, Edwards S (eds.) *Flora of Ethiopia and Eritrea*, Vol. 7. The National Herbarium, Addis Ababa University, Addis Ababa & Uppsala.

- Ramdhani, S. Barker, N. P. Baijnath, H. and Ebach, M. (2008). Exploring the Afromontane Centre of Endemism: *Kniphofia Moench* (Asphodelaceae) as a Floristic Indicator. *Journal of Biogeography*, 35(12), 2258-2273.
- Ring, U. (2014). The East African Rift System. *Austrian Journal of Earth Sciences*, 107 (1), 132-146.
- Schmera, D. and Podani, J. (2018). Through the jungle of methods quantifying multiple-site resemblance. *Ecological Informatics*, 44, 1-6.
- Senbeta, F. Scmitt, C. Woldemariam, T. Boehmer, H. J. and Denich, M. (2014). Plant diversity, vegetation structure and relationship between plant communities and environmental variables in the Afromontane forests of Ethiopia. *SINET: Ethiopian Journal of Science*, 37(2), 113-130.
- Sepulchre, P. Ramstein, G. Fluteau, F. Schuster, M. Tiercelin, J-J and Brunet, M. (2006). Tectonic Uplift and Eastern Africa Aridification. *Science*, 313(5792), 1419-1423.
- Shevenell, A.E. Kennett, J.P. and Lea, D.W. (2004). Middle Miocene southern ocean cooling and Antarctic cryosphere expansion. *Science*, 305, 1766-1770.
- Sørensen, T. A. (1948). A method of establishing groups of equal amplitude in plant sociology based on similarity of species content, and its application to analyses of the vegetation on Danish commons. *Kongelige Danske Viden- skabernes Selskabs Biologiske Skrifter*, 5, 1-34.
- Stirling, G. and Wilsey, B. (2001). Empirical Relationships between Species Richness, Evenness, and Proportional Diversity. *The American Naturalist*, 158(3), 286-299.
- Strong, W. L. (2016). Biased richness and evenness relationships within Shannon–Wiener index values. *Ecological Indicators*, 67, 703-713.
- Tadesse, G. Zavaleta, E. Shennan, C. and FitzSimmons, M. (2014). Policy and demographic factors shape deforestation patterns and socio-ecological processes in southwest Ethiopian coffee agroecosystems. *Applied Geography*, 54, 149-159.
- Tadesse, M. (2004). Asteraceae (Compositae). In: Hedberg I, Friis I, Edwards S (eds.) *Flora of Ethiopia and Eritrea*. Vol 4 (1). The National Herbarium, Addis Ababa University, Addis Ababa & Uppsala.
- Taylor, S. J. (2015). African biodiversity hotspots and other important conservation designations for unique areas which may include mountains. AFroMont, Centre for Environmental Studies, University of Pretoria, Hatfield, South Africa.
- Teketay, D. (2005). Seed and regeneration ecology in dry Afromontane forests of Ethiopia: II. Forest disturbances and succession. *Tropical Ecology*, 46(1), 45-64.
- Teketay, D. and Bekele, T. (1995). Floristic Composition of Wof-Washa of natural forest: implications for the conservation of biodiversity. *Feddes Repertorium*, 106 (1-2), 127-147.

- Teketay, D. and Granstrom, A. (1997). Seed viability of Afromontane tree species in forest soils. *Journal of Tropical Ecology*, 13, 81-95.
- Tóthmérész, B. (1995). Comparison of different methods for diversity ordering. *Journal of Vegetation Science*, 6(2), 283-290.
- Vivero, J. L. Kelbessa, E. and Demissew, S. (2005). The Red List of Endemic Trees & Shrubs of Ethiopia and Eritrea. Fauna & Flora International, Cambridge, UK.
- Wale, H.A (2006). Study on Indigenous Tree and Shrub Species of Churches and Monasteries of Wag-Lasta districts. Proceedings of the 1st Annual Regional Conference on Completed Research Activities on Natural Resources Management. 14-17 August 2006, Amhara Regional Agricultural Research Institute, Bahir Dar, Ethiopia.
- Wale, H. A. Bekele, T. and Dalle, G. (2012a). Floristic Diversity, Regeneration Status and Vegetation Structure of the Woodland Vegetation in Metema Area, Amhara National Regional State, Northwestern Ethiopia. *Journal of Forestry Research*, 23(3), 391-398.
- Wale, H. A. Bekele, T. and Dalle, G. (2012b). Plant Community and Ecological Analysis of the Woodland Vegetation in Metema Area, Amhara National Regional State, Northwestern Ethiopia. *Journal of Forestry Research*, 23(4), 599-607. DOI: 10.1007/s11676-012-0300-2.
- Wassie, A. and Teketay, D. (2006). Soil seed banks in church forests of northern Ethiopia: Implications for the conservation of woody plants. *Flora*, 201, 32-43.
- Wassie, A. Sterck, F. J. and Bongers, F. (2010). Species and structural diversity of church forests in a fragmented Ethiopian Highland landscape. *Journal of Vegetation Science*, 21, 938-948. DOI: 10.1002/9781118445112.stat07684.
- White, F. (1983). The vegetation of Africa. A descriptive memoir to accompany the UNESCO/AETFAT/UNSO Vegetation map of Africa, Paris, UNESCO.
- Yeboah, D. and Chen, H. Y. H. (2016). Diversity–disturbance relationship in forest landscapes. *Landscape Ecology*, 31, 981-987.
- Yineger, H. Kelbessa, E. Bekele, T. and Lulekal, E. (2008). Floristic composition and structure of the dry afromontane forest at Bale Mountains National Park, Ethiopia. *SINET: Ethiopian Journal of Science*, 31(2), 103-120.
- Yong, Z. LiJun, J. Yan, K. E. Qian, L. Li, Z. JiaDong, L. Han, H. U. and Bo, L. (2012). The relationship between species diversity and ecosystem function (productivity) of the late Middle Permian brachiopods community at the region of Hechuan, Chongqing, China. *Science China Earth Science*, 55: 1248-1254. DOI: 10.1007/s11430-012-4437-9.

Zegeye, H., Teketay, D. and Kelbessa, E. (2011). Diversity and regeneration status of woody species in Tara Gedam and Abebaye forests, Northeastern Ethiopia. *Journal of Forestry Research*, 22(3), 5–328.

Zhang, H. John, R. Peng, Z. Yuan, J. Chu, C. Du, G. and Zhou, S. (2012). The Relationship between Species Richness and Evenness in Plant Communities along a Successional Gradient: A Study from Sub-Alpine Meadows of the Eastern Qinghai-Tibetan Plateau, China. *PLoS ONE*, 7(11): e49024.

Appendices

Appendix 2.1 List of woody plant species with their botanical names, family, growth form and presence in each study forest (indicated as x), for Afromontane forests of Northwest Ethiopia.

Note that the species presence in other areas, outside of the present study area, are indicated by numbers: 1, 2, 3...,13; each number representing a particular Afromontane forest or woodland observed previously from Ethiopia and parts of Africa.

Botanical Name (* = Endemic species)	Family Name	Growth Form+	Propagule type \$	Alem Saga	Gelawudiwos	Tara Gedam	Other Afromontane forests and woodlands++
+Growth form symbols: T = canopy tree, Ts = Sub-canopy tree, S = shrub, Ss = subshrub, L = Liana, Scs = Scandent shrub and Sct = Scandent tree). \$ Propagule types: 1 = Fleshy large, 2 = Fleshy small, 3 = Dry large and 4 = Dry small ++Other previously reported Afromontane forests and woodlands from Ethiopia and parts of Africa: 1 = Denkoro; 2 = Bale Mountains National Park; 3 = Bibita; 4 = Gendo; 5 = Kimphe Lafa; 6 = Mana Angetu; 7 = Wondo Genet; 8 = Mount Kilimanjaro (Northern Slope, Tanzania); 9 = Metema; 10 = Delo Mena; 11 = Miombo (Tanzania); 12 = Southern Cape and 13 = Wof Washa.							
<i>Abutilon longicuspe</i> Hochst. ex A. Rich	Malvaceae	Ss	1	x		x	5
<i>Acanthus sennii</i> Chiov.*	Acanthaceae	Ss	1	x	x	x	1
<i>Afrocarpus falcatus</i> (Thunb.) C.N.Page	Podocarpaceae	T	1		x	x	1,4,5,6, 7 & 12
<i>Albizia schimperiana</i> Oliv.	Fabaceae	T	3	x	x	x	1,4 & 7
<i>Albizia sp.</i>	Fabaceae	T	3			x	
<i>Allophylus abyssinicus</i> (Hochst.) Radlk.	Sapindaceae	T	2	x		x	3,4 & 7
<i>Apodytes dimidiata</i> E. Mey. ex Arn.	Icacinaceae	T	1	x	x	x	1,3,4,7 & 12
<i>Asparagus africanus</i> Lam.	Asparagaceae	Scs	2	x	x	x	1,2,4,7,8 & 9
<i>Bersama abyssinica</i> Fresen.	Melianthaceae	Ts	1	x	x	x	1,3,4,5,7, 8 & 13
<i>Bridelia micrantha</i> (Hochst.) Baill.	Euphorbiaceae	Ts	2	x	x		3 & 9
<i>Brucea antidysenterica</i> JF. Mill.	Simaroubaceae	Ts	2	x	x		4 & 7
<i>Buddleja polystachya</i> Fresen.	Loganiaceae	Ts	4	x		x	1,4,5,6 & 7
<i>Cadia purpurea</i> (Picc.) Ait.	Fabaceae	S	3	x			
<i>Calpurnia aurea</i> (Ait.) Benth.	Fabaceae	Ts	3	x	x	x	1,5,6,7 & 12
<i>Canthium oligocarpum</i> Hiern	Rubiaceae	S	1		x	x	4 & 7
<i>Capparis tomentosa</i> Lam.	Capparidaceae	Scs	1	x	x	x	1,5 & 8

Botanical Name (* = Endemic species)	Family Name	Growth Form+	Propagule type \$	Alem Saga	Gelawudiwos	Tara Gedam	Other Afromontane forests and woodlands++
+Growth form symbols: T = canopy tree, Ts = Sub-canopy tree, S = shrub, Ss = subshrub, L = Liana, Scs = Scandent shrub and Sct = Scandent tree). \$ Propagule types: 1 = Fleshy large, 2 = Fleshy small, 3 = Dry large and 4 = Dry small ++Other previously reported Afromontane forests and woodlands from Ethiopia and parts of Africa: 1 = Denkoro; 2 = Bale Mountains National Park; 3 = Bibita; 4 = Gendo; 5 = Kimphe Lafa; 6 = Mana Angetu; 7 = Wondo Genet; 8 = Mount Kilimanjaro (Northern Slope, Tanzania); 9 = Metema; 10 = Delo Mena; 11 = Miombo (Tanzania); 12 = Southern Cape and 13 = Wof Washa.							
<i>Carissa spinarum</i> L.	Apocynaceae	S	1	x	x	x	3,4,5,6,7,8 & 10
<i>Celtis africana</i> Burm.f.	Ulmaceae	T	2	x			1,3,4,5,7,8 & 12
<i>Clausena anisata</i> (Willd.) Benth.	Rutaceae	Ts	1	x	x	x	3,4,5 & 12
<i>Clematis hirsuta</i> Perr. & Guill.	Ranunculaceae	L	4	x	x	x	2,3,6 & 7
<i>Clerodendrum myricoides</i> (Hochst.) Vatke.	Lamiaceae	Scs	2	x	x	x	3,6,7,8 & 10
<i>Clutia abyssinica</i> Jaub. & Spach.	Euphorbiaceae	S	4	x	x	x	8
<i>Clutia lanceolata</i> Forssk.	Euphorbiaceae	S	4	x		x	7
<i>Combretum molle</i> R.Br.ex G.Don.	Combretaceae	T	3	x	x	x	7,9,10 & 11
<i>Croton macrostachyus</i> Del.	Euphorbiaceae	T	3	x	x	x	1,3,4,5,6,7 & 10
<i>Discopodium penninervium</i> Hochst.	Solanaceae	Ts	2		x		13
<i>Dodonaea angustifolia</i> L.f.	Sapindaceae	S	3	x	x	x	4,5,6 & 7
<i>Dombeya torrida</i> (J. F. Gmel.) P. Bamps	Sterculiaceae	T	3	x	x	x	1,3,4 & 5
<i>Dovyalis abyssinica</i> (A. Rich.) Warp.	Flacourtiaceae	Ts	1	x	x	x	1, 6 & 13
<i>Dracaena steudneri</i> Engler	Dracaenaceae	Ts	2		x		3,4,6 & 7
<i>Dregea schimperi</i> (Decne.) Bullock	Asclepiadaceae	L	3	x	x	x	6
<i>Ekebergia capensis</i> Sparrm.	Meliaceae	T	1	x	x	x	1,4,7, 12 & 13
<i>Embelia schimperi</i> Vatke.	Myrsinaceae	Sct	2	x	x	x	1,3,4,6 & 7
<i>Entada abyssinica</i> Steud.ex A.Rich.	Fabaceae	Ts	3	x			7
<i>Euphorbia abyssinica</i> Gmel.	Euphorbiaceae	Ts	1	x	x	x	
<i>Ficus sur</i> Forssk.	Moraceae	T	2	x	x	x	1,3,4,5,6,7 & 12
<i>Ficus sycomorus</i> L.	Moraceae	T	2	x	x	x	5 & 9

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<i>Ficus thonningii</i> Blume	Moraceae	T	2	x			3,4,5,6,7,8,9 & 10
<i>Flacourtia indica</i> (Burm. f) Merr.	Flacourtiaceae	Ts	1			x	
<i>Galiniera saxifraga</i> (Hochst.) Bridson.	Rubiaceae	T	2			x	1, 3 & 13
<i>Gnidia glauca</i> (Fresen) Gilg	Thymelaceaceae	Ts	4	x		x	4
<i>Grewia ferruginea</i> Hochst. ex A. Rich.	Tiliaceae	Ts	1	x		x	3,4,5,6,7 & 10
<i>Helinus mystacinus</i> (Ait) E. Mey. ex Steud.	Rhamenaceae	L	3	x		x	
<i>Heteromorpha arborescens</i> (Spreng.) Cham. & Schlecht.	Apiaceae	S	4			x	7
<i>Hypericum quartinianum</i> A. Rich	Clusiaceae	Ts	3	x		x	1,4 & 7
<i>Jasminum abyssinicum</i> Hochst. ex DC.	Oleaceae	L	2	x	x	x	1,3,6,7 & 10
<i>Jasminum grandiflorum</i> L.	Oleaceae	L	2	x		x	1
<i>Juniperus procera</i> Hochst.ex Endl.	Cupperssacae	T	4	x		x	1,2, 4 & 13
<i>Justicia schimperiana</i> (Hochst. ex Nees) T Anders.	Acanthaceae	S	3	x	x		4,5,6,7
<i>Lantana triflora</i> L.	Verbanaceae	S	2	x			4
<i>Lippia adoensis</i> Hochst. ex Walp.*	Verbenaceae	S	2	x	x	x	6
<i>Maesa lanceolata</i> Forssk.	Myrsinaceae	Ts	2	x	x	x	1,3,4,6, 7 & 13
<i>Maytenus arbutifolia</i> (A. Rich.) Wilczek	Celastraceae	Ts	2	x		x	1,5,6, 7 & 13
<i>Maytenus gracilipes</i> (Welw.ex Oliv.) Exell	Celastraceae	Ts	2	x	x	x	1,3,4,6 & 10
<i>Maytenus senegalensis</i> (Lam.) Excell	Celastraceae	Ts	1			x	5,8,9 & 10

Botanical Name (* = Endemic species)	Family Name	Growth Form+	Propagule type \$	Alem Saga	Gelawudiwos	Tara Gedam	Other Afromontane forests and woodlands++
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<i>Maytenus undata</i> (Thunb.) Blakelock	Celastraceae	Ts	2			x	5,7,8,9, 12 & 13
<i>Mimusops kummel</i> A.DC.	Sapotaceae	T	1			x	5 & 6
<i>Myrica salicifolia</i> A.Rich.	Myricaceae	T	2	x			
<i>Myrsine africana</i> L.	Myrsinaceae	Ts	2	x		x	1,7, 12 & 13
<i>Nuxia congesta</i> R.Br.ex Fresen.	Loganiaceae	T	4	x	x	x	1,4, 7 & 13
<i>Ocimum lamiifolium</i> Hochst. ex Benth.	Lamiaceae	Ss	4	x	x	x	3,5 & 7
<i>Olea capensis</i> L. subsp. <i>macrocarpa</i> (C.A Wright) Verdc	Oleaceae	T	1		x		5,6 & 12
<i>Olea europaea</i> L. subsp. <i>cuspidata</i> (Wall. ex G.Don) Cif	Oleaceae	T	1	x	x	x	1,6,7, 10 & 13
<i>Olinia rochetiana</i> A.Juss.	Oliniaceae	T	1	x			6 & 7
<i>Osyris quadripartita</i> Decn.	Santalaceae	Ts	2	x	x	x	1,6 & 7
<i>Otostegia integrifolia</i> Benth.	Lamiaceae	S	4	x		x	1
<i>Periploca linearifolia</i> Quart. -Dill. & A. Rich.	Asclepiadaceae	L	4	x	x	x	1,4 & 7
<i>Phoenix reclinata</i> Jacq.	Arecaceae	Ts	1	x		x	1,3, 5 & 7
<i>Phytolacca dodecandra</i> L 'Herit.	Phytolaccaceae	Scs	2	x	x	x	1,3,4,5 & 6
<i>Piliostigma thonningii</i> (Schumach.)Milne-Redh.	Fabaceae	T	3			x	9
<i>Pittosporum abyssinicum</i> Del.	Pittosporaceae	Ts	2		x		
<i>Premna schimperi</i> Engl.	Lamiaceae	Ts	2	x		x	3,6 & 7
<i>Prunus africana</i> (Hook. f) Kalkm.	Rosaceae	T	1		x		1,3,6,7,8 & 12
<i>Prunus persica</i> (L.) Batsch.	Rosaceae	T	1	x	x	x	
<i>Pterolobium stellatum</i> (Forssk.) Brenan.	Fabaceae	L	3			x	4,5 & 6

Botanical Name (* = Endemic species)	Family Name	Growth Form+	Propagule type \$	Alem Saga	Gelawudiwos	Tara Gedam	Other Afromontane forests and woodlands++
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<i>Rhamnus prinoides</i> L 'Herit.	Rhamnaceae	Ts	2			x	3,4,6,7 & 12
<i>Rhamnus staddo</i> A. Rich.	Rhamnaceae	Ts	2			x	
<i>Rhoicissus tridentata</i> (L. f) Wild & Drummond	Vitaceae	Scs	1	x	x	x	5,7,10 & 12
<i>Rhynchosia resinosa</i> (Hochst.ex A.Rich) Mast.	Fabaceae	L	3		x		
<i>Ritchiea albersii</i> Gilg	Capparidaceae	Ts	3	x	x	x	7
<i>Rosa abyssinica</i> Lindley	Rosaceae	S	1	x	x	x	1 & 2
<i>Rubus apetalus</i> Poir.	Rosaceae	L	1		x		1,2,4,5 & 6
<i>Rubus steudneri</i> Schweinf	Rosaceae	Scs	1	x			1,2,3,4,6 & 7
<i>Rumex nervosus</i> Vahl.	Polygonaceae	S	4			x	1 & 4
<i>Schefflera abyssinica</i> (Hochst. ex A. Rich.) Harms	Araliaceae	T	2	x	x	x	3 & 6
<i>Schrebera alata</i> (Hochst.) Welw.	Oleaceae	T	1	x		x	7
<i>Scolopia theifolia</i> Gilg.	Flacourtiaceae	T	1	x	x	x	1
<i>Searsia pyroides</i> (Burch.) Moffett	Anacardiaceae	Ts	2	x		x	8,7. 10 & 12
<i>Solanum giganteum</i> Jacq	Solanaceae	S	1	x		x	4,5,6,7 & 12
<i>Solanum indicum</i> L.	Solanaceae	S	1			x	4 & 5
<i>Steganotaenia araliacea</i> Hochst. ex A. Rich.	Araliaceae	Ts	4			x	7
<i>Stephania cyanantha</i> Welw.ex Hiern	Menispermaceae	L	1	x			
<i>Stereospermum kunthianum</i> Cham.	Bignoniaceae	Ts	3	x			1,9
<i>Syzygium guineense</i> (Willd.) DC.	Myrtaceae	T	1	x		x	2,4,5,6,7 & 10
<i>Teclea nobilis</i> Del.	Rutaceae	Ts	1	x	x	x	1,3,4,6,7 & 10

Botanical Name (* = Endemic species)	Family Name	Growth Form+	Propagule type \$	Alem Saga	Gelawudiwos	Tara Gedam	Other Afromontane forests and woodlands++
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<i>Terminalia schimperiana</i> Hochst.	Combretaceae	T	4		x		
<i>Triumfetta tomentosa</i> Boj.	Tiliaceae	S	3			x	
<i>Urera hypselodendron</i> (A. Rich.) Wedd.	Urticaceae	L	4	x	x	x	1,3,4 & 6
<i>Vachellia abyssinica</i> (Hochst. ex Benth.) Kyal. & Boatwr.	Fabaceae	T	3			x	4,5 & 7
<i>Vachellia etbaica</i> (Schweinf.) Kyal. & Boatwr.	Fabaceae	T	3	x		x	4,5 & 10
<i>Vachellia lahai</i> (Steud. & Hochst. ex Benth.) Kyal. & Boatwr.	Fabaceae	Ts	3	x		x	
<i>Vachellia seyal</i> (Delile) P.Hurter	Fabaceae	T	3	x			5, 9, 10 & 11
<i>Vernonia adoensis</i> Sch. Bip. ex Walp.	Asteraceae	Ss	4			x	4,6 & 8
<i>Vernonia amygdalina</i> Del.	Asteraceae	Ts	4	x	x	x	3,4,5,6 & 11
<i>Vernonia hochstetteri</i> Sch. Bip. ex Walp.	Asteraceae	S	4			x	3,4 & 7
<i>Vernonia myriantha</i> Hook.f.	Asteraceae	Ts	4	x	x		6
<i>Vernonia sp</i>	Asteraceae	S	4			x	
<i>Ximenia americana</i> L.	Olacaceae	Ts	1	x			5,10 & 11
<i>Ziziphus mucronata</i> Willd.	Rhamnaceae	Ts	1			x	5 & 11

Appendix 2.2 List of herbaceous plant species with their botanical names, family, growth form and presence in each study forest (indicated as x), for Afromontane forests of Northwest Ethiopia.

Note that the species presence in other areas, outside of the present study area, are indicated by numbers: 1, 2, 3...,13; each number representing a particular Afromontane forest or woodland observed previously from Ethiopia and parts of Africa.

Botanical Name (* = Endemic species)	Family Name	Growth forms+	Propagule type \$	Alem Saga	Gelawudiwos	Tara Gedam	Other Afromontane forests and woodlands++
+Growth forms: Fo = Forb, Fe = Fern, Se= Sedge, Gr = Grass, V = Vine.							
\$ Propagule types: 1 = Fleshy large, 2 = Fleshy small, 3 = Dry large and 4 = Dry small							
++ Other previously reported Afromontane forests and woodlands in Ethiopia and parts of Africa: 1 = Denkoro; 2 = Bale Mountains National Park; 3 = Bibita; 4 = Gendo; 5 = Kimphe Lafa; 6 = Mana Angetu; 7 = Wondo Genet; 8 = Mount Kilimanjaro (Tanzania, Northern slope); 9 = Metema; and 10 = Delo Mena; and 12 = Southern Cape.							
<i>Achyranthes aspera</i> L.	Amaranthaceae	Fo	2			x	1,2,3,4,5,8,9 & 10
<i>Achyrospermum schimperi</i> (Hochst. ex Briq.) Perkins	Lamiaceae	Fo	4			x	1,3,4 & 6
<i>Adiantum poiretii</i> Wikstr.	Adiantaceae	Fe	4	x		x	
<i>Aeollanthus abyssinicus</i> Hochst. ex Benth.*	Lamiaceae	Fo	4	x		x	7
<i>Alchemilla abyssinica</i> Fresen.	Rosaceae	Fo	4	x		x	1,2 & 4
<i>Andropogon gayanus</i> Kunth.	Poaceae	Gr	4	x		x	
<i>Arisaema schimperanum</i> Schott	Araceae	Fo	1			x	1,2 & 6
<i>Australina flasscida</i> (A.Rich) Webb.	Urticaceae	Fo	4			x	
<i>Bartsia trixago</i> L.	Scrophulariaceae	Fo	4	x			
<i>Bidens ghedoensis</i> Mesfin*	Asteraceae	Fo	4	x			
<i>Bidens pilosa</i> L.	Asteraceae	Fo	4	x		x	4,7,8,9 & 10
<i>Bidens prestinaria</i> (Sch.Bip.) Cufod.	Asteraceae	Fo	4	x		x	2
<i>Canarina abyssinica</i> Engl.	Campanulaceae	V	1			x	
<i>Carduus leptacanthus</i> Fresen.	Asteraceae	Fo	4		x		2,4,6 & 7
<i>Cerastium octandrum</i> A.Rich.	Caryophyllaceae	Fo	3			x	1
<i>Chlorophytum tetraphyllum</i> (Lf) Baker	Anthericaceae	Fo	1		x		
<i>Chrysopogon aucheri</i> (Boiss.) Stapf	Poaceae	Gr	4			x	

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<i>Commelina africana</i> L.	Commelinaceae	Fo	2	x		x	1,2,5,6,7,8,10 & 12
<i>Crotalaria glauca</i> Willd.	Fabaceae	Fo	3	x			
<i>Crotalaria retusa</i> L.	Fabaceae	Fo	3	x		x	
<i>Cyanotis barbata</i> D.Don.	Commelinaceae	Fo	2			x	1
<i>Cynodon dactylon</i> (L.) Pers.	Poaceae	Gr	4	x	x	x	7 & 8
<i>Cynoglossum coeruleum</i> Hochst.ex A. DC. In DC.	Boraginaceae	Fo	2	x		x	1,2,4,6 & 7
<i>Cyperus fischerianus</i> A. Rich.	Cyperaceae	Se	2	x	x	x	1 & 4
<i>Cyperus sanguinolentus</i> Vahl	Cyperaceae	Se	2	x	x		
<i>Cyperus sesquiflorus</i> (Torr.) Mattf. & Kük	Cyperaceae	Se	2	x			1
<i>Cyphostemma adenocaula</i> (Steud.ex A.Rich) Desc.ex Wild & Drummond	Vitaceae	V	2			x	
<i>Desmodium repandum</i> (Vahl) DC	Fabaceae	V	4	x	x		1,3,4,7 & 12
<i>Digitaria abyssinica</i> (Hochst.ex A.Rich) Stapf.	Poaceae	Gr	4	x			
<i>Dryopteris lewalleana</i> Pic.Serm.	Dryopteridaceae	Fe	4	x		x	
<i>Echinochloa pyramidalis</i> (Lam.) Hitchc. & Chase	Poaceae	Gr	4	x			
<i>Eleusine africana</i> Kenn.-O 'Byrne	Poaceae	Gr	4	x		x	
<i>Eleusine floccifolia</i> (Forssk.) Spreng.	Poaceae	Gr	4	x			2
<i>Euphorbia schimperiana</i> Scheele.	Euphorbiaceae	Fo	4		x		1,3 & 7
<i>Galinsoga parviflora</i> Cav.	Asteraceae	Fo	4			x	5,6 & 8
<i>Galinsoga quadriradiata</i> Ruiz & Pavon	Asteraceae	Fo	4	x			
<i>Galium spurium</i> L.	Rubiaceae	Fo	2	x	x		

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<i>Geranium arabicum</i> Forssk.	Geraniaceae	Fo	4			x	1,2 & 4
<i>Girardinia bullosa</i> (Steudel) Wedd.	Urticaceae	Fo	4	x	x	x	1,4 & 7
<i>Glycine wightii</i> (Wight. & Arn.) Verdc.	Fabaceae	V	3	x			3 & 6
<i>Gomphocarpus fruticosus</i> (L.) Ait.f.	Asciepiadaceae	Fo	3	x			10
<i>Guizotia scabra</i> (Vis.) Chiov.	Asteraceae	Fo	4	x	x	x	1 & 2
<i>Guizotia schimperi</i> Sch. Bip. ex Walp.	Asteraceae	Fo	4	x		x	4
<i>Helichrysum schimperi</i> (Sch. Bip. ex A. Rich.) Moeser	Asteraceae	Fo	4	x		x	2 & 7
<i>Hibiscus macranthus</i> Hochst.ex A.Rich.	Malvaceae	Fo	3	x	x	x	3,5,8 & 10
<i>Hypericum peplidifolium</i> A.Rich	Hypericaceae	Fo	1	x		x	1,2 & 7
<i>Hyperrhenia hirta</i> (L.) Stapf	Poaceae	Gr	4	x		x	
<i>Hypoestes forskaolii</i> (Vahl) R. Br.	Acanthaceae	Fo	4	x	x	x	4,5,6,8,9 & 12
<i>Impatiens hochstetteri</i> Warb.	Balsaminaceae	Fo	2			x	7 & 12
<i>Impatiens rothii</i> Hook.f. *	Balsaminaceae	Fo	1	x		x	2
<i>Indigofera atriceps</i> Hook.f	Fabaceae	Fo	3	x			
<i>Isoglossa somalensis</i> Lindau	Acanthaceae	Fo	4			x	3
<i>Justicia ladanoides</i> Lam.	Acanthaceae	Fo	2	x			
<i>Kalanchoe petitiana</i> A. Rich.	Crassulaceae	Fo	2	x	x	x	1,2 & 6
<i>Kosteletzkya adoensis</i> (A.Rich.) Mast.	Malvaceae	Fo	4			x	
<i>Lactuca inermis</i> Frossk.	Asteraceae	Fo	4			x	
<i>Lactuca</i> sp.	Asteraceae	Fo	4			x	
<i>Laggera crispata</i> (Vahl) Hepper & Wood	Asteraceae	Fo	4			x	1,4 & 6
<i>Laggera tomentosa</i> (Sch.Bip. ex A. Rich) Oliv. & Hiern	Asteraceae	Fo	4	x		x	1

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<i>Leonotis ocymifolia</i> (Burm.f) Iwarsson	Lamiaceae	Fo	4	x			
<i>Leucas martinicensis</i> (Jacq.) R. br.	Lamiaceae	Fo	4			x	7 & 9
<i>Mikaniopsis clematoides</i> (Sch. Bip. ex A. Rich.) Milne-Redh. *	Asteraceae	Fo	4		x		2 & 6
<i>Orobanche minor</i> Smit	Orobanchaceae	Fo	4	x	x	x	
<i>Oxalis corniculata</i> L.	Oxalidaceae	Fo	4	x		x	8
<i>Panicum monticola</i> Hook.f	Poaceae	Gr	4	x	x	x	8 & 9
<i>Pavonia</i> Sp.	Malvaceae	Fo	3			x	
<i>Pavonia urens</i> Cav.	Malvaceae	Fo	3	x		x	3
<i>Pennisetum thunbergii</i> Kunth	Poaceae	Gr	4	x			7
<i>Pennisetum unisetum</i> (Nees) Benth.	Poaceae	Gr	4	x	x	x	
<i>Pentas</i> sp.	Rubiaceae	Fo	4			x	
<i>Persicaria nepalensis</i> (Meisn.) Miyabe	Polygonaceae	Fo	4	x			
<i>Pilea tetraphyla</i> (Hochst.ex Steud.)Blume	Urticaceae	Fo	4			x	
<i>Pimpinella hirtella</i> (Hochst.) A.Rich	Apiaceae	Fo	4	x	x	x	6
<i>Plantago lanceolata</i> L.	Plantaginaceae	Fo	2	x		x	1,4 & 7
<i>Plectranthus lactiflorus</i> (Vatke) Agnew	Lamiaceae	Fo	4		x		12
<i>Plectranthus longipes</i> Baker	Lamiaceae	Fo	4		x		
<i>Plectranthus punctatus</i> (L.f) L 'Her.	Lamiaceae	Fo	4	x	x	x	1,7
<i>Rhynchosia elegans</i> A. Rich.	Fabaceae	V	3	x			
<i>Rumex nepalensis</i> Spreng.	Polygonaceae	Fo	2			x	1,2,4,6 & 7
<i>Sanicula elata</i> Buch.-Ham.ex.D.Don	Apiaceae	Fo	2		x		1,2,3,6 & 12
<i>Satureja punctata</i> (Benth.) Briq.	Lamiaceae	Fo	4			x	1 & 2

Botanical Name (* = Endemic species)	Family Name	Growth forms+	Propagule type \$	Alem Saga	Gelawudiwos	Tara Gedam	Other Afromontane forests and woodlands++
+Growth forms: Fo = Forb, Fe = Fern, Se= Sedge, Gr = Grass, V = Vine. \$ Propagule types: 1 = Fleshy large, 2 = Fleshy small, 3 = Dry large and 4 = Dry small ++ Other previously reported Afromontane forests and woodlands in Ethiopia and parts of Africa: 1 = Denkoro; 2 = Bale Mountains National Park; 3 = Bibita; 4 = Gendo; 5 = Kimphe Lafa; 6 = Mana Angetu; 7 = Wondo Genet; 8 = Mount Kilimanjaro (Tanzania, Northern slope); 9 = Metema; and 10 = Delo Mena; and 12 = Southern Cape.							
<i>Selaginella abyssinica</i> Spring	Selaginellaceae	Fe	4	x			
<i>Selaginella kraussiana</i> (Kunze) A.Braun.	Selaginellaceae	Fe	4			x	7 & 12
<i>Setaria pumila</i> (Poir.) Roem. & Schult	Poaceae	Gr	4			x	9
<i>Sida ovata</i> Forssk.	Malvaceae	Fo	4	x			10
<i>Sida rhombifolia</i> L.	Malvaceae	Fo	4	x		x	4
<i>Snowdenia polystachya</i> (Fresen.)Pilg.	Poaceae	Gr	4	x		x	4 & 9
<i>Solanecio gigas</i> (Vatke) C. Jeffrey*	Asteraceae	Fo	4			x	1,3,4,6 & 7
<i>Solanum anguivi</i> Lam.	Solanaceae	Fo	1		x		2,3,4,6 & 9
<i>Sporobolus africanus</i> (Poir.)Robyns & Tournay	Poaceae	Gr	4	x			2 & 4
<i>Tacca leontopetaloides</i> (L.) O. Ktze.	Taccaceae	Fo	3			x	
<i>Tagetes minuta</i> L.	Asteraceae	Fo	4	x			1,4,7 & 10
<i>Thalictrum rhynchocarpum</i> Dill. & A. Rich.	Ranunculaceae	Fo	2	x	x	x	1,2,3,4,6 & 7
<i>Themeda triandra</i> Forssk	Poaceae	Gr	4	x			7 & 8
<i>Trifolium rueppellianum</i> Fresen.	Fabaceae	Fo	4	x	x	x	2 & 4
<i>Trifolium steudneri</i> Schweinf	Fabaceae	Fo	4	x			
<i>Vernonia purpurea</i> Sch.Bip.ex Walp.	Asteraceae	Fo	4			x	
<i>Vicia sativa</i> L.	Fabaceae	Fo	3	x			2
<i>Vigna schimperi</i> Bak.	Fabaceae	V	3	x	x	x	
<i>Zehneria scabra</i> (Linn.f.) Sond.	Cucurbitaceae	V	2	x		x	2,3,5,7,9 & 12

Chapter 3: Floristic composition of forest communities in relation to environmental gradients in three Afromontane Forests of Northwest Ethiopia

Abstract

Plant-plant interactions and their assemblages potentially influence regeneration, growth and mortality in a particular forest stand. Their associations and interactions can be influenced by different environmental variables. This study was carried out in remnant Afromontane Forests of Northwest Ethiopia, to assess plant communities and their relationship with environmental gradients. A systematic sampling design in homogenous stands was used to collect vegetation and environmental data. A total of 150 nested circular plots were sampled: a main plot of 100 m² for woody species by species and stem diameter; and a subplot of 1 m² for herbaceous species including ferns, graminoids, forbs and vines, soils and leaf litters. Topographical variables of altitude, aspect and slope, were collected from each plot. TWINSpan and DCA analyses were used separately for woody and herbaceous species to identify plant communities. Four main woody communities and two main herbaceous communities were identified. Direct gradient analysis (CCA) was used to investigate the relationship between the identified communities and various environmental variables. Different communities showed different affinities towards various gradients. Some overlap occurred among communities because of similarity in their environmental requirements. Radiation Index and altitude were found to be the common highly significant environmental variables to explain the occurrence and composition of both woody and herbaceous communities. Radiation index influences the amount of solar energy reaching a site (affecting air and soil temperatures), wind and evapotranspiration regimes of the forest ecosystem. Altitude interacts with other ecological parameters such as atmospheric pressure and temperature. Soil nitrogen, phosphorus and moisture were other significant explanatory variables explaining the composition of both woody and herbaceous communities.

Keywords: Afromontane; remnant, herbs; woody; TWINSpan; DCA; CCA; environmental variables; radiation index, altitude, litters, CEC, EC, OC, N, Moisture, slope, pH, texture

3.1 Introduction

Information on the floristic composition of plant communities and how that varies along environmental gradients is fundamental to sustainable management of a given forest ecosystem. The relative importance of different environmental variables and how they determine the spatial distribution of species and their dynamics in diverse plant communities remains a challenging question in ecology (May *et al.*, 2015). A plant community, the smallest unit of a discrete association of plants, is conceived by some as a superorganism where species are tightly bound together, both now and in their common evolutionary history (Clements, 1916, 1936). It is important to understand the concept of the plant community in the identification and assessment of the assemblages of plant species of different growth forms, sizes and relative importance in relation to the underlying site relationships, and ecological processes (Tsheboeng *et al.*, 2016).

The concept of the plant community is considered to be a useful approach towards the assessment, planning and management of the vegetation for different land uses, such as resource use and conservation. It provides useful information on the species in a particular group of stands with similar site factors, underlying environmental drivers of species distribution, disturbance history, and stage of recovery (Berg *et al.*, 2014). This provides a basis for zonation of the area, even though resource use may focus on specific species of interest. It is important to understand the pattern of well-defined plant communities in a given forest ecosystem, and their environmental relationships (Adela *et al.*, 2014). This can help to locate specific groups of plant species in a landscape with their explanatory ecological variables. In doing so, it could be possible to recognize and identify the floristic continuity or discontinuity of plant communities against environmental variables (Minissale & Sciandrello, 2016). Some believe that plant communities are discrete in nature, while some believe that they are continuum in a given forest landscape. Malanson *et al.* (2017) and Safont *et al.* (2016) reported that such kind of investigation could be useful to identify climatically adaptive or vulnerable parts of a given forest ecosystem by using climatic variables such as temperature as explanatory variable.

Forest succession, in response to the disturbance-recovery processes, is shaped by how the intrinsic variables are adapted to the extrinsic variables of the environment. Extrinsic variables include climatic variables such as temperature and rainfall, topographical variables such as elevation, aspect and slope, and substrate variables such as geology and physical and chemical soil properties. Intrinsic variables of the species include potential growth and mortality rate, tolerance to shading/lighting, competitive ability, and relative resilience to disturbances (Kienast and Kuhn, 1989; Kienast and Krauchi, 1991). Altitude, aspect and slope, pH, nutrients, light, temperature and water are some

environmental variables that affect physiological growth, competition and distribution patterns of plant species growing in a specific landscape (Austin, 1980, 2002).

Some studies on forest composition and structure, focus on only the woody component of trees and shrubs (Seymour *et al.*, 2016; Steinaker *et al.* 2016). Other studies combine the woody species in the canopy with the herbaceous and woody species in the understory, including the ground flora (Dalle *et al.*, 2005; Wale *et al.*, 2012a,b). Some studies, similar to this study, record both the canopy and understory composition, but analyse the data separately (Geldenhuys, 1993; Graves *et al.*, 2006). The reasons for the separate analyses of the two components are primarily because the tree species associations are driven by different factors than the understory species. Another reason is that the tree component is often recorded as individual stems by species, whereas the understory species composition is recorded by their cover abundance.

People hold the view that the highland natural forests of Ethiopia are dwindling both in their extent of coverage and condition, because of various biotic and abiotic drivers. The highlands of Northwest Ethiopia, are inhabited by a high density of agrarian communities, causing deforestation and degradation of forests (IBC, 2005; Alelign *et al.*, 2007). Afromontane forests are one of the natural vegetation types that showed significant shrinkage in their area coverage, although in some areas the forest cover increased and species expanded their range because of the establishment of *Eucalyptus* plantations for commercial timber (Wassie, 2017). The overriding challenge is to understand the influence of the environmental variables that enable the forests to grow here, in relation to the natural and anthropogenic disturbance-recovery processes that prevailed and determined the actual extent and condition of the natural forests in this area. Studies by Wassie *et al.* (2010) and Aerts *et al.* (2016) focused on various ecological parameters of the remnant forests of Northwest Ethiopia, particularly the churchyard forests, which are owned and managed by Ethiopian Orthodox Tewahido Church. In general, churchyard forests are protected from the natural disturbance-recovery processes, at the end of the continuum of a gradient of intensity of disturbance.

There is a need to understand the variation in the floristic and structural composition of vascular plant communities in relation to environmental variables. This study was done to develop an ecological understanding of the plant-plant and plant-environment interactions as basis for improved conservation management of Afromontane forests in Northwest Ethiopia. The main objective of this study was to assess the floristic composition of different plant associations in three different Afromontane forest communities of Northwest Ethiopia, and their relationships with physical site factors. This objective was pursued through addressing the following questions:

1. What are the identifiable associations of the woody species in three Afromontane forests of Northwest Ethiopia?
2. What are the identifiable associations of the herbaceous species (ferns, graminoids, forbs and vines) in three Afromontane forests of Northwest Ethiopia?
3. What is the relationship between the identified woody and herbaceous plant associations?
4. What is the relationship between the identified woody and herbaceous plant associations with physical environmental variables (Soil chemical and physical properties, slope, altitude and radiation index)?

3.2 Materials and Methods

3.2.1 Study Area

The study was carried out in three selected Afromontane forests, Alem Saga, Gelawudiwos and Tara Gedam, in the South Gonder zone of Northwestern Ethiopia (Figure 3.1). South Gonder zone is located at 600 km north of Addis Ababa and 50 km east of Lake Tana (Wassie *et al.*, 2010), with geographic coordinates 11°50'59.87"N, 37°00'59.55"E, and altitude masl. Alem Saga forest is 35 km away from both Gelawudiwos and Tara Gedam, the distance between Gelawudiwos and Tera Gedam is 70 km. Afromontane forests of Semien Mountains National Park and Lasta-Lalibela Afromontane forest complexes such as Mount Abune Yoseph, Nakuto Leab, Yimrhane Kirstos, and Ayna Eyesus forests, occur about 300 to 350 km North and Northeast of these study forests (Wale, 2006). Afromontane forest complexes of Mount Chokie and Borena Sayint National Park occur, about 200 to 250 km to the South and Southeast of the study forests.

The annual rainfall ranges between 1097 mm and 1646 mm (based on meteorological data collected from the Debre Tabor meteorological station of the Amhara Regional Meteorological Agency, over 13 years, i.e.1999 to 2011). The mean annual rainfall is 1476 mm and mean monthly temperature is 16°C. The rainfall distribution pattern is unimodal, with maximum rainfall in summer between July and August (Figure 3.2).

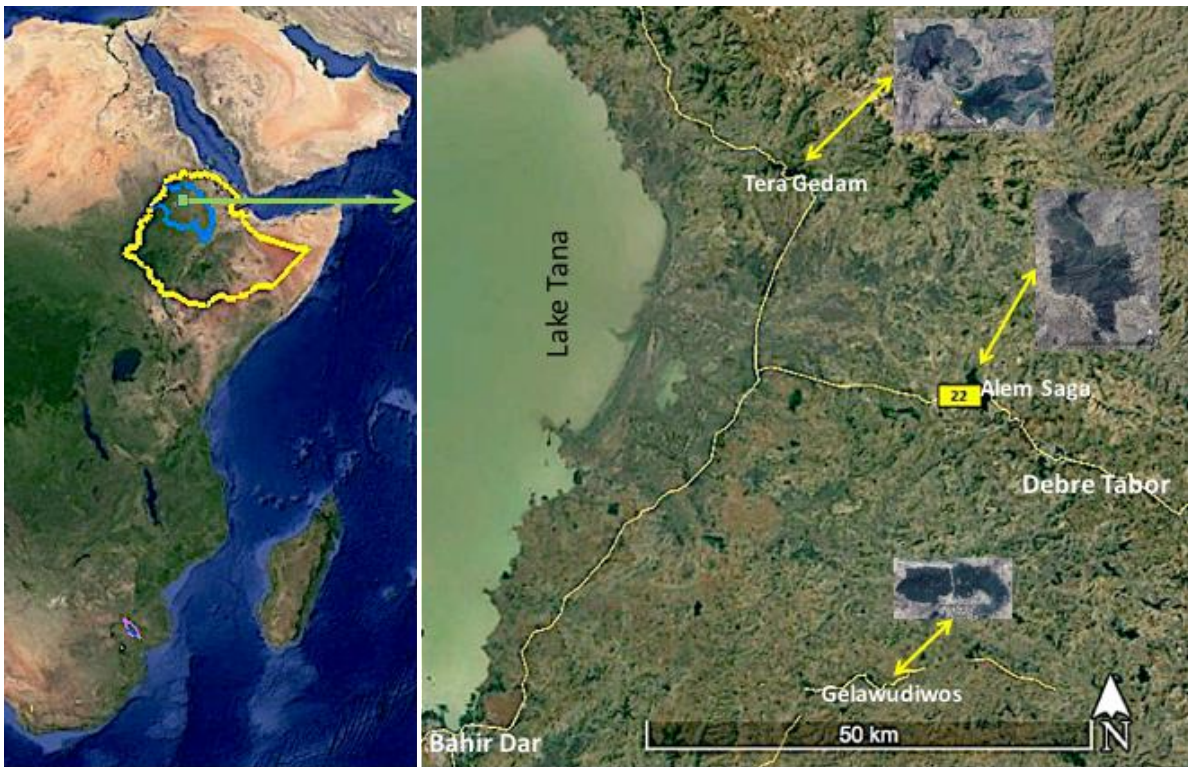


Figure 3.1 Location of the Alem Saga, Gelawudiwos and Tara Gedam Afromontane Forests in Northwest Ethiopia, with the inserts showing the shape and orientation of each forest.

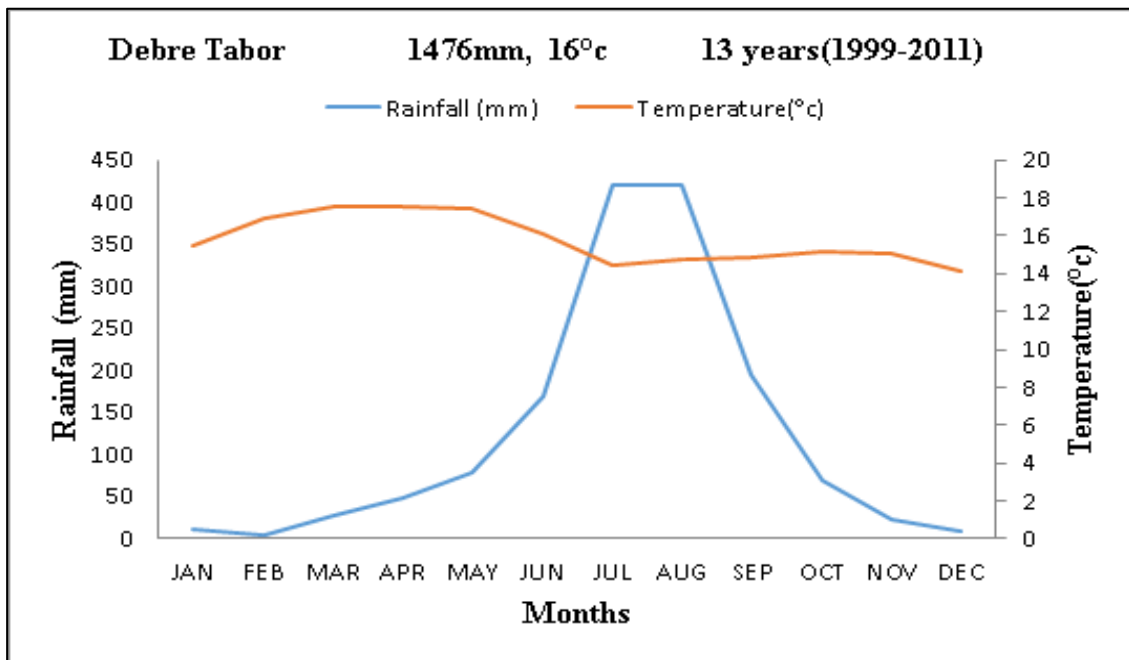


Figure 3.2 Climatic graph of the areas of Afromontane Forests of Northwest Ethiopia.

Thirteen years' meteorological data was taken from the meteorological station situated in Debre Tabor (11°50'59.87"N, 37°00'59.55"E, 2690 masl).

3.2.2 Sampling Design

A systematic random sampling method was used for the vegetation inventory in the three selected Afromontane forests. Transect lines were located in the selected forests with each plot sampled within a homogenous part along the transect, to cover most of the variation along the transect. Woody species were recorded on circular plots of 100 m² (5.65 m radius) located at 100 m to 150 m apart along each transect line. A 1 m² circular plot (5.65 cm radius) located at the center of the main plot, was used to record herbaceous species, and to collect litter and soil samples (Figure 3.3). A total of 150 plots was sampled; 50 plots from each selected Afromontane forests.

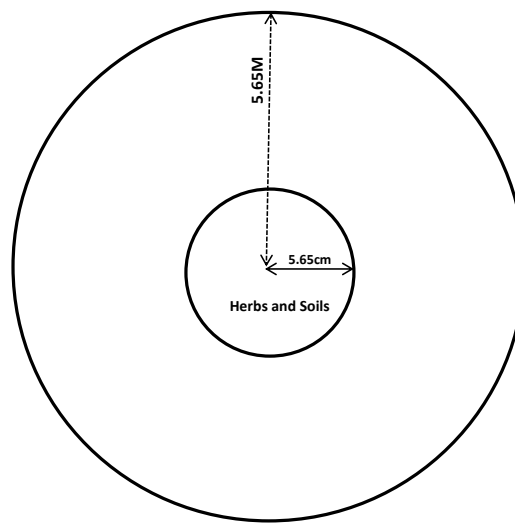


Figure 3.3 Nested plot design for data collection of woody and herbaceous species in the three Afromontane forests of Northwest Ethiopia along environmental gradients

3.2.3 Vegetation Data Collection

Tree height and stem diameter at breast height (DBH), i.e. 1.3 m above ground level, of stems ≥ 2 cm DBH, were recorded for tree species on the main plot. Herbaceous species, including ferns, graminoids, forbs and vines, were recorded by visual cover estimates by species on the inner 1 m² circular plot, using the modified Braun Blanquet approach, with a 1-9 scale (van der Maarel, 1979, 2005): 1 = rare, 1-3 individuals; 2 = sporadic (few individuals), 0.5-1.5%; 3 = abundant, 1.5-3%; 4 = very abundant, 3-5%; 5 = 5-12%; 6 = 12.5-25%; 7 = 25-50%; 8 = 50-75%; and 9 = 75-100%. Species names were coded, using four letters for the genus name and four letters for the species name, and were used as such in the subsequent analyses.

3.2.4 Environmental Data Collection

The following environmental variables were recorded on each plot: Geographical coordinates, altitude (Alt) and aspect were recorded, using a GPS, slope, using a clinometer. Radiation index (RI) was calculated based on latitude, slope and aspect, following [Bruce & Dylan \(2002\)](#). Soil samples were collected from each inner 1 m² circular subplot, with a soil auger, to a depth of 30 cm. The soil samples were analysed at the Bahir Dar Soils Laboratory and Fertility Improvement Center, for the following: total Nitrogen (N), available Phosphorus (P), pH (pH_H2O), Cation Exchange Capacity (CEC), Soil Moisture, Electrical Conductivity (EC), Organic carbon (OC) and texture (percentage sand, silt and clay). Leaf litter was collected from the total area of the 1 m² circular subplot; no larger material (twigs or branches) was included. The field weight (g/m²) was used as one environmental variable ([Tarmi and Hyvönen, 2012](#); [Adela et al., 2014](#)).

3.2.5 Classification and Indirect Gradient Analysis

The floristic composition of the plots was analysed to identify the association of species in plant communities in the study areas, using TWINSpan (Two-way INdicator SPecies Analysis). Woody and herbaceous plants were considered separately in the analyses because they were considered to have different relationships and causal factors ([Geldenhuys, 1993](#); [Graves et al., 2006](#)). For woody species, the classification was based on number of stems per species in a plot. For herbaceous species, the classification was based on the percentage canopy cover-abundance values of each species per plot, using the 1-9 Braun-Blanquet scale. The TWINSpan program first constructs a classification of the samples, and then uses this classification to obtain a classification of the species according to their ecological preferences ([Hill and Šmilauer, 2005](#); [Willner et al., 2017](#)). The data were converted into CANOCO condensed format, using WCanImp Help File ([Šmilauer, 2002](#)), a subprogram in CANOCO for Windows version 4.5 ([ter Braak and Šmilauer, 2002](#)). The condensed data entry reduced the large number of zero entries that make the data entry and checking prone to error ([Hill and Šmilauer, 2005](#)).

The following options were chosen to run the classification analyses:

- Pseudospecies cut levels: 5 (0, 2, 5, 10, and 20) for woody species and 3 (0, 2 and 5) for herbaceous species
- Minimum group size for division: 9 plots (for woody species) and 6 plots (for herbaceous species)
- Maximum division level: 5 (for woody species) and 4 (for herbaceous species)

- Weights for levels of pseudospecies at different cut levels: set to 1 to 5 (for woody species) and 1 to 3 (for herbaceous species)

The identified communities from the Ordered two-way WinTWINS table output, were diagrammatically displayed to show the schematic relationship between communities and sub-communities. An indirect gradient analysis for plots, using Detrended Correspondence Analysis (DCA), was performed using CANOCO 5, window release 5.04 ([ter Braak and Šmilauer, 2012](#)). The nomenclature for the identified communities were followed ([Brown *et al.*, 2013](#)).

The Importance Values (IV) for the species across the different identified communities were calculated as follows:

IV Index for woody species in a community was computed from Relative Density, Relative Dominance and Relative Frequency, which describes the structural role of a species in the community. It considered to be a relevant estimator of the importance of each species in a given forest community ([Netto *et al.*, 2015](#)). IV was calculated as the mean value of Relative Density (RD), Relative Basal Area (RBA) and Relative Frequency (RF), i.e. $IV = (RD+RBA+RF)/3$, where,

$$RD = \left(\frac{\text{Number of individuals of a woody species in the community}}{\text{Total number of individuals of all woody species in the community}} \right) * 100$$

$$RBA = \left(\frac{\text{Basal Area occupied by a species in the community}}{\text{Total Basal Area of all woody species in the community}} \right) * 100$$

$$RF = \left(\frac{\text{Frequency of a woody species in the community}}{\text{Total frequency of all woody species in the community}} \right) * 100$$

IV Index for herbaceous species in a community was calculated from Relative Frequency (RF) and Relative Cover Abundance (RCA, i.e. a substitute for density, using the Braun Blanquet cover abundance values recorded for each species). IV was calculated as $(RF+ RCA)/2$, where,

$$RCA = \left(\frac{\text{Cover abundance occupied by a herbaceous species in the community}}{\text{Total cover abundance of all herbaceous species in the community}} \right) * 100$$

$$RF = \left(\frac{\text{Frequency of a herbaceous species in the community}}{\text{Total frequency of all herbaceous species in the community}} \right) * 100$$

The Shannon-Weiner Index was used to analyse diversity across the identified communities ([Kent and Coker, 1992](#); [Magurran, 2004](#)).

3.2.6 Direct Gradient Analysis

A direct gradient analysis using Canonical Correspondence Analysis (CCA), was done to assess the relationship between identified plant communities and different environmental variables (Lepš & Šmilauer, 2003; Palo *et al.*, 2013; Sekulova *et al.*, 2013; Gao *et al.*, 2017), using CANOCO 5.04 (ter Braak and Šmilauer, 2012). The CCA method combines a multivariate ordination of species occurrence data with a constrained regression, maximising the correlation between the species ordination axes and selected environmental variables (Austin, 2002). The statistical significance of the effect of environmental variables on the variation in species composition in the CCA ordination was tested, using the Monte-Carlo permutation test with the forward selection procedure (Wale *et al.*, 2012b).

3.3 Results

3.3.1 Classification of communities of woody species

The TWINSpan analysis, with five levels of division, grouped the woody species into four communities with sixteen sub-communities (Appendix 3.1). The schematic dendrogram shows the relationship between the communities and sub-communities, and indicate the indicator species for each sub-division (Figure 3.4).

At level 1, with eigenvalue 0.503, the 150 plots separated into association 1 with indicator species *Olea capensis* sub. *macrocarpa*, *Maytenus gracilipes*, *Teclea nobilis* and *Dovyalis abyssinica*, and association 2 with indicator species *Searsia pyroides*, *Acanthus sennii*, *Grewia ferruginea*, *Premna schimperi*, *Osyris quadripartita* and *Dodonea angustifolia*.

At level 2 division, association 1, with eigenvalue 0.382, separated into community 1 with indicator species *Olea capensis* sub. *macrocarpa*, and community 2 with indicator species *Vernonia adoensis* and *Olea europaea* subsp. *cuspidata*. Association 2, with eigenvalue 0.310, separated into community 3 with species *Vachellia lahai*, *Vachellia etbaica*, *Acanthus sennii* and *Clutia abyssinica*, as dominant species and community 4 with indicator species *Dodonea angustifolia*.

At level 3 division, community 1, with eigenvalue 0.255, separated into sub-community 1.1 with indicator species *Calpurnia aurea*, *Clutia abyssinica*, *Euphorbia abyssinica* and *Afrocarpus falcatus*, and sub-community 1.2 with indicator species *Terminalia schimperiana*, *Urera hypselodendron*, *Carissa spinarum*, *Dombeya torrida* and *Bridelia micrantha*. Community 2, with eigenvalue 0.367, separated into sub-community 2.1 with indicator species *Clutia abyssinica*, and sub-community 2.2

with indicator species *Pterolobium stellatum* and *Albizia schimperiana* (with no further subdivisions) Community 3, with eigenvalue 0.303, separated into sub-community 3.1 with indicator species *Calpurnia aurea*, *Vernonia adoensis* and *Albizia schimperiana*, and sub-community 3.2 with indicator species *Acanthus sennii*, *Osyris quadripartita*, *Dodonea angustifolia* and *Hypericum quartinianum*. Community 4 was not divided into sub-communities.

At level 4 division, sub-community 1.1, with eigenvalue 0.249, separated into sub-community 1.11 with indicator species *Discopodium penninervium*, and sub-community 1.2 with indicator species *Afrocarpus falcatus*, a dominant tree species, with no further subdivisions. Sub-community 1.2, with eigenvalue 0.267, separated into sub-community 1.21 with indicator species *Terminalia schimperiana* and *Vernonia myriantha*, and sub-community 1.22 with indicator species *Clausena anisata*, *Capparis tomentosa*, *Dovyalis abyssinica* and *Albizia schimperiana* (with no further subdivision). Sub-community 2.1, with eigenvalue 0.387, separated into sub-community 2.11 with indicator species *Scolopia theifolia* a dominant tree species, and sub-community 2.12 with indicator species *Euphorbia abyssinica*, *Schefflera abyssinica* and *Maesa lanceolata*, with no further subdivisions. Sub-community 3.1, with eigenvalue 0.322, separated into sub-community 3.11 with indicator species *Clutia abyssinica* (with no further subdivisions) and sub-community 3.12 with indicator species *Grewia ferruginea*. Sub-community 3.2, with eigenvalue 0.271, separated into sub-communities 3.21 with indicator species *Nuxia congesta*, *Albizia schimperiana*, *Vachellia lahai*, *Vernonia myriantha*, *Clausena anisata* and *Buddleja polystachya* (with no further subdivision), and sub-community 3.22 with indicator species *Combretum molle*, *Dodonea angustifolia*, *Allophylus abyssinicus* and *Clematis hirsuta*.

At level 5 division, sub-community 1.21, with eigenvalue 0.235, separated into sub-community 1.211 with indicator species *Terminalia schimperiana*, *Calpurnia aurea* and *Carissa spinarum*, and sub-community 1.212 with indicator species *Ekebergia capensis*, *Vernonia myriantha*, *Embelia schimperi* and *Urera hypselodendron*. Sub-community 3.12, with eigenvalue 0.344, separated into sub-communities 3.121 with indicator species *Allophylus abyssinicus*, and sub-community 3.122 with indicator species *Galiniera saxifraga*, a dominant tree species. Sub-community 3.21, with eigenvalue 0.292, separated into sub-community 3.211 with indicator species *Clausena anisata*, *Bersama abyssinica* and *Schrebera alata*, and sub-community 3.212 with indicator species *Nuxia congesta* and *Acanthus sennii*. Sub-community 3.22, with eigenvalue 0.267, separated into sub-community 3.221 with indicator species *Calpurnia aurea*, *Maytenus gracilipes*, *Maesa lanceolata* and *Vernonia adoensis*, and sub-community 3.222 with indicator species *Allophylus abyssinicus*, *Combretum molle* and *Premna schimperi*.

The importance values of prominent woody species (with IV $\geq 10\%$ in at least one community), across communities and sub-communities (vegetation units), are presented and highlighted in Table 3.1, and for all species are presented in Appendix 3.2. Details of the relative frequency, relative density and relative basal area of all woody species across the vegetation units are presented, in Appendices 3.3, 3.4 and 3.5. Importance values are mean values for each species based on the observed relative frequency, relative density and relative basal area, indicating the absence/presence, rarity/dominance and continuity/discontinuity of distribution for each species across sub-communities. Most of the prominent species (IV $\geq 10\%$) were important in only one vegetation unit (community or sub-community), except for *Vachellia lahai* and *Olea europaea* subsp. *cuspidata* in two units, *Olea capensis* sub. *macrocarpa* in three units, and *Maytenus gracilipes* in five units. Six species showed an IV of $\geq 20\%$: *V. lahai* (25% in 3.211); *Dodonaea angustifolia* (40.3% in 4); *Euphorbia abyssinica* (21.9% in 1.11), *M. gracilipes* (20.3% in 1.212); *O. europaea cuspidata* (20.3% in 2.12; and *Schefflera abyssinica* (23.7% in 3.221). Most vegetation units had two or maximum three prominent species, but vegetation units 1.22, 2.11, 3.221, 3.222 and 4 had only one, and unit 3.122 had none.

Total number of woody species, mean number of species per plot, diversity, evenness, stem density/ha and basal area/ha recorded in all communities and sub-communities are presented in Table 3.2. Stem density generally ranged between 1200 and 2800 stems/ha, but vegetation unit 4 showed a much higher density of 3450 stems/ha with a relative low basal area/ha, and unit 3.222 had a low 705 stems/ha. Community 1 generally had a high stem density and a very high basal area per ha. The mean number of species ranged between 2 and 11 per plot, with no specific patterns between the vegetation units.

The DCA ordination (indirect gradient analysis) shows the spatial distribution of sampled plots in ordination space (Figure 3.5). The respective eigenvalues were 0.471 for axis 1 and 0.219 for axis 2, explaining respectively 47.1% and 21.9% of the variation. The graph showed some overlap between communities, because they may be separated along the third axis. The four main communities are clearly separated along axis 1. Communities 1 and 2 are also clearly separated along axis 2. The sub-communities of community 3 are well separated along axis 2, but at a different point than communities 1 and 2. At this stage, it was difficult to understand what would be the driving environmental factors for such community groupings and their variation in spatial ordination. Hence, a direct gradient analysis was done to sort out the possible environmental gradients that influence this community groupings and variation in their spatial distribution.

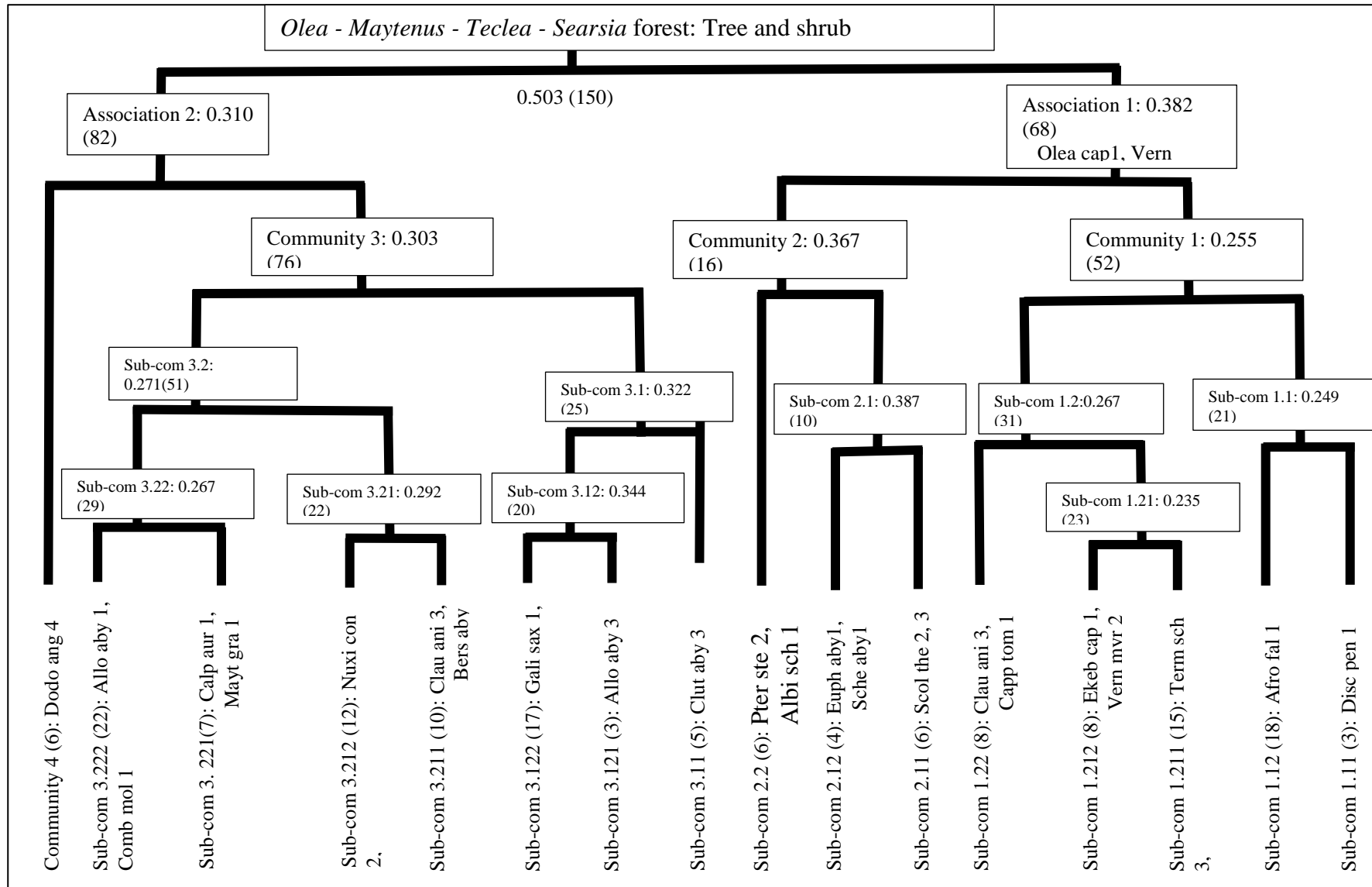


Figure 3.4 Schematic relationship between communities and sub-communities of woody species. Note that eigenvalues, indicator species and number of plots are indicated between brackets for each division.

Table 3.1 Importance Values (%) of woody species across all communities and sub-communities.

Only species with an IV $\geq 10\%$ (high-lighted) in at least one sub-community, are listed here. The complete table of importance values is presented in Appendix 3.2.

Community Types	1.11	1.12	1.211	1.212	1.22	2.11	2.12	2.2	3.11	3.121	3.122	3.211	3.212	3.221	3.222	4
No. of Plots	3	18	15	8	8	6	4	6	5	3	17	10	12	7	22	6
<i>Acanthus sennii</i>	2.9	0.9	0.4	0.8	1.0	0.8	1.4	0.8	3.5	0.9	1.7	4.4	13.4	9.5	9.1	0.5
<i>Allophylus abyssinicus</i>	-	-	-	-	-	0.5	-	3.0	4.3	14.1	2.7	0.9	0.4	0.4	3.1	2.8
<i>Bersama abyssinica</i>	2.1	1.9	1.5	2.3	1.1	3.0	4.6	2.4	10.3	2.1	2.1	2.3	1.3	1.8	0.8	-
<i>Calpurnia aurea</i>	3.0	10.6	2.1	0.7	2.7	1.6	3.7	1.6	3.6	1.9	6.5	1.6	1.4	5.7	0.4	2.1
<i>Capparis tomentosa</i>	-	1.1	-	0.7	4.8	0.4	1.4	0.4	-	-	1.0	11.8	2.1	0.7	1.9	-
<i>Carissa spinarum</i>	-	0.8	3.7	1.4	6.9	3.7	2.5	3.4	3.2	13.0	3.7	2.3	2.5	3.3	3.8	6.1
<i>Clutia abyssinica</i>	1.1	3.5	1.0	1.2	0.3	2.4	3.0	0.4	11.7	4.5	1.6	1.7	3.2	4.1	3.9	-
<i>Combretum molle</i>	1.1	0.8	1.4	1.5	0.7	-	-	0.4	-	-	0.4	-	-	0.4	10.3	2.6
<i>Dodonaea angustifolia</i>	-	-	-	0.3	-	-	-	-	-	5.8	0.4	0.9	1.8	2.1	6.1	40.3
<i>Dombeya torrida</i>	-	0.8	1.8	5.4	0.7	11.0	0.7	0.4	2.1	2.9	1.2	0.4	-	1.2	0.1	-
<i>Ekebergia capensis</i>	-	1.8	0.8	16.8	2.3	0.4	-	0.4	0.9	-	4.1	0.2	0.2	-	0.3	-
<i>Euphorbia abyssinica</i>	21.9	5.1	2.3	1.8	0.8	-	2.7	-	-	-	-	-	-	0.7	-	-
<i>Grewia ferruginea</i>	-	-	-	-	0.6	0.5	0.7	0.6	-	11.7	3.7	2.1	2.7	1.8	3.0	3.6
<i>Juniperus procera</i>	-	-	-	-	-	4.9	10.9	-	-	-	-	-	-	5.2	0.1	-
<i>Maytenus gracilipes</i>	12.4	16.7	18.0	20.3	13.5	8.6	3.6	7.2	3.0	0.9	2.7	2.2	4.0	4.0	1.9	0.5
<i>Nuxia congesta</i>	-	0.4	0.2	-	1.4	1.9	0.7	3.8	6.6	2.4	5.0	2.4	12.0	1.4	1.3	1.9
<i>Olea capensis</i> sub. <i>macrocarpa</i>	14.4	18.3	18.8	7.7	6.1	-	-	-	-	-	-	-	-	-	-	-
<i>Olea europaea</i> subsp. <i>cuspidata</i>	-	-	-	-	2.4	6.1	20.3	13.8	9.8	2.6	1.5	0.2	0.4	3.5	2.5	5.2
<i>Prunus africana</i>	3.5	0.5	11.3	1.1	7.5	-	-	-	-	-	-	-	-	-	-	-
<i>Pterolobium stellatum</i>	-	-	-	-	-	0.8	1.6	12.2	1.5	0.9	2.3	-	0.2	0.7	-	0.5
<i>Schefflera abyssinica</i>	-	10.3	0.4	0.3	0.3	-	2.7	1.4	-	-	-	0.2	0.3	23.7	-	0.5
<i>Vachellia lahai</i>	-	-	-	-	0.7	-	-	-	-	-	3.2	25.0	10.6	-	0.3	-

Table 3.2 Number of woody species, Shannon diversity, evenness, stems/ha and basal area/ha across all communities and sub-communities.

Community Types	No. of plots	No. of species		Diversity	Evenness	Stem density/ha	Basal area m ² /ha
		Total	Mean per plot				
1.11	3	21	7	2.4	0.50	2567	70
1.12	18	43	2	2.2	0.21	2144	80
1.211	15	42	3	2.2	0.21	2513	99
1.212	8	38	5	2.1	0.23	1763	87
1.22	8	51	6	2.4	0.23	2338	41
2.11	6	46	8	3.0	0.44	1867	46
2.12	4	35	9	3.2	0.67	1375	38
2.2	6	39	7	2.6	0.36	1867	45
3.11	5	42	8	2.8	0.38	1660	19
3.121	3	33	11	3.1	0.66	2567	21
3.122	17	69	4	3.5	0.46	2782	24
3.211	10	51	5	2.7	0.30	1130	44
3.212	12	55	5	2.9	0.34	1242	23
3.221	7	47	7	3.1	0.47	1543	50
3.222	22	53	2	3.2	0.47	705	7
4	6	32	5	2.1	0.26	3450	12

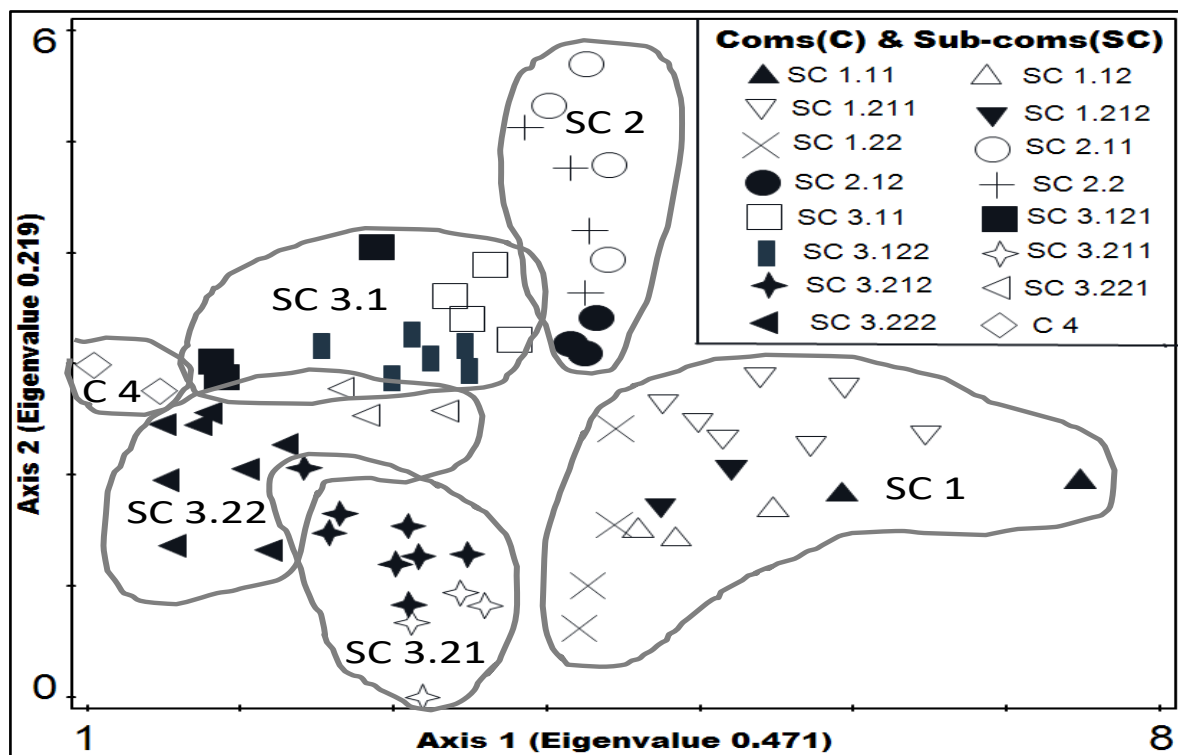


Figure 3.5 DCA ordination diagram of plots for all communities (coms) and sub-communities (sub-coms) of woody species.

Note that about 68 plots (by weight) were used in the ordination for clear display.

3.3.2 Woody communities in relation to environmental variables

Results from the Canonical Correspondence Analysis (CCA) (direct gradient analysis) are shown in Figure 3.6. In this ordination diagram, each environmental arrow points in the direction of the steepest increase in the values of the environmental variables. The angle between arrows indicates the correlation between individual environmental variables. More precisely, we can read the approximated correlations of one environmental variable with the others by projecting their arrowheads onto the imaginary line running in the direction of the arrow of that variable. In sample symbols, the distance between the symbols approximates the dissimilarity of their species composition as measured by their chi-square distance. The sample symbols can be projected perpendicularly onto the line overlaying the arrow of each particular environmental variable. These projections can be used to approximate the variable values in individual samples. The sample symbols are in the order of predicted increase of values of the particular environmental variable. Predicted increase occurs in the direction indicated by the arrow. The sample points projecting onto the coordinate origin are predicted to correspond to samples with an average value of that environmental variable (ter Braak and Šmilauer, 2012).

Different sub-communities were distributed along gradients of different environmental variables. Most plots of sub-communities 1.11, 1.12, 1.211, 1.212 and 1.22 distributed along nitrogen, altitude, radiation index and litter. Other environmental variables, organic carbon, electrical conductivity, moisture, CEC, sand and silt, were also important environmental variables for the composition and distribution of these communities. In these communities, species *Discopodium penninervium*, *Afrocarpus falcatus*, *Terminalia schimperiana* and *Calpurnia aurea* were some of the indicator species, respectively for sub-communities 1.11, 1.12, 1.211, 1.212 and 1.22. Most plots of sub-communities 2.11, 2.12 and 2.2 distributed along the slope and pH variables. Species *Scolopia theifolia*, *Euphorbia abyssinica* and *Pterolobium stellatum* were some of the indicator species observed, respectively in sub-communities 2.11, 2.12 and 2.2.

Plots of sub-communities 3.11, 3.121 and 3.122, occurred along the environmental variables of slope, clay and pH. *Clausena anisata* and *Allophylus abyssinicus* were indicator species respectively in sub-communities 3.11 and 3.121, while *Galiniera saxifraga* is a dominant tree species in sub-community 3.122. Plots of sub-communities 3.211, 3.212, 3.221 and 3.222 distributed along the available Phosphorus. Some of the indicator species, observed respectively in each sub-community, were *Bersama abyssinica*, *Nuxia congesta*, *Calpurnia aurea* and *Allophylus abyssinicus*. Plots of community 4 distributed along the environmental variable of clay, with available Phosphorus also being an important environmental variable for the distribution and occurrence of this community.

Species *Dodonea angustifolia* was indicator the species in this community (Figure 3.6). See Figure 3.4 for the indicator species.

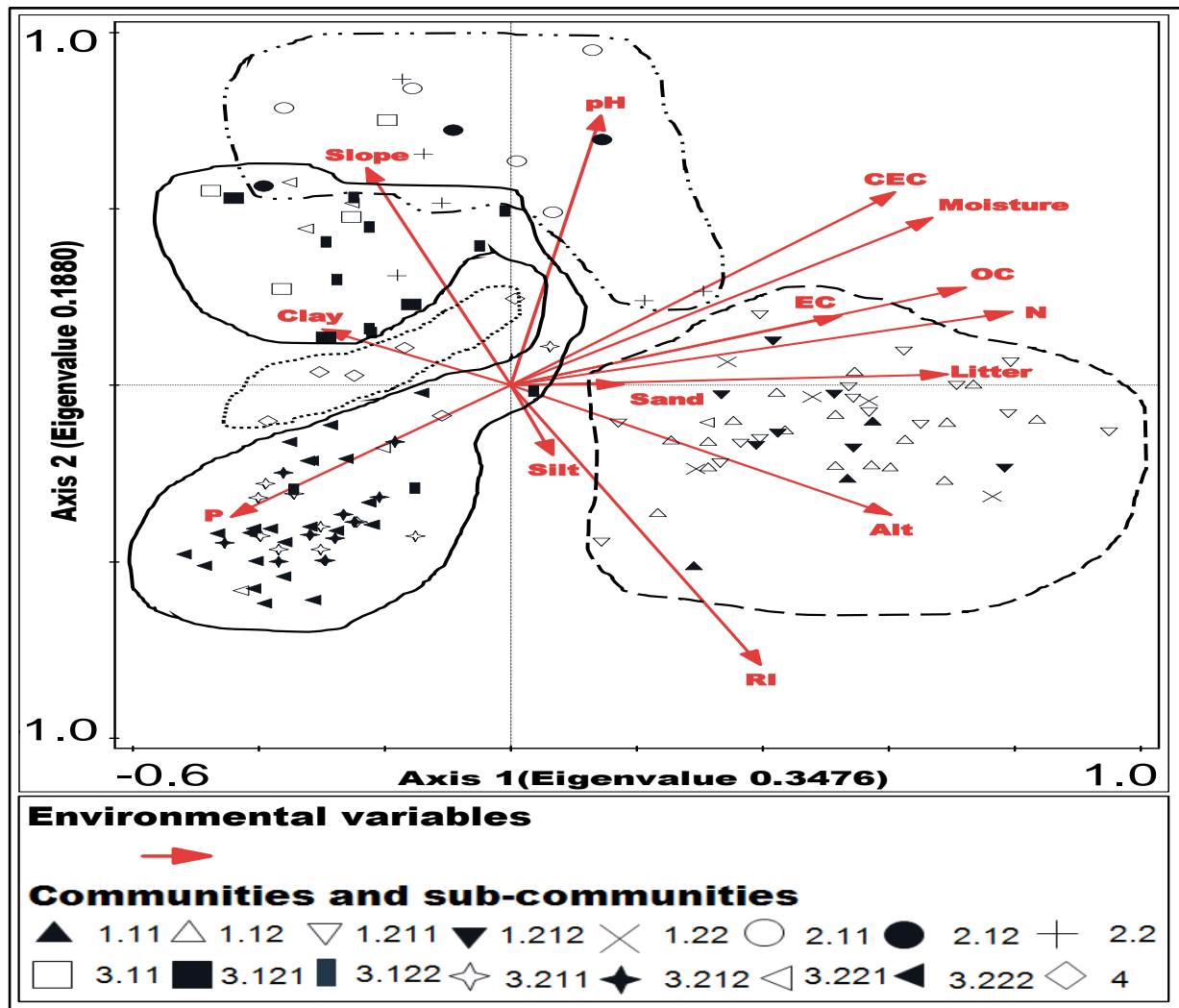


Figure 3.6 Sample/Environment biplot ordination diagram of woody communities and sub-communities from Canonical Correspondence Analysis.

Environmental variables abbreviated were: RI (Radiation Index), Alt (Altitude), P (Phosphorus), N (Total Nitrogen), EC (Electrical Conductivity), OC (Organic Carbon), and CEC (Cation Exchange Capacity). Communities I, II, III, and IV respectively encircled with dash (---), dash dot dot (-----), solid (—) and dot (.....) lines. For clear display of the diagram, the encirclement excluded a few samples that were outside of each main community.

The Monte-Carlo test, at $p < 0.01$, showed Nitrogen and radiation index were to be statistically, the two most highly significant variables explaining the occurrence and distribution pattern of woody species in the study area (Table 3.3). Altitude, CEC, litter, phosphorus and soil moisture were other statistically significant environmental variables at $p < 0.01$, and organic carbon was a significant

variable at $p < 0.05$. The environmental variables of EC, clay, pH, silt, sand and slope, were non-significant in explaining the total composition and distribution pattern of woody species (Table 3.3).

Table 3.3 Monte-Carlo Test of environmental variables, explaining the variation in the composition of woody communities

Environmental Variables	Eigenvalues	F	P
Total Nitrogen	0.068	10.7	0.002
Radiation Index	0.050	8.3	0.002
Altitude	0.021	3.6	0.002
Cation Exchange Capacity	0.021	3.7	0.002
Litter	0.014	2.4	0.002
Available Phosphorus	0.012	2.0	0.007
Moisture	0.010	1.9	0.004
Organic Carbon	0.008	1.5	0.018
Electrical Conductivity	0.008	1.4	0.069
Clay	0.008	1.3	0.051
pH-H ₂ O	0.007	1.3	0.051
Silt	0.006	1.1	0.22
Slope	0.005	1.0	0.573

N.B. Note that variable sand was removed from the list due to collinearity with silt.

3.3.3 Classification of communities of herbaceous species

The TWINSpan analysis of herbaceous species, with four levels of division, produced two main communities with eight sub-communities (Appendix 3.6). This output was further schematically simplified using indicator species of each community and sub-community (Figure 3.7).

At level 1, with eigenvalue 0.407, the 150 plots separated into plots of community 1 with indicator species *Hypoestes forskoolii* and *Cyperus fischerianus*, and community 2 with indicator species *Bidens prestinaria*, *Trifolium rueppellianum*, *Guizotia scabra* and *Snowdenia polystachya* (with further subdivision at level 3).

At level 2 division, community 1, with eigenvalue 0.250, separated into sub-community 1.1 with indicator species *Panicum monticola* (with further subdivision at level 4), and sub-community 1.2

with indicator species *Cyperus fischerianus*, *Bidens pilosa*, *Guizotia scabra* and *Isoglossa somalensis*.

At level 3 division, sub-community 1.2, with eigenvalue 0.245, separated into sub-community 1.21 with indicator species *Girardinia bulbosa* and *Thalictrum rhynchocarpum*, and sub-community 1.22 with indicator species *Panicum monticola*, *Guizotia scabra*, *Cyperus fischerianus* and *Bidens pilosa*. Community 2, with eigenvalue 0.326, separated into sub-community 2.1 with dominant species *Hyperhemia hirta* and *Snowdenia polystachya*, and sub-community 2.2 with indicator species *Plectranthus punctatus*, both with no further subdivisions.

At level 4 division, sub-community 1.1, with eigenvalue 0.247, separated into sub-community 1.11 with indicator species *Rhynchosia elegans*, and sub-community 1.12 with indicator species *Panicum monticola*. Sub-community 1.21, with eigenvalue of 0.225, separated into sub-communities 1.211 with no indicator species but with *Kalanchoe petitiiana* as dominant species, and sub-community 1.212 with indicator species *Cyperus fischerianus*, *Girardinia bulbosa*, *Adiantum poiretii*, *Isoglossa somalensis*, *Thalictrum rhynchocarpum* and *Pennisetum unisetum*. Sub-community 1.22, with eigenvalue 0.289, separated into sub-community 1.221 with indicator species *Bidens prestinaria* and *Snowdenia polystachya*, and sub-community 1.222 with indicator species *Guizotia scabra* and *Plectranthus punctatus*.

The importance values of all herbaceous species (with IV $\geq 5\%$ in at least one community), across communities and sub-communities (vegetation units), are presented and highlighted in Table 3.4 and for all species are presented in Appendix 3.7. Details of the relative frequency and relative cover abundance of all herbaceous species across the vegetation units are presented in Appendices 3.8 and 3.9. Importance values for herbaceous species are mean values for each species based on the observed relative frequency and relative cover abundance, indicating the absence/presence, rarity/dominance and continuity/discontinuity of distribution for each species across sub-communities.

Most of the prominent species (IV $\geq 5\%$) were important in only one vegetation unit (community or sub-community), except for *Snowdenia polystachya* and *Trifolium rueppellianum* in two units, *Guizotia scabra* in three units, *Bidens prestinaria* and *Cyperus fischerianus* in four units, and *Hypoestes forskoolii* and *Panicum monticola* in seven units. Two species showed an IV of $\geq 20\%$: *Hypoestes forskoolii* (22.7% in 1.11, 30.4% in 1.12, 34.3% in 1.211 and 24.2% in 1.212) and *Panicum monticola* (25.3% in 1.12). Most vegetation units had two or maximum three prominent species (with IV $\geq 10\%$), but vegetation unit 1.211 had only one.

The total number of herbaceous species, mean number of species per plot, diversity and evenness, recorded in all communities and sub-communities are presented, in Table 3.5. The number of species ranged between 14 and 52, but vegetation unit 2.2 generally had high a mean number of four species per plot, diversity 2.8 and evenness 0.57; while unit 1.12 showed a low mean number of one species per plot, diversity 2.1 and evenness 0.16. A low mean number of species ranged between 1 and 4 per plot, were observed across vegetation units.

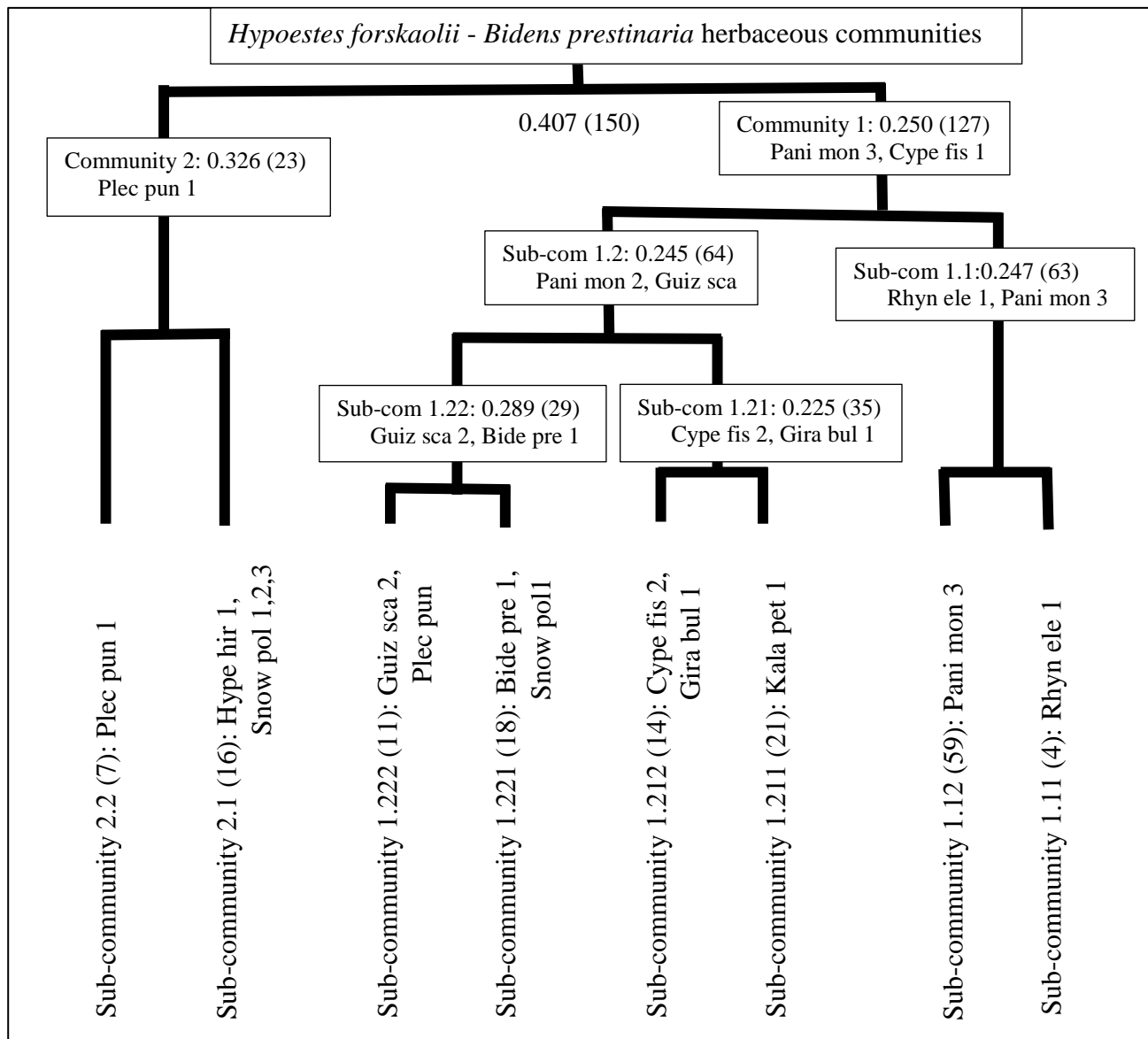


Figure 3.7 Schematic relationship between communities and sub-communities of herbaceous species. Eigenvalues, indicator species and number of plots are indicated between brackets for each division.

The DCA ordination (indirect gradient analysis) for herbaceous species shows the spatial distribution of sampled plots in ordination space (Figure 3.8). The eigenvalues were 0.386 for axis 1 and 0.194 for axis 2, explaining respectively 38.6% and 19.4% of the variations. Communities 1 and 2 separated

well along axis 1. Sub-communities (SC) of community 1 further separated along axis 2. Sub-communities of 1.1 separated along axis 1, while sub-communities of 1.21 and 1.22 along axis 2. At this stage, it was difficult to understand what would be the driving environmental variables for such community groupings, and their variation in spatial ordination were not clear from this analysis. Hence, a direct gradient analysis was done to determine what gradients in possible environmental variables could influence the spatial distribution of the community groupings (Figure 3.9).

Table 3.4 Importance values (IV, as %) of herbaceous species across all sub-communities (calculated as mean value of relative cover abundance and relative frequency).

Only species with an IV $\geq 5\%$ (highlighted) in at least one sub-community are listed. Appendix 3.7 shows IV of all species.

Community Types	1.11	1.12	1.211	1.212	1.221	1.222	2.1	2.2
No. of Plots	4	59	21	14	18	11	16	7
<i>Bidens pilosa</i>	-	2.1	2.7	3.9	7.1	4.8	1.7	1.1
<i>Bidens prestinaria</i>	6.9	2.5	1.1	2.8	6.9	0.6	13.7	9.0
<i>Cynodon dactylon</i>	-	0.5	1.1	-	0.8	1.2	0.4	6.3
<i>Cyperus fischerianus</i>	-	4.9	7.3	12.3	14.2	9.7	1.7	-
<i>Girardinia bullosa</i>	-	3.3	2.2	6.1	0.4	0.6	-	-
<i>Glycine wightii</i>	11.0	0.3	-	-	-	-	0.7	-
<i>Guizotia scabra</i>	-	2.0	3.3	3.3	4.2	13.0	9.6	10.1
<i>Hypericum peplidifolium</i>	8.2	0.9	0.5	-	-	-	0.9	-
<i>Hypoestes forskoolii</i>	22.7	30.4	34.3	24.2	18.2	16.2	5.8	3.8
<i>Isoglossa somalensis</i>	-	-	3.4	6.9	4.5	0.6	-	-
<i>Panicum monticola</i>	11.8	25.3	7.3	4.8	11.8	10	10.2	10.4
<i>Pavonia urens</i>	-	-	-	0.6	-	0.6	-	6.1
<i>Pennisetum thunbergii</i>	8.3	0.8	-	-	-	-	-	-
<i>Plectranthus punctatus</i>	-	1.3	1.6	1.7	0.8	6.1	-	4.9
<i>Rhynchosia elegans</i>	10.4	0.3	-	-	-	-	0.7	-
<i>Snowdenia polystachya</i>	-	0.7	1.1	-	6.0	-	9.5	1.1
<i>Thalictrum rhynhocarpum</i>	-	2.8	3.8	5.5	2.0	1.2	-	-
<i>Trifolium rueppellianum</i>	-	-	-	0.6	-	0.9	6.4	10.4

Table 3.5 Number of herbaceous species, Shannon diversity and evenness across all communities and sub-communities

Community Types	No. of plots	No. of species		Diversity	Evenness
		Total	Mean per plot		
1.11	4	14	4	2.1	0.60
1.12	59	52	1	2.1	0.16
1.211	21	41	2	2.3	0.23
1.212	14	37	3	2.5	0.32
1.221	18	38	2	2.5	0.33
1.222	11	38	4	2.7	0.40
2.1	16	43	3	2.9	0.42
2.2	7	28	4	2.8	0.57

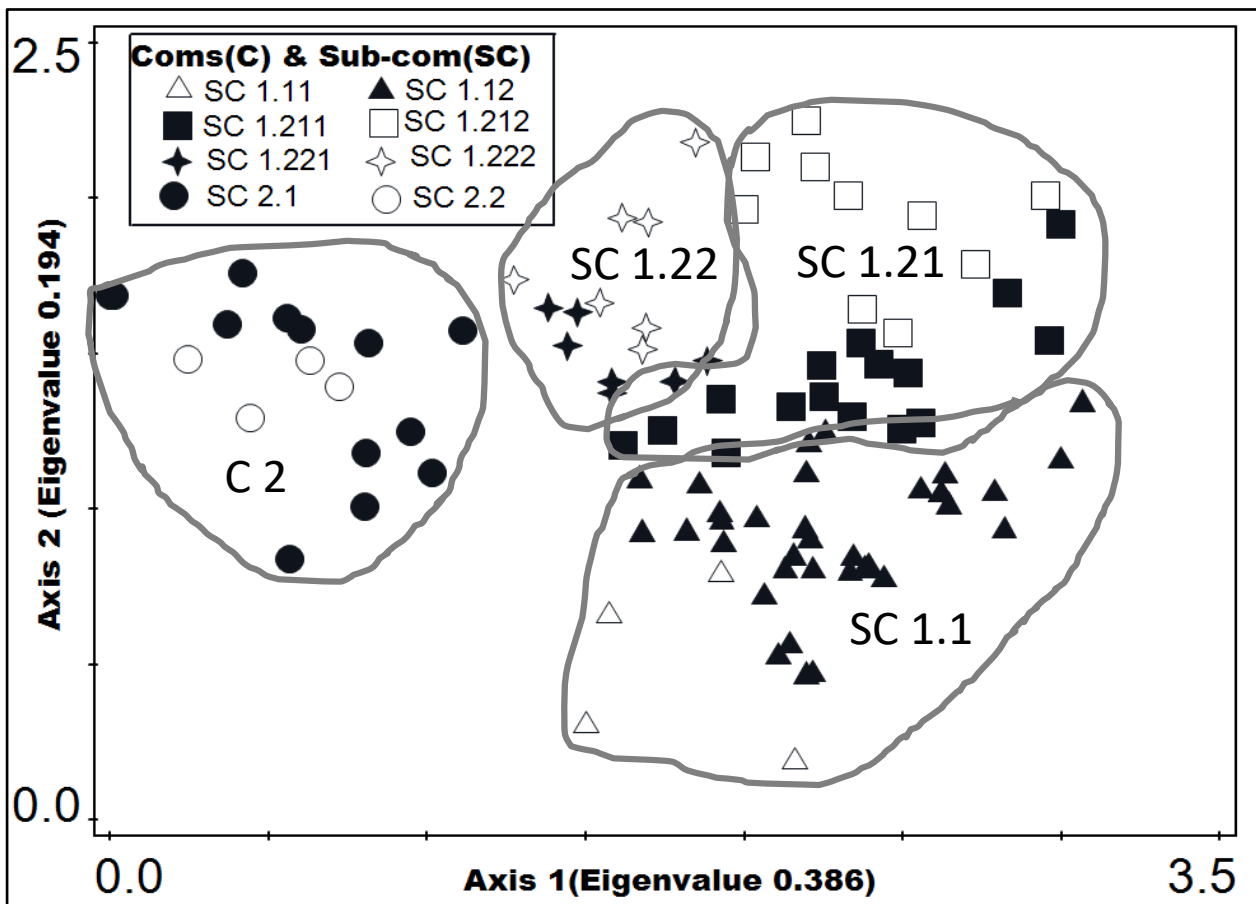


Figure 3.8 DCA ordination diagram of plots for all communities (coms) and sub-communities (sub-coms) of herbaceous species.

Note that about 83 plots (by weight) were used in the ordination for clear display.

3.3.4 Herbaceous communities in relation to environmental variables

Results from the Canonical Correspondence Analysis (CCA) (direct gradient analysis) are shown in Figure 3.9. Different herbaceous sub-communities were distributed along gradients of different environmental variables. Most plots of sub-communities 1.11, 1.12 and 1.211 occurred along gradients of radiation index, altitude, litter, available Phosphorus, EC, nitrogen and organic carbon, with sand and silt showing a lower gradient strength to explain the composition and distribution of these sub-communities. *Rhynchosia elegans* and *Panicum monticola* were indicator species respectively in sub-communities 1.11 and 1.12, while *Kalanchoe petitiiana* was a dominant species in sub-community 1.211. Most plots of sub-community 1.212 were associated with soil moisture, with Nitrogen, CEC, electrical conductivity and organic carbon. Species *Cyperus fischerianus* and *Girardinia bullosa* were some of the indicator species observed in this sub-community. Most plots of sub-communities 1.221 and 1.222 distributed along the environmental variables of pH, slope, clay and CEC. *Bidens prestinaria* and *Guizotia scabra* were indicator species, respectively in each sub-community.

Plots of sub-communities 2.1 and 2.2 were strongly associated with clay and Phosphorus and to a lesser extent with altitude. *Hypoestes forskoolii* and *Snowdenia polystachya* were some of the dominant species in sub-community 2.1, while *Plectranthus punctatus* as indicator species in sub-community 2.2 (Figure 3.9).

The Monte-Carlo test for herbaceous communities, at $p < 0.01$, showed four environmental variables to be statistically most significant in explaining the total composition and distribution of herbaceous communities: moisture, radiation index, altitude and Phosphorus. Total Nitrogen was statistically significant at $p < 0.05$, and the variables CEC, clay, EC, slope, organic carbon, silt, sand, pH, and litter were statistically non-significant (Table 3.6).

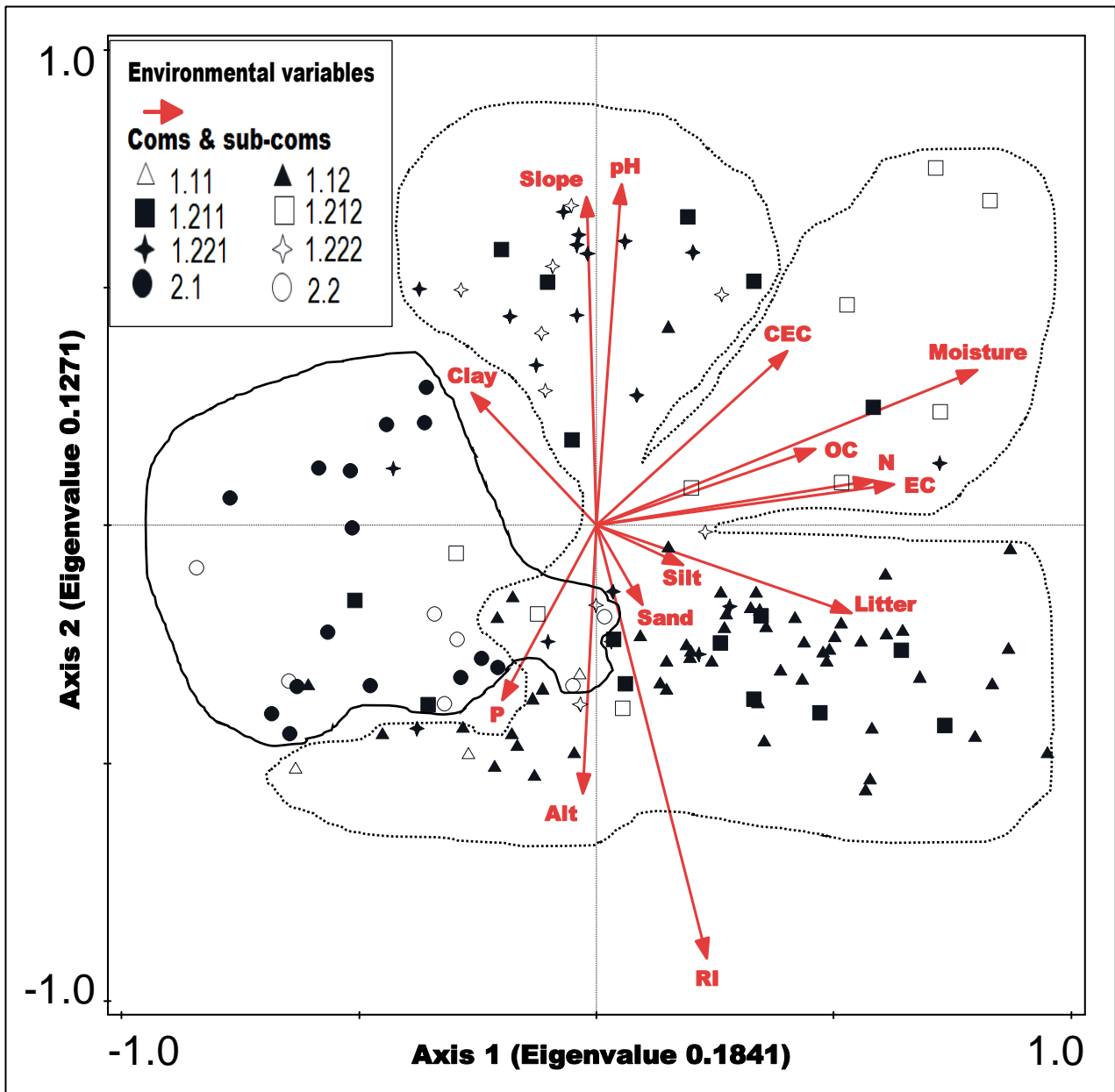


Figure 3.9 Sample/Environment biplot ordination diagram of herbaceous communities (coms) and sub-communities (sub-coms) from Canonical Correspondence Analysis.

Environmental variables abbreviated were: RI (Radiation Index), Alt (Altitude), P (Phosphorus), N (Total Nitrogen), EC (Electrical Conductivity), OC (Organic carbon), and CEC (Cation Exchange Capacity). Communities I, and II respectively encircled with dot (---) and solid (—) lines. For vivid display of the diagram, the encirclement excludes a few samples that were outside of each main community.

Table 3.6 Monte-Carlo Test of environmental variables, explaining the variation in the composition of Herbaceous Communities.

Environmental Variables	Eigenvalues	F	P
Moisture	0.044	6.8	0.002
Radiation Index	0.038	6.0	0.002
Altitude	0.024	3.9	0.002
Available Phosphorus	0.014	2.2	0.002
Total Nitrogen	0.010	1.7	0.013
Cation Exchange Capacity	0.008	1.3	0.140
Clay	0.008	1.3	0.158
Electrical Conductivity	0.007	1.1	0.273
Slope	0.005	0.9	0.660
Organic Carbon	0.005	0.8	0.720
Silt	0.005	0.8	0.716
pH-H ₂ O	0.005	0.8	0.787
Litter	0.005	0.8	0.773

N.B. Note that variable sand removed from the list due to collinearity with silt.

3.3.5 Relationship between woody and herbaceous communities

Each herbaceous community appeared in a range of woody species communities, and each woody community include plots of one or more different herbaceous communities. Herbaceous sub-communities 1.11 and 2.1 showed strong association with woody sub-community 3.222, while 1.12 with woody sub-communities 1.12 and 1.211. Sub-community 1.12 showed also relatively strong association with woody sub-communities 1.212, 1.22 and 3.222. Herbaceous sub-community 1.221 showed strong association with woody sub-community 3.122 (Table 3.7). The study further tried to infer and sort out some common environmental variables for their association and distribution by looking into the results in Figure 3.6 and 3.9. Common environmental variables for each woody community and its associated herbaceous community presented in the Discussion section.

Table 3.7 Relationship between woody and herbaceous plant communities

Woody Communities		Herbaceous Communities							
		Code							
		1.11	1.12	1.211	1.212	1.221	1.222	2.1	2.2
Code	Plots	Number of Plots							
		4	59	21	14	18	11	16	7
1.11	3		2	1					
1.12	18		10	4		1	2	1	
1.211	15		14	1					
1.212	8		8						
1.22	8	1	7						
2.11	6		1	2	3				
2.12	4		1	1			2		
2.2	6			2	3	1			
3.11	5					2	3		
3.121	3			2				1	
3.122	17			3	4	6	3	1	
3.211	10		4	2	2	1	1		
3.212	12		5	2	1	2			2
3.221	7			1	1	3			2
3.222	22	3	7			2		8	2
4	6							5	1

3.3.6 Description of woody plant communities

The results from the TWINSpan classification, indirect gradient analysis (DCA Ordination), direct gradient analysis with environmental variables (CCA Ordination) and the calculation of the Importance values (IVs) of woody species across the sub-communities, formed the basis for the description of the identified four main and 16 sub-communities.

Community 1: *Olea capensis* sub. *macrocarpa*

The indicator species of this community, *Olea capensis* sub. *macrocarpa*, was observed with different frequencies and abundance in different sub-communities. Two sub-communities were identified, one

with two sub-communities and the other with three sub-communities. Prominent species in this community were *Calpurnia aurea*, *Ekebergia capensis*, *Euphorbia abyssinica*, *Maytenus gracilipes*, *Prunus africana* and *Schefflera abyssinica*. The community generally had high stem density and much higher basal area per ha. It occurred in high values of radiation index, altitude, litter, Nitrogen and organic carbon, and to low values of pH, slope, clay and available phosphorus.

Sub-community 1.1: *Calpurnia aurea* - *Clutia abyssinica* - *Euphorbia abyssinica* - *Afrocarpus falcatus*

The indicator species of this sub-community, *Calpurnia aurea*, *Clutia abyssinica*, *Euphorbia abyssinica* and *Afrocarpus falcatus*, were observed with different frequencies and abundance. *Olea capensis* sub. *macrocarpa* and *Maytenus gracilipes* were prominent tree species in this sub-community.

Sub-community 1.11: *Discopodium penninervium*

Discopodium penninervium was the indicator species in this sub-community. Prominent tree species in this sub-community were *Olea capensis* subsp *macrocarpa* and *Maytenus gracilipes*. *Dovyalis abyssinica*, *Euphorbia abyssinica*, *Ficus sycomorus*, *Pittosporum abyssinicum* and *Vernonia myriantha* were other associated species in this sub-community.

Sub-community 1.12: *Afrocarpus falcatus*

No indicator species were identified, and the important preferential tree species was used to name the sub-community. *Afrocarpus falcatus* was observed as important preferential tree species in this sub-community. Prominent tree species included *Calpurnia aurea*, *Olea capensis* subsp *macrocarpa*, *Maytenus gracilipes* and *Schefflera abyssinica*. *Dregea schimperi* was observed only in this sub-community.

Sub-community 1.2: *Terminalia schimperiana* - *Urera hypselodendron* - *Carissa spinarum* - *Dombeya torrida* - *Bridelia micrantha*

The indicator species of this sub-community, *Terminalia schimperiana*, *Urera hypselodendron*, *Carissa spinarum*, *Dombeya torrida* and *Bridelia micrantha*, were observed with different frequencies and abundance. *Maytenus gracilipes* was the other prominent tree species in this sub-community.

Sub-community 1.21: *Terminalia schimperiana* - *Vernonia myriantha*

The indicator species of this sub-community, *Terminalia schimperiana* and *Vernonia myriantha*, were observed with different frequencies and abundance. *Maytenus gracilipes* was the prominent tree species in this sub-community.

Sub-community 1.211: *Terminalia schimperiana* - *Calpurnia aurea* - *Carissa spinarum*

The indicator species of this sub-community, *Terminalia schimperiana*, *Calpurnia aurea* and *Carissa spinarum*, were observed with different frequencies and abundance. Prominent tree species in this sub-community included *Maytenus gracilipes*, *Olea capensis* subsp. *macrocarpa* and *Prunus africana*. *Bridelia micrantha* were observed as strongly associated species.

Sub-community 1.212: *Ekebergia capensis*, *Vernonia myriantha*, *Embelia schimperi* and *Urera hypselodendron*

The indicator species of this sub-community, *Ekebergia capensis*, *Vernonia myriantha*, *Embelia schimperi* and *Urera hypselodendron*, were observed with different frequencies and abundance. *Maytenus gracilipes* was the prominent tree species in this sub-community. *Justicia schimperiana*, *Prunus persica* and *Ritchiea albersii* were strongly associated species.

Sub-community 1.22: *Clausena anisate* - *Capparis tomentosa* - *Dovyalis abyssinica* - *Albizia schimperiana*

The indicator species of this sub-community, *Clausena anisata*, *Capparis tomentosa*, *Dovyalis abyssinica* and *Albizia schimperiana*, were observed with different frequencies and abundance. *Dracaena steudneri*, *Periploca linearifolia* and *Rhynchosia resinosa* were strongly associated species.

Community 2: *Vernonia adoensis* - *Olea europaea* subsp. *cuspidata*

The indicator species of this community, *Vernonia adoensis* and *Olea europaea* subsp. *cuspidata*, were observed with different frequencies and abundance in different sub-communities. Three sub-communities were identified. Prominent species observed in this community were *Dombeya torrida*, *Juniperus procera*, *Olea europaea* subsp. *cuspidata* and *Pterolobium stellatum*. It occurred in high values of pH, slope, CEC and clay, and to low values of available phosphorus, radiation index, altitude, litter, nitrogen, organic carbon, EC and soil moisture.

Sub-community 2.1: *Clutia abyssinica*

Clutia abyssinica was an indicator species in this sub-community. It had relatively high mean number of species per plot, diversity, evenness, stem density/ha and basal area/ha.

Sub-community 2.11: *Scolopia theifolia*

No indicator species were identified, and the important preferential tree species was used to name the sub-community. *Scolopia theifolia* was an important preferential tree species in this sub-community. *Dombeya torrida* was a prominent tree species in this sub-community. *Apodytes dimidiata*, *Celtis Africana*, *Ficus sur*, *Heteromorpha arborescens*, *Maytenus undata* and *Solanum giganteum* were strongly associated.

Sub-community 2.12: *Euphorbia abyssinica* - *Schefflera abyssinica* - *Maesa lanceolata*

The indicator species of this sub-community, *Euphorbia abyssinica*, *Schefflera abyssinica* and *Maesa lanceolata*, were observed with different frequencies and abundance. *Juniperus procera* was a prominent tree species in this sub-community. *Clusia lanceolata*, *Maesa lanceolata* and *Solanum indicum* were strongly associated species in this sub-community.

Sub-community 2.2: *Pterolobium stellatum* - *Albizia schimperiana*

The indicator species of this sub-community, *Pterolobium stellatum* and *Albizia schimperiana*, were observed with different frequencies and abundance. *Canthium oligocarpum*, *Galiniera saxifraga*, *Jasminum abyssinicum*, *Maytenus arbutifolia* and *Teclea nobilis* were strongly associated species in this sub-community.

Community 3: *Vachellia lahai* - *Vachellia etbaica* - *Acanthus sennii* - *Clusia abyssinica*

No indicator species were identified, and the important preferential species were used to name the community. Prominent species *Vachellia lahai*, *Vachellia etbaica*, *Acanthus sennii* and *Clusia abyssinica*, were observed with different frequencies and abundance in different sub-communities. Two sub-communities were identified, one with three sub-communities and the other with four sub-communities. Prominent species in this community were *Allophylus abyssinicus*, *Bersama abyssinica*, *Capparis tomentosa*, *Carissa spinarum*, *Combretum molle*, *Grewia ferruginea*, *Nuxia congesta* and *Schefflera abyssinica*. It occurred in high values of clay, pH, slope, and high available Phosphorus and to low values of radiation index, altitude, litter, CEC, soil moisture, nitrogen, EC and organic carbon.

Sub-community 3.1: *Calpurnia aurea* - *Vernonia adoensis* - *Albizia schimperiana*

The indicator species of this sub-community, *Calpurnia aurea*, *Vernonia adoensis* and *Albizia schimperiana*, were observed with different frequencies and abundance. It observed in high values of

Clay, pH and slope, and to low values of radiation index, altitude, litter, nitrogen, organic carbon, soil moisture and CEC.

Sub-community 3.11: *Clutia abyssinica*

Clutia abyssinica was an indicator species. *Bersama abyssinica* was observed as a prominent tree species. Other associated species included *Ocimum lamiifolium* and *Vernonia adoensis*. It had relatively high mean number of species per plot and diversity with relatively low evenness, stem density/ha and basal area/ha.

Sub-community 3.12: *Grewia ferruginea*

Grewia ferruginea was an indicator species in this sub-community. Generally, the sub-community had high mean number of species per plot, diversity, evenness and stem density/ha with a relatively low basal area/ha.

Sub-community 3.121: *Allophylus abyssinicus*

Allophylus abyssinicus was an indicator species. *Carissa spinarum*, *Clerodendrum myricoides*, *Osyris quadripartita*, *Phytolacca dodecandra*, *Rhamnus staddo*, *Rosa abyssinica* and *Vernonia sp* were strongly associated species. Relatively, it had a much higher mean number of species per plot, high diversity, evenness, stem density/ha and a low basal area/ha.

Sub-community 3.122: *Galiniera saxifraga*

No indicator species were identified, and the important preferential tree species was used to name the sub-community. *Galiniera saxifraga* was an important preferential tree species in this sub-community. *Flacourtia indica*, *Gnidia glauca*, *Maytenus senegalensis*, *Mimusops kummel*, *Vernonia amygdalina* and *Vernonia hochstetteri* were strongly associated species in this sub-community.

Sub-community 3.2: *Acanthus sennii* - *Osyris quadripartite* - *Dodonea angustifolia* - *Hypericum quartinianum*

The indicator species of this sub-community, *Acanthus sennii*, *Osyris quadripartita*, *Dodonea angustifolia* and *Hypericum quartinianum*, were observed with different frequencies and abundance. The sub-community occurred in high available Phosphorus and low values of slope, pH, CEC, soil moisture, EC, organic carbon, nitrogen, litter, altitude and radiation index.

Sub-community 3.21: *Nuxia congesta* - *Albizia schimperiana* - *Vachellia lahai* - *Vernonia myriantha*, *Clausena anisata* - *Buddleja polystachya*

The indicator species of this sub-community, *Nuxia congesta*, *Albizia schimperiana*, *Vachellia lahai*, *Vernonia myriantha*, *Clausena anisata* and *Buddleja polystachya*, were observed with different frequencies and abundance.

Sub-community 3.211: *Clausena anisate* - *Bersama abyssinica* - *Schrebera alata*

The indicator species of this sub-community, *Clausena anisata*, *Bersama abyssinica* and *Schrebera alata*, were observed with different frequencies and abundance. *Vachellia lahai* was observed as prominent tree species in this sub-community. *Capparis tomentosa* was observed as prominent species in this sub-community. *Abutilon longicuspe*, *Albizia schimperiana*, *Ficus thonningii*, *Rubus steudneri* and *Ximenia americana* were strongly associated species in this sub-community.

Sub-community 3.212: *Nuxia congesta* - *Acanthus sennii*

The indicator species of this sub-community, *Nuxia congesta* and *Acanthus sennii*, were observed with different frequencies and abundance. *Vachellia abyssinica*, *Brucea antidysenterica*, *Buddleja polystachya*, *Croton macrostachyus*, *Helinus mystacinus*, *Olinia rochetiana* and *Stephania cyanantha* were strongly associated species.

Sub-community 3.22: *Combretum molle* - *Dodonea angustifolia* - *Allophylus abyssinicus* - *Clematis hirsuta*

The indicator species of this sub-community, *Combretum molle*, *Dodonea angustifolia*, *Allophylus abyssinicus* and *Clematis hirsuta*, were observed with different frequencies and abundance.

Sub-community 3.221: *Calpurnia aurea* - *Maytenus gracilipes* - *Maesa lanceolata* - *Vernonia adoensis*

The indicator species of this sub-community, *Calpurnia aurea*, *Maytenus gracilipes*, *Maesa lanceolata* and *Vernonia adoensis*, were observed with different frequencies and abundance. *Phoenix reclinata*, *Piliostigma thonningii*, *Rhamnus prinoides*, *Rumex nervosus* and *Ziziphus mucronata* were strongly associated species in this sub-community.

Sub-community 3.222: *Allophylus abyssinicus* - *Combretum molle* - *Premna schimperi*

The indicator species of this sub-community, *Allophylus abyssinicus*, *Combretum molle* and *Premna schimperi*, were observed with different frequencies and abundance. *Vachellia etbaica*, *Vachellia seyal*, *Cadia purpurea*, *Clematis hirsuta*, *Entada abyssinica*, *Hypericum quartinianum*, *Lantana*

triflora, *Myrica salicifolia*, *Myrsine africana*, *Premna schimperi*, *Rhoicissus tridentata*, *Stereospermum kunthianum* and *Syzygium guineense* were strongly associated species in this sub-community. The sub-community had much lower stems/ha, basal area/ha, and mean number of species per plot, with relatively high diversity and evenness.

Community 4: *Dodonea angustifolia*

In this community, species *Dodonea angustifolia* was an indicator species. Other associated species included *Albizia sp.*, *Dregea schimperi*, *Jasminum grandiflorum*, *Lippia adoensis*, *Otostegia integrifolia*, *Searsia pyroides*, *Schrebera alata* and *Steganotaenia araliacea*. A much higher density of 3450 stems/ha with a relative low basal area/ha were recorded. Relatively, it had low mean number of species per plot, diversity and evenness. The community occurred in high clay content of the soil and to low values of available phosphorus, slope, pH, CEC, soil moisture, EC, organic carbon, nitrogen, litter, altitude and radiation index.

3.3.7 Description of herbaceous plant communities

Community 1: *Hypoestes forskoolii* - *Cyperus fischerianus*

The indicator species of this community, *Hypoestes forskoolii* and *Cyperus fischerianus*, were observed with different frequencies and abundance in different sub-communities. Two sub-communities were identified, one with two sub-communities and the other with four sub-communities. Prominent herbaceous species in this community were *Bidens pilosa*, *Girardinia bulbosa*, *Glycine wightii*, *Hypericum peplidifolium*, *Isoglossa somalensis*, *Panicum monticola*, *Pennisetum thunbergii*, *Rhynchosia elegans* and *Thalictrum rhynchocarpum*.

Sub-community 1.1: *Panicum monticola*

Panicum monticola was indicator species in this sub-community. *Hypoestes forskoolii* was observed as prominent species. It related to high values of radiation index, altitude, available phosphorus, litter, EC and nitrogen, and to the low values of organic carbon, soil moisture, CEC, pH, slope and clay.

Sub-community 1.11: *Rhynchosia elegans*

Rhynchosia elegans was indicator species in this sub-community. Other strongly associated species included *Commelina africana*, *Cyperus sesquiflorus*, *Eleusine africana*, *Glycine wightii*, *Gomphocarpus fruticosus*, *Hypericum peplidifolium*, *Pennisetum thunbergii*, *Pennisetum unisetum*,

Tagetes minuta and *Vigna schimperi*. Relatively it had a high mean number of species and evenness with a relatively a much lower diversity.

Sub-community 1.12: *Panicum monticola*

Panicum monticola was indicator species in this sub-community. Other strongly associated species included *Carduus leptacanthus*, *Cyperus sanguinolentus*, *Desmodium repandum*, *Dryopteris lewalleana*, *Eleusine floccifolia*, *Galium spurium*, *Leonotis ocymifolia*, *Mikaniopsis clematoides*, *Orobanche minor*, *Plectranthus lactiflorus*, *Sanicula elata*, *Sida ovata* and *Solanum anguivi*. It had a much lower mean number of species per plot, diversity and evenness.

Sub-community 1.2: *Cyperus fischerianus* - *Bidens pilosa* - *Guizotia scabra* - *Isoglossa somalensis*

The indicator species of this sub-community, *Cyperus fischerianus*, *Bidens pilosa*, *Guizotia scabra* and *Isoglossa somalensis*, were observed with different frequencies and abundance. *Hypoestes forskalii* and *Panicum monticola* were observed as prominent species in this sub-community. It showed relationship to high values of soil moisture, EC, CEC, nitrogen, organic carbon, slope, pH, clay and CEC, and to low values of litter, radiation index, altitude, available phosphorus, clay, slope and pH, and to low values of available phosphorus, altitude, radiation index and litter.

Sub-community 1.21: *Girardinia bullosa* - *Thalictrum rhynchocarpum*

The indicator species of this sub-community, *Girardinia bullosa* and *Thalictrum rhynchocarpum*, were observed with different frequencies and abundance.

Sub-community 1.211: *Kalanchoe petitiiana*

No indicator species were identified, and the important preferential species was used to name the sub-community. *Kalanchoe petitiiana* was important preferential species in this sub-community. Other strongly associated species included *Achyropermum schimperi*, *Aeollanthus abyssinicus*, *Chlorophytum tetraphyllum*, *Cyphostemma adenocaula*, *Hypoestes forskalii*, *Persicaria nepalensis* and *Sida rhombifolia*

Sub-community 1.212: *Cyperus fischerianus* - *Girardinia bullosa* - *Adiantum poiretii* - *Isoglossa somalensis* - *Thalictrum rhynchocarpum* - *Pennisetum unisetum*

The indicator species of this sub-community, *Cyperus fischerianus*, *Girardinia bullosa*, *Adiantum poiretii*, *Isoglossa somalensis*, *Thalictrum rhynchocarpum* and *Pennisetum unisetum*, were observed with different frequencies and abundance. Other strongly associated species included *Arisaema schimperanum*, *Cynoglossum coeruleum*, *Geranium arabicum*, *Hibiscus macranthus*, *Impatiens*

hochstetteri, *Impatiens rothii*, *Lactuca sp.*, *Pavonia sp.*, *Pentas sp.*, *Pilea tetraphyla*, *Rumex nepalensis*, *Setaria pumila* and *Zehneria scabra*.

Sub-community 1.22: *Panicum monticola* - *Guizotia scabra* - *Cyperus fischerianus* - *Bidens pilosa*

The indicator species of this sub-community, *Panicum monticola*, *Guizotia scabra*, *Cyperus fischerianus* and *Bidens pilosa*, were observed with different frequencies and abundance.

Sub-community 1.221: *Bidens prestinaria* - *Snowdenia polystachya*

The indicator species of this sub-community, *Bidens prestinaria* and *Snowdenia polystachya*, were observed with different frequencies and abundance. Other associated species included *Australina flasscida*, *Bidens pilosa*, *Canarina abyssinica*, *Cyperus fischerianus*, *Galinsoga parviflora*, *Selaginella kraussiana*, *Trifolium steudneri* and *Vernonia purpurea*.

Sub-community 1.222: *Guizotia scabra* - *Plectranthus punctatus*

The indicator species of this sub-community, *Guizotia scabra* and *Plectranthus punctatus*, were observed with different frequencies and abundance. Other associated species included *Alchemilla abyssinica*, *Bidens ghedoensis*, *Kosteletzkya adoensis*, *Lactuca inermis*, *Leucas martinicensis*, *Oxalis corniculata* and *Tacca leontopetaloides*.

Community 2: *Bidens prestinaria* - *Trifolium rueppellianum* - *Guizotia scabra*- *Snowdenia polystachya*

The indicator species of this community, *Bidens prestinaria*, *Trifolium rueppellianum*, *Guizotia scabra* and *Snowdenia polystachya*, were observed with different frequencies and abundance in different two sub-communities identified in this community. *Cynodon dactylon* and *Pavonia urens* were prominent herbaceous species observed in this community.

Sub-community 2.1: *Hyperhemia hirta* - *Snowdenia polystachya*

No indicator species were identified, and the important preferential species were used to name the sub-community. *Hyperhemia hirta* and *Snowdenia polystachya* were some of important preferential species in this sub-community. Other associated species included *Andropogon gayanus*, *Bartsia trixago*, *Bidens prestinaria*, *Cyanotis barbata*, *Digitaria abyssinica*, *Euphorbia schimperiana*, *Pimpinella hirtella*, *Satureja punctata*, *Selaginella abyssinica*, *Sporobolus africanus* and *Themeda triandra*. Relatively, it had high mean number of species and a much higher diversity. The sub-

community showed relationship to high values of available phosphorus, clay and altitude, and to low values of slope, pH, CEC, soil moisture, organic carbon, nitrogen, EC, litter and radiation index.

Sub-community 2.2: *Plectranthus punctatus*

Plectranthus punctatus was an indicator species in this sub-community. Other associated species included *Cerastium octandrum*, *Cynodon dactylon*, *Echinochloa pyramidalis*, *Galinsoga quadriradiata*, *Helichrysum schimperi*, *Justicia ladanoides*, *Laggera tomentosa*, *Pavonia urens*, *Plantago lanceolata*, *Trifolium rueppellianum* and *Vicia sativa*. Relatively, it had high mean number of species per plot, diversity and evenness. It related to high values of available Phosphorus, altitude and radiation index, and to low values of slope, pH, CEC, soil moisture, organic carbon, nitrogen, EC and litter.

3.4 Discussion

3.4.1 Plant communities and their composition

This study identified four communities and 16 sub-communities for woody plant species, and two communities and eight sub-communities for herbaceous species. This may indicate that the area has a high floral diversity, but not all communities have a high diversity. Sub-community 3.2 has the lowest mean number of species per plot, stem density/ha and basal area/ha. Community 4 has the highest density/ ha, a small basal area/ha and a relatively small mean number of species per plot, which suggests that this may be a plant association in an early recovery stage because of the dominance of *Dodonaea angustifolia*, a pioneer-like species (Mengistu *et al.*, 2005). The sub-communities of Community 1, except perhaps sub-community 1.2, have a relatively very high basal area/ha, but a low number of species per plot, diversity and evenness. These different observations on the stand composition across sub-communities may indicate the need for different conservation interventions accordingly, thereby to maximize diversity, productivity, stability and sustainability (Table 3.2). In herbaceous communities, relatively high mean number of species per plot, diversity and evenness were observed in sub-communities 1.11, 1.222, 2.1 and 2.2, while the lowest values for these variables were observed in sub-communities 1.12 and 1.211. The observation of the higher mean number of species/plot, diversity and evenness may be related to the stand conditions provided by the overhead layers of tree and/or shrub species. Herbaceous species are dependent on the

conditions of light, humidity and diverse nutrients provided by the upper stand layers, and the substrate (Table 3.5).

According to the organismic concept of plant communities, a plant community could be considered as one organism composed of various species, as recognizable and definable entities which repeat themselves over a given region of the earth's surface (Clements, 1916, 1936). Aerts *et al.* (2016) reported on four woody communities from the central and northern highlands of Ethiopia, namely *Olea-Acacia*, *Juniperus-Olea*, *Juniperus* and *Juniperus-Afrocarpus*. Shrub species were relatively dominating indicator species in all of the reported communities. *Calpurnia aurea*, a shrub species, was reported as one of the top frequent species across all the identified communities and *Dodonea angustifolia* as one of the top indicator species in community *Juniperus-Olea*. Afromontane conifer species *Afrocarpus falcatus* and *Juniperus procera* were reported with low frequency. Similar to this report, the present study also observed *Calpurnia aurea* as one of the top two indicator species in communities 1 and 3, and *Dodonea angustifolia* as the only indicator species in community 4. This may indicate that characteristic tree genera of the Afromontane ecosystem (such as *Olea*, *Juniperus*, *Afrocarpus*, and *Prunus*), were decreasing in their abundance and dominance. Guillozet *et al.* (2015) also reported similar observation about the problem of characteristic Afromontane tree species from Ashoka forest, in southcentral Ethiopia. All the mentioned species, except *Olea capensis* subsp. *macrocarpa*, are basically shade-intolerant species that need disturbed forest conditions, with more light, to regenerate and establish.

Community 4 is dominated by shrub species commonly seen as pioneer species, in disturbed parts of forests. These shrub species included *Dodonea angustifolia*, *Rumex nervosus*, *Jasminum grandiflorum*, *Lippia adoensis* and *Otostegia integrifolia*. Such observation, may possibly indicate the ongoing disturbance and / or degradation in the studied forests. On the other hand, it may possibly indicate also about the development of the former grassland or shrubland towards forest under reduced disturbance. The importance of *Combretum molle* and *Vachellia seyal* in sub-community 3.222 may indicate a change from former woodland vegetation towards forest. *Combretum molle* and *Vachellia seyal* were reported as dominant tree species, in geographically nearby woodland vegetation of this study area in Northwest Ethiopia (Wale *et al.*, 2012a). Yongqi *et al.* (2003), Aerts *et al.* (2004) and Abiyu *et al.* (2017) reported the dominant presence of these species in various degraded forest landscapes. *Nuxia congesta* is also reported as a common species in a disturbed forest (Aerts *et al.*, 2011). In this study, this particular species was observed as indicator species in the sub-community 3.212 *Nuxia congesta* - *Acanthus sennii*. Such observations may also indicate that this forest community is in an earlier stage of forest development, recovering from probably diverse natural/anthropogenic disturbances. However, the stage of development, the severity of disturbance

and/or degradation and the extent of forest change towards woodland or woodland to forest, need further in-depth study.

3.4.2 Plant communities in relation to environmental variables

Nitrogen and radiation index were, statistically, the two highly significant variables at $p < 0.01$, in explaining the total occurrence and distribution pattern of woody species in the study area, but altitude, CEC, litter, phosphorus and soil moisture were also statistically significant at $p < 0.01$. This may indicate that most woody species have shown to occur towards the warmer conditions (towards Southwest aspect) and towards high value of nitrogen, which is an important nutrient for shoot and root growth. Community 1 related to high values of radiation index, altitude, litter, nitrogen and organic carbon, and to low values of pH, slope, clay and available phosphorus. Similarly, as compared to other identified woody communities, this particular community has shown to occur towards warmer conditions and high nitrogen content of the soils. Its observation towards high value of litter, nitrogen and organic carbon, may indicate a relative high biomass production by the dominant species in this particular community. Low evenness value was observed in this community, suggesting the dominance of few species and their associated high biomass production which in turn affect the availability of litter, soil carbon and nitrogen (Whisler *et al.*, 2016).

Community 2 related to high values of pH, slope, CEC and clay, and to low values of available phosphorus, radiation index, altitude, litter, nitrogen, organic carbon, EC and soil moisture. It is related to better-drained soils, toward steeper slopes. Sub-communities 3.11, 3.121 and 3.122 related to high values of clay, pH and slope, and to low values of radiation index, altitude, litter, nitrogen, organic carbon, soil moisture and CEC. These sub-communities related to more fertile soils, due to high clay contents which naturally could adsorb important soil nutrients (such as calcium, magnesium, potassium and sodium). Sub-communities 3.211, 3.212, 3.221 and 3.222 related to high available phosphorus and low values of slope, pH, CEC, soil moisture, EC, organic carbon, nitrogen, litter, altitude and radiation index. The sub-communities were associated with high values of available phosphorus, which may suggest the availability of relatively high values of usable nutrients in the soils. Phosphorus is important to plants in converting other nutrients into usable forms for plants, thereby increasing their nutrient use efficiency. Community 4 related to high clay content of the soil and to low values of available phosphorus, slope, pH, CEC, soil moisture, EC, organic carbon, nitrogen, litter, altitude and radiation index. The observation of this community along the higher clay gradient, possibly indicating the presence of good soil texture and fertile soils in this community (Figure 3.6 and Table 3.3).

Moisture, radiation index, altitude and phosphorus were highly statistically significant environmental variables at $p < 0.01$ in explaining the total composition and distribution of herbaceous species in this study area. CEC, clay, EC, slope, organic carbon, silt, sand, pH, and litters, were statistically non-significant to do so. This maybe an implication that more herbaceous species of the studied forests occurred towards higher elevation facing Southwest orientation and as well as towards soils with higher available phosphorus and soil moisture contents. The availability of more soil moisture may have facilitated for more sedimentation and infiltration of available phosphorus in the herbaceous species composition (Schoumans *et al.*, 2014). Given herbaceous species growing beneath the shadow of woody tree species, a relatively more soil moisture maybe available which inturn may explain most of the observed composition and distribution of herbaceous species.

Herbaceous sub-communities 1.11, 1.12 and 1.211 related to high values of radiation index, altitude, available phosphorus, litter, EC and nitrogen, and to the low values of organic carbon, soil moisture, CEC, pH, slope and clay. These sub-communities occurred towards warmer conditions (towards Southwest orientation). High litter and nitrogen availability maybe the reflection of high biomass production by few dominant species. Low diversity and evenness were observed in these particular sub-communities, reflecting the dominance of few species. Sub-community 1.212 related to high values of soil moisture, EC, CEC, nitrogen and organic carbon, and to low values of litter, radiation index, altitude, available phosphorus, clay, slope and pH. The availability of relatively high soil moisture in these particular sub-communities may play in facilitating to have a relatively better soil EC (nutrient transmission) and CEC (nutrient holding capacity). These particular sub-communities may include those herbaceous species growing in a relatively shadowy places beneath woody tree species. Sub-communities 1.221 and 1.222 related to high values of slope, pH, clay and CEC, and to low values of available phosphorus, altitude, radiation index, litter, EC, nitrogen, organic carbon and soil moisture. They occurred towards in a relatively moisture drained (towards steepy slope) landscapes which have relatively fine soil textures. Sub-community 2.1 related to high values of available phosphorus, clay and altitude, and to low values of slope, pH, CEC, soil moisture, organic carbon, nitrogen, EC, litter and radiation index. This sub-community maybe related to more fertile soils, due to high clay contents which naturally could adsorb important soil nutrients and relatively high usable nutrients due to higher available phosphorus. Sub-community 2.2 related to high values of available Phosphorus, altitude and radiation index, and to low values of slope, pH, CEC, soil moisture, organic carbon, nitrogen, EC and litter. It occurred towards high elevation area which have relatively high phosphorous (Figure 3.9 and Table 3.6).

3.4.3 Relationship between woody and herbaceous communities

The study observed plots of each herbaceous community appeared in a range of woody species communities. Such relationship in their association formation is because of the possibility that trees have species-specific impact on resource availability and soil conditions that in turn influence the understorey diversity and composition (Geldenhuys, 1993; Ampoorter *et al.*, 2014). Most plots of herbaceous sub-community 1.12, with low diversity and evenness, were shared with some woody sub-communities of community 1, which showed relatively low diversity and evenness with high stem density/ha and basal area/ha. Most plots of herbaceous sub-communities 1.11 and 2.1, with relatively high diversity and evenness, were shared with the woody sub-community 3.222, which showed high diversity and evenness with a much lower stem density/ha and basal area/ha. Relatively low diversity and evenness was observed in herbaceous sub-community 1.221 and, a high diversity and evenness with relatively high stem density/ha and low basal area/ha in the associated woody sub-community 3.122. This may indicate the sub-community is a young regrowth forest or mature forest on marginal site conditions. A direct relationship of diversity and evenness among herbaceous and woody communities may indicate the different stages of development of the particular communities in their disturbance-recovery processes. Observations of low diversity and evenness in both shared herbaceous and woody communities may reflect about their late stages in disturbance-recovery processes, particularly on the observed shared plots. On the other hand, the observation of low diversity and evenness in herbaceous communities and, high diversity and evenness in shared woody communities may indicate about the limited resource provisions by tree species in their earlier stage of development, from disturbance-recovery processes. It may be due to high resource competition among woody tree species, fast recovery processes, at the expenses of resources for herbaceous species. Herbaceous species are highly dependent on the upper layer tree species, in resource provisions such as nutrients and shading (Table 3.2 and 3.5).

3.4.4 Common important environmental variables explaining both woody and herbaceous communities

This study tried to identify the common environmental variables that may explain the distribution of both woody and herbaceous communities. Based on the CCA ordination diagrams in Figures 3.6 and 3.9, woody sub-communities of community 1 and herbaceous sub-communities 1.11, 1.12 and 1.211, distributed along high values of radiation index, altitude, litter, nitrogen, organic carbon, EC and to a lesser extent, sand and silt. This may possibly indicate that the distribution and composition of herbaceous species such as *Rhynchosia elegans*, *Panicum monticola* and *Kalanchoe petitiiana* might

have positive relationship with the occurrence and distribution of woody species of *Discopodium penninervium*, *Afrocarpus falcatus*, *Terminalia schimperiana*, *Ekebergia capensis* and *Clausena anisata*.

Woody communities of 2.11, 2.12, 2.2, 3.11, 3.121 and 3.122 and herbaceous communities of 1.221 and 1.222 distributed along high values of clay, slope and pH. This may imply that herbaceous species including *Bidens prestinaria*, *Snowdenia polystachya*, *Guizotia scabra* and *Plectranthus punctatus* might have positive ecological affinity with the occurrence and composition patterns of woody species *Scolopia theifolia*, *Euphorbia abyssinica*, *Schefflera abyssinica*, *Pterolobium stellatum*, *Albizia schimperiana*, *Clusia abyssinica*, *Allophylus abyssinicus* and *Galiniera saxifraga*. Woody community 4 along with sub-communities of 3.211, 3.212 and 3.222, and herbaceous sub-communities 2.1 and 2.2 distributed along high values of Phosphorus and clay. This may also possibly indicate that species of herbaceous communities including *Hypoestes forskalii*, *Snowdenia polystachya* and *Plectranthus punctatus* might have strong ecological affinity with the distribution and composition of woody species such as *Clausena anisata*, *Bersama abyssinica*, *Nuxia congesta*, *Acanthus sennii*, *Allophylus abyssinicus*, *Combretum molle* and *Premna schimperi*. These observations, however, need further in-depth investigation to have detailed knowledge, about the relationship between these particular field and upper layer vascular plant species.

Radiation index may play pivotal role by affecting the temperature conditions of the air and substrate, which in turn may affect the wind, air humidity and evapotranspiration regimes of these forest ecosystems (Piedallu and G'egout, 2008; Košir *et al.*, 2013; Paudel and Vetaas, 2014; Måren *et al.*, 2015). Altitude may influence atmospheric pressure and temperature, which may indirect influence species composition and distribution patterns (Čarni *et al.*, 2011; Kamrani *et al.*, 2011; Samaras, 2015). The influence of nitrogen, phosphorus and soil moisture on the composition of both herbaceous and woody communities may be in terms of plant shoot and root growth, and nutrient use efficiency (Richardson *et al.*, 2009; Franklin *et al.*, 2017; Grogan and Zamin, 2018). Zelnik and Čarni (2008) indicated the importance of the soil moisture gradient in shaping the distribution patterns of herbaceous species.

3.5 Conclusion

This study showed a clear differentiation of woody and herbaceous plant communities in the Afromontane forest of Northwest Ethiopia. They are differentiated on the basis of specific plant species associations, each with one or more indicator species, with clear relationships between the identified vegetation units (communities and sub-communities) of woody and herbaceous species in ordination space of indirect (without environmental variables) and direct gradient analyses (with environmental variables). The calculation of importance values of species across the identified plant associations indicated how the importance of species varied, and that they may be very important in one or more vegetation units, and relatively less important in other units. Similarly, each vegetation unit may have one to several more important species, with many other associated species that may occur across several other vegetation units. One woody vegetation unit may have several associated herbaceous vegetation units, and one herbaceous vegetation unit may occur in more than one woody vegetation unit. Several environmental variables were found to be important in determining the composition and distribution of the woody and herbaceous vegetation units, and their associated species. In particular, the following environmental variables were found to be of particular significance: radiation index (combination of aspect and slope), altitude, nitrogen, available phosphorus and soil moisture. The identified vegetation units show some relationship with other Afromontane forest areas in Ethiopia. There is also some relationship with woodland vegetation, in that former grassland and/or woodland seem to develop towards forest.

The species associations identified through this study, both in terms of woody and herbaceous species, provided a useful framework for zonation of the Afromontane forest vegetation in this biogeographical region in Ethiopia, as basis of better management of these forests. It indicated which of the woody and herbaceous communities are part of mature forest and which associations represent disturbed forest in recovery, or which are degraded forest, and which of the forests are ecologically in a good condition.

In conclusion, the findings of this study may provide base line information about which species naturally grow together be it in terms of herbaceous or woody species, along with their associated gradients. From these findings, this study recommends a need to consider the identified associations and their gradients, during conservation planning in studied forests. The observation of different composition across sub-communities, in terms of number of species, diversity, evenness, stem density/ha and basal area/ha, may indicate and suggest the need for various conservation interventions based on the observed variability. The findings of woody sub-communities with some characteristic species of dry woodland vegetation and secondary scrublands may indicate about the presence of

significant ecosystem fragmentation, degradation and transformation. This also further suggests the need for strong stewardship and conservation efforts of Afromontane species and their habitats. The study also recommends further and long-term studies considering other possible and potential environmental variables, to have in depth understanding about the observed plant community composition and the associated gradients.

References

- Abiyu, A. Teketay, D. Glatzel, G. Aerts, R. and Gratzer, G. (2017). Restoration of degraded ecosystems in the Afromontane highlands of Ethiopia: comparison of plantations and natural regenerations. *Southern Forests*, 79(2), 103-108.
- Adela, M. N. Pourbabaeia, H. Deyb, D. C. (2014). Ecological species group-Environmental factors relationships in unharvested beech forests in the north of Iran. *Ecological Engineering*, 69:1-7.
- Aerts, R. Thijs, K. W. Lehouck, V. Beentje, H. Bytebier, B. Matthysen, E. Gulinck, H. Lens, L. and Muys, B. (2011). Woody plant communities of isolated Afromontane cloud forests in Taita Hills, Kenya. *Plant Ecology*, 212, 639-649.
- Aerts, R. Van Overtveld, K. November, E. Wassie, A. Abiyu, A. Demissew, S. Daye, D. D. Giday, K. Haile, M. TewoldeBerhan, S. Teketay, D. Teklehaimanot, Z. Binggeli, P. Deckers, J. Friis, I. Gratzer, G. Hermy, M. Heyn, M. Honnay, O. Paris, M. Sterck, F. J. Muys, B. Bongers, F. and Healey, J. R. (2016). Conservation of the Ethiopian church forests: threats, opportunities and implications for their management. *Science of the Total Environment*, 551-552, 404-414.
- Aerts, R. Wagendorp, T. November, E. Behailu, M. Deckers, J. and Muys, B. (2004). Ecosystem Thermal Buffer Capacity as an Indicator of the Restoration Status of Protected Areas in the Northern Ethiopian Highlands. *Restoration Ecology*, 12(4), 586-596.
- Alelign, A. Teketay, D. Yemishaw, Y. & Edwards, S. (2007). Diversity and status of regeneration of woody plants on the peninsula of Zegie, Northwestern Ethiopia. *Tropical Ecology*, 48(1), 37-49.
- Ampoorter, E. Baeten, L. Koricheva, J. Vanhellefont, M. and Verheyen, K. (2014). Do diverse overstoreys induce diverse understoreys? Lessons learnt from an experimental-observational platform in Finland. *Forest Ecology and Management*, 318, 206-215.
- Austin, M. P. (1980). Searching for a model for use in vegetation analysis. *Vegetatio*, 42, 11-21.
- Austin, M. P. (2002). Spatial prediction of species distribution: an interface between ecological theory and statistical modelling. *Ecological Modelling*, 157, 101-118.
- Berg, C., Abdank, A., Isermann, M., Jansen, F., Timmermann, T., and Dengler, J. (2014). Red Lists and conservation prioritization of plant communities—a methodological framework. *Applied Vegetation Science*, 17, 504-515.
- Brown, L.R., Du Preez, P.J., Bezuidenhout, H., Bredenkamp, G.J., Mostert, T.H.C. & Collins, N.B. (2013). 'Guidelines for phytosociological classifications and descriptions of vegetation in southern Africa', *Koedoe*, 55(1), Art. #1103, 10 pages. <http://dx.doi.org/10.4102/koedoe.v55i1.1103>.

- Bruce, M & Dylan, K. (2002). Equations for potential annual direct incident radiation and heat load. *Journal of Vegetation Science*, 13, 603-606.
- Čarni, A. Juvan, N. Košir, P. Marinšek, A. Paušič, A & Šil, U. (2011). Plant communities in gradients. *Plant Biosystems*, 145, 54–64.
- Clements, F. E. (1916). *Plant succession: An analysis of the development of vegetation*. Carnegie Institute of Washington Publication, Washington.
- Clements, F. E. (1936). Nature and Structure of Climax. *The Journal of Ecology*, 24(1), 252-284.
- Dalle, G. B. L. Maass, B.L. and Isselstein, J. (2005). Plant communities and their species diversity in the semi-arid rangelands of Borana lowlands, southern Oromia, Ethiopia. *Community Ecology*, 6(2), 167-176.
- Eshete, A. W. (2007). Ethiopian Church Forests: opportunities and challenges for restoration. PhD thesis, Wageningen University, Wageningen, The Netherlands.
- Franklin, O. Cambui, C. A. Gruffman, L. Palmroth, S. Oren, R. and Nasholm, T. (2017). The carbon bonus of organic nitrogen enhances nitrogen use efficiency of plants. *Plant, Cell and Environment*, 40, 25-35.
- Gao, N. Zhou, J. Zhang, X. Cai, W. Guan, T. Jiang, L. Du, H. Yang, D. Cong, Z. Zheng, Y. (2017). Correlation between vegetation and environment at different levels in an arid, mountainous region of China. *Ecology and Evolution*, 1-11.
- Geldenhuys, C. J. (1993). Composition and dynamics of plant communities in the southern Cape forests. FOR-DEA 612, Division of Forest Science and Technology, CSIR, Pretoria. 56.
- Graves, J. H. Peet, R. K. & White, P. S. (2006). The influence of carbon - nutrient balance on herb and woody plant abundance in temperate forest understories. *Journal of Vegetation Science*, 17, 217-226.
- Grogan, P. and Zamin, T. J. (2018). Growth responses of the common arctic graminoid *Eriophorum vaginatum* to simulated grazing are independent of soil nitrogen availability. *Oecologia*, 186, 151-162.
- Guillozet, K. Bliss, J. C. and Kelecha, T.S. (2015). Degradation in an Afromontane Forest in Highland Ethiopia, 1969–2010. *Small-scale Forestry*, 14, 121-137.
- Hill, M. O. & Šmilauer, P. (2005). TWINSPAN for Windows version 2.3. Centre for Ecology and Hydrology & University of South Bohemia, Huntingdon & Ceske Budejovice.

- IBC (Institute of Biodiversity Conservation). (2005). National Biodiversity Strategy and Action Plan. Addis Ababa, Ethiopia.
- Kamrani, A., Jalili, A. Naqinezhad, A. Attar, F. Maassoumi, A. A. and Shaw, S. C. (2011). Relationships between environmental variables and vegetation across mountain wetland sites, N. Iran. *Biologia*, 66(1), 76-87. DOI: 10.2478/s11756-010-0127-2.
- Kent, M. and Coker, P. (1992). *Vegetation Description and Analysis: A practical approach*. Belhaven Press, London.
- Kienast, F. and Krauchi, N. (1991). Simulated successional characteristics of managed and unmanaged low-elevation forests in central Europe. *Forest Ecology and Management*, 42, 49-61.
- Kienast, F. and Kuhn, N. (1989). Simulating forest succession along ecological gradients in southern Central Europe. *Vegetatio*, 79, 7-20.
- Košir, P. Casavecchia, S. Čarni, A. Škvorc, Ž. Zivkovic, L. & Biondi, E. (2013). Ecological and phytogeographical differentiation of oak-hornbeam forests in southeastern Europe. *Plant Biosystems*, 147(1), 84-98, DOI: 10.1080/11263504.2012.717550.
- Lepš, J & Šmilauer, P. (2003). *Multivariate Analysis of Ecological Data Using CANOCO*. Cambridge University Press.
- Magurran, A. E. (2004). *Measuring Biological Diversity*. Blackwell Science Ltd, USA.
- Malanson, G. P. Zimmerman, D. L. Kinney, M. and Fagrez, D. B. (2017). Relations of Alpine Plant Communities across Environmental Gradients: Multilevel versus Multiscale Analyses. *Annals of the American Association of Geographers*, 107(1), 41-53.
- Måren, I.E. Karki, S. Prajapati, C. Yadav, R.K. and Shrestha, B.B. (2015). Facing north or south: Does slope aspect impact forest stand characteristics and soil properties in a semiarid trans-Himalayan valley? *Journal of Arid Environments*, 121, 112-123.
- May, F., Huth, A. & Wiegand, T. (2015). Moving beyond abundance distributions: neutral theory and spatial patterns in a tropical forest. *Proceedings of the Royal Society B: Biological Sciences*, 282, 20141657.
- Mengistu, T. Teketay, D. Hulten, H. and Yemshaw, Y. (2005). The role of enclosures in the recovery of woody vegetation in degraded dryland hillsides of central and northern Ethiopia. *Journal of Arid Environments*, 60, 259-281.

- Minissale, P. & Sciandrello, S. (2016). Ecological features affect patterns of plant communities in Mediterranean temporary rock pools. *Plant Biosystems*, 150(1), 171-179.
- Netto, S.P. Amaral, M.K. and Coraiola, M. (2015). A new index for assessing the value of importance of species –VIS. *Anais da Academia Brasileira de Ciências*, 87(4), 2265-2279.
- Palo, A. Ivask, M. and Liira, J. (2013). Biodiversity composition reflects the history of ancient semi-natural woodland and forest habitats - Compilation of an indicator complex for restoration practice. *Ecological Indicators*, 34, 336-344.
- Paudel, S, and Vetaas, O. R. (2014). Effects of Topography and Land use on Woody Plant Species Composition and Beta Diversity in an Arid Trans-Himalayan Landscape, Nepal. *Journal of Mountain Science*, 11(5), 1112-1122.
- Piedallu, C. and Gégout, J-C. (2008). Efficient assessment of topographic solar radiation to improve plant distribution models. *Agricultural and Forest Meteorology*, 148, 1696-1706.
- Richardson, A. E. Barea, J-M. McNeill, A. M. and Prigent-Combaret, C. (2009). Acquisition of phosphorus and nitrogen in the rhizosphere and plant growth promotion by microorganisms. *Plant Soil*, 321, 305-339.
- Safont, E. Vegas-vilarrúbia, T. Rull, V. Holst, B. K. Huber, O. Nozawa, S. Vivas, Y. Font, X. & Silva, A. (2016). Plant communities and environmental factors in the Guayana Highlands: monitoring for conservation under future climate change. *Systematics and Biodiversity*, 14(4), 327-344.
- Samaras, D. A. Gaertner, S. Reif, A. and Theodoropoulos, K. (2015). Drought effects on the floristic differentiation of Greek fir forests in the mountains of central Greece. *IForest*, 8, 786-797.
- Schoumans, O. F. Chardon, W. J. Bechmann, M. E. Gascuel-Oudou, C. Hofman, G. Kronvang, B. Rubæk, G. H. Uléng, B. and Dorioz, J. -M. (2014). Mitigation options to reduce phosphorus losses from the agricultural sector and improve surface water quality: A review. *Science of the Total Environment*. 468-469, 1255-1266.
- Sekulova, L. Hajek, M. & Syrovatka, V. (2013). Vegetation–environment relationships in alpine mires of the West Carpathians and the Alps. *Journal of Vegetation Science*, 24, 1118-1128.
- Seymour, C.L. Joseph, G.S. Makumbe, M. Cumming, G.S. Mahlangu, Z. and Cumming, D.H.M. (2016). Woody species composition in an African savanna: determined by centuries of termite activity but modulated by 50 years of ungulate herbivory. *Journal of Vegetation Science*, 27, 824-833.

- Šmilauer, P. (2002). WCanImp Help File. Biometrics-Plant Research International, Wageningen University and Research Centre, The Netherlands.
- Steinaker, D.F Jobbagy, E.G. Martini, J.P. Arroyo, D.N. Pacheco, J.L. and Marchesini, V.A. (2016). Vegetation composition and structure changes following roller-chopping deforestation in central Argentina woodlands. *Journal of Arid Environments*, 133, 19-24.
- Tarmi, S. & Hyvönen, T. (2012). Plant Species Diversity and Composition of Plant Communities in Buffer Zones with Variable Management Regimes. *Sustainable Agriculture Research*, 1(2): 152-161.
- ter Braak, C. J. F. & Šmilauer, P (2012). Canoco Reference Manual and Users Guide: Software for Ordination, Version 5.0. Microcomputer Power, Ithaca, New York.
- ter Braak, C. J. F. and Šmilauer, P. (2002). Canoco version 4.5. Biometrics, Plant Research International, Wageningen, The Netherlands.
- Tsheboeng, G. Hudson, M. M. and Kashe, K. (2016). A baseline classification of riparian woodland plant communities in the Okavango Delta, Botswana. *Southern Forests*, 78(2), 97-104
- van der Maarel, E. (1979). Transformation of cover abundance values in phytosociology and its effect on Community. *Vegetatio*, 39 (2), 97-114.
- van der Maarel, E. (2005). Vegetation ecology-an overview. In: van der Maarel, E. (ed.). *Vegetation Ecology*. Oxford, Blackwell Publishing, 1-51.
- Wale, H.A. (2006). Study on Indigenous Tree and Shrub Species of Churches, and Monasteries of Wag-Lasta districts. Proceedings of the 1st Annual Regional Conference on Completed Research Activities on Natural Resources Management. 14-17 August 2006, Amhara Regional Agricultural Research Institute, Bahir Dar, Ethiopia.
- Wale, H. A. Bekele, T. and Dalle, G. (2012a). Floristic Diversity, Regeneration Status and Vegetation Structure of the Woodland Vegetation in Metema Area, Amhara National Regional State, Northwestern Ethiopia. *Journal of Forestry Research*, 23(3), 391-398.
- Wale, H. A., Bekele, T., & Dalle, G. (2012b). Plant Community and Ecological Analysis of the Woodland Vegetation in Metema Area, Amhara National Regional State, Northwestern Ethiopia. *Journal of Forestry Research*, 23(4), 599-607. DOI: 10.1007/s11676-012-0300-2.
- Wassie, A. Sterck, F. J. & Bongers, F. (2010). Species and structural diversity of church forests in a fragmented Ethiopian Highland landscape. *Journal of Vegetation Science*, 21, 938-948. DOI: 10.1002/9781118445112.stat07684.

- Wassie, A. (2017). Forest Resources in Amhara: Brief Description, Distribution and Status. In: Stave, K. Goshu, G. and Aynalem, S. (eds.) Social and Ecological System Dynamics. AESS Interdisciplinary Environmental Studies and Sciences Series. Springer, Cham.
- Whisler, K.M. Rowe, H.I. and Dukes, J.S. (2016). Relationships among land use, soil texture, species richness, and soil carbon in Midwestern tallgrass prairie, CRP and crop lands. *Agriculture, Ecosystems and Environment*, 216, 237-246.
- Willner, W. Kuzemko, A. Dengler, J. Chytry, M. Bauer, N. Becker, T. Bitá-Nicolae, C. Botta-Dukat, Z. Cami, A. Csiky, J. Igić, R. Kacki, Z. Korotchenko, I. Kropf, M. Krstivojević-Cuk, M. Krstonosić, D. Redei, T. Ruprecht, E. Schrott-Ehrendorfer, L. Semenishchenkov, Y. Stancic, Z. Vashenyak, Y. Vynokurov, D. and Janisova, M. (2017). A higher-level classification of the Pannonian and western Pontic steppe grasslands (Central and Eastern Europe). *Applied Vegetation Science*, 20, 143-158.
- Yongqi, L. Shengxi, L. Dachang, L. Jun, L. Jianrong, S. and Yanping. (2003). Reclaiming Degraded Forest lands in the Dry, Hot Climate of Yuanmou County, China. In: Dachang, L. ed. Rehabilitation of Degraded Forests to Improve Livelihoods of Poor Farmers in South China. Center for International Forestry Research, Bogor, Indonesia, 29-43.
- Zegeye, H., Teketay, D., & Kelbessa, E. (2011). Diversity and regeneration status of woody species in Tara Gedam and Abebaye forests, Northeastern Ethiopia. *Journal of Forestry Research*, 22(3): 5–328.
- Zelnik, I. and Carni, A. (2008). Distribution of plant communities, ecological strategy types and diversity along a moisture gradient. *Community Ecology*, 9(1), 1-9.

Appendices

Appendix 3.1 TWINSPAN classification output of woody plant species in the study area

(Forests: A = Alem Saga, B = Gelawudiwos and C = Tara Gedam)

Community Forests	1.11	1.12	1.211	1.212	1.22	2.11	2.12	2.2	3.11	3.121	3.122	3.211	3.212	3.221	3.222	4	
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74 Afro fal	-----11-----1--1212-	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1110
73 Pitt aby	1-----1-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1110
64 Olea cap	122 1121212-1122121312	-2212-221121121	111-1112	-----11121	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1110
48 Jasm aby	-----	-----1-----	-----	-----1-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1110
39 Ficu syc	--2 --1-----	-----1-----	-----1--	1-----1-	--1--1-	1--	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1110
37 Euph aby	443 2---1422-3-21---13	311-1-----1-3	2--2-----	-----2-1-	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1110
35 Embe sch	-- 21-----1-----112-	-----1--	2--12-2-	1-1-1-1-	--2--	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1110
31 Dovy aby	21- 111-211--2111-2111	-1122--111-221-	-----11--	-2-22123	11-----	--2-	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1110
104 Vern myr	332 --2111122-322121--	3111--212-111-	352-1-42	1-----	1-----	-----	-----	-----	-----	-----	-----	2123231--1	3222-1-221--	212----	-----	-----	110
98 Tecl nob	1-2 1-222-113122-22-22	1---211-25--22	2112-211	11--2113	-21122	--2-	334-22	-1--	-----	-----	-----	-----	-----	-----	-----	-----	110
89 Sche aby	-----1-11--1-1-1-	-----1-----	-----1-	-----1-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	110
69 Peri lin	-----	-----	-----	-----1-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	110
56 Mayt gra	154 15555554314314555	52555435455215-	55255535	55543554	432423	2211	232513	12121	--1	1112---1222121212	1--2421-1-	11222-134121	1212332	22---2-1-11--1-2-1-	-----	-----	110
38 Ficu sur	-----1-----1--1-	-----1-----	-----1-1-1-	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	110
34 Ekeb cap	-----11--112--1-1-1-	-----1-12-----	21111-11	21--1--	1-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	110
93 Sola ind	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1011
91 Scol the	-----1-----	221-----	-----1	-----1-	-42332	-13	131211	33--	--2	-----	-----	-----	-----	-----	-----	-----	1011
58 Mayt und	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1011
57 Mayt sen	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1011
17 Cant oli	1-- 1-----1-1-1-12	2-2-----11	-----1	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1011
54 Maes lan	-- 1-----111-2--	-----1-----11-	1-----	1-----	1-----	1-----	1234	-----	--12	-----	-----	-----	-----	-----	-----	-----	1010
50 Juni pro	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1010
11 Bers aby	3-- --22--2-1-2-1-21	2-2--11-11--1	21--122-	2-1--2--	2222-2	-223	22211-	12133	1-1	42---1--12-1-122	22-2-3-2-1	-1---1-1111	1111--1	--1-111-	-----	-----	1010
10 Apod dim	-----	-----1-2--11-1-	1-1-----	-----1-----	1-1-11	1--	-1-11-	-1-1-	-----	-----	-----	-----	-----	-----	-----	-----	1010
51 Just sch	-----	-----1-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	100
30 Domb tor	-----	-----1-1--1-	2--11--1--11-11	1-11111	-1-1-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	100
26 Comb mol	-1 1-----1-111-	-----2-1-1-1-111	-21--3--	-----2-1	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	100
16 Calp aur	12- 323254244444-53443	-21--1-1211-111	1-----	-----2-3	1-1--2	1221	1111--	21222	11-	-34-333343222233	111-1-111-	-----1-21--2-	113432-	-1-----11-----	-----	-----	100
101 Vern ado	-----	-----	-----	-----	-24353	-222	1-1112	13552	--2	-----	-----	-----	-----	-----	-----	-----	0111
92 Sola gig	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	0111
78 Pter ste	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	0111
46 Hete arb	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	0111
42 Gali sax	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	0111
7 Albi sch	-- 1-11--1-1-11--	-----1-21--2--	1-----	-----212--12	3-2--	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	0111
102 Vern amy	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	0110
65 Olea eur	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	0110
55 Mayt arb	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	0110
25 Clut lan	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	0110
84 Ritc alb	-----1-----	1-----1-	21--1--	--1--2-	1-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	0101
71 Phyt dod	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	0101
27 Crot mac	--1 -----11-1--11-11-	-----1-11-1-	-12-1--2	211--1	1--1-	--1	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	0101
24 Clut aby	--1 411122-13222-1-111	111---1-----1	1-1-2--	--1----	221--2	1211	--1--	43355	213	11-1--23--1-212	2-11121-1-	24-11--13-11	143-2-1	111-3123132131-31--3-	-----	0101	

21	Clau	ani	1-2	11-1----	2211122--1	2--11--1-1--211	11--22-1	14541542	112-4-	1211	23--41	331-2	---	4124525-22222-412	44214-3354	-23-21----	-31	-1-1----	-31----	-2-212--	-221--2-	2-----	0101
19	Cari	spi	---	-21--1-----	1--	43--23-1--4-13-	1-111---	1-1554--	121221	11-2	12-221	113--	331	242221-12-221--22	2---112231	1-11112212-1	21-2113	1-122121211122121-1-11	321131				0101
87	Rubu	ste	---	-----	-----	-----	-----	1-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	0100
85	Rosa	aby	---	-----11--1-111-	2-----2--1--1-	2-----	-----1-	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	0100
18	Capp	tom	---	-----1-2--1-1-1-1-	-----	-----	-----	1-----	424--15	-----	11--	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	0100
1	Abut	lon	---	-----	-----	-----	-----	2-1-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	0100
63	Ocim	lam	---	2-----	-----1-	1-----	-----	1-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00111
62	Nuxi	con	---	-----1-----	-----1-	-----	-----	-----1-1-	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00111
20	Celt	afra	---	-----	-----	-----	-----	-----	1-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00111
2	Vach	aby	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00111
81	Rhoi	tri	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00110
33	Dreg	sch	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00110
22	Clem	hir	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00110
13	Bruc	ant	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00110
6	Acan	sen	2-1	-----11-3--2	-----	1--1--	-----	-2--1	2-1--1	11--	11--	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00110
94	Steg	ara	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00101
88	Rume	ner	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00101
82	Sear	pyr	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00101
68	Otos	int	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00101
53	Lipp	ado	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00101
49	Jasm	gra	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00101
44	Grew	fer	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00101
29	Dodo	ang	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00101
8	Albi	spp	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00101
90	Schr	ala	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00100
80	Rham	sta	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00100
61	Myrs	afra	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00100
23	Cler	myr	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00100
9	Allo	aby	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00100
97	Syzy	gui	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00101
75	Prem	sch	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00011
67	Osyra	qua	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00011
43	Gnid	gla	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00011
14	Budd	pol	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00011
105	Vern	spp	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00010
103	Vern	hoc	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00010
70	Phoe	rec	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00010
59	Mimu	kum	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00010
41	Flac	ind	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00010
107	Zizi	muc	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00001
106	Xime	ame	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00001
96	Ster	kun	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00001
95	Step	cya	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00001
79	Rham	pri	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00001
72	Pili	tho	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00001
60	Myri	sal	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00001
52	Lant	tri	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00001
47	Hype	qua	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00001
45	Heli	mys	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00001
40	Ficu	tho	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00001
36	Enta	aby	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00001
15	Cadi	pur	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00001
5	Vach	sey	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00001
4	Vach	lah	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00001
3	Vach	etb	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00001
66	Olin	roc	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	00000
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Appendix 3.2 Importance values (IV) in percentages of woody species across all communities and sub-communities.

Note that IV calculated based on the mean values of relative basal area, relative density and relative frequency). * = species associated with woodland.

Community Types	1.1	1.1	1.21	1.21	1.2	2.1	2.1	2	3.1	3.12	3.12	3.21	3.21	3.22	3.22	
No. of Plots	3	18	15	8	8	6	4	6	5	3	17	10	12	7	22	6
<i>Abutilon longicuspe</i>	-	-	-	-	0.7	-	-	-	-	-	0.1	0.7	0.2	-	-	-
<i>Acanthus sennii</i>	2.9	0.9	0.4	0.8	1.0	0.8	1.4	0.8	3.5	0.9	1.7	4.4	13.4	9.5	9.1	0.5
<i>Afrocarpus falcatus</i>	-	1.4	-	-	-	-	0.7	-	-	-	-	-	-	-	-	-
<i>Albizia schimperiana</i>	-	1.0	1.6	0.3	6.7	1.6	-	6.2	3.6	0.9	5.3	7.5	3.4	0.8	1.3	1.7
<i>Albizia sp.</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.5
<i>Allophylus abyssinicus</i>	-	-	-	-	-	0.5	-	3.0	4.3	14.1	2.7	0.9	0.4	0.4	3.1	2.8
<i>Apodytes dimidiata</i>	-	-	2.0	0.7	1.3	3.8	0.7	1.2	0.9	-	1.0	-	-	0.8	-	-
<i>Bersama abyssinica</i>	2.1	1.9	1.5	2.3	1.1	3.0	4.6	2.4	10.	2.1	2.1	2.3	1.3	1.8	0.8	-
									3							
<i>Bridelia micrantha*</i>	-	0.3	1.6	0.7	0.7	-	-	-	-	-	-	0.3	0.3	-	-	-
<i>Brucea antidysenterica</i>	-	-	-	-	-	0.4	1.4	0.4	-	-	0.1	0.8	1.4	0.4	-	-
<i>Buddleja polystachya</i>	-	-	-	-	0.3	-	-	-	-	-	1.5	1.6	1.6	-	0.2	0.5
<i>Cadia purpurea</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	-
<i>Calpurnia aurea</i>	3.0	10.	2.1	0.7	2.7	1.6	3.7	1.6	3.6	1.9	6.5	1.6	1.4	5.7	0.4	2.1
		6														
<i>Canthium oligocarpum</i>	1.1	2.3	0.9	0.7	-	0.4	-	4.3	0.4	0.9	0.7	-	-	1.6	-	0.5
<i>Capparis tomentosa</i>	-	1.1	-	0.7	4.8	0.4	1.4	0.4	-	-	1.0	11.8	2.1	0.7	1.9	-
<i>Carissa spinarum</i>	-	0.8	3.7	1.4	6.9	3.7	2.5	3.4	3.2	13.0	3.7	2.3	2.5	3.3	3.8	6.1
<i>Celtis africana</i>	-	-	-	-	-	0.4	-	-	-	-	0.3	0.2	-	-	-	-
<i>Clausena anisata</i>	3.1	2.0	1.7	2.2	8.0	3.2	3.2	3.7	3.1	-	7.7	6.9	2.2	0.7	2.4	0.7
<i>Clematis hirsuta</i>	-	0.2	0.2	-	0.6	-	-	-	0.4	-	-	-	0.4	0.7	1.5	1.1
<i>Clerodendrum myricoides</i>	-	0.2	0.2	-	0.3	0.5	0.7	-	1.1	3.2	2.0	0.7	0.8	0.8	1.0	0.5
<i>Clutia abyssinica</i>	1.1	3.5	1.0	1.2	0.3	2.4	3.0	0.4	11.	4.5	1.6	1.7	3.2	4.1	3.9	-
									7							

Community Types	1.1	1.1	1.21	1.21	1.2	2.1	2.1	2	3.1	3.12	3.12	3.21	3.21	3.22	3.22	
	1	2	1	2	2	1	2	.2	1	1	2	1	2	1	2	4
No. of Plots	3	18	15	8	8	6	4	6	5	3	17	10	12	7	22	6
<i>Clutia lanceolata</i>	-	-	-	-	-	-	1.0	-	-	0.9	0.3	-	-	-	0.3	-
<i>Combretum molle*</i>	1.1	0.8	1.4	1.5	0.7	-	-	0.4	-	-	0.4	-	-	0.4	10.3	2.6
<i>Croton macrostachyus</i>	1.1	1.5	0.8	2.8	5.4	1.4	1.1	-	0.9	0.9	4.6	2.8	6.8	3.6	2.7	1.6
<i>Discopodium penninervium</i>	3.3	-	0.4	1.0	-	-	-	-	-	-	-	-	-	-	-	-
<i>Dodonea angustifolia</i>	-	-	-	0.3	-	-	-	-	-	5.8	0.4	0.9	1.8	2.1	6.1	40.3
<i>Dombeya torrida</i>	-	0.8	1.8	5.4	0.7	11.0	0.7	0.4	2.1	2.9	1.2	0.4	-	1.2	0.1	-
<i>Dovyalis abyssinica</i>	4.0	3.0	3.1	1.6	3.2	0.9	0.9	-	-	-	0.3	-	0.2	-	-	-
<i>Dracaena steudneri</i>	-	-	-	-	0.3	-	-	-	-	-	-	-	-	-	-	-
<i>Dregea schimperi</i>	-	0.2	-	-	-	-	-	-	-	-	-	-	-	-	0.2	0.5
<i>Ekebergia capensis</i>	-	1.8	0.8	16.8	2.3	0.4	-	0.4	0.9	-	4.1	0.2	0.2	-	0.3	-
<i>Embelia schimperi</i>	-	1.1	0.2	1.6	1.4	0.5	-	0.4	0.4	-	0.2	-	-	-	0.2	-
<i>Entada abyssinica</i>	-	-	-	-	-	-	-	-	-	-	0.1	0.2	-	-	1.5	-
<i>Euphorbia abyssinica</i>	21.9	5.1	2.3	1.8	0.8	-	2.7	-	-	-	-	-	-	0.7	-	-
<i>Ficus sur</i>	-	1.2	1.1	3.4	0.6	5.2	-	-	-	-	0.1	-	0.2	-	-	-
<i>Ficus sycomorus*</i>	4.2	0.2	0.2	0.7	1.5	0.8	1.8	-	-	-	-	-	-	-	-	-
<i>Ficus thonningii*</i>	-	-	-	-	-	-	-	-	-	-	-	0.2	-	-	-	-
<i>Flacourtia indica</i>	-	-	-	-	-	-	-	-	-	-	0.2	-	0.2	-	-	-
<i>Galiniera saxifraga</i>	-	-	-	-	-	1.7	2.4	3.0	0.9	-	2.9	-	0.3	0.4	-	-
<i>Gnidia glauca</i>	-	-	-	-	-	-	-	-	-	-	0.8	0.5	0.3	-	0.3	-
<i>Grewia ferruginea</i>	-	-	-	-	0.6	0.5	0.7	0.6	-	11.7	3.7	2.1	2.7	1.8	3.0	3.6
<i>Helinus mystacinus</i>	-	-	-	-	-	-	-	-	-	-	-	0.2	0.2	-	-	-
<i>Heteromorpha arborescens</i>	-	-	-	-	-	0.4	-	-	0.4	-	0.1	-	-	-	-	-
<i>Hypericum quartinianum</i>	-	-	-	-	0.3	-	-	-	0.7	1.4	0.1	0.9	1.8	1.7	1.9	0.5
<i>Jasminum abyssinicum</i>	-	0.2	-	-	0.3	-	-	0.4	-	-	-	-	-	-	-	-
<i>Jasminum grandiflorum</i>	-	-	-	-	-	-	-	-	0.4	-	0.8	0.4	0.7	1.4	1.3	3.1

Community Types	1.1	1.1	1.21	1.21	1.2	2.1	2.1	2	3.1	3.12	3.12	3.21	3.21	3.22	3.22	
No. of Plots	1	2	1	2	2	1	2	.2	1	1	2	1	2	1	2	4
<i>Juniperus procera</i>	-	-	-	-	-	4.9	10.	-	-	-	-	-	-	5.2	0.1	-
							9									
<i>Justicia schimperiana</i>	-	-	0.2	0.3	-	-	-	-	-	-	0.1	-	0.2	-	-	-
<i>Lantana triflora</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	-
<i>Lippia adoensis</i>	-	0.2	-	-	-	-	-	-	-	-	0.1	1.2	0.9	0.4	0.7	2.7
<i>Maesa lanceolata</i>	-	0.9	0.7	0.4	0.3	0.9	8.7	-	1.3	-	0.1	0.7	1.5	1.9	0.3	-
<i>Maytenus arbutifolia</i>	-	-	-	-	-	-	-	3.1	2.1	-	-	0.4	-	-	-	-
<i>Maytenus gracilipes</i>	12.	16.	18.0	20.3	13.	8.6	3.6	7.2	3.0	0.9	2.7	2.2	4.0	4.0	1.9	0.5
	4	7			5											
<i>Maytenus senegalensis*</i>	-	-	-	-	-	1.2	-	2.5	0.8	0.9	3.9	-	-	-	-	-
<i>Maytenus undata*</i>	-	-	-	-	-	3.6	2.1	1.8	1.6	1.1	0.1	-	-	-	-	-
<i>Mimusops kummel</i>	-	-	-	-	-	-	-	-	-	-	0.8	-	-	-	-	-
<i>Myrica salicifolia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7.5	-
<i>Myrsine africana</i>	-	-	-	-	-	0.6	-	0.4	1.7	-	1.4	-	0.4	-	1.7	-
<i>Nuxia congesta</i>	-	0.4	0.2	-	1.4	1.9	0.7	3.8	6.6	2.4	5.0	2.4	12.0	1.4	1.3	1.9
<i>Ocimum lamiifolium</i>	-	0.4	0.4	-	0.6	-	-	-	1.3	0.9	0.7	0.2	1.0	1.1	0.3	-
<i>Olea capensis</i> subsp. <i>macrocarpa</i>	14.	18.	18.8	7.7	6.1	-	-	-	-	-	-	-	-	-	-	-
	4	3														
<i>Olea europaea</i> subsp. <i>cuspidata</i>	-	-	-	-	2.4	6.1	20.	13.	9.8	2.6	1.5	0.2	0.4	3.5	2.5	5.2
							3	8								
<i>Olinia rochetiana</i>	-	-	-	-	0.6	-	-	-	-	-	0.2	0.2	1.7	-	0.4	-
<i>Osyris quadripartita</i>	-	-	-	-	0.3	1.5	-	-	-	4.7	1.2	1.5	2.4	2.0	3.5	2.2
<i>Otostegia integrifolia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	2.2
<i>Periploca linearifolia</i>	-	-	-	-	0.7	0.4	-	-	-	-	0.1	-	-	-	0.1	-
<i>Phoenix reclinata</i>	-	-	-	-	-	-	-	-	-	-	0.3	-	-	0.4	-	-
<i>Phytolacca dodecandra</i>	-	0.2	-	-	0.5	-	-	-	-	0.9	0.1	0.5	-	-	-	-
<i>Piliostigma thonningii*</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	-	-
<i>Pittosporum abyssinicum</i>	1.1	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Premna schimperi</i>	-	-	-	-	-	-	-	0.9	0.9	1.7	2.6	1.5	1.2	1.5	4.2	0.5

Community Types	1.1	1.1	1.21	1.21	1.2	2.1	2.1	2	3.1	3.12	3.12	3.21	3.21	3.22	3.22	
	1	2	1	2	2	1	2	.2	1	1	2	1	2	1	2	4
No. of Plots	3	18	15	8	8	6	4	6	5	3	17	10	12	7	22	6
<i>Prunus africana</i>	3.5	0.5	11.3	1.1	7.5	-	-	-	-	-	-	-	-	-	-	-
<i>Prunus persica</i>	1.1	0.3	1.2	1.8	1.5	0.4	-	-	-	-	0.5	0.3	-	-	-	-
<i>Pterolobium stellatum</i>	-	-	-	-	-	0.8	1.6	12.	1.5	0.9	2.3	-	0.2	0.7	-	0.5
								2								
<i>Rhamnus prinoides</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	-	-
<i>Rhamnus staddo</i>	-	-	-	-	-	-	1.4	-	0.4	3.8	1.5	-	0.3	0.8	-	3.4
<i>Rhoicissus tridentata</i>	-	0.2	0.2	-	-	0.4	-	-	0.4	-	0.3	-	0.2	0.4	0.8	-
<i>Rhynchosia resinosa</i>	-	-	0.2	0.4	0.8	-	-	-	-	-	-	-	-	-	-	-
<i>Ritchiea albersii</i>	-	0.2	0.5	2.4	0.7	0.4	2.0	1.0	0.4	-	0.6	0.2	0.4	-	1.7	-
<i>Rosa abyssinica</i>	-	1.0	1.0	0.5	0.4	-	0.7	-	1.1	2.9	0.4	1.1	1.5	1.1	1.8	-
<i>Rubus apetalus</i>	-	-	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Rubus steudneri</i>	-	-	-	-	0.3	-	-	-	-	-	-	0.4	-	-	-	-
<i>Rumex nervosus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.2
<i>Schefflera abyssinica</i>	-	10.	0.4	0.3	0.3	-	2.7	1.4	-	-	-	0.2	0.3	23.7	-	0.5
		3														
<i>Schrebera alata</i>	-	-	-	-	-	0.8	-	0.4	1.0	1.2	1.8	1.9	0.8	0.7	0.8	2.6
<i>Searsia pyroides</i>	-	-	-	-	-	1.0	-	0.4	1.2	3.5	3.5	2.1	2.1	1.4	4.4	5.0
<i>Scolopia theifolia</i>	-	0.2	0.7	0.4	0.4	7.9	4.0	4.1	3.0	3.2	1.8	-	-	-	-	-
<i>Solanum giganteum</i>	-	-	-	-	0.3	1.3	-	-	0.5	-	0.4	-	0.6	-	-	-
<i>Solanum indicum</i>	-	-	-	-	-	-	0.9	0.4	-	-	0.1	-	-	-	-	-
<i>Steganotaenia araliacea</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.9
<i>Stephania cyanantha</i>	-	-	-	-	-	-	-	-	-	-	-	-	0.2	-	-	-
<i>Stereospermum kunthianum</i>	-	-	-	-	-	-	-	-	-	-	0.1	0.3	-	-	0.7	-
<i>Syzygium guineense</i>	-	-	-	-	-	-	-	-	-	-	0.1	-	-	-	0.3	-
<i>Teclea nobilis</i>	4.5	3.3	4.2	3.3	4.0	3.0	1.7	9.1	0.4	-	0.7	0.2	-	-	-	-
<i>Terminalia schimperiana*</i>	5.2	1.6	9.1	2.7	1.5	-	-	-	-	-	-	-	-	-	-	-
<i>Urera hypselodendron</i>	1.5	0.3	1.2	2.9	1.6	0.4	-	0.8	-	-	-	0.4	-	-	-	-
<i>Vachellia abyssinica</i>	-	-	-	-	-	-	-	0.4	0.4	0.9	0.1	-	3.0	0.4	-	-
<i>Vachellia etbaica*</i>	-	-	-	-	-	-	-	-	-	-	-	0.9	0.7	1.0	3.1	-

Community Types	1.1	1.1	1.21	1.21	1.2	2.1	2.1	2	3.1	3.12	3.12	3.21	3.21	3.22	3.22	
	1	2	1	2	2	1	2	.2	1	1	2	1	2	1	2	4
No. of Plots	3	18	15	8	8	6	4	6	5	3	17	10	12	7	22	6
<i>Vachellia lahai</i> *	-	-	-	-	0.7	-	-	-	-	-	3.2	25.0	10.6	-	0.3	-
<i>Vachellia seyal</i> *	-	-	-	-	-	-	-	-	-	-	-	-	0.2	-	3.2	-
<i>Vernonia adoensis</i>	-	-	-	-	-	7.5	3.4	2.1	7.6	1.4	1.3	-	0.2	1.4	-	-
<i>Vernonia amygdalina</i>	-	-	0.2	0.4	-	-	-	0.8	-	-	1.3	-	0.4	-	-	-
<i>Vernonia hochstetteri</i>	-	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-	-
<i>Vernonia myriantha</i>	7.5	2.7	2.3	6.3	0.3	0.4	0.7	-	-	-	-	2.7	2.4	1.5	0.1	-
<i>Vernonia sp</i>	-	-	-	-	-	-	-	-	-	1.1	-	-	-	-	-	-
<i>Ximения americana</i> *	-	-	-	-	-	-	-	-	-	-	-	0.2	-	-	0.1	-
<i>Ziziphus mucronata</i> *	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	-	-

Appendix 3.3 Relative frequency in percentages for woody species across all communities and sub-communities

Community Types	1.1	1.1	1.21	1.21	1.2	2.1	2.1	2	3.1	3.12	3.12	3.21	3.21	3.22	3.22	
No. of Plots	1	2	1	2	2	1	2	.2	1	1	2	1	2	1	2	4
	3	18	15	8	8	6	4	6	5	3	17	10	12	7	22	6
<i>Abutilon longicuspe</i>	-	-	-	-	0.5	-	-	-	-	-	0.1	0.5	0.2	-	-	-
<i>Acanthus sennii</i>	3.5	1.1	0.2	0.7	0.7	0.7	1.5	0.6	3.2	0.8	2.4	8.4	33.2	24.0	22.1	0.4
<i>Afrocarpus falcatus</i>	-	0.9	-	-	-	-	0.7	-	-	-	-	-	-	-	-	-
<i>Albizia schimperiana</i>	-	0.6	0.6	0.2	1.8	2.5	-	5.3	1.9	0.8	6.6	3.4	2.3	0.9	0.6	1.1
<i>Albizia sp.</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.7
<i>Allophylus abyssinicus</i>	-	-	-	-	-	0.4	-	1.4	1.6	13.2	1.1	0.6	0.4	0.3	3.1	2.8
<i>Apodytes dimidiata</i>	-	-	0.9	0.5	0.2	1.5	0.7	0.8	0.6	-	1.6	-	-	0.9	-	-
<i>Bersama abyssinica</i>	3.5	1.5	1.1	1.8	0.8	4.4	8.8	2.5	5.2	1.6	2.5	2.3	1.1	1.5	0.6	-
<i>Bridelia micrantha</i>	-	0.2	1.1	0.5	0.3	-	-	-	-	-	-	0.3	0.2	-	-	-
<i>Brucea antidysenterica</i>	-	-	-	-	-	0.4	1.5	0.3	-	-	0.1	1.0	0.7	0.3	-	-
<i>Buddleja polystachya</i>	-	-	-	-	0.2	-	-	-	-	-	0.5	1.1	0.7	-	0.3	0.4
<i>Cadia purpurea</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	-
<i>Calpurnia aurea</i>	2.8	20.	1.4	0.5	2.5	1.8	5.1	1.1	3.5	1.6	10.3	1.1	1.4	10.2	0.4	1.8
		2														
<i>Canthium oligocarpum</i>	0.7	0.5	0.6	0.5	-	0.4	-	2.2	0.3	0.8	0.4	-	-	2.4	-	0.4
<i>Capparis tomentosa</i>	-	0.8	-	0.5	9.6	0.4	1.5	0.3	-	-	1.1	32.3	2.9	0.6	2.2	-
<i>Carissa spinarum</i>	-	0.6	6.0	0.9	12.	4.4	2.9	2.8	2.6	10.1	4.7	2.9	2.3	3.9	4.0	5.6
					3											
<i>Celtis africana</i>	-	-	-	-	-	0.4	-	-	-	-	0.5	0.2	-	-	-	-
<i>Clausena anisata</i>	3.5	1.5	1.1	2.1	16.	5.8	3.6	6.4	4.8	-	13.7	15.6	3.9	0.6	4.3	0.7
					5											
<i>Clematis hirsuta</i>	-	0.1	0.1	-	0.3	-	-	-	0.3	-	-	-	0.4	0.6	1.6	0.7
<i>Clerodendrum myricoides</i>	-	0.1	0.1	-	0.2	0.4	0.7	-	1.0	5.4	2.2	0.5	0.7	0.9	1.5	0.4
<i>Clutia abyssinica</i>	0.7	4.5	0.5	1.1	0.2	3.6	3.6	0.3	3-	7.8	2.0	1.6	6.1	8.4	7.5	-
<i>Clutia lanceolata</i>	-	-	-	-	-	-	1.5	-	-	0.8	0.2	-	-	-	0.3	-
<i>Combretum molle</i>	0.7	0.5	0.9	2.1	0.5	-	-	0.3	-	-	0.3	-	-	0.3	2.8	2.5
<i>Croton macrostachyus</i>	0.7	0.8	0.4	1.6	0.8	0.7	0.7	-	0.6	0.8	1.3	1.4	2.9	2.4	1.9	1.1

Community Types	1.1	1.1	1.21	1.21	1.2	2.1	2.1	2	3.1	3.12	3.12	3.21	3.21	3.22	3.22	
	1	2	1	2	2	1	2	.2	1	1	2	1	2	1	2	4
No. of Plots	3	18	15	8	8	6	4	6	5	3	17	10	12	7	22	6
<i>Discopodium penninervium</i>	2.1	-	0.2	0.7	-	-	-	-	-	-	-	-	-	-	-	-
<i>Dodonea angustifolia</i>	-	-	-	0.2	-	-	-	-	-	8.5	0.2	0.6	1.6	3.0	6.6	53.7
<i>Dombeya torrida</i>	-	0.4	1.0	1.6	0.3	0.4	0.7	0.3	1.0	4.7	1.2	0.3	-	1.2	0.1	-
<i>Dovyalis abyssinica</i>	2.8	2.1	1.6	0.7	2.8	0.7	1.5	-	-	-	0.2	-	0.2	-	-	-
<i>Dracaena steudneri</i>	-	-	-	-	0.2	-	-	-	-	-	-	-	-	-	-	-
<i>Dregea schimperi</i>	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-	0.3	0.4
<i>Ekebergia capensis</i>	-	0.9	0.4	2.1	0.7	0.4	-	0.3	0.6	-	0.8	0.2	0.2	-	0.3	-
<i>Embelia schimperi</i>	-	0.9	0.1	1.6	0.7	0.7	-	0.3	0.3	-	0.2	-	-	-	0.1	-
<i>Entada abyssinica</i>	-	-	-	-	-	-	-	-	-	-	0.1	0.2	-	-	0.9	-
<i>Euphorbia abyssinica</i>	18.8	3.7	1.6	0.9	0.7	-	2.9	-	-	-	-	-	-	0.6	-	-
<i>Ficus sur</i>	-	0.4	0.3	0.9	0.3	2.2	-	-	-	-	0.1	-	0.2	-	-	-
<i>Ficus sycomorus</i>	2.1	0.1	0.1	0.2	0.3	0.7	0.7	-	-	-	-	-	-	-	-	-
<i>Ficus thonningii</i>	-	-	-	-	-	-	-	-	-	-	-	0.2	-	-	-	-
<i>Flacourtia indica</i>	-	-	-	-	-	-	-	-	-	-	0.1	-	0.2	-	-	-
<i>Galiniera saxifraga</i>	-	-	-	-	-	1.5	2.9	3.9	0.6	-	4.8	-	0.4	0.3	-	-
<i>Gnidia glauca</i>	-	-	-	-	-	-	-	-	-	-	2.2	0.8	0.4	-	0.6	-
<i>Grewia ferruginea</i>	-	-	-	-	0.3	0.7	0.7	0.3	-	7.0	2.3	1.3	2.5	1.8	2.5	2.8
<i>Helinus mystacinus</i>	-	-	-	-	-	-	-	-	-	-	-	0.2	0.2	-	-	-
<i>Heteromorpha arborescens</i>	-	-	-	-	-	0.4	-	-	0.3	-	0.1	-	-	-	-	-
<i>Hypericum quartinianum</i>	-	-	-	-	0.2	-	-	-	0.6	2.3	0.1	0.6	1.8	1.8	1.9	0.4
<i>Jasminum abyssinicum</i>	-	0.1	-	-	0.2	-	-	0.3	-	-	-	-	-	-	-	-
<i>Jasminum grandiflorum</i>	-	-	-	-	-	-	-	-	0.3	-	0.8	0.8	0.7	1.2	1.3	3.5
<i>Juniperus procera</i>	-	-	-	-	-	0.4	2.9	-	-	-	-	-	-	0.9	0.1	-
<i>Justicia schimperiana</i>	-	-	0.1	0.2	-	-	-	-	-	-	0.1	-	0.2	-	-	-
<i>Lantana triflora</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	-
<i>Lippia adoensis</i>	-	0.1	-	-	-	-	-	-	-	-	0.1	1.9	1.1	0.3	1.2	2.8

Community Types	1.1	1.1	1.21	1.21	1.2	2.1	2.1	2	3.1	3.12	3.12	3.21	3.21	3.22	3.22	
No. of Plots	3	18	15	8	8	6	4	6	5	3	17	10	12	7	22	6
<i>Maesa lanceolata</i>	-	0.6	0.3	0.2	0.2	0.7	18.	-	1.0	-	0.1	0.6	1.1	1.5	0.3	-
							2									
<i>Maytenus arbutifolia</i>	-	-	-	-	-	-	-	0.8	0.6	-	-	0.3	-	-	-	-
<i>Maytenus gracilipes</i>	29.	42.	46.7	51.7	34.	16.	5.1	14.	2.6	0.8	3.0	3.1	6.1	5.7	2.2	0.4
	2	7			2	7		2								
<i>Maytenus senegalensis</i>	-	-	-	-	-	1.1	-	1.9	0.3	0.8	0.7	-	-	-	-	-
<i>Maytenus undata</i>	-	-	-	-	-	4.7	2.9	1.7	1.6	0.8	0.1	-	-	-	-	-
<i>Mimusops kummel</i>	-	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-	-
<i>Myrica salicifolia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	-
<i>Myrsine africana</i>	-	-	-	-	-	0.7	-	0.3	1.9	-	2.4	-	0.4	-	4.1	-
<i>Nuxia congesta</i>	-	0.2	0.1	-	0.5	0.7	0.7	1.4	2.9	2.3	2.7	1.3	6.4	1.5	0.4	1.4
<i>Ocimum lamiifolium</i>	-	0.4	0.2	-	0.3	-	-	-	1.0	0.8	0.6	0.2	0.9	1.8	0.3	-
<i>Olea capensis</i> subsp. <i>macrocarpa</i>	3.5	3.4	2.5	2.1	1.0	-	-	-	-	-	-	-	-	-	-	-
<i>Olea europaea</i> subsp. <i>cuspidata</i>	-	-	-	-	0.2	1.8	3.6	1.7	1.0	2.3	1.4	0.2	0.4	4.2	1.3	1.4
<i>Olinia rochetiana</i>	-	-	-	-	0.3	-	-	-	-	-	0.1	0.2	1.2	-	0.4	-
<i>Osyris quadripartita</i>	-	-	-	-	0.2	1.1	-	-	-	4.7	0.8	1.3	2.0	2.1	2.8	1.4
<i>Otostegia integrifolia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	1.4
<i>Periploca linearifolia</i>	-	-	-	-	0.7	0.4	-	-	-	-	0.1	-	-	-	0.1	-
<i>Phoenix reclinata</i>	-	-	-	-	-	-	-	-	-	-	0.3	-	-	0.3	-	-
<i>Phytolacca dodecandra</i>	-	0.1	-	-	0.2	-	-	-	-	0.8	0.1	0.3	-	-	-	-
<i>Piliostigma thonningii</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3	-	-
<i>Pittosporum abyssinicum</i>	0.7	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Premna schimperi</i>	-	-	-	-	-	-	-	0.6	0.6	2.3	1.9	1.0	0.9	2.1	4.1	0.4
<i>Prunus africana</i>	2.8	0.3	2.3	0.9	1.1	-	-	-	-	-	-	-	-	-	-	-
<i>Prunus persica</i>	0.7	0.2	0.6	0.9	1.0	0.4	-	-	-	-	0.1	0.3	-	-	-	-
<i>Pterolobium stellatum</i>	-	-	-	-	-	0.7	2.2	30.	1.6	0.8	4.1	-	0.2	0.6	-	0.4
								9								
<i>Rhamnus prinoides</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3	-	-

Community Types	1.1	1.1	1.21	1.21	1.2	2.1	2.1	2	3.1	3.12	3.12	3.21	3.21	3.22	3.22	
No. of Plots	1	2	1	2	2	1	2	.2	1	1	2	1	2	1	2	4
<i>Rhamnus staddo</i>	-	-	-	-	-	-	1.5	-	0.3	3.9	1.4	-	0.2	0.9	-	2.8
<i>Rhoicissus tridentata</i>	-	0.1	0.1	-	-	0.4	-	-	0.3	-	0.3	-	0.2	0.3	0.9	-
<i>Rhynchosia resinosa</i>	-	-	0.1	0.2	0.5	-	-	-	-	-	-	-	-	-	-	-
<i>Ritchiea albersii</i>	-	0.1	0.2	0.9	0.5	0.4	2.2	0.6	0.3	-	0.3	0.2	0.4	-	1.5	-
<i>Rosa abyssinica</i>	-	0.6	0.8	0.5	0.2	-	0.7	-	1.0	3.9	0.4	0.8	1.4	0.9	1.9	-
<i>Rubus apetalus</i>	-	-	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Rubus steudneri</i>	-	-	-	-	0.2	-	-	-	-	-	-	0.3	-	-	-	-
<i>Rumex nervosus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.1
<i>Schefflera abyssinica</i>	-	0.6	0.2	0.2	0.2	-	3.6	0.6	-	-	-	0.2	0.2	0.9	-	0.4
<i>Schrebera alata</i>	-	-	-	-	-	0.7	-	0.3	1.0	0.8	1.5	1.3	0.7	0.6	0.6	1.8
<i>Searsia pyroides</i>	-	-	-	-	-	0.7	-	0.3	0.6	3.1	3.2	1.8	1.6	1.8	3.7	5.3
<i>Scolopia theifolia</i>	-	0.1	0.5	0.2	0.2	10.	4.4	3.9	4.2	1.6	3.4	-	-	-	-	-
						5										
<i>Solanum giganteum</i>	-	-	-	-	0.2	1.1	-	-	0.6	-	0.3	-	0.5	-	-	-
<i>Solanum indicum</i>	-	-	-	-	-	-	1.5	0.3	-	-	0.1	-	-	-	-	-
<i>Steganotaenia araliacea</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4
<i>Stephania cyanantha</i>	-	-	-	-	-	-	-	-	-	-	-	-	0.2	-	-	-
<i>Stereospermum kunthianum</i>	-	-	-	-	-	-	-	-	-	-	0.1	0.2	-	-	0.7	-
<i>Syzygium guineense</i>	-	-	-	-	-	-	-	-	-	-	0.1	-	-	-	0.4	-
<i>Teclea nobilis</i>	2.1	3.1	7.7	2.5	2.1	3.3	1.5	8.1	0.3	-	0.8	0.2	-	-	-	-
<i>Terminalia schimperiana</i>	6.3	1.7	14.4	3.4	1.3	-	-	-	-	-	-	-	-	-	-	-
<i>Urera hypselodendron</i>	0.7	0.1	0.5	1.6	0.8	0.4	-	0.6	-	-	-	0.3	-	-	-	-
<i>Vachellia abyssinica</i>	-	-	-	-	-	-	-	0.3	0.3	0.8	0.1	-	0.2	0.3	-	-
<i>Vachellia etbaica</i>	-	-	-	-	-	-	-	-	-	-	-	0.5	0.5	0.9	1.9	-
<i>Vachellia lahai</i>	-	-	-	-	0.3	-	-	-	-	-	0.5	1.9	1.6	-	0.3	-
<i>Vachellia seyal</i>	-	-	-	-	-	-	-	-	-	-	-	-	0.2	-	1.3	-
<i>Vernonia adoensis</i>	-	-	-	-	-	17.	5.8	1.7	16.	2.3	1.6	-	0.2	1.2	-	-
						5			1							
<i>Vernonia amygdalina</i>	-	-	0.1	0.2	-	-	-	0.6	-	-	1.7	-	0.4	-	-	-

	1.1	1.1	1.21	1.21	1.2	2.1	2.1	2	3.1	3.12	3.12	3.21	3.21	3.22	3.22	
Community Types	1	2	1	2	2	1	2	.2	1	1	2	1	2	1	2	4
No. of Plots	3	18	15	8	8	6	4	6	5	3	17	10	12	7	22	6
<i>Vernonia hochstetteri</i>	-	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-	-
<i>Vernonia myriantha</i>	12.	2.6	1.9	12.5	0.2	0.4	0.7	-	-	-	-	3.4	3.6	2.1	0.1	-
	5															
<i>Vernonia sp</i>	-	-	-	-	-	-	-	-	-	1.6	-	-	-	-	-	-
<i>Ximenia americana</i>	-	-	-	-	-	-	-	-	-	-	-	0.2	-	-	0.1	-
<i>Ziziphus mucronata</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3	-	-

Appendix 3.4 Relative density in percentages of woody species across all communities and sub-communities

Community Types	1.11	1.12	1.211	1.212	1.22	2.11	2.12	2.2	3.11	3.121	3.122	3.211	3.212	3.221	3.222	4
No. of Plots	3	18	15	8	8	6	4	6	5	3	17	10	12	7	22	6
<i>Abutilon longicuspe</i>	-	-	-	-	0.5	-	-	-	-	-	0.1	0.5	0.2	-	-	-
<i>Acanthus sennii</i>	3.5	1.1	0.2	0.7	0.7	0.7	1.5	0.6	3.2	0.8	2.4	8.4	33.2	24.0	22.1	0.4
<i>Afrocarpus falcatus</i>	-	0.9	-	-	-	-	0.7	-	-	-	-	-	-	-	-	-
<i>Albizia schimperiana</i>	-	0.6	0.6	0.2	1.8	2.5	-	5.3	1.9	0.8	6.6	3.4	2.3	0.9	0.6	1.1
<i>Albizia sp.</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.7
<i>Allophylus abyssinicus</i>	-	-	-	-	-	0.4	-	1.4	1.6	13.2	1.1	0.6	0.4	0.3	3.1	2.8
<i>Apodytes dimidiata</i>	-	-	0.9	0.5	0.2	1.5	0.7	0.8	0.6	-	1.6	-	-	0.9	-	-
<i>Bersama abyssinica</i>	3.5	1.5	1.1	1.8	0.8	4.4	8.8	2.5	5.2	1.6	2.5	2.3	1.1	1.5	0.6	-
<i>Bridelia micrantha</i>	-	0.2	1.1	0.5	0.3	-	-	-	-	-	-	0.3	0.2	-	-	-
<i>Brucea antidysenterica</i>	-	-	-	-	-	0.4	1.5	0.3	-	-	0.1	1.0	0.7	0.3	-	-
<i>Buddleja polystachya</i>	-	-	-	-	0.2	-	-	-	-	-	0.5	1.1	0.7	-	0.3	0.4
<i>Cadia purpurea</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	-
<i>Calpurnia aurea</i>	2.8	20.2	1.4	0.5	2.5	1.8	5.1	1.1	3.5	1.6	10.3	1.1	1.4	10.2	0.4	1.8
<i>Canthium oligocarpum</i>	0.7	0.5	0.6	0.5	-	0.4	-	2.2	0.3	0.8	0.4	-	-	2.4	-	0.4
<i>Capparis tomentosa</i>	-	0.8	-	0.5	9.6	0.4	1.5	0.3	-	-	1.1	32.3	2.9	0.6	2.2	-
<i>Carissa spinarum</i>	-	0.6	6.0	0.9	12.3	4.4	2.9	2.8	2.6	10.1	4.7	2.9	2.3	3.9	4.0	5.6
<i>Celtis africana</i>	-	-	-	-	-	0.4	-	-	-	-	0.5	0.2	-	-	-	-
<i>Clausena anisata</i>	3.5	1.5	1.1	2.1	16.5	5.8	3.6	6.4	4.8	-	13.7	15.6	3.9	0.6	4.3	0.7
<i>Clematis hirsuta</i>	-	0.1	0.1	-	0.3	-	-	-	0.3	-	-	-	0.4	0.6	1.6	0.7
<i>Clerodendrum myricoides</i>	-	0.1	0.1	-	0.2	0.4	0.7	-	1.0	5.4	2.2	0.5	0.7	0.9	1.5	0.4
<i>Clutia abyssinica</i>	0.7	4.5	0.5	1.1	0.2	3.6	3.6	0.3	3-	7.8	2.0	1.6	6.1	8.4	7.5	-
<i>Clutia lanceolata</i>	-	-	-	-	-	-	1.5	-	-	0.8	0.2	-	-	-	0.3	-
<i>Combretum molle</i>	0.7	0.5	0.9	2.1	0.5	-	-	0.3	-	-	0.3	-	-	0.3	2.8	2.5
<i>Croton macrostachyus</i>	0.7	0.8	0.4	1.6	0.8	0.7	0.7	-	0.6	0.8	1.3	1.4	2.9	2.4	1.9	1.1
<i>Discopodium penninervium</i>	2.1	-	0.2	0.7	-	-	-	-	-	-	-	-	-	-	-	-
<i>Dodonea angustifolia</i>	-	-	-	0.2	-	-	-	-	-	8.5	0.2	0.6	1.6	3.0	6.6	53.7
<i>Dombeya torrida</i>	-	0.4	1.0	1.6	0.3	0.4	0.7	0.3	1.0	4.7	1.2	0.3	-	1.2	0.1	-

Community Types	1.11	1.12	1.211	1.212	1.22	2.11	2.12	2.2	3.11	3.121	3.122	3.211	3.212	3.221	3.222	4
No. of Plots	3	18	15	8	8	6	4	6	5	3	17	10	12	7	22	6
<i>Dovyalis abyssinica</i>	2.8	2.1	1.6	0.7	2.8	0.7	1.5	-	-	-	0.2	-	0.2	-	-	-
<i>Dracaena steudneri</i>	-	-	-	-	0.2	-	-	-	-	-	-	-	-	-	-	-
<i>Dregea schimperi</i>	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-	0.3	0.4
<i>Ekebergia capensis</i>	-	0.9	0.4	2.1	0.7	0.4	-	0.3	0.6	-	0.8	0.2	0.2	-	0.3	-
<i>Embelia schimperi</i>	-	0.9	0.1	1.6	0.7	0.7	-	0.3	0.3	-	0.2	-	-	-	0.1	-
<i>Entada abyssinica</i>	-	-	-	-	-	-	-	-	-	-	0.1	0.2	-	-	0.9	-
<i>Euphorbia abyssinica</i>	18.8	3.7	1.6	0.9	0.7	-	2.9	-	-	-	-	-	-	0.6	-	-
<i>Ficus sur</i>	-	0.4	0.3	0.9	0.3	2.2	-	-	-	-	0.1	-	0.2	-	-	-
<i>Ficus sycomorus</i>	2.1	0.1	0.1	0.2	0.3	0.7	0.7	-	-	-	-	-	-	-	-	-
<i>Ficus thonningii</i>	-	-	-	-	-	-	-	-	-	-	-	0.2	-	-	-	-
<i>Flacourtia indica</i>	-	-	-	-	-	-	-	-	-	-	0.1	-	0.2	-	-	-
<i>Galiniera saxifraga</i>	-	-	-	-	-	1.5	2.9	3.9	0.6	-	4.8	-	0.4	0.3	-	-
<i>Gnidia glauca</i>	-	-	-	-	-	-	-	-	-	-	2.2	0.8	0.4	-	0.6	-
<i>Grewia ferruginea</i>	-	-	-	-	0.3	0.7	0.7	0.3	-	7.0	2.3	1.3	2.5	1.8	2.5	2.8
<i>Helinus mystacinus</i>	-	-	-	-	-	-	-	-	-	-	-	0.2	0.2	-	-	-
<i>Heteromorpha arborescens</i>	-	-	-	-	-	0.4	-	-	0.3	-	0.1	-	-	-	-	-
<i>Hypericum quartinianum</i>	-	-	-	-	0.2	-	-	-	0.6	2.3	0.1	0.6	1.8	1.8	1.9	0.4
<i>Jasminum abyssinicum</i>	-	0.1	-	-	0.2	-	-	0.3	-	-	-	-	-	-	-	-
<i>Jasminum grandiflorum</i>	-	-	-	-	-	-	-	-	0.3	-	0.8	0.8	0.7	1.2	1.3	3.5
<i>Juniperus procera</i>	-	-	-	-	-	0.4	2.9	-	-	-	-	-	-	0.9	0.1	-
<i>Justicia schimperiana</i>	-	-	0.1	0.2	-	-	-	-	-	-	0.1	-	0.2	-	-	-
<i>Lantana triflora</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	-
<i>Lippia adoensis</i>	-	0.1	-	-	-	-	-	-	-	-	0.1	1.9	1.1	0.3	1.2	2.8
<i>Maesa lanceolata</i>	-	0.6	0.3	0.2	0.2	0.7	18.2	-	1.0	-	0.1	0.6	1.1	1.5	0.3	-
<i>Maytenus arbutifolia</i>	-	-	-	-	-	-	-	0.8	0.6	-	-	0.3	-	-	-	-
<i>Maytenus gracilipes</i>	29.2	42.7	46.7	51.7	34.2	16.7	5.1	14.2	2.6	0.8	3.0	3.1	6.1	5.7	2.2	0.4
<i>Maytenus senegalensis</i>	-	-	-	-	-	1.1	-	1.9	0.3	0.8	0.7	-	-	-	-	-
<i>Maytenus undata</i>	-	-	-	-	-	4.7	2.9	1.7	1.6	0.8	0.1	-	-	-	-	-
<i>Mimusops kummel</i>	-	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-	-

Community Types	1.11	1.12	1.211	1.212	1.22	2.11	2.12	2.2	3.11	3.121	3.122	3.211	3.212	3.221	3.222	4
No. of Plots	3	18	15	8	8	6	4	6	5	3	17	10	12	7	22	6
<i>Myrica salicifolia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	-
<i>Myrsine africana</i>	-	-	-	-	-	0.7	-	0.3	1.9	-	2.4	-	0.4	-	4.1	-
<i>Nuxia congesta</i>	-	0.2	0.1	-	0.5	0.7	0.7	1.4	2.9	2.3	2.7	1.3	6.4	1.5	0.4	1.4
<i>Ocimum lamiifolium</i>	-	0.4	0.2	-	0.3	-	-	-	1.0	0.8	0.6	0.2	0.9	1.8	0.3	-
<i>Olea capensis</i> subsp <i>macrocarpa</i>	3.5	3.4	2.5	2.1	1.0	-	-	-	-	-	-	-	-	-	-	-
<i>Olea europaea</i> subsp. <i>cuspidata</i>	-	-	-	-	0.2	1.8	3.6	1.7	1.0	2.3	1.4	0.2	0.4	4.2	1.3	1.4
<i>Olinia rochetiana</i>	-	-	-	-	0.3	-	-	-	-	-	0.1	0.2	1.2	-	0.4	-
<i>Osyris quadripartita</i>	-	-	-	-	0.2	1.1	-	-	-	4.7	0.8	1.3	2.0	2.1	2.8	1.4
<i>Otostegia integrifolia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	1.4
<i>Periploca linearifolia</i>	-	-	-	-	0.7	0.4	-	-	-	-	0.1	-	-	-	0.1	-
<i>Phoenix reclinata</i>	-	-	-	-	-	-	-	-	-	-	0.3	-	-	0.3	-	-
<i>Phytolacca dodecandra</i>	-	0.1	-	-	0.2	-	-	-	-	0.8	0.1	0.3	-	-	-	-
<i>Piliostigma thonningii</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3	-	-
<i>Pittosporum abyssinicum</i>	0.7	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Premna schimperii</i>	-	-	-	-	-	-	-	0.6	0.6	2.3	1.9	1.0	0.9	2.1	4.1	0.4
<i>Prunus africana</i>	2.8	0.3	2.3	0.9	1.1	-	-	-	-	-	-	-	-	-	-	-
<i>Prunus persica</i>	0.7	0.2	0.6	0.9	1.0	0.4	-	-	-	-	0.1	0.3	-	-	-	-
<i>Pterolobium stellatum</i>	-	-	-	-	-	0.7	2.2	30.9	1.6	0.8	4.1	-	0.2	0.6	-	0.4
<i>Rhamnus prinoides</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3	-	-
<i>Rhamnus staddo</i>	-	-	-	-	-	-	1.5	-	0.3	3.9	1.4	-	0.2	0.9	-	2.8
<i>Rhoicissus tridentata</i>	-	0.1	0.1	-	-	0.4	-	-	0.3	-	0.3	-	0.2	0.3	0.9	-
<i>Rhynchosia resinosa</i>	-	-	0.1	0.2	0.5	-	-	-	-	-	-	-	-	-	-	-
<i>Ritchiea albersii</i>	-	0.1	0.2	0.9	0.5	0.4	2.2	0.6	0.3	-	0.3	0.2	0.4	-	1.5	-
<i>Rosa abyssinica</i>	-	0.6	0.8	0.5	0.2	-	0.7	-	1.0	3.9	0.4	0.8	1.4	0.9	1.9	-
<i>Rubus apetalus</i>	-	-	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Rubus steudneri</i>	-	-	-	-	0.2	-	-	-	-	-	-	0.3	-	-	-	-
<i>Rumex nervosus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.1
<i>Schefflera abyssinica</i>	-	0.6	0.2	0.2	0.2	-	3.6	0.6	-	-	-	0.2	0.2	0.9	-	0.4
<i>Schrebera alata</i>	-	-	-	-	-	0.7	-	0.3	1.0	0.8	1.5	1.3	0.7	0.6	0.6	1.8

Community Types	1.11	1.12	1.211	1.212	1.22	2.11	2.12	2.2	3.11	3.121	3.122	3.211	3.212	3.221	3.222	4
No. of Plots	3	18	15	8	8	6	4	6	5	3	17	10	12	7	22	6
<i>Searsia pyroides</i>	-	-	-	-	-	0.7	-	0.3	0.6	3.1	3.2	1.8	1.6	1.8	3.7	5.3
<i>Scolopia theifolia</i>	-	0.1	0.5	0.2	0.2	10.5	4.4	3.9	4.2	1.6	3.4	-	-	-	-	-
<i>Solanum giganteum</i>	-	-	-	-	0.2	1.1	-	-	0.6	-	0.3	-	0.5	-	-	-
<i>Solanum indicum</i>	-	-	-	-	-	-	1.5	0.3	-	-	0.1	-	-	-	-	-
<i>Steganotaenia araliacea</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4
<i>Stephania cyanantha</i>	-	-	-	-	-	-	-	-	-	-	-	-	0.2	-	-	-
<i>Stereospermum kunthianum</i>	-	-	-	-	-	-	-	-	-	-	0.1	0.2	-	-	0.7	-
<i>Syzygium guineense</i>	-	-	-	-	-	-	-	-	-	-	0.1	-	-	-	0.4	-
<i>Teclea nobilis</i>	2.1	3.1	7.7	2.5	2.1	3.3	1.5	8.1	0.3	-	0.8	0.2	-	-	-	-
<i>Terminalia schimperiana</i>	6.3	1.7	14.4	3.4	1.3	-	-	-	-	-	-	-	-	-	-	-
<i>Urera hypselodendron</i>	0.7	0.1	0.5	1.6	0.8	0.4	-	0.6	-	-	-	0.3	-	-	-	-
<i>Vachellia abyssinica</i>	-	-	-	-	-	-	-	0.3	0.3	0.8	0.1	-	0.2	0.3	-	-
<i>Vachellia etbaica</i>	-	-	-	-	-	-	-	-	-	-	-	0.5	0.5	0.9	1.9	-
<i>Vachellia lahai</i>	-	-	-	-	0.3	-	-	-	-	-	0.5	1.9	1.6	-	0.3	-
<i>Vachellia seyal</i>	-	-	-	-	-	-	-	-	-	-	-	-	0.2	-	1.3	-
<i>Vernonia adoensis</i>	-	-	-	-	-	17.5	5.8	1.7	16.1	2.3	1.6	-	0.2	1.2	-	-
<i>Vernonia amygdalina</i>	-	-	0.1	0.2	-	-	-	0.6	-	-	1.7	-	0.4	-	-	-
<i>Vernonia hochstetteri</i>	-	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-	-
<i>Vernonia myriantha</i>	12.5	2.6	1.9	12.5	0.2	0.4	0.7	-	-	-	-	3.4	3.6	2.1	0.1	-
<i>Vernonia sp</i>	-	-	-	-	-	-	-	-	-	1.6	-	-	-	-	-	-
<i>Ximenia americana</i>	-	-	-	-	-	-	-	-	-	-	-	0.2	-	-	0.1	-
<i>Ziziphus mucronata</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3	-	-

Appendix 3.5 Relative basal area in percentages of woody species across all communities and sub-communities

Community Types	1.1 1	1.1 2	1.21 1	1.21 2	1.2 2	2.1 1	2.1 2	2 .2	3.1 1	3.12 1	3.12 2	3.21 1	3.21 2	3.22 1	3.22 2	4
No. of Plots	3	18	15	8	8	6	4	6	5	3	17	10	12	7	22	6
<i>Abutilon longicuspe</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Acanthus sennii</i>	-	-	-	-	-	-	-	-	3.2	-	0.2	0.3	2.0	0.1	-	-
<i>Afrocarpus falcatus</i>	-	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Albizia schimperiana</i>	-	-	2.2	-	14. 6	0.5	-	8.7	5.0	-	4.8	14.6	5.0	-	2.4	0.2
<i>Albizia sp.</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.5
<i>Allophylus abyssinicus</i>	-	-	-	-	-	0.2	-	4.7	8.4	23.4	4.6	0.1	-	0.1	1.3	1.8
<i>Apodytes dimidiata</i>	-	-	2.7	-	3.1	6.4	-	-	-	-	0.3	-	-	-	-	-
<i>Bersama abyssinica</i>	0.2	0.9	0.1	1.1	0.2	0.2	0.8	-	20. 7	1.1	0.9	1.5	0.3	0.1	0.8	-
<i>Bridelia micrantha</i>	-	-	0.2	0.1	0.3	-	-	-	-	-	-	0.1	0.1	-	-	-
<i>Brucea antidysenterica</i>	-	-	-	-	-	-	-	-	-	-	-	-	2.1	-	-	-
<i>Buddleja polystachya</i>	-	-	-	-	-	-	-	-	-	-	3.4	0.5	2.4	-	0.1	-
<i>Cadia purpurea</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Calpurnia aurea</i>	1.2	4.7	0.1	-	1.8	0.3	0.4	-	2.2	0.5	4.7	0.1	1.0	2.4	-	0.7
<i>Canthium oligocarpum</i>	-	4.8	0.1	-	-	-	-	6.9	-	-	0.3	-	-	-	-	-
<i>Capparis tomentosa</i>	-	0.1	-	-	1.1	-	-	-	-	-	-	0.1	-	-	0.2	-
<i>Carissa spinarum</i>	-	0.1	1.2	0.1	4.6	1.3	0.5	2.9	4.0	23.4	2.5	0.5	0.8	1.6	2.4	5.1
<i>Celtis africana</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Clausena anisata</i>	0.7	0.1	0.1	0.5	1.5	0.1	0.4	1.1	0.5	-	4.9	0.5	-	-	0.1	0.1
<i>Clematis hirsuta</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Clerodendrum myricoides</i>	-	-	0.1	-	0.1	0.3	-	-	0.4	0.3	0.3	-	0.1	-	0.1	-
<i>Clutia abyssinica</i>	-	-	-	-	-	-	-	-	-	-	-	-	0.1	-	-	-
<i>Clutia lanceolata</i>	-	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-	-
<i>Combretum molle</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24.6	1.4
<i>Croton macrostachyus</i>	-	0.4	0.1	3.4	12. 3	1.6	1.2	-	-	-	9.8	2.5	14.2	4.5	2.7	-

Community Types	1.1	1.1	1.21	1.21	1.2	2.1	2.1	2	3.1	3.12	3.12	3.21	3.21	3.22	3.22	
No. of Plots	1	2	1	2	2	1	2	.2	1	1	2	1	2	1	2	4
<i>Discopodium penninervium</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Dodonea angustifolia</i>	-	-	-	-	-	-	-	-	-	5.2	0.3	0.1	1.2	0.2	6.5	59.5
<i>Dombeya torrida</i>	-	0.3	0.6	9.0	0.1	31.7	-	-	2.3	0.3	0.7	-	-	-	-	-
<i>Dovyalis abyssinica</i>	4.2	1.4	2.7	1.7	2.2	-	-	-	-	-	-	-	-	-	-	-
<i>Dracaena steudneri</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Dregea schimperi</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Ekebergia capensis</i>	-	1.3	0.7	42.8	4.1	-	-	-	-	-	1-	-	-	-	-	-
<i>Embelia schimperi</i>	-	0.1	-	0.1	0.4	-	-	-	-	-	0.1	-	-	-	0.1	-
<i>Entada abyssinica</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.1	-
<i>Euphorbia abyssinica</i>	39.1	7.7	2.3	2.8	0.2	-	1.0	-	-	-	-	-	-	-	-	-
<i>Ficus sur</i>	-	1.6	1.6	6.8	-	9.7	-	-	-	-	-	-	-	-	-	-
<i>Ficus sycomorus</i>	8.0	-	-	1.0	2.6	-	3.3	-	-	-	-	-	-	-	-	-
<i>Ficus thonningii</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Flacourtia indica</i>	-	-	-	-	-	-	-	-	-	-	0.3	-	-	-	-	-
<i>Galiniera saxifraga</i>	-	-	-	-	-	0.9	-	0.6	-	-	1.2	-	-	-	-	-
<i>Gnidia glauca</i>	-	-	-	-	-	-	-	-	-	-	-	0.3	-	-	-	-
<i>Grewia ferruginea</i>	-	-	-	-	-	-	-	0.6	-	22.5	5.6	1.5	1.2	0.4	3.0	1.6
<i>Helinus mystacinus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Heteromorpha arborescens</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Hypericum quartinianum</i>	-	-	-	-	-	-	-	-	0.3	-	-	-	0.6	0.4	0.6	-
<i>Jasminum abyssinicum</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Jasminum grandiflorum</i>	-	-	-	-	-	-	-	-	-	-	0.3	-	0.1	-	0.2	0.7
<i>Juniperus procera</i>	-	-	-	-	-	13.3	27.1	-	-	-	-	-	-	14.1	-	-
<i>Justicia schimperiana</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Lantana triflora</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Community Types	1.1	1.1	1.21	1.21	1.2	2.1	2.1	2	3.1	3.12	3.12	3.21	3.21	3.22	3.22	
No. of Plots	1	2	1	2	2	1	2	.2	1	1	2	1	2	1	2	4
<i>Lippia adoensis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.2
<i>Maesa lanceolata</i>	-	0.2	0.3	0.2	-	0.1	2.3	-	0.9	-	-	-	1.8	0.5	-	-
<i>Maytenus arbutifolia</i>	-	-	-	-	-	-	-	7.5	4.7	-	-	-	-	-	-	-
<i>Maytenus gracilipes</i>	0.3	0.1	0.5	2.6	0.2	3.6	0.2	1.8	1.5	-	0.8	0.5	1.1	0.8	1.2	-
<i>Maytenus senegalensis</i>	-	-	-	-	-	0.8	-	0.8	1.1	-	9.7	-	-	-	-	-
<i>Maytenus undata</i>	-	-	-	-	-	2.3	0.8	0.9	1.3	0.7	-	-	-	-	-	-
<i>Mimusops kummel</i>	-	-	-	-	-	-	-	-	-	-	1.9	-	-	-	-	-
<i>Myrica salicifolia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	21.4	-
<i>Myrsine africana</i>	-	-	-	-	-	-	-	-	-	-	0.1	-	-	-	0.1	-
<i>Nuxia congesta</i>	-	0.1	-	-	1.3	3.2	-	7.4	11.	1.0	8.5	2.0	24.4	1.2	2.5	1.8
									9							
<i>Ocimum lamiifolium</i>	-	-	-	-	-	-	-	-	-	-	0.1	-	-	0.1	-	-
<i>Olea capensis</i> subsp. <i>macrocarpa</i>	32.	44.	47.7	15.4	13.	-	-	-	-	-	-	-	-	-	-	-
	1	7			5											
<i>Olea europaea</i> subsp. <i>cuspidata</i>	-	-	-	-	6.3	11.	53.	35.	25.	1.8	0.5	-	0.1	3.1	3.8	10.
					9	3	2	4								3
<i>Olinia rochetiana</i>	-	-	-	-	0.1	-	-	-	-	-	0.3	-	1.8	-	-	-
<i>Osyris quadripartita</i>	-	-	-	-	-	0.6	-	-	-	5.8	1.7	0.3	1.5	0.1	3.1	2.5
<i>Otostegia integrifolia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1
<i>Periploca linearifolia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Phoenix reclinata</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Phytolacca dodecandra</i>	-	-	-	-	0.5	-	-	-	-	-	-	0.1	-	-	-	-
<i>Piliostigma thonningii</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	-	-
<i>Pittosporum abyssinicum</i>	-	0.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Premna schimperi</i>	-	-	-	-	-	-	-	0.3	-	0.8	2.7	0.9	0.5	0.8	3.4	-
<i>Prunus africana</i>	-	-	27.2	-	19.	-	-	-	-	-	-	-	-	-	-	-
					1											
<i>Prunus persica</i>	-	-	0.9	1.3	1.9	-	-	-	-	-	1.2	0.1	-	-	-	-
<i>Pterolobium stellatum</i>	-	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-	-

Community Types	1.1	1.1	1.21	1.21	1.2	2.1	2.1	2	3.1	3.12	3.12	3.21	3.21	3.22	3.22	
No. of Plots	1	2	1	2	2	1	2	.2	1	1	2	1	2	1	2	4
<i>Rhamnus prinoides</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Rhamnus staddo</i>	-	-	-	-	-	-	-	-	-	1.8	1.5	-	0.1	-	-	3.7
<i>Rhoicissus tridentata</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Rhynchosia resinosa</i>	-	-	0.1	-	0.3	-	-	-	-	-	-	-	-	-	-	-
<i>Ritchiea albersii</i>	-	-	0.3	3.7	0.2	0.1	1.2	0.6	-	-	0.6	-	-	-	1.3	-
<i>Rosa abyssinica</i>	-	0.1	0.2	0.2	0.2	-	-	-	0.5	0.9	-	-	0.5	0.1	0.4	-
<i>Rubus apetalus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Rubus steudneri</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Rumex nervosus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Schefflera abyssinica</i>	-	27. 8	-	-	-	-	0.3	2.8	-	-	-	-	0.2	67.8	-	-
<i>Schrebera alata</i>	-	-	-	-	-	-	-	-	-	0.9	1.3	0.7	-	-	0.9	2.1
<i>Searsia pyroides</i>	-	-	-	-	-	0.4	-	-	0.9	3.6	3.8	1.5	1.3	0.2	4.4	4.6
<i>Scolopia theifolia</i>	-	-	0.3	0.1	0.4	8.7	4.9	2.7	2.9	6.1	0.5	-	-	-	-	-
<i>Solanum giganteum</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Solanum indicum</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Steganotaenia araliacea</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.1
<i>Stephania cyanantha</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Stereospermum kunthianum</i>	-	-	-	-	-	-	-	-	-	-	-	0.3	-	-	-	-
<i>Syzygium guineense</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Teclea nobilis</i>	6.4	1.2	1.2	1.6	5.3	1.2	2.2	14. 5	-	-	0.3	-	-	-	-	-
<i>Terminalia schimperiana</i>	4.3	0.3	5.7	1.6	1.0	-	-	-	-	-	-	-	-	-	-	-
<i>Urera hypselodendron</i>	1.2	0.3	0.8	2.3	0.1	-	-	-	-	-	-	-	-	-	-	-
<i>Vachellia abyssinica</i>	-	-	-	-	-	-	-	-	-	-	-	-	8.5	0.2	-	-
<i>Vachellia etbaica</i>	-	-	-	-	-	-	-	-	-	-	-	0.7	0.3	0.5	4.4	-
<i>Vachellia lahai</i>	-	-	-	-	0.3	-	-	-	-	-	8.1	69.5	26.7	-	-	-
<i>Vachellia seyal</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.1	-
<i>Vernonia adoensis</i>	-	-	-	-	-	0.6	0.2	0.1	1.7	-	-	-	-	-	-	-

	1.1	1.1	1.21	1.21	1.2	2.1	2.1	2	3.1	3.12	3.12	3.21	3.21	3.22	3.22	
Community Types	1	2	1	2	2	1	2	.2	1	1	2	1	2	1	2	4
No. of Plots	3	18	15	8	8	6	4	6	5	3	17	10	12	7	22	6
<i>Vernonia amygdalina</i>	-	-	-	0.1	-	-	-	-	-	-	1.2	-	-	-	-	-
<i>Vernonia hochstetteri</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Vernonia myriantha</i>	2.2	0.2	0.1	1.4	-	-	-	-	-	-	-	0.6	0.1	0.2	-	-
<i>Vernonia sp</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Ximenia americana</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Ziziphus mucronata</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix 3.6 TWINSPLAN classification output of herbaceous plant species in the study area

(Forests: A = Alem Saga, B = Gelawudiwos and C = Tara Gedam)

Community Forests	1.11	1.12	1.211	1.212	1.221	1.222	2.1	2.2	
	AAAA	AAAAAAAAAAAAAAAAABBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBCCCC	AAAAABBBBBBCCCCCCCC	AAACCCCCCCCC	AAAABCCCCCCCCCCCC	ABBCCCCCCCC	AAAAAAAAABCCCCC	AAAAAAC	
4 Alch aby	444	111111122223444555555555556666666777777788888899999900	11	1111111111	111111111111	111111111111	11111111	11111111	1
21 Cyno coe	1348	56801467890569725601234567891234678901246789034568012458903	435115312367743956019	23779567826780	926851223568012145	77940789234	5249017903456901	3480328	0000
25 Cyph ade									0000
61 Oxal cor									0000
73 Plec pun									0000
79 Sela kra									0000
1 Achy sch									0001
2 Adia poi									0001
6 Aris sch									0001
7 Aust fla									0001
10 Bide pil									0001
12 Cana aby									0001
17 Comm afr									0001
22 Cype fis									0001
33 Gali par									0001
36 Gera ara									0001
39 Gomp fru									0001
41 Guiz sch									0001
47 Impa hoc									0001
49 Isog som									0001
51 Kala pet									0001
52 Kost ado									0001
53 Lact ine									0001
54 Lact spp									0001
55 Lagg cri									0001
58 Leuc mar									0001
63 Pavo Spp									0001
66 Penn uni									0001
67 Pent spp									0001
68 Pers nep									0001
69 Pile tet									0001
75 Rume nep									0001
82 Sida rho									0001
86 Tacc leo									0001
89 Thal rhy									0001
93 Vern pur									0001
3 Aeol aby									0010
9 Bide ghe									0010
13 Card lep									0010
24 Cype ses									0010
26 Desm rep									0010
28 Dryo lew									0010
30 Eleu afr									0010
31 Eleu flo									0010
37 Gira bul									0010
48 Impa rot									0010
57 Leon ocy									0010
59 Mika cle									0010
65 Penn thu									0010
72 Plec lac									0010
76 Sani ele									0010
81 Sida ova									0010

Appendix 3.7 Importance values (IV) in percentages of herbaceous species across all communities and sub-communities.

Note that IV was calculated based on the mean value of Relative Cover Abundance and Relative Frequency). * = species associated with woodland.

Community Types	1.11	1.12	1.211	1.212	1.221	1.222	2.1	2.2
No. of Plots	4	59	21	14	18	11	16	7
<i>Achyrospermum schimperi</i>	-	0.2	1.2	0.6	-	-	-	-
<i>Adiantum poiretii</i>	-	0.5	0.5	3.9	1.6	0.6	-	-
<i>Aeollanthus abyssinicus</i>	-	0.2	0.5	-	-	-	-	-
<i>Alchemilla abyssinica</i>	-	-	0.5	0.6	1.2	4.8	1.4	-
<i>Andropogon gayanus</i>	-	0.5	-	0.6	-	0.8	4.6	3.2
<i>Arisaema schimperanum</i>	-	-	0.5	0.6	-	0.6	-	-
<i>Australina flasscida</i>	-	-	-	-	0.9	-	-	-
<i>Bartsia trixago</i>	-	-	-	-	-	-	0.4	-
<i>Bidens ghedoensis</i>	-	0.5	-	-	-	1.2	-	-
<i>Bidens pilosa*</i>	-	2.1	2.7	3.9	7.1	4.8	1.7	1.1
<i>Bidens prestinaria</i>	6.9	2.5	1.1	2.8	6.9	0.6	13.7	9.0
<i>Canarina abyssinica</i>	-	-	-	-	0.4	-	-	-
<i>Carduus leptacanthus</i>	-	0.5	0.5	-	-	-	-	-
<i>Cerastium octandrum</i>	-	-	-	-	-	-	-	3.5
<i>Chlorophytum tetraphyllum</i>	-	0.5	1.6	-	-	1.2	1.5	1.1
<i>Chrysopogon aucheri</i>	-	-	-	-	-	-	0.4	-
<i>Commelina africana</i>	2.8	-	1.2	-	2.0	1.7	-	-
<i>Crotalaria retusa</i>	-	-	-	-	0.8	-	1.0	2.1
<i>Cyanotis barbata</i>	-	-	-	-	-	-	1.4	-
<i>Cynodon dactylon</i>	-	0.5	1.1	-	0.8	1.2	0.4	6.3
<i>Cynoglossum coeruleum</i>	-	0.2	1.1	2.2	1.6	1.9	0.4	1.1
<i>Cyperus fischerianus</i>	-	4.9	7.3	12.3	14.2	9.7	1.7	-
<i>Cyperus sanguinolentus</i>	-	0.2	-	-	-	-	0.4	-
<i>Cyperus sesquiflorus</i>	4.1	0.2	-	-	-	-	-	-
<i>Cyphostemma adenocaula</i>	-	-	1.6	-	0.4	0.6	0.4	-
<i>Desmodium repandum</i>	-	0.9	-	-	-	-	-	-
<i>Digitaria abyssinica</i>	-	-	-	-	-	-	0.4	-
<i>Dryopteris lewalleana</i>	-	0.7	0.5	-	0.4	-	-	-
<i>Echinochloa pyramidalis</i>	-	-	-	-	-	0.9	0.4	3.8
<i>Eleusine africana</i>	2.8	0.8	0.5	0.6	-	-	-	-
<i>Eleusine floccifolia</i>	-	0.2	-	-	-	-	-	-
<i>Euphorbia schimperiana</i>	-	0.2	-	-	-	-	0.4	-
<i>Galinsoga parviflora</i>	-	-	-	-	2.1	-	-	-
<i>Galinsoga quadriradiata</i>	-	-	-	-	-	-	-	1.1
<i>Galium spurium</i>	-	1.1	0.5	-	-	0.9	0.4	1.1

Community Types	1.11	1.12	1.211	1.212	1.221	1.222	2.1	2.2
No. of Plots	4	59	21	14	18	11	16	7
<i>Geranium arabicum</i>	-	-	-	0.6	0.4	-	-	-
<i>Girardinia bullosa</i>	-	3.3	2.2	6.1	0.4	0.6	-	-
<i>Glycine wightii</i>	11.0	0.3	-	-	-	-	0.7	-
<i>Gomphocarpus fruticosus</i>	2.8	-	-	-	-	0.9	-	-
<i>Guizotia scabra</i>	-	2.0	3.3	3.3	4.2	13.0	9.6	10.1
<i>Guizotia schimperii</i>	-	-	0.5	-	0.4	-	-	-
<i>Helichrysum schimperii</i>	-	-	1.1	-	-	0.6	2.2	4.3
<i>Hibiscus macranthus</i>	-	1.2	1.4	1.5	0.4	-	-	1.1
<i>Hypericum peplidifolium</i>	8.2	0.9	0.5	-	-	-	0.9	-
<i>Hyperrhenia hirta</i>	-	0.2	-	0.7	-	-	3.8	-
<i>Hypoestes forskoolii*</i>	22.7	30.4	34.3	24.2	18.2	16.2	5.8	3.8
<i>Impatiens hochstetteri</i>	-	-	-	0.6	-	-	-	-
<i>Impatiens rothii</i>	-	0.8	0.5	2.2	-	-	-	-
<i>Isoglossa somalensis</i>	-	-	3.4	6.9	4.5	0.6	-	-
<i>Justicia ladanoides</i>	-	0.2	-	-	-	-	-	1.1
<i>Kalanchoe petitiiana</i>	-	0.5	3.5	0.6	0.8	-	-	-
<i>Kosteletzkya adoensis</i>	-	-	0.5	1.7	1.2	2.5	-	-
<i>Lactuca inermis</i>	-	-	0.5	-	-	1.7	-	-
<i>Lactuca sp.</i>	-	-	-	0.6	-	-	-	-
<i>Laggera crispata</i>	-	-	-	0.6	0.8	1.2	-	-
<i>Laggera tomentosa</i>	-	0.2	1.6	-	0.4	-	-	2.1
<i>Leonotis ocymifolia</i>	-	0.5	0.5	-	-	-	-	-
<i>Leucas martinicensis</i>	-	-	-	-	0.4	0.6	-	-
<i>Mikaniopsis clematoides</i>	-	0.5	-	-	-	-	-	-
<i>Orobanche minor</i>	-	2.4	1.6	-	-	-	0.4	-
<i>Oxalis corniculata</i>	-	0.2	0.5	-	-	1.2	0.4	-
<i>Panicum monticola*</i>	11.8	25.3	7.3	4.8	11.8	1-	10.2	10.4
<i>Pavonia Sp.</i>	-	-	-	1.1	-	-	-	-
<i>Pavonia urens</i>	-	-	-	0.6	-	0.6	-	6.1
<i>Pennisetum thunbergii</i>	8.3	0.8	-	-	-	-	-	-
<i>Pennisetum unisetum</i>	2.8	0.6	-	2.4	1.8	1.9	0.4	-
<i>Pentas sp.</i>	-	-	-	0.6	-	-	-	-
<i>Persicaria nepalensis</i>	-	-	0.5	-	-	-	-	-
<i>Pilea tetraphylla</i>	-	-	-	0.6	-	-	-	-
<i>Pimpinella hirtella</i>	-	1.2	2.2	1.1	0.8	3.7	4.8	-
<i>Plantago lanceolata</i>	-	-	-	-	-	-	0.4	3.7
<i>Plectranthus lactiflorus</i>	-	0.9	-	-	-	-	-	-
<i>Plectranthus punctatus</i>	-	1.3	1.6	1.7	0.8	6.1	-	4.9
<i>Rhynchosia elegans</i>	10.4	0.3	-	-	-	-	0.7	-
<i>Rumex nepalensis</i>	-	-	-	1.1	-	-	-	-
<i>Sanicula eleta</i>	-	0.2	-	-	-	-	-	-
<i>Satureja punctata</i>	-	-	-	-	-	-	1.4	-
<i>Selaginella abyssinica</i>	-	0.3	-	-	0.6	-	1.2	1.1

Community Types	1.11	1.12	1.211	1.212	1.221	1.222	2.1	2.2
No. of Plots	4	59	21	14	18	11	16	7
<i>Selaginella kraussiana</i>	-	-	-	-	0.8	0.6	0.4	-
<i>Setaria pumila*</i>	-	-	-	0.6	-	-	0.4	-
<i>Sida ovata</i>	-	0.2	-	-	-	-	-	-
<i>Sida rhombifolia</i>	-	-	1.8	-	-	0.6	-	-
<i>Snowdenia polystachya</i>	-	0.7	1.1	-	6.0	-	9.5	1.1
<i>Solanum anguivi</i>	-	0.5	-	-	-	-	-	-
<i>Sporobolus africanus</i>	-	1.1	-	-	-	-	1.3	1.1
<i>Tacca leontopetaloides</i>	-	-	-	-	-	0.6	-	-
<i>Tagetes minuta</i>	2.8	-	-	-	-	-	-	-
<i>Thalictrum rhynchocarpum</i>	-	2.8	3.8	5.5	2.0	1.2	-	-
<i>Themeda triandra</i>	-	0.9	-	-	-	-	3.7	2.1
<i>Trifolium rueppellianum</i>	-	-	-	0.6	-	0.9	6.4	10.4
<i>Trifolium steudneri</i>	-	0.2	-	-	0.4	-	-	-
<i>Vernonia purpurea</i>	-	-	-	-	0.8	-	-	-
<i>Vicia sativa</i>	-	-	-	-	-	-	0.4	1.1
<i>Vigna schimperii</i>	2.8	1.2	1.8	0.6	0.8	1.9	0.9	2.1
<i>Zehneria scabra</i>	-	0.2	-	1.7	-	-	0.4	-

Appendix 3.8 Relative frequency in percentages of all herbaceous communities across all communities and sub-communities

Community Types	1.11	1.12	1.211	1.212	1.221	1.222	2.1	2.2
No. of Plots	4	59	21	14	18	11	16	7
<i>Achyrospermum schimperi</i>	-	0.4	0.8	0.7	-	-	-	-
<i>Adiantum poiretii</i>	-	0.7	0.8	5.1	2.4	0.9	-	-
<i>Aeollanthus abyssinicus</i>	-	0.4	0.8	-	-	-	-	-
<i>Alchemilla abyssinica</i>	-	-	0.8	0.7	1.8	3.7	1.3	-
<i>Andropogon gayanus</i>	-	0.7	-	0.7	-	0.9	3.8	4.6
<i>Arisaema schimperanum</i>	-	-	0.8	0.7	-	0.9	-	-
<i>Australina flasscida</i>	-	-	-	-	0.6	-	-	-
<i>Bartsia trixago</i>	-	-	-	-	-	-	0.6	-
<i>Bidens ghedoensis</i>	-	0.4	-	-	-	0.9	-	-
<i>Bidens pilosa</i>	-	2.9	3.8	5.1	7.9	6.5	2.5	1.5
<i>Bidens prestinaria</i>	8.3	3.6	1.5	3.7	7.9	0.9	9.6	7.7
<i>Canarina abyssinica</i>	-	-	-	-	0.6	-	-	-
<i>Carduus leptacanthus</i>	-	0.7	0.8	-	-	-	-	-
<i>Cerastium octandrum</i>	-	-	-	-	-	-	-	1.5
<i>Chlorophytum tetraphyllum</i>	-	0.7	2.3	-	-	1.9	1.9	1.5
<i>Chrysopogon aucheri</i>	-	-	-	-	-	-	0.6	-
<i>Commelina africana</i>	4.2	-	0.8	-	1.8	1.9	-	-
<i>Crotalaria retusa</i>	-	-	-	-	1.2	-	1.3	3.1
<i>Cyanotis barbata</i>	-	-	-	-	-	-	1.9	-
<i>Cynodon dactylon</i>	-	0.4	1.5	-	1.2	0.9	0.6	4.6
<i>Cynoglossum coeruleum</i>	-	0.4	1.5	2.9	2.4	2.8	0.6	1.5
<i>Cyperus fischerianus</i>	-	6.2	9.8	9.6	9.7	9.3	1.9	-
<i>Cyperus sanguinolentus</i>	-	0.4	-	-	-	-	0.6	-
<i>Cyperus sesquiflorus</i>	4.2	0.4	-	-	-	-	-	-
<i>Cyphostemma adenocaula</i>	-	-	2.3	-	0.6	0.9	0.6	-
<i>Desmodium repandum</i>	-	0.7	-	-	-	-	-	-
<i>Digitaria abyssinica</i>	-	-	-	-	-	-	0.6	-
<i>Dryopteris lewalleana</i>	-	1.1	0.8	-	0.6	-	-	-
<i>Echinochloa pyramidalis</i>	-	-	-	-	-	0.9	0.6	4.6
<i>Eleusine africana</i>	4.2	1.1	0.8	0.7	-	-	-	-
<i>Eleusine floccifolia</i>	-	0.4	-	-	-	-	-	-
<i>Euphorbia schimperiana</i>	-	0.4	-	-	-	-	0.6	-
<i>Galinsoga parviflora</i>	-	-	-	-	2.4	-	-	-
<i>Galinsoga quadriradiata</i>	-	-	-	-	-	-	-	1.5
<i>Galium spurium</i>	-	1.5	0.8	-	-	0.9	0.6	1.5
<i>Geranium arabicum</i>	-	-	-	0.7	0.6	-	-	-
<i>Girardinia bullosa</i>	-	4.7	3.0	8.1	0.6	0.9	-	-
<i>Glycine wightii</i>	8.3	0.4	-	-	-	-	0.6	-
<i>Gomphocarpus fruticosus</i>	4.2	-	-	-	-	0.9	-	-
<i>Guizotia scabra</i>	-	2.5	4.5	4.4	4.8	10.3	8.9	9.2

Community Types	1.11	1.12	1.211	1.212	1.221	1.222	2.1	2.2
No. of Plots	4	59	21	14	18	11	16	7
<i>Guizotia schimperii</i>	-	-	0.8	-	0.6	-	-	-
<i>Helichrysum schimperii</i>	-	-	1.5	-	-	0.9	2.5	6.2
<i>Hibiscus macranthus</i>	-	1.5	1.5	1.5	0.6	-	-	1.5
<i>Hypericum peplidifolium</i>	4.2	0.7	0.8	-	-	-	0.6	-
<i>Hyperrhenia hirta</i>	-	0.4	-	0.7	-	-	4.5	-
<i>Hypoestes forskoolii</i>	12.5	21.1	15.8	10.3	10.9	10.3	5.7	4.6
<i>Impatiens hochstetteri</i>	-	-	-	0.7	-	-	-	-
<i>Impatiens rothii</i>	-	1.1	0.8	2.9	-	-	-	-
<i>Isoglossa somalensis</i>	-	-	3.8	6.6	5.5	0.9	-	-
<i>Justicia ladanoides</i>	-	0.4	-	-	-	-	-	1.5
<i>Kalanchoe petitiiana</i>	-	0.7	4.5	0.7	1.2	-	-	-
<i>Kosteletzkya adoensis</i>	-	-	0.8	2.2	1.8	3.7	-	-
<i>Lactuca inermis</i>	-	-	0.8	-	-	0.9	-	-
<i>Lactuca sp.</i>	-	-	-	0.7	-	-	-	-
<i>Laggera crispata</i>	-	-	-	0.7	1.2	1.9	-	-
<i>Laggera tomentosa</i>	-	0.4	2.3	-	0.6	-	-	3.1
<i>Leonotis ocymifolia</i>	-	0.7	0.8	-	-	-	-	-
<i>Leucas martinicensis</i>	-	-	-	-	0.6	0.9	-	-
<i>Mikaniopsis clematoides</i>	-	0.7	-	-	-	-	-	-
<i>Orobanche minor</i>	-	3.6	2.3	-	-	-	0.6	-
<i>Oxalis corniculata</i>	-	0.4	0.8	-	-	0.9	0.6	-
<i>Panicum monticola</i>	16.7	18.9	9.0	5.9	10.3	9.3	7.6	9.2
<i>Pavonia Sp.</i>	-	-	-	1.5	-	-	-	-
<i>Pavonia urens</i>	-	-	-	0.7	-	0.9	-	3.1
<i>Pennisetum thunbergii</i>	8.3	1.1	-	-	-	-	-	-
<i>Pennisetum unisetum</i>	4.2	0.4	-	2.9	2.4	2.8	0.6	-
<i>Pentas sp.</i>	-	-	-	0.7	-	-	-	-
<i>Persicaria nepalensis</i>	-	-	0.8	-	-	-	-	-
<i>Pilea tetraphylla</i>	-	-	-	0.7	-	-	-	-
<i>Pimpinella hirtella</i>	-	1.8	3.0	1.5	1.2	4.7	5.7	-
<i>Plantago lanceolata</i>	-	-	-	-	-	-	0.6	3.1
<i>Plectranthus lactiflorus</i>	-	1.5	-	-	-	-	-	-
<i>Plectranthus punctatus</i>	-	1.8	2.3	2.2	1.2	5.6	-	6.2
<i>Rhynchosia elegans</i>	12.5	0.4	-	-	-	-	0.6	-
<i>Rumex nepalensis</i>	-	-	-	1.5	-	-	-	-
<i>Sanicula eleta</i>	-	0.4	-	-	-	-	-	-
<i>Satureja punctata</i>	-	-	-	-	-	-	1.9	-
<i>Selaginella abyssinica</i>	-	0.4	-	-	0.6	-	0.6	1.5
<i>Selaginella kraussiana</i>	-	-	-	-	1.2	0.9	0.6	-
<i>Setaria pumila</i>	-	-	-	0.7	-	-	0.6	-
<i>Sida ovata</i>	-	0.4	-	-	-	-	-	-
<i>Sida rhombifolia</i>	-	-	1.5	-	-	0.9	-	-
<i>Snowdenia polystachya</i>	-	0.7	1.5	-	6.1	-	8.3	1.5

Community Types	1.11	1.12	1.211	1.212	1.221	1.222	2.1	2.2
No. of Plots	4	59	21	14	18	11	16	7
<i>Solanum anguivi</i>	-	0.7	-	-	-	-	-	-
<i>Sporobolus africanus</i>	-	1.1	-	-	-	-	1.3	1.5
<i>Tacca leontopetaloides</i>	-	-	-	-	-	0.9	-	-
<i>Tagetes minuta</i>	4.2	-	-	-	-	-	-	-
<i>Thalictrum rhynchocarpum</i>	-	4.4	5.3	7.4	3.0	1.9	-	-
<i>Themeda triandra</i>	-	1.1	-	-	-	-	4.5	3.1
<i>Trifolium rueppellianum</i>	-	-	-	0.7	-	0.9	7.6	6.2
<i>Trifolium steudneri</i>	-	0.4	-	-	0.6	-	-	-
<i>Vernonia purpurea</i>	-	-	-	-	1.2	-	-	-
<i>Vicia sativa</i>	-	-	-	-	-	-	0.6	1.5
<i>Vigna schimperii</i>	4.2	1.8	2.3	0.7	1.2	2.8	1.3	3.1
<i>Zehneria scabra</i>	-	0.4	-	2.2	-	-	0.6	-

Appendix 3.9 Relative cover abundance in percentages of herbaceous species across all communities and sub-communities

Community Types	1.11	1.12	1.211	1.212	1.221	1.222	2.1	2.2
No. of Plots	4	59	21	14	18	11	16	7
<i>Achyrospermum schimperi</i>	-	-	1.7	0.4	-	-	-	-
<i>Adiantum poiretii</i>	-	0.2	0.3	2.6	0.8	0.3	-	-
<i>Aeollanthus abyssinicus</i>	-	0.1	0.3	-	-	-	-	-
<i>Alchemilla abyssinica</i>	-	-	0.3	0.4	0.6	5.9	1.6	-
<i>Andropogon gayanus</i>	-	0.2	-	0.4	-	0.6	5.4	1.8
<i>Arisaema schimperanum</i>	-	-	0.3	0.4	-	0.3	-	-
<i>Australina flasscida</i>	-	-	-	-	1.3	-	-	-
<i>Bartsia trixago</i>	-	-	-	-	-	-	0.2	-
<i>Bidens ghedoensis</i>	-	0.5	-	-	-	1.6	-	-
<i>Bidens pilosa</i>	-	1.3	1.7	2.6	6.4	3.1	0.9	0.6
<i>Bidens prestinaria</i>	5.5	1.3	0.7	1.9	5.9	0.3	17.9	10.4
<i>Canarina abyssinica</i>	-	-	-	-	0.2	-	-	-
<i>Carduus leptacanthus</i>	-	0.2	0.3	-	-	-	-	-
<i>Cerastium octandrum</i>	-	-	-	-	-	-	-	5.5
<i>Chlorophytum tetraphyllum</i>	-	0.2	1.0	-	-	0.6	1.1	0.6
<i>Chrysopogon aucheri</i>	-	-	-	-	-	-	0.2	-
<i>Commelaina africana</i>	1.4	-	1.7	-	2.1	1.6	-	-
<i>Crotalaria retusa</i>	-	-	-	-	0.4	-	0.7	1.2
<i>Cyanotis barbata</i>	-	-	-	-	-	-	0.9	-
<i>Cynodon dactylon</i>	-	0.7	0.7	-	0.4	1.6	0.2	7.9
<i>Cynoglossum coeruleum</i>	-	0.1	0.7	1.5	0.8	0.9	0.2	0.6
<i>Cyperus fischerianus</i>	-	3.6	4.8	15.0	18.6	1-	1.6	-
<i>Cyperus sanguinolentus</i>	-	0.1	-	-	-	-	0.2	-
<i>Cyperus sesquiflorus</i>	4.1	0.1	-	-	-	-	-	-
<i>Cyphostemma adenocaula</i>	-	-	1.0	-	0.2	0.3	0.2	-
<i>Desmodium repandum</i>	-	1.0	-	-	-	-	-	-
<i>Digitaria abyssinica</i>	-	-	-	-	-	-	0.2	-
<i>Dryopteris lewalleana</i>	-	0.3	0.3	-	0.2	-	-	-
<i>Echinochloa pyramidalis</i>	-	-	-	-	-	0.9	0.2	3.0
<i>Eleusine africana</i>	1.4	0.5	0.3	0.4	-	-	-	-
<i>Eleusine floccifolia</i>	-	0.1	-	-	-	-	-	-
<i>Euphorbia schimperiana</i>	-	0.1	-	-	-	-	0.2	-
<i>Galinsoga parviflora</i>	-	-	-	-	1.7	-	-	-
<i>Galinsoga quadriradiata</i>	-	-	-	-	-	-	-	0.6
<i>Galium spurium</i>	-	0.7	0.3	-	-	0.9	0.2	0.6
<i>Geranium arabicum</i>	-	-	-	0.4	0.2	-	-	-
<i>Girardinia bullosa</i>	-	1.9	1.4	4.1	0.2	0.3	-	-
<i>Glycine wightii</i>	13.7	0.3	-	-	-	-	0.7	-
<i>Gomphocarpus fruticosus</i>	1.4	-	-	-	-	0.9	-	-
<i>Guizotia scabra</i>	-	1.4	2.1	2.2	3.6	15.6	10.3	11.0

Community Types	1.11	1.12	1.211	1.212	1.221	1.222	2.1	2.2
No. of Plots	4	59	21	14	18	11	16	7
<i>Guizotia schimperii</i>	-	-	0.3	-	0.2	-	-	-
<i>Helichrysum schimperii</i>	-	-	0.7	-	-	0.3	1.8	2.4
<i>Hibiscus macranthus</i>	-	0.9	1.4	1.5	0.2	-	-	0.6
<i>Hypericum peplidifolium</i>	12.3	1.1	0.3	-	-	-	1.1	-
<i>Hyperrhenia hirta</i>	-	0.1	-	0.7	-	-	3.1	-
<i>Hypoestes forskoolii</i>	32.9	39.6	52.8	38.2	25.4	22.2	5.8	3.0
<i>Impatiens hochstetteri</i>	-	-	-	0.4	-	-	-	-
<i>Impatiens rothii</i>	-	0.5	0.3	1.5	-	-	-	-
<i>Isoglossa somalensis</i>	-	-	3.1	7.1	3.6	0.3	-	-
<i>Justicia ladanoides</i>	-	0.1	-	-	-	-	-	0.6
<i>Kalanchoe petitiiana</i>	-	0.2	2.4	0.4	0.4	-	-	-
<i>Kosteletzkya adoensis</i>	-	-	0.3	1.1	0.6	1.3	-	-
<i>Lactuca inermis</i>	-	-	0.3	-	-	2.5	-	-
<i>Lactuca sp.</i>	-	-	-	0.4	-	-	-	-
<i>Laggera crispata</i>	-	-	-	0.4	0.4	0.6	-	-
<i>Laggera tomentosa</i>	-	0.1	1.0	-	0.2	-	-	1.2
<i>Leonotis ocymifolia</i>	-	0.2	0.3	-	-	-	-	-
<i>Leucas martinicensis</i>	-	-	-	-	0.2	0.3	-	-
<i>Mikaniopsis clematoides</i>	-	0.2	-	-	-	-	-	-
<i>Orobanche minor</i>	-	1.1	1.0	-	-	-	0.2	-
<i>Oxalis corniculata</i>	-	0.1	0.3	-	-	1.6	0.2	-
<i>Panicum monticola</i>	6.8	31.8	5.5	3.7	13.3	10.6	12.7	11.6
<i>Pavonia Sp.</i>	-	-	-	0.7	-	-	-	-
<i>Pavonia urens</i>	-	-	-	0.4	-	0.3	-	9.1
<i>Pennisetum thunbergii</i>	8.2	0.5	-	-	-	-	-	-
<i>Pennisetum unisetum</i>	1.4	0.8	-	1.9	1.3	0.9	0.2	-
<i>Pentas sp.</i>	-	-	-	0.4	-	-	-	-
<i>Persicaria nepalensis</i>	-	-	0.3	-	-	-	-	-
<i>Pilea tetraphylla</i>	-	-	-	0.4	-	-	-	-
<i>Pimpinella hirtella</i>	-	0.5	1.4	0.7	0.4	2.8	3.8	-
<i>Plantago lanceolata</i>	-	-	-	-	-	-	0.2	4.3
<i>Plectranthus lactiflorus</i>	-	0.4	-	-	-	-	-	-
<i>Plectranthus punctatus</i>	-	0.8	1.0	1.1	0.4	6.6	-	3.7
<i>Rhynchosia elegans</i>	8.2	0.3	-	-	-	-	0.7	-
<i>Rumex nepalensis</i>	-	-	-	0.7	-	-	-	-
<i>Sanicula eleta</i>	-	0.1	-	-	-	-	-	-
<i>Satureja punctata</i>	-	-	-	-	-	-	0.9	-
<i>Selaginella abyssinica</i>	-	0.3	-	-	0.6	-	1.8	0.6
<i>Selaginella kraussiana</i>	-	-	-	-	0.4	0.3	0.2	-
<i>Setaria pumila</i>	-	-	-	0.4	-	-	0.2	-
<i>Sida ovata</i>	-	0.1	-	-	-	-	-	-
<i>Sida rhombifolia</i>	-	-	2.1	-	-	0.3	-	-
<i>Snowdenia polystachya</i>	-	0.7	0.7	-	5.9	-	10.7	0.6

Community Types	1.11	1.12	1.211	1.212	1.221	1.222	2.1	2.2
No. of Plots	4	59	21	14	18	11	16	7
<i>Solanum anguivi</i>	-	0.2	-	-	-	-	-	-
<i>Sporobolus africanus</i>	-	1.1	-	-	-	-	1.3	0.6
<i>Tacca leontopetaloides</i>	-	-	-	-	-	0.3	-	-
<i>Tagetes minuta</i>	1.4	-	-	-	-	-	-	-
<i>Thalictrum rhynchocarpum</i>	-	1.3	2.4	3.7	1.1	0.6	-	-
<i>Themeda triandra</i>	-	0.8	-	-	-	-	2.9	1.2
<i>Trifolium rueppellianum</i>	-	-	-	0.4	-	0.9	5.1	14.6
<i>Trifolium steudneri</i>	-	0.1	-	-	0.2	-	-	-
<i>Vernonia purpurea</i>	-	-	-	-	0.4	-	-	-
<i>Vicia sativa</i>	-	-	-	-	-	-	0.2	0.6
<i>Vigna schimperi</i>	1.4	0.5	1.4	0.4	0.4	0.9	0.4	1.2
<i>Zehneria scabra</i>	-	0.1	-	1.1	-	-	0.2	-

Chapter 4: Impact of disturbance-recovery processes on community and population dynamics in three Afromontane Forests of Northwest Ethiopia.

Abstract

Gap dynamics at different scales, expressed as fine to coarse grain, determine the spatial scales of regeneration success and population structure of forests. The concept is that in a fine-grain forest, the canopy tree species in the canopy are shade-tolerant and have regularly good regeneration under their own canopies, with such species having inverse J-shape stem diameter class distributions. By contrast, in a coarse-grain forest, the canopy tree species in the canopy are intolerant of shade, regenerate occasionally when large gaps are formed, with such species having bell-shaped stem diameter class distributions. This was the focus of this study in three remnant Afromontane forests in northwest Ethiopia. A systematic random sampling design, implemented in homogenous vegetation units across the three forest complexes, was used to record data from 150 circular plots of 100 m² each. The data were used to assess regeneration success of canopy tree species with different scales of disturbance (regeneration gaps), through grain analysis. This ordination analysis (Detrended Correspondence Analysis [DCA], using CANOCO 5.04) was done by using the number of stems of canopy tree species in the canopy and regeneration of the same stand, across the identified forest tree communities. The population structure of selected sub-canopy and canopy tree species was analysed using diagrams of the frequency distribution of their stems across stem diameter classes. The study observed variable scales of regeneration gaps across forest communities, ranging from fine-grained to coarse-grained regeneration gaps. This variability in regeneration gaps might be a reflection of heterogeneity in the prevailing environment and disturbances. Tree species observed in fine-grained forest communities were *Apodytes dimidiata*, *Olea capensis* subsp. *macrocarpa*, *Olea europaea* subsp. *cuspidata* and *Scolopia theifolia*; tree species *Ekebergia capensis*, *Croton macrostachyus* and *Terminalia schimperiana* were observed in relatively coarser-grained sub-communities. Most tree species reflected stem diameter distribution patterns with multiple cohorts, indicating the presence of disturbance heterogeneity in the studied forests. Some tree species, including *Prunus africana*, *Olea capensis* subsp. *macrocarpa* and *Schefflera abyssinica*, showed poor regeneration status, maybe due to the forest being too closed, preventing their regeneration.

Keywords: Northwest Ethiopia; Afromontane; grain; gap dynamics; indirect gradient analysis; DCA; ordination; population structure; regeneration status.

4.1 Introduction

Relative forest gap size has a significant role in forest dynamics. When canopy trees die (or are injured), small gaps are formed in the forest canopy and generally more shade-tolerant tree and/or shrub species regenerate to fill the gap. When tree falls create large gaps, such as with strong winds, cyclones, landslides or devastating fires, then more light-demanding species regenerate. This kind of forest ecosystem process is termed gap dynamics (Yamamoto, 2000). Diverse gap disturbances create heterogeneous habitats, which enhance and promote diversity in species and functional traits (Schnitzer and Carson, 2010; Kern *et al.*, 2014; Hunter *et al.*, 2015). However, a severe disturbance can limit the regeneration of some tree species (Almazán-Núñez *et al.*, 2016). There has to be an optimum spatial and temporal range in gaps formed to maintain species diversity and structural heterogeneity, which in turn can enhance ecosystem productivity, resilience to uncertain environmental changes and its sustainability (Dyakov, 2013; Kern *et al.*, 2013; Lobo and Dalling, 2014). Different species in a given vegetation have various adaptations to different disturbance regimes, to have their optimum development in different recovery stages of the vegetation (Geldenhuys, 2011).

Grain explains the relationship between the composition of canopy species in the regeneration and in the canopy of the same stand, which helps to understand the scale of forest disturbance processes (Midgley *et al.*, 1990; Everard, 1992; Geldenhuys, 1996). A combined investigation of grain and stem diameter distribution, as part of an analysis of structural diversity, provide crucial information towards an initial understanding of forest dynamics (Geldenhuys, 2010). In forest ecosystems, structural diversity can be seen as the heterogeneity of horizontal structures (variation in size, shape and spatial distribution of DBH) and vertical structures (variation in tree height, vertical layering, and gaps in stands) (Pach and Podlaski, 2015). Forest structure determines forest function and provides a baseline to formulate a feasible forest management approach to achieve various objectives. It plays a paramount role in forest management, conservation and restoration (Meng *et al.*, 2016; Mura *et al.*, 2016). Age (size) class structure is a more sensitive indicator of disturbance history than species composition. Information on disturbance patterns and size structure should therefore form the basis of the silvicultural practice (Geldenhuys and Maliepaard, 1983). In the analysis of stem diameter distributions, there are three types of curves i.e. Inverse J-shaped, Bell-shaped and Static-shaped curves, each reflecting different ecological and historical characteristics of species in a given stand or forest landscape (Geldenhuys, 2010).

Understanding the scales of regeneration gaps is fundamental to sustainable resource-use management of forests. It is particularly important to understand relative regeneration success of canopy tree species with prevailing conditions in a given forest (Enright *et al.*, 1993; Geldenhuys, 1993a,b,c, 1996, 2010; Kubota, 2006; Hytteborn and Werwijst, 2011; Pastur *et al.*, 2012). Regeneration patterns have been used to understand the survival strategies of species, and to monitor the effects of forest management practices on stand dynamics and/or on a particular species (King and Antrobus, 2005; Zagidullina and Tikhodeyeva, 2006; Kenders *et al.*, 2009). It has been used to locate and identify harvestable tree species in a given forest ecosystem (Lawes and Obiri, 2003).

The variation in the spatial scales of regeneration can help to understand the scales of disturbances across stands or forests. Grain and stem diameter distribution analysis are useful to determine the specific shade- or fire-tolerance characteristics of the key tree species, and the relevant silvicultural system (Midgley *et al.*, 1990; Geldenhuys, 1996; Sturtevant *et al.*, 2014). Any forest restoration scheme should have to understand the disturbance regime and its scale of variability in the target forest ecosystem (Rentch *et al.*, 2010). Such an investigation can be approached in two ways (Geldenhuys, 2010): In a practical approach, it can be done by looking at where the regeneration of the canopy species occur within the relevant forest stands. In an analytical approach, it can be done by using inventory data of the forest. Data for each sample plot in each community are separated into two data sets i.e. regeneration data and canopy data of canopy tree species. An ordination analysis with the two data sets of all plots will show the relative ordination distance between the regeneration data and canopy data within each community. Stem diameter distributions in tree species populations across identified tree communities in a forest show the structural diversity of a forest ecosystem (Geldenhuys, 2010). It has been applied for analysing the regeneration of tree species and their successional patterns in forest communities, guiding insights about their current population status and possible interventions on their sustainability (Halpin and Lorimer, 2017; Kang *et al.*, 2017).

Ethiopian forests in general, and the remnant Afromontane forests of northwest Ethiopia in particular, need potentially feasible forest management options to circumvent the ongoing deforestation and thereby to utilize the remnant and fragmented forests on a sustainable basis. There is no readily available documentatiuon on resource use and deforestation about this forest area. Observations in the area indicated people had been utilizing forest resources for various purposes such as house construction (Plate 1), fuel wood (Plate 2) and cattle grazing (Plate 3). Logs of fallen trees were observed in some parts of the forests, but it was not clear whether they were from human tree cutting

or natural wind falls (Plate 4). These and other natural and/or anthropogenic disturbances might have shaped population structures of tree species, plant associations, and stand dynamics.



Plate 4.1. Churches with wooden doors, windows and roofs.

The photos taken from Kibran St. Gabriel Unity and Tana Hike Debre Mareyam Monasteries in December 2015, both located in Tana Lake area about 50 km from current study area. Note the size of the panels of the doors, indicating the large stem diameters of the trees that had been cut from the forests.



Plate 4.2 Logs at Alem Ber village, about 5 km away from Alem Saga forest, that may have been collected from that forest.

Note that the picture was taken in December 2015



Plate 4.3 Cattle grazing observed in Tara Gedam Forest.

Note that the pictures were taken in October 2015



Plate 4.4 Old fallen logs observed in Gelawudiwos Forest.

Note that it was not clear whether the fallen logs were due to human tree cutting or natural wind falls. The pictures were taken in October 2015.

This particular study tried to assess and identify the scales of regeneration gaps across identified plant communities, and the population structure of selected canopy tree species, to provide a basis for recommendations towards possible management options.

Objective: To assess the scale of ecological processes of disturbance and recovery and how these affect the population structure and regeneration status of canopy tree species across forest communities in three Afromontane forest of Northwest Ethiopia.

This objective was pursued through addressing the following research questions:

1. Which forest communities regularly disturbed (relatively early regrowth stage) and which are relatively stable (relatively mature forest) ?
2. Which species can regenerate under the forest canopy (relative shade-tolerant species), and which species typically require larger gaps, with more light, to regenerate (cannot regenerate under the canopy, i.e. shade-intolerant species)?

3. What are the typical stem diameter class distributions of the main canopy tree species in the studied forests, and how do they vary across the identified tree communities?

4.2 Materials and Methods

4.2.1 Study Area

The study was carried out in three selected Afromontane forests, Alem Saga, Gelawudiwos and Tara Gedam, in the South Gonder zone of Northwestern Ethiopia (Figure 4.1). South Gonder zone is located 600 km north of Addis Ababa and 50 km east of Lake Tana (Wassie *et al.*, 2010), with geographic coordinates 11°50'59.87"N, 37°00'59.55"E, and altitude of 1800 to 2500 m asl. Alem Saga forest is 35 km away from both Gelawudiwos and Tara Gedam, the distance between Gelawudiwos and Tera Gedam is 70 km. Afromontane forests of Semien Mountains National Park and Lasta-Lalibela Afromontane forest complexes such as Mount Abune Yoseph, Nakuto Leab, Yimrhane Kirstos, and Ayna Eyesus forests, occur about 300 to 350 km North and Northeast of these study forests (Wale, 2006). Afromontane forest complexes of Mount Chokie and Borena Sayint National Park occur, about 200 to 250 km to the South and Southeast of the study forests.

The annual rainfall ranges between 1097 mm and 1646 mm (based on meteorological data collected from the Debre Tabor meteorological station of the Amhara Regional Meteorological Agency, over 13 years, i.e. 1999 to 2011). The mean annual rainfall is 1476 mm and mean monthly temperature is 16°C. Rainfall shows a unimodal distribution, with maximum rainfall in summer between July and August (Figure 4.2).

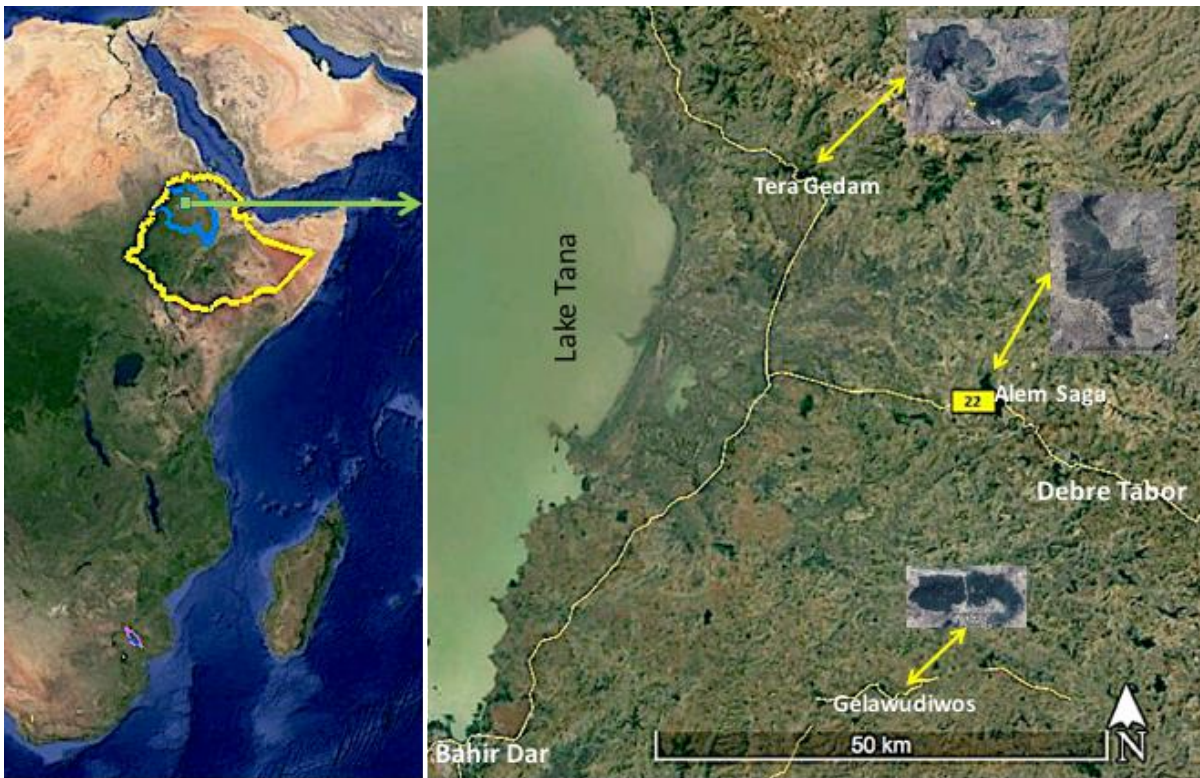


Figure 4.1 Location of the Gelawudiwos, Alem Saga, and Tara Gedam Afromontane Forests in Northwest Ethiopia, with the inserts showing the shape and orientation of each forest.

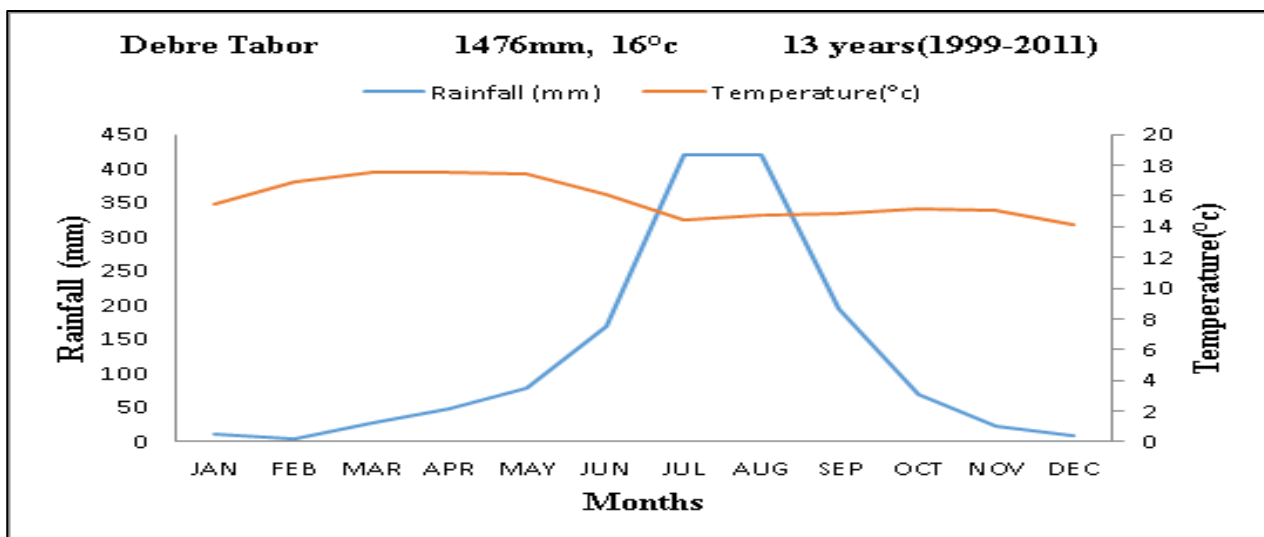


Figure 4.2 Climatic graph of the areas of Afromontane Forests of Northwest Ethiopia.

Thirteen years' meteorological data was taken from the meteorological station situated in Debre Tabor (11°50'59.87"N, 37°00'59.55"E, 2690 masl).

4.2.2 Sampling Design and data collection

A systematic random sampling method was used for the vegetation inventory in the three selected Afromontane forests. Transect lines were located in the selected forests with each plot sampled within a homogenous part along the transect, to cover most of the variation along the transect. Tree species were recorded on circular plots of 100 m² (5.65 m radius), located at 100 m to 150 m apart along each transect line. A total of 150 plots was sampled; 50 plots from each selected Afromontane forests. In each sample plot, all stems with stem diameter at 1.3 m above ground level (DBH) from 2 cm and larger were recorded by species name and DBH.

4.2.3 Analysis

A spatial ordination analysis was employed, as an analytical approach (Midgley *et al.*, 1990; Geldenhuys, 1996; Jonasova *et al.*, 2010; Sharma *et al.*, 2016), with data from the identified woody plant communities and sub-communities in chapter 3. The first step was to remove all data of non-canopy tree species from the dataset. The tree data (stem DBH and species) for the canopy tree species for each plot, were then separated into two sub-plots, i.e. a regeneration sub-plot with trees of 2 to 10 cm DBH, and a canopy sub-plot with trees with DBH >20 cm. The stems of 11 to 20 cm DBH were removed to avoid a potential overlap between regeneration and trees of the canopy species. The data for the number of plots used in the original TWINSPAN classification and DCA ordination analysis, were then subjected to DCA ordination, using CANOCO 5.04 (ter Braak and Šmilauer, 2012). The output values for the axis 1 (x-axis) and axis 2 (y-axis) for all plots within a sub-community were used to calculate a mean x-value and a mean y-value for each identified sub-community, separately for the regeneration and canopy sub-plots. These mean x and y values for each of the 16 sub-communities were then plotted in ordination space.

The tree DBH data for canopy tree species, for each sub-community, were pooled by species and sorted into number of stems per each 5-cm wide DBH class, i.e. ≤5 cm, 5.1-10.0 cm, 10.1-15.0 cm, ... up to 60+ cm. The number of stems per DBH class per species per sub-community was then converted to number of stems (stem density) per ha. Histograms were prepared from the stems/ha per DBH class for selected species in each sub-community, and compared across the different sub-communities. For sub-canopy tree species, in a similar way as for canopy tree species, number of

stems per each 5-cm wide DBH class but up to 30+ cm were compiled and analysed. Important canopy and sub-canopy tree species that showed repetitive and consistent stem diameter distribution patterns over different communities, were presented and further discussed.

4.3 Results

4.3.1 Distance between regeneration and canopy composition of canopy trees (Grain)

The four communities show a range of distances between the points representing regeneration composition and points representing canopy composition of canopy tree species (Figure 4.3). Community 2 shows the closest similarity between regeneration composition and canopy composition of canopy species. Community 3 shows the biggest difference between the two sets (regeneration vs canopy composition), with communities 1 and 4 showing an intermediate similarity.

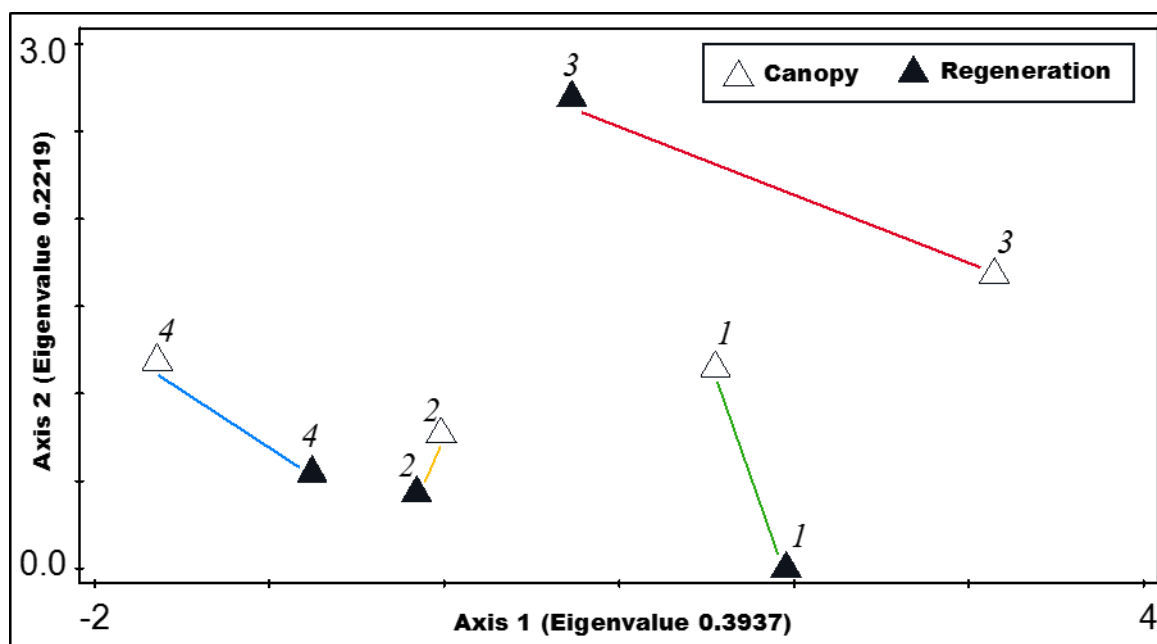


Figure 4.3 The distance in ordination space between regeneration composition and canopy composition of canopy tree species in the four identified woody communities in Afromontane Forests of Northwest Ethiopia.

Note that the four communities are connected by different colors.

The 16 sub-communities show a similar pattern as their main communities (Figure 4.4). However, they show much variation in distance between the mean points for regeneration composition and canopy composition of canopy tree species within the different main communities. Sub-community 3.222 shows the largest difference between regeneration and canopy composition (coarsest grain), followed by sub-communities 3.11, 3.121 and 3.122 with similar relatively coarser grain. Sub-communities 3.221 and 3.211 show an intermediate grain, and sub-community 3.212 shows a relatively finer grain. In community 1, sub-communities 1.11, 1.12 and 1.22 show the coarser grain, and coarser than the grain of sub-communities 3.221, 3.211 and 3.212, and sub-communities 1.211 and 1.212 showed relatively finer grain. Community 4 shows a coarser grain, but less coarse than sub-communities 3.11, 3.121 and 3.122. Sub-communities 2.11, 2.12 and 2.2 all have relatively finer grain.

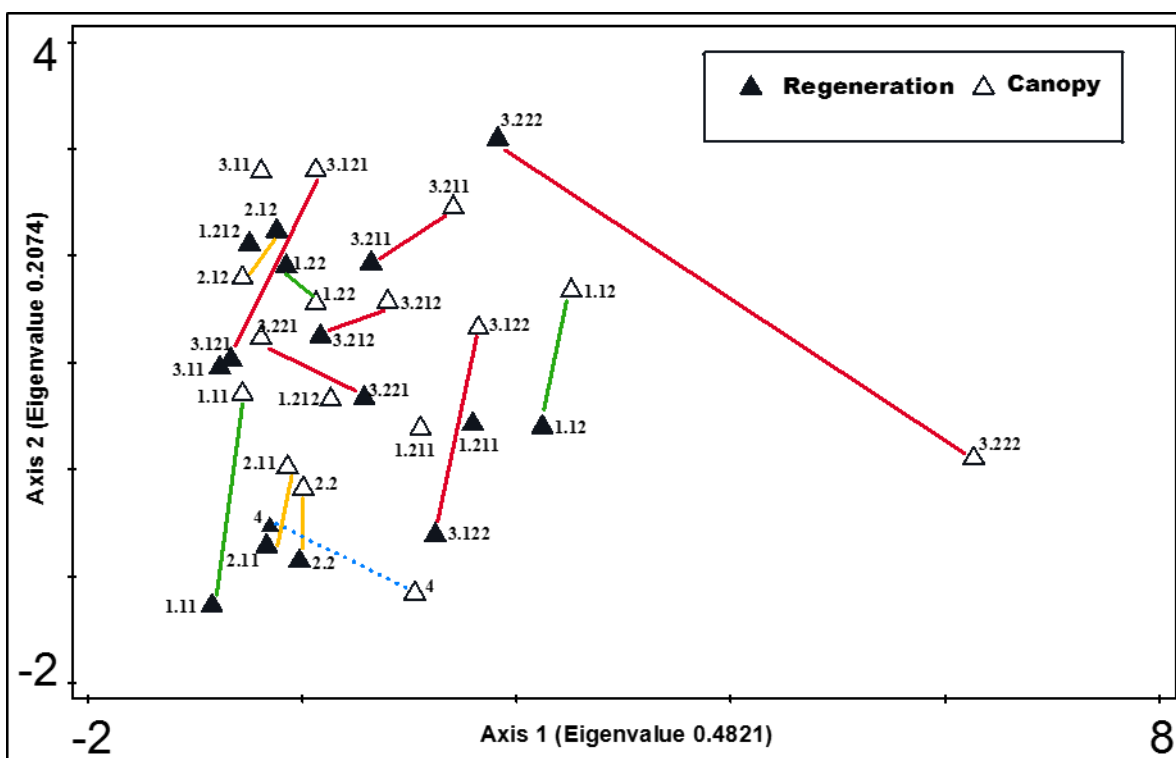


Figure 4.4 The distance in ordination space between regeneration composition and canopy composition of canopy tree species in the 16 identified woody sub-communities in Afromontane Forests of Northwest.

The points for regeneration and canopy for sub-communities 1.211, 1.212, 3.11 and community 4 were not connected with a solid line, for a clearer display of the graph. Sub-communities of a

particular community are connected by solid lines in a similar color, while community 4 connected by dotted line in blue color.

4.3.2 Stem diameter distributions of all stems of canopy and sub-canopy tree species

Stem diameter distributions of all stems for canopy and sub-canopy tree species, show inverse J-shaped stem diameter distributions (Figure 4.5). Sub-canopy trees have much higher stems in the lower DBH classes ≤ 15 cm. Similarly, all sub-communities show similar inverse J-shaped stem diameter distributions with much higher stems of sub-canopy trees in the lower DBH classes. In most cases, < 5 cm DBH has fewer stems than the 5-10 cm DBH class, as it only consists of stems 2-5 cm DBH (Figure 4.6). Generally, all sub-communities of community 1 show wide ranges of stem diameters, while sub-communities 3.11, 3.121, 3.222 and community 4 show narrower ranges of stem diameter.

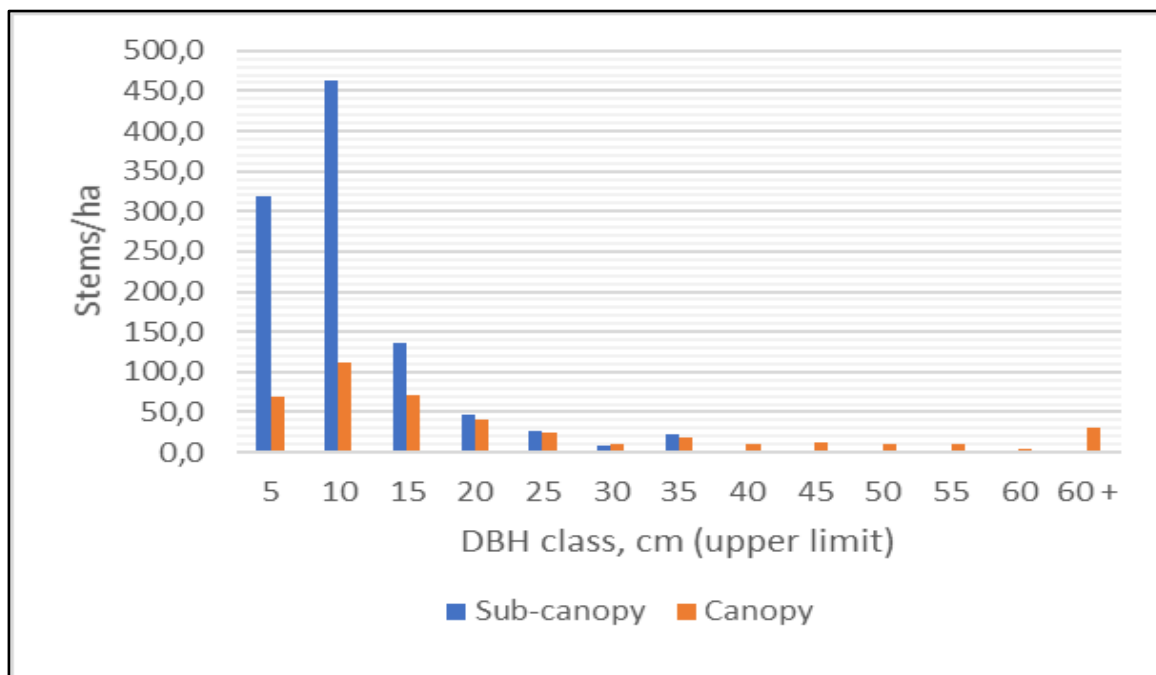


Figure 4.5 Stem diameter distributions of all stems of canopy and sub-canopy species

In canopy tree species, most stems occur in the lower and middle DBH classes (< 55 cm), with a decreasing trend towards the end of the higher DBH classes. All sub-communities show a general

low level of stems ≤ 5 cm DBH, except for community 4 (Table 4.1). Community 4 does not have stems >25 cm DBH. Density of stems ≤ 5 cm DBH ranged between 9 stems/ha in sub-community 3.222 and 229 stems/ha in sub-community 3.122. Similarly, most sub-canopy tree species have most trees with stems in the lower and middle classes (<25 cm DBH), with a decreasing trend towards the end of the higher DBH classes. All sub-communities show a general low level of stems ≤ 5 cm DBH, except for sub-communities 1.11, 1.211, 1.212, 2.12 and 3.11. Sub-community 3.221 has no stems $15+$ cm DBH. Density of stems ≤ 5 cm DBH ranged between 64 stems/ha in sub-community 3.222 and 750 stems/ha in sub-community 1.11 (Table 4.1). The different trends in stem diameter distributions for all canopy and sub-canopy tree species across all communities and sub-communities in which they grow, are shown in respectively Appendix 4.1 and 4.2.

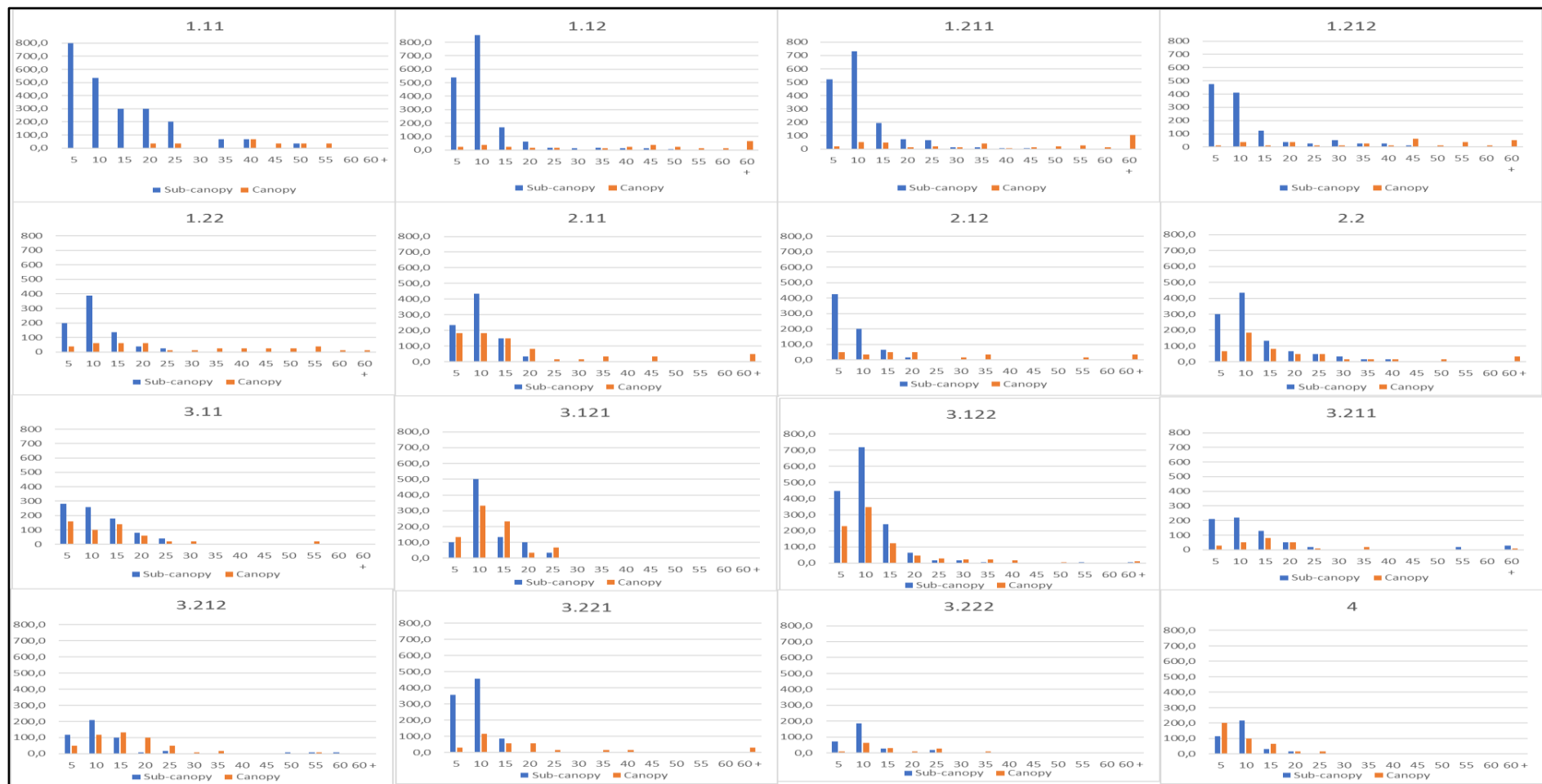


Figure 4.6 Stem diameter distributions of all stems of canopy and sub-canopy tree species for different communities and sub-communities.

Note that X- and Y-axes represent respectively for number of stems per ha and upper limit of DBH class in cm.

Table 4.1 Summary of stem diameter distributions across all communities and sub-communities.*

In each community and sub-community, the first row refers to canopy trees and the second row to sub-canopy trees. The details for each canopy and sub-canopy tree species are presented respectively in Appendix 4.1 and 4.2.

Canopy	Upper limit of DBH class, cm												
	5	10	15	20	25	30	35	40	45	50	55	60+	
Sub-canopy	5	10	15	20	25	30+							
*	Number of stems per ha												
1.11	33	133	67	100	33	-	-	67	33	67	-	-	
	750	433	250	233	167	200	-	-	-	-	-	-	
1.12	50	94	22	17	17	-	11	22	39	89	6	17	
	525	822	156	78	17	56	-	-	-	-	-	-	
1.211	113	547	180	47	53	13	40	7	13	153	7	7	
	460	213	60	33	40	53	-	-	-	-	-	-	
1.212	25	163	75	25	25	-	38	13	63	50	13	51	
	463	275	75	38	13	113	-	-	-	-	-	-	
1.22	63	100	88	50	25	13	25	13	38	13	63	13	
	150	375	113	38	25	-	-	-	-	-	-	-	
2.11	183	183	150	83	17	-	50	-	33	-	-	51	
	217	417	150	33	-	-	-	-	-	-	-	-	
2.12	50	50	75	75	-	25	50	-	-	-	25	50	
	400	300	125	25	-	-	-	-	-	-	-	-	
2.2	67	183	83	50	50	17	17	17	-	17	-	33	
	300	433	133	67	50	67	-	-	-	-	-	-	
3.11	117	100	117	50	17	17	-	-	-	-	-	17	
	617	217	150	67	33	-	-	-	-	-	-	-	
3.121	133	300	267	33	67	-	-	-	-	-	-	-	
	100	467	133	100	33	-	-	-	-	-	-	-	
3.122	229	324	141	53	29	24	24	18	-	6	-	12	
	288	741	218	71	24	33	-	-	-	-	-	-	
3.211	20	70	80	50	10	-	20	-	-	-	-	10	
	150	270	120	50	20	50	-	-	-	-	-	-	
3.212	50	117	133	92	58	8	17	-	-	-	17	-	
	125	192	83	8	-	37	-	-	-	-	-	-	
3.221	29	114	43	71	14	-	14	14	-	-	-	28	
	343	457	86	-	-	-	-	-	-	-	-	-	
3.222	9	64	32	9	27	5	9	5	5	5	-	-	
	64	159	27	5	-	-	-	-	-	-	-	-	
4	183	117	67	17	17	-	-	-	-	-	-	-	
	117	183	33	17	-	-	-	-	-	-	-	-	

4.3.3 Stem diameter distributions in selected canopy and sub-canopy tree species

Selected canopy tree species show Bell-shaped and inverse J-shaped curves in stem diameter distributions over different communities. *Albizia schimperiana*, *Croton macrostachyus*, *Nuxia congesta* and *Olea capensis* subsp. *macrocarpa* show Bell-shaped stem diameter distributions, while *Olea europaea* subsp. *cuspidata* and *Scolopia theifolia* (when stems ≤ 5 cm DBH are excluded) show inverse J-shaped stem diameter distributions (Figure 4.7). Similarly, selected sub-canopy tree species show Bell-shaped and inverse J-shaped stem diameter distributions over different communities. *Calpurnia aurea* shows a Bell-shaped stem diameter distribution, while *Bersama abyssinica* and *Teclea nobilis* show inverse J-shaped stem diameter distributions. *Euphorbia abyssinica* shows a double-bell shaped stem diameter distribution (Figure 4.8).

4.4 Discussion

4.4.1 Scales of disturbance-recovery processes (Grain analysis)

The results of the grain analysis are shown for the four communities in Figure 4.3 and for sub-communities in Figure 4.4. The canopy species involved in these analyses, and their stem diameter distributions within each sub-community are presented in Appendix 4.1. Species were either present only in the regeneration, or in the canopy or in both.

Community 1 shows a relatively intermediate distance (intermediate grain) between canopy composition and regeneration composition of canopy species, but sub-communities vary between fine and coarse grain. Sub-communities 1.211 and 1.212 show a fine grain, with *Dombeya torrida*, *Ekebergia capensis*, *Ficus sur*, *Prunus persica* and *Terminalia schimperiana* in sub-community 1.211 and *Croton macrostachyus*, *Dombeya torrida* and *Olea capensis* subsp. *macrocarpa* in sub-community 1.212 in both the regeneration and canopy composition. They respectively have two and two species only present in the regeneration, and three and four species only in the canopy. Sub-communities 1.11, 1.12 and 1.22 show a coarse grain and they have the following species in both regeneration and canopy composition (numbers between brackets show respectively number of species only in the regeneration or in the canopy): Sub-community 1.11 has none (one and two); *Afrocarpus falcatus*, *Dombeya torrida*, *Ficus sur* and *Olea capensis* subsp. *macrocarpa* in community 1.12 (six and two) and *Nuxia congesta* and *Olea europaea* subsp. *cuspidata* in sub-

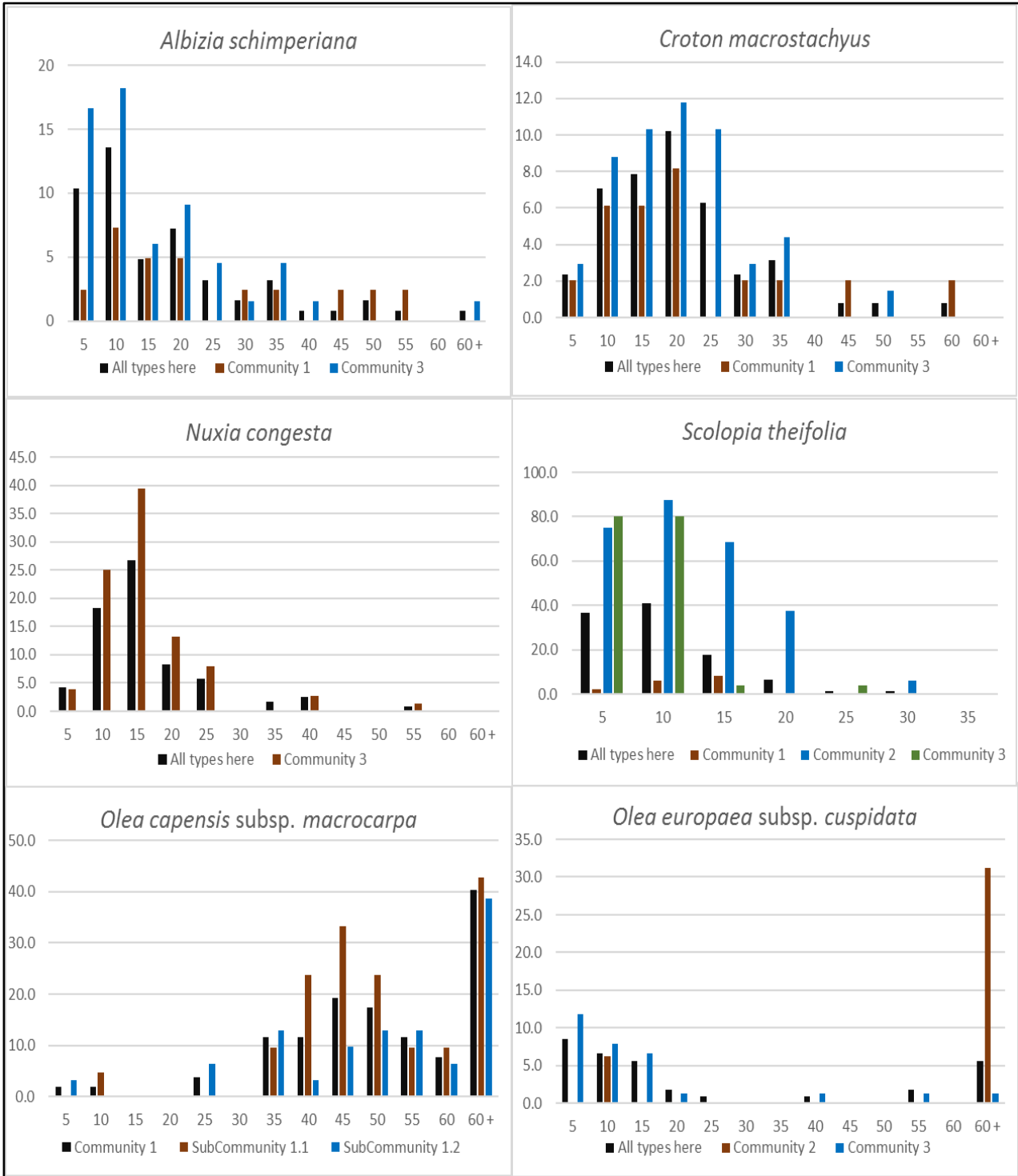


Figure 4.7 Stem diameter distributions of selected canopy tree species over different communities and sub-communities.

Note that X- and Y-axes represent respectively for number of stems per ha and upper limit of DBH class in cm.

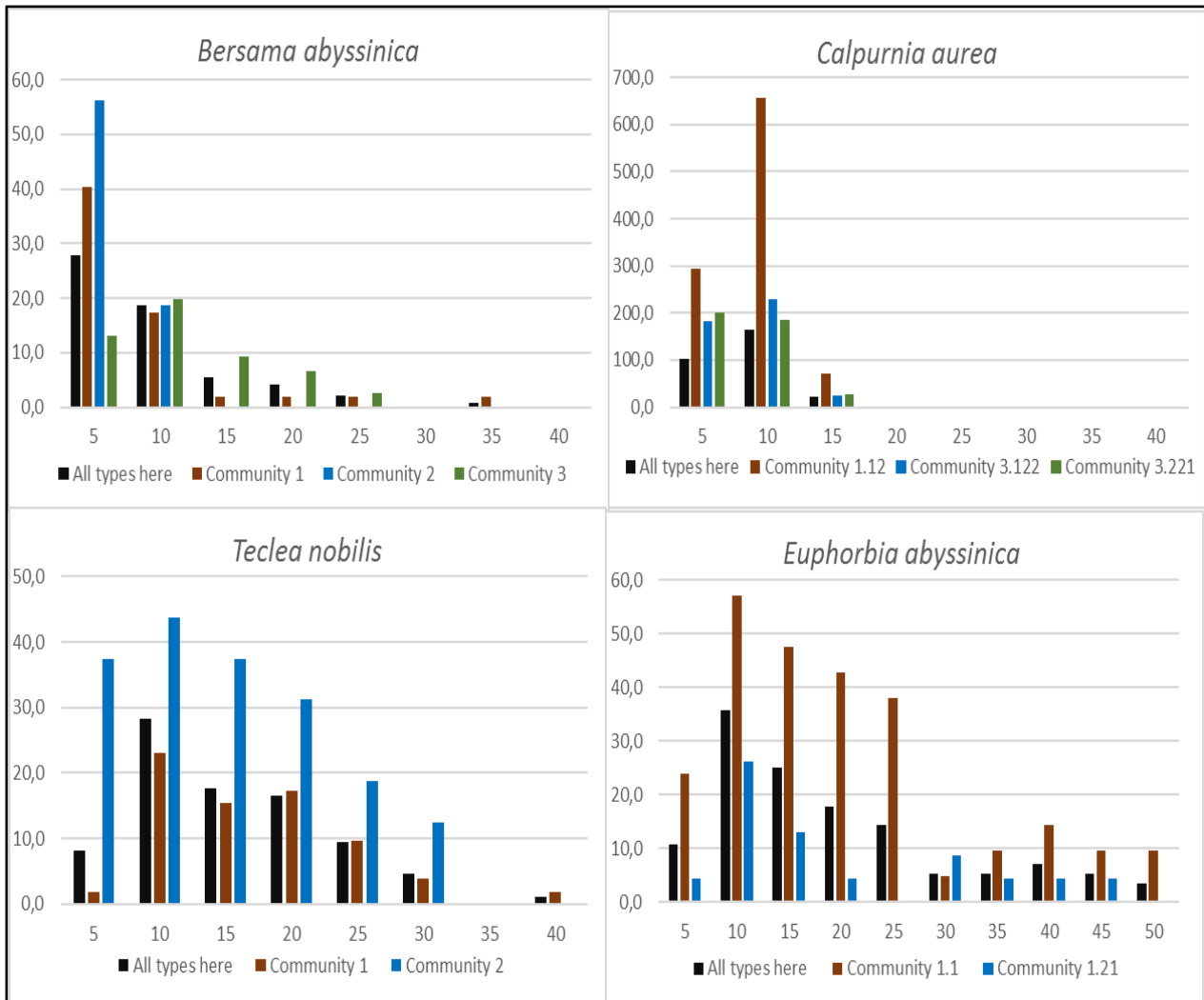


Figure 4.8 Stem diameter distributions of selected sub-canopy tree species over different communities and sub-communities.

Note that X- and Y-axes represent respectively for number of stems per ha and upper limit of DBH class in cm.

community 1.22 (four and seven). *Terminalia schimperiana* was the most abundant species in the regeneration composition of all these sub-communities, while *Albizia schimperiana* with good regeneration in sub-community 1.22. *Olea capensis* subsp. *macrocarpa* was the most abundant species in canopies of all these sub-communities, with no other species with such abundance. The observation of *Dombeya torrida* in both regeneration and canopy composition of fine-grained sub-communities 1.211 and 1.212, may indicate that it is a relatively shade-tolerant forest species.

Community 2 shows a relatively short distance between canopy composition and regeneration composition of canopy species (fine grain). This is also shown by the three sub-communities (2.11, 2.12 and 2.2). Sub-community 2.11 has *Nuxia congesta* and *Scolopia theifolia* in both regeneration and canopy composition, and sub-community 2.2 has *Nuxia congesta* and *Olea europaea* subsp. *cuspidata* in both regeneration and canopy composition, but sub-community 2.12 has no species that were present in both regeneration and canopy composition. Sub-community 2.11 has two species that were only present in the regeneration and six species only in the canopy, Sub-community 2.12 has respectively three and three species, and sub-community 2.2 has respectively two and three species. The most abundant species in these sub-communities in the regeneration were *Scolopia theifolia* in both sub-communities 2.11 and 2.2 (which also had good regeneration of *Galiniera saxifraga*), but no species was abundant in any of the canopies. Sub-community 2.12 had very few stems of canopy tree species in both their regeneration and in the canopy. This suggests that *Scolopia theifolia* is a relatively shade-tolerant forest species.

Community 3 shows the longest distance (coarse grain) between canopy composition and regeneration composition of canopy species, but the sub-communities vary from fine to coarse grain. Sub-community 3.212 has a fine grain, with *Croton macrostachyus* and *Nuxia congesta* in both the regeneration and canopy composition, and four species only in the regeneration and two species only in the canopy. Sub-communities 3.211 and 3.221 show an intermediate grain, with *Albizia schimperiana* in sub-community 3.211, and *Croton macrostachyus*, *Nuxia congesta* and *Olea europaea* subsp. *cuspidata* in sub-community 3.221 occurring in both regeneration and in the canopy. They respectively have five and two species only present in the regeneration, and one and two species only in the canopy. Sub-communities 3.11, 3.121, 3.122 and 3.222 show a coarse grain and they have the following species in both regeneration and canopy composition (numbers between brackets show respectively number of species only in the regeneration or in the canopy): *Nuxia congesta* in sub-community 3.11 (two with *Scolopia theifolia* most abundant in the regeneration, and two), *Allophylus abyssinicus* (most abundant in regeneration) and *Scolopia theifolia* in sub-community 3.121 (four and none), *Albizia schimperiana*, *Allophylus abyssinicus*, *Croton macrostachyus*, *Ekebergia capensis*, *Nuxia congesta*, *Olea europaea* subsp. *cuspidata* and *Schrebera alata* in sub-community 3.122 (four and two) and *Combretum molle*, *Croton macrostachyus*, *Myrica salicifolia*, *Vachellia etbaica* and *Vachellia seyal* in sub-community 3.222 (three and two). No species were abundant in the canopy of all these sub-communities. The observation of *Croton macrostachyus* in both the regeneration and

canopy composition of the coarse-grained sub-communities 3.122, 3.221 and 3.222, may indicate that it is a relatively light-demanding forest species (Tesfaye *et al.*, 2010).

Community 4 has no sub-communities, and has shown an intermediate distance (intermediate grain) between the composition of canopy species in the canopy (only *Olea europaea* subsp. *cuspidata*, with no regeneration) and the regeneration (five species, with no trees in the canopy). *Allophylus abyssinicus*, *Combretum molle* and *Nuxia congesta* were the most abundant in the regeneration, in this order of importance.

Olea europaea subsp. *cuspidata* was observed in the regeneration strata of intermediate to coarse-grained sub-communities 3.121, 3.122 and 3.221, but also as canopy species in fine-grained sub-communities 2.11, 2.12 and 2.2, reflecting its shade-tolerant characteristics. About 268 (60%) of its stems were observed in the <20.0 cm DBH classes, with 149 (33%) of the stems in the DBH classes ≥ 55.0 cm. *Schefflera abyssinica* was observed in the regeneration strata of fine-grained sub-communities 2.12, 2.2 and 3.212, suggesting it to be a shade-tolerant species. *Olea europaea* subsp. *cuspidata* has longer and *Schefflera abyssinica* has shorter seed dispersal distances, as their survival strategies (Abiyu *et al.*, 2016). This may relate to the observation of Lawes *et al.* (2007) that fine-grained species have dispersal limitations, while this may not be a problem in coarse-grained species.

Forest grain represents the relative similarity between composition of canopy species in the canopy and regeneration of the same stand. It is important to know whether tree species in the current canopy can regenerate under that canopy and associated conditions, or whether they need other conditions to regenerate and grow (Whitmore, 1978; Midgley *et al.*, 1990; Everard *et al.*, 1995; Geldenhuys, 1996, 2010). Tree community type 2 observed in a relatively closed regeneration gap; implying that this particular community has fine spatial grain with high representation of both canopy and regeneration species in its stands (Zywiec *et al.*, 2013; Nieto-Lugilde *et al.*, 2015). *Olea europaea* subsp. *cuspidata* and *Scolopia theifolia* have been observed in this community both in the regeneration and canopy composition, reflecting their shade-tolerance. The most wide regeneration gap was seen in tree community 3, followed by community 1 and 4. *Albizia schimperiana*, *Croton macrostachyus* and *Nuxia congesta* occurred in both the regeneration and canopy composition in community 3, reflecting their light-demanding characteristics. The observation of communities and sub-communities with various regeneration gaps, ranging from relatively fine to coarse spatial scales, might be possibly due to the relative disturbance heterogeneity of the stands (Garbarino *et al.*, 2012).

4.4.2 Community and population stem diameter distribution

Community stem diameter distribution

All the identified forest communities and sub-communities types have shown an inverse J-shaped stem diameter distribution. However, they varied in the ranges of their stem diameters. All sub-communities of community 1 showed wide ranges in stem diameters, but sub-communities 3.11, 3.121, 3.222 and community 4 showed narrower ranges in stem diameters. The narrower ranges of stem diameter in these tree communities may indicate their earlier stage of development, i.e. they may be recovering from diverse natural/anthropogenic disturbances.

Stem diameter distribution of canopy tree species

This study has also observed variability in stem diameter distributions across tree species (Figure 4.7 and see the stem diameter distribution of all canopy tree species in Appendix 4.1 and Appendix 4.1). *Olea capensis* subsp. *macrocarpa* showed low stem density in the lower DBH classes, despite the species considered to be a shade-tolerant species in South Africa (Geldenhuys, 1993a,b). *Afrocarpus* (*Podocarpus*) *falcatus* has few stems in the lower tree sizes, with no stems in the middle and higher DBH classes. Although it can tolerate some shade, it is dioecious, bat-dispersed, with germination constraints, regenerates in groups around parent trees, but grows fast in gaps and becomes an emergent tree (Geldenhuys, 1993a,b,c). The observed pattern in the forests of north-western Ethiopia may have been the result of earlier cutting most large trees of this species for various structural uses, and a gradual re-colonisation of the forests from different isolated trees. This is also another tree species considered to be, as one of the most common shade-tolerant species in Afromontane forests (Midgley *et al.*, 1990; Geldenhuys, 1993a). *Prunus africana* has relatively very few stems below 10 cm DBH (in sub-communities 1.12 and 1.211) but most stems are above 50 cm DBH (sub-communities 1.211 and 1.22). This is in accordance with studies in South Africa where it has been shown to be a light-demanding species, with scattered large trees but no regeneration in mature forest (Geldenhuys & Murray, 1993; Geldenhuys 2004), but with good regeneration in disturbed sites and under pine stands adjacent to the forest (Geldenhuys 1981; Geldenhuys & Delvaux 2007). This species is often targeted for use of its bark for traditional medicine (Geldenhuys, 2004; Abebe, 2016), but debarked wounds recover well, and the species needs more open, partially disturbed forest, to regenerate. *Juniperus procera* is present in three sub-communities, has no stems below 10 cm, but has similar numbers in the 10-20 cm DBH class (sub-communities 2.12 and 3.221), in the 30-35 cm DBH class (sub-community 2.12) and the 50+ cm DBH class (2.11, 2.12 and 3.221). This is a typical

light-demanding, pioneer species that occurs as scattered large emergent trees in the canopy of mature forest, with scattered to abundant regeneration to small trees outside the forest, in several forests in Ethiopia where this species grows. It functions as a nurse species to facilitate the regeneration of more shade-tolerant forest species (Bussmann, 2001; Abiyu *et al.*, 2018). The mentioned species show the impairments in their regeneration in closed forest (Vlam *et al.*, 2017).

The bell-shaped stem diameter distribution of *Croton macrostachyus* in this study in various fine-, intermediate- and coarse-grained tree communities, is in accordance with studies indicating it as a light demanding and early successional tree species on disturbed forests (Hitimana *et al.*, 2004; Shibistova *et al.*, 2012). It can also be regenerate well under closed-canopy forest conditions (Senbeta *et al.*, 2002). The bell-shaped stem diameter distribution of *Nuxia congeta* indicate about its light demanding characteristic for regeneration, similar to observations by Sslai *et al.* (2018) of higher recruitment of *Nuxia congesta* in the bracken (*Pteridium aquilinum*) vegetation with open canopy than in the interior of the closed-canopy forest. *Scolopia theifolia* shows an inverse J-shaped stem diameter distribution, indicating its shade-tolerance, as reported from different Afromontane forests (Bussmann, 1999; Teketay, 1997). *Albizia schimperiana* occurred in both the regeneration and canopy composition, in stands from fine to coarse-grain communities, showing its wider ecological breadth and better population status than most of the other tree species. The observation of *Terminalia schimperiana* with bell-shaped stem diameter distribution in coarser-grained communities, reflects its relative intolerance of shade (Lahoreau *et al.*, 2006).

Some tree species have shown a single-cohort age structure, either in the lower or middle diameter classes, in various forest communities. For instance, *Celtis africana* and *Albizia sp.* have shown single cohorts, respectively in the lower and middle diameter classes. Such distribution pattern with a single cohort may happen, when the species have a relatively strong conservatism in their lower or intermediate size classes (Bin *et al.*, 2012). It may also reflect an early stage of recruitment in the post-disturbance stage (Popa *et al.*, 2017). Few stems in limited DBH classes were recorded for some species, including *Albizia sp.*, *Mimusops kummel*, *Piliostigma thonningii*, *Schefflera abyssinica* and *Vachellia abyssinica*. This may reflect irregular suitable events for their regeneration.

Stem diameter distribution of sub-canopy tree species

Sub-canopy tree species showed similar variability in stem diameter distribution (Figure 4.8; Appendix 4.2), as seen for canopy species. The inverse J-shaped stem diameter distribution of

Bersama abyssinica in most fine-grained sub-communities, and of *Teclea nobilis* in fine to coarse-grained communities, indicate their shade-tolerance, in accordance with results of [Teketay \(2005\)](#) on *Bersama abyssinica* and [Tesfaye et al. \(2002\)](#) on *Teclea nobilis*. The seed of *B. abyssinica* is easily desiccable and adapted to germination immediately after seed shed ([Teketay and Granström, 1995](#)). *Euphorbia abyssinica* showed a double-bell-shaped stem diameter distribution in coarser-grain sub-communities 1.1 and 1.21, indicating its need for better light conditions in canopy gaps for better regeneration. *Grewia ferruginea* showed an inverse J-shaped stem diameter distribution in coarse-grained sub-communities, which suggests good regeneration in more disturbed conditions, similar to its dominance as pioneer-like species, in the early successional stage of secondary forests ([Mengistu et al., 2005](#)). *Calpurnia aurea* shows Bell-shaped stem diameter distribution, which may indicate also its light-demanding characteristic, and establishment in forest gaps or the forest margin.

Some sub-canopy tree species have shown a single-cohort age structure in various forest communities, either in the lower (such as *Dregea schimperi*) or middle diameter classes (*Flacourtia indica* and *Gnidia glauca*). Some species showed a few stems in limited DBH classes, such as *Brucea antidysenterica*, *Entada abyssinica*, *Dregea schimperi*, *Flacourtia indica*, *Gnidia glauca*, *Myrsine africana*, *Pittosporum abyssinicum* and *Stereospermum kunthianum*, indicating irregular suitable events for their regeneration.

Species have characteristic stem diameter distributions which indicate success or failure of their regeneration and hence population status in a particular forest ([Geldenhuys, 2010](#); [Teketay, 2005a](#)). Stem diameter distribution of a given species provides information about the history of disturbance and its environment ([Teketay, 2005b](#); [Alelign et al., 2007](#); [Zegeye et al., 2011](#); [Wale et al., 2012](#)). A variety of stem diameter distributions ranging from a single to multiple peaks or cohorts, were observed in different tree species. Most of tree species showed more than two cohorts, in their stem distribution patterns. Such a pattern is a direct reflection of disturbance heterogeneity of a forest ecosystem. The more heterogeneity in disturbance in a forest ecosystem, the more cohorts can be observed in stem diameter distribution ([Antao et al., 2017](#)). High heterogeneity in tree mortality might lead also to such a distribution pattern ([Harmon and Pabst, 2015](#)). According to [Velazquez et al. \(2016\)](#) and [Wang et al. \(2017\)](#), such a formation of variable size distributions within cohorts might happen also because of asymmetric or unbalanced resource competition among cohorts. It is, therefore, a direct indication about the presence of high heterogeneity of stand structures and gap dynamics in the studied forests ([Maltamo et al., 2000](#)).

4.4.3 Relative shade-tolerance of species and forest stand dynamics

This study showed variability in stem diameter distributions across tree species and communities. Some tree species were present in both regeneration and canopy composition of some fine-grained sub-communities, indicating their relative higher shade-tolerance, as with *Olea europaea* subsp. *cuspidata* and *Scolopia theifolia*. Some tree species were present in both regeneration and canopy composition of some coarse-grained sub-communities, indicating their relative lower shade-tolerance, such as *Croton macrostachyus* and *Ekebergia capensis*.

The lowest stems per ha for stems ≤ 5 cm DBH, both in canopy (9 stems/ha) and sub-canopy (64 stems/ha) tree species, was recorded in the most coarse-grained sub-community 3.222. Such a low stem densities in the most open stand conditions may indicate an abnormal stand condition, possibly indicating the severity of disturbance. Given the large canopy gaps of this community, regeneration triggering factors, such as light, was expected to show more pronounced response in regeneration in this particular community. High stem density per ha in the < 20 cm DBH classes, was observed in the coarse-grained sub-communities 3.121 and 3.122 (in the canopy tree composition) and 1.11, 1.12, 3.11 and 3.122 (in sub-canopy tree composition). This may reflect a post-disturbance recruitment in these particular communities. A similar relatively high stem density per ha in the < 20 cm DBH classes was observed for both canopy and sub-canopy tree composition, fine-grained sub-communities 1.211 and 2.11, and in sub-canopy tree composition in fine-grained sub-communities 1.212, 2.12, and 2.2. Relatively low stem density per ha in both canopy and sub-canopy tree composition occurred in the fine to intermediate-grained sub-communities 2.12, 3.211 and 3.212. This may suggest the need for selective thinning of canopy species in these particular communities to trigger regeneration through better light conditions.

The stem diameter distribution analysis in this study showed the contribution of some species in forest gap dynamics (gap making and filling) of this particular biogeographical region. It can be said that late-successional species such as *Olea capensis* subsp. *macrocarpa*, *Olea europaea* subsp. *cuspidata* and *Prunus africana* have a gap-making role, while the early-successional species such as *Afrocarpus falcatus*, *Combretum molle*, *Scolopia theifolia* and *Terminalia schimperiana* perform a gap-filling role. Variability in their dynamics might be due to differences in age, competitive status, growth rate, genetic properties, and the variability of disturbances and available resources (Rouvinena and Kuuluvainen, 2005; Svoboda *et al.*, 2010; Panayotov *et al.*, 2015).

4.5 Conclusion

In this study showed variability in terms of both spatial scales in grain (disturbance regimes) and stem diameter distribution. Such variability suggests the need to consider different interventions and approaches according to the observed variability. Most of recorded stems accumulated in the lower DBH classes, as compared to the middle and higher DBH classes. Conversely, some of the observed canopy and sub-canopy tree species showed a tendency towards the Bell-shaped stem diameter distribution. This indicate the presence of light-demanding species, which need moderate disturbance and canopy gaps for their successful regeneration, such as *Ekebergia capensis*, *Croton macrostachyus*, *Juniperus procera*, *Nuxia congesta*, *Olea capensis* subsp. *macrocarpa*, *Prunus africana*, *Schefflera abyssinica* and *Terminalia schimperiana*.

Some species showed a few stems in limited DBH classes, which may indicate irregular suitable regeneration events, such as in canopy tree species *Albizia sp.*, *Mimusops kummel*, *Piliostigma thonningii*, *Schefflera abyssinica* and *Vachellia abyssinica*, and sub-canopy tree species *Brucea antidysenterica*, *Entada abyssinica*, *Dregea schimperi*, *Flacourtia indica*, *Gnidia glauca*, *Myrsine africana*, *Pittosporum abyssinicum* and *Stereospermum kunthianum*. A too close forest canopy may prevent or inhibit the regeneration some light-demanding species. However, free livestock grazing and trampling, and illegal logging for fuelwood and farm implements, are other possible factors that contributed to irregular regeneration of some tree species. This study observed cattle grazing in Tara Geda forest, during data collection.

The relatively low density in stems <20 cm DBH in the fine to intermediate-grain sub-communities 2.12, 3.211 and 3.212, suggests the need for appropriate forest management, such as selective thinning to improve the stand conditions these particular tree communities to improve regeneration. The low density in stems <20 cm DBH in the most coarse-grained sub-community 3.222 possibly indicate the severity of disturbance and a need to reduce or regulate disturbance through forest management intervention in such situations. The narrow range in stem diameter in sub-communities 3.11, 3.121, 3.222 and community 4, may also indicate that they are in an earlier stage of development, and selective stem thinning may facilitate the development of stems towards larger size classes. Results from this study indicate different kinds of interventions that suit different species according to their ecological characteristics, and the observed stage of development over different communities. This study recommends further study about the determination of the optimum spatial and temporal scales of disturbance, to keep the structural diversity and productivity of the forest ecosystem on a sustainable basis, and in balance with the natural disturbance-recovery processes.

References

- Abebe, W. (2016). An Overview of Ethiopian Traditional Medicinal Plants Used for Cancer Treatment. *European Journal of Medicinal Plants*, 14(4), 1-16.
- Abiyu, A. Teketay, D. Glatzel, G. and Gratzner, G. (2016). Seed production, seed dispersal and seedling establishment of two afro-montane tree species in and around a church forest: implications for forest restoration. *Forest Ecosystems*, 3, 16. DOI 10.1186/s40663-016-0076-5.
- Abiyu, A. Mokria, M. Gebrekirstos, A. and Bräuning, A. (2018). Tree-ring record in Ethiopian church forests reveals successive generation. Differences in growth rates and disturbance events. *Forest Ecology and Management*, 409, 835-844.
- Alelign, A., Teketay, D., Yemshaw, Y. and Edwards, S. (2007). Diversity and status of regeneration of woody plants on the peninsula of Zegie, northwestern Ethiopia. *Tropical Ecology*, 48, 37-49.
- Almazán-Núñez, R. C. Corcuera, P. Parra-Juárez, L. Jiménez-Hernández, J. and Charre, G. M. (2016). Changes in Structure and Diversity of Woody Plants in a Secondary Mixed Pine-Oak Forest in the Sierra Madre del Sur of Mexico. *Forests*, 7, 90. Doi: 10.3390/f7040090.
- Antao, L. H. Connolly, S. R. Magurran, A. E. Soares, A. and Dornelas, M. (2017). Prevalence of multimodal species abundance distributions is linked to spatial and taxonomic breadth. *Global Ecology and Biogeography*, 26, 203-215.
- Bin, Y. Ye, W. Muller-Landau, H. C. Linfang Wu, L. Lian, J. and Cao, H. (2012). Unimodal Tree Size Distributions Possibly Result from Relatively Strong Conservatism in Intermediate Size Classes. *PLoS ONE*, 7(12). e52596. Doi: 10.1371/journal.pone.0052596.
- Bussmann, R. W. (1999). Notes on the vegetation of Menagesha Forest (Shoa Province, Central Ethiopia). *Bayreuther Forum Ökologie*, 64, 105-118.
- Bussmann, R. W. (2001). Succession and regeneration patterns of East African mountain forests A review. *Systematics and Geography of Plants*, 71, 959-974.
- Dyakov, N. R. (2013). Successional Pattern, Stand Structure and Regeneration of Forest Vegetation According to Local Environmental Gradients. *Ecologia balkanica*, 5(1), 69-85.
- Enright, N. J. Bartlett, R. M. and DeFreitas. (1993). Patterns of species composition, recruitment, and growth within canopy gaps in two New Zealand kauri (*Agathis australis*) forests. *New Zealand Journal of Botany*, 31, 361-373.

- Eshete, A. W. (2007). Ethiopian Church Forests: opportunities and challenges for restoration. PhD thesis, Wageningen University, Wageningen, The Netherlands.
- Everard, D. A. (1992). On the feasibility of developing a functional classification as a decision support system for the management of the indigenous forests in Natal, Report No. FOR-DEA 458, Division of Forest Science and Technology, CSIR, Pretoria.
- Everard, D. A. Midgley, J. J. and van Wyk, G. F. (1995). Dynamics of some forests in KwaZulu-Natal, South Africa, based on ordinations and stem-diameter distributions. *South African Journal of Botany*, 61, 283-292.
- Garbarino, M. Mondino, E. B. Lingua, E. Nagel, T. A. Dukić, V. Govedar, Z. and Motta, R. (2012). Gap disturbances and regeneration patterns in a Bosnian old-growth forest: a multispectral remote sensing and ground-based approach. *Annals of Forest Science*, 69, 617- 625.
- Geldenhuys, C. J. (1981). *Prunus africana* in the Bloukrans River Gorge, southern Cape. *South African Forestry Journal*, 118, 61-66.
- Geldenhuys, C. J. (1993a). The Use of Diameter Distribution in sustained use management of forests: examples from southern Africa. In: Pearce, G. D. and Gumbo, D. J. (eds.), The ecology and management of indigenous forests in southern Africa, Proceedings of an International Symposium, Victoria Falls, Zimbabwe, 27-29 July 1992. Zimbabwe Forestry Commission and SAREC, 154-167.
- Geldenhuys, C. J. (1993b). Composition and dynamics of plant communities in the southern Cape forests. Unpublished report FOR-DEA 612, Division of Forest Science and Technology, CSIR, Pretoria. 56 pp.
- Geldenhuys, C. J. (1993c). Reproductive biology and population structures of *Podocarpus falcatus* and *P.latifolius* in southern Cape forests. *Botanical Journal of Linnean Society*, 112, 59-74.
- Geldenhuys, C. J. (1996). Forest management systems to sustain resource use and biodiversity: examples from the southern Cape, South Africa. In: Van der Maesen, L. J. G. Van der Burgt, X. M. and Van Medenbach de Rooy, J.M. (eds.), The Biodiversity of African Plants, 317-322. Kluwer Academic Publishers, Netherlands.

- Geldenhuys, C. J. 2004. Bark harvesting for traditional medicine: from illegal resource degradation to participatory management. *Scandinavian Journal of Forest Research*, 19 (Supplement 4), 103-115.
- Geldenhuys, C. J. (2010). Managing forest complexity through application of disturbance-recovery knowledge in development of silvicultural systems and ecological rehabilitation in natural forest systems in Africa. *Journal of Forest Research*, 15, 3-13. Doi: 10.1007/s10310-009-0159-z.
- Geldenhuys, C. J. (2011). Disturbance and Recovery in Natural Forests and Woodlands in Africa: Some Concepts for the Design of Sustainable Forest Management and Rehabilitation Practices. In: Geldenhuys, C. J. Ham, C. & Ham, H. (eds.), Sustainable Forest Management in Africa: Some Solutions to Natural Forest Management Problems in Africa, Proceedings of the Sustainable Forest Management in Africa Symposium, Stellenbosch, 3-7 November 2008.
- Geldenhuys, C. J. & Delvaux, C. (2007). The *Pinus patula* plantation ... A nursery for natural forest seedlings. In: Bester, J. J., Seydack, A. H. W., Vorster, T., Van der Merwe, I. J. & Dzivhani, S. (eds). Multiple use management of natural forests and woodlands: Policy refinement and scientific progress. Natural Forests and Savanna Woodland Symposium IV, Port Elizabeth, South Africa, 15-18 May 2006. Pp 94-107.
- Geldenhuys, C. J. and Maliepaard, W. (1983). The Causes and Sizes of Canapoy Gaps in the Southern Cape forests. *South African Forestry Journal*, 124, 50-55.
- Geldenhuys, C. J. & Murray, B. (1993). Floristic and structural composition of Hanglip forest in the Soutpansberg, northern Transvaal. *South African Forestry Journal* 165, 9-19.
- Halpin, C. R. and Lorimer, C. G. (2017). A Demographic Approach to Evaluating Tree Population Sustainability. *Forests*, 8, 46. Doi: 10.3390/f8020046.
- Harmon, M. E. and Pabst, R. J. (2015). Testing predictions of forest succession using longterm measurements: 100 yrs of observations in the Oregon Cascades. *Journal of Vegetation Science*, 26, 722-732.
- Hitimana, J. Kiyiapi, J. L. and Njunge, J. T. (2004). Forest structure characteristics in disturbed and undisturbed sites of Mt. Elgon Moist Lower Montane Forest, western Kenya. *Forest Ecology and Management*, 194, 269-291.

- Hunter, M. O. Keller, M. Morton, D. Cook, B. Lefsky, M. Ducey, M. Saleska, S. de Oliveira Jr, R. C. and Schiatti, J. (2015). Structural Dynamics of Tropical Moist Forest Gaps. *PLoS ONE*, 10(7). e0132144.
- Hytteborn, H. and Werwijst, T. (2011). The importance of gaps and dwarf trees in the regeneration of Swedish spruce forests: the origin and content of sernander's (1936) gap dynamics theory. *Scandinavian Journal of Forest Research*, 26(10), 3-16.
- Jonasova, M. Vavrova, E. and Cudlin, P. (2010). Western Carpathian Mountain spruce forest after a windthrow: Natural regeneration in cleared and uncleared areas. *Forest Ecology and Management*, 259 1127-1134.
- Kang, H. Zheng, Y. Liu, S. Chai, Z. Chang, M. Hu, Y. Li, G. and Wang, D. (2017). Population structure and spatial pattern of predominant tree species in a pine–oak mosaic mixed forest in the Qinling Mountains, China. *Journal of Plant Interactions*, 12(1), 78-86.
- Kenders, K. Kral, K. Vrska, T. and Standovar, T. (2009). Natural gap dynamics in a Central European mixed beech-spruce-fir old-growth forest. *Écoscience*, 16(1), 39-47.
- Kern, C. C. D'Amato, A. W. and Strong, T. F. (2013). Diversifying the composition and structure of managed, late-successional forests with harvest gaps: What is the optimal gap size? *Forest Ecology and Management*, 304, 110-120.
- Kern, C. C. Montgomery, R. A. Reich, P. B. Strong, T. F. (2014). Harvest-Created Canopy Gaps Increase Species and Functional Trait Diversity of the Forest Ground-Layer Community. *Forest Science*, 60 (2), 335-344.
- King, S. L. and Antrobus, T. J. (2005). Relationships between gap makers and gap fillers in an Arkansas floodplain forest. *Journal of Vegetation Science*, 16, 471-480.
- Kubota, Y. (2006). Spatial pattern and regeneration dynamics in a temperate *Abies-Tsuga* forest in southwestern Japan. *Journal of Forest Research*, 11, 191-201.
- Lahoreau, G. Barot, S. Gignoux, J. Hoffmann, W. A. Setterfield, S. A. and Williams, P. R. (2006). Positive effect of seed size on seedling survival in fire-prone savannas of Australia, Brazil and West Africa. *Journal of Tropical Ecology*, 22, 719-722.
- Lawes, M. J. and Obiri, J. A. F. (2003). Using the spatial grain of regeneration to select harvestable tree species in subtropical forest. *Forest Ecology and Management*, 184, 105-114.

- Lawes, M. J. Joubert, R. Griffiths, M. E. Boudreau, S. and Chapman, C. A. (2007). The effect of the spatial scale of recruitment on tree diversity in Afromontane forest fragments. *Biological Conservation*, 139, 447-456.
- Lobo, E. and Dalling, J. W. (2014). Spatial scale and sampling resolution affect measures of gap disturbance in a lowland tropical forest: implications for understanding forest regeneration and carbon storage. *Proceedings of Royal Society B*, 281: 20133218. Doi: 0.1098/rspb.2013.3218.
- Maltamo, M. Annika Kangas, A. Uuttera, J. Torniainen, T. and SaramaÈeki, J. (2000). Comparison of percentile based prediction methods and the Weibull distribution in describing the diameter distribution of heterogeneous Scots pine stands. *Forest Ecology and Management*, 133, 263-274.
- Mengistu, T. Teketay, D. Hulten, H. and Yemshaw, Y. (2005). The role of enclosures in the recovery of woody vegetation in degraded dryland hillsides of central and northern Ethiopia. *Journal of Arid Environments*, 60, 259-281.
- Meng, J. Li, S. Wang, W. Liu, Q. Xie, S. and Ma, W. (2016). Estimation of Forest Structural Diversity Using the Spectral and Textural Information Derived from SPOT-5 Satellite Images. *Remote Sensing*, 8,125. Doi: 10.3390/rs8020125.
- Midgley, J., Seydack, A. Reynell, D. and McKelly, D. (1990). Fine-grain pattern in Southern Cape plateau forests. *Journal of Vegetation Science*, 1, 539-546.
- Mura, M. McRoberts, R. E. Chirici, G. and Marchetti, M. (2016). Statistical inference for forest structural diversity indices using airborne laser scanning data and the k-Nearest Neighbors technique. *Remote Sensing of Environment*, 186, 678-686.
- Nieto-Lugilde, D. Lenoir, J. Abdulhak, S. Aeschmann, D. Dullinger, S. Gégout, J. C. Guisan, A. Pauli, H. Renaud, J. Theurillat, J. P. Thuiller, W. Van Es, J. Vittoz, P. Willner, W. Wohlgemuth, T. Zimmermann, N. E. and Svenning, J. C. (2015). Tree cover at fine and coarse spatial grains interacts with shade tolerance to shape plant species distributions across the Alps. *Ecography*, 2015, 38(6), 578-589. Doi:10.1111/ecog.00954.
- Pach, M and Podlaski, R. (2015). Tree diameter structural diversity in Central European forests with *Abies alba* and *Fagus sylvatica*: managed versus unmanaged forest stands. *Ecological Research*, 30, 367-384. Doi: 10.1007/s11284-014-1232-4.

- Panayotov, M. Bebi, P. Tsvetanov, N. Alexandrov, N. Laranjeiro, L. and Kulakowski, D. (2015). The disturbance regime of Norway spruce forests in Bulgaria. *Canadian Journal of Forest Research*, 45, 1143-1153.
- Pastur, G. M. Jordan, C. Esteban, R. S. Lencinas, M. V. Ivancich, H. and Kreps, G. (2012). Landscape and micro environmental conditions influence over regeneration dynamics in old-growth *Nothofagus betuloides* Southern Patagonian forests. *Plant Biosystems*, 146(1), 201-213.
- Popa, I. Nechita, C. and Hofgaard, A. (2017). Stand structure, recruitment and growth dynamics in mixed subalpine spruce and Swiss stone pine forests in the Eastern Carpathians. *Science of the Total Environment*, 598, 1050-1057.
- Rentch, J. S. Schuler, T. M. Nowacki, G. J. Beane, N. R. and Ford, W. M. (2010). Canopy gap dynamics of second-growth red spruce-northern hardwood stands in West Virginia. *Forest Ecology and Management*, 260, 1921-1929.
- Rouvinena, S. and Kuuluvainen, T. (2005). Tree diameter distributions in natural and managed old *Pinus sylvestris*-dominated forests. *Forest Ecology and Management*, 208, 45-61.
- Schnitzer, S. A. and Carson, W. P. (2010). Lianas suppress tree regeneration and diversity in treefall gaps. *Ecology Letters*, 13, 849-857.
- Senbeta, F. Teketay, D. and Naslund, B. (2002). Native woody species regeneration in exotic tree plantations at Munessa-Shashemene Forest, southern Ethiopia. *New Forests*, 24, 131-145.
- Sharma, L. N. Grytnes, J. A. Maren, L. E. and Vetaas, O.R. (2016). Do composition and richness of woody plants vary between gaps and closed canopy patches in subtropical forests? *Journal of Vegetation Science*, 27, 1129-1139.
- Shibistova, O. Yohannes, Y. Boy, J. Richter, A. Wild, B. Watzka, M. and Guggenberger, G. (2012). Rate of belowground carbon allocation differs with successional habit of two afro-montane trees. *PLoS ONE*, 1-7, e45540.
- Ssali, F. Moe, S. R. and Sheil, D. (2018). Tree seed rain and seed removal, but not the seed bank, impede forest recovery in bracken (*Pteridium aquilinum* (L.) Kuhn)-dominated clearings in the African highlands. *Ecology and Evolution*, 8, 4224-4236.
- Sturtevant, B. R. Miranda, B. R. Wolter, P. T. James, P. M. A. Fortin, M. J. and Townsend, P. A. (2014). Forest recovery patterns in response to divergent disturbance regimes in the Border Lakes

- region of Minnesota (USA) and Ontario (Canada). *Forest Ecology and Management*, 313, 199-211.
- Svoboda, M. Fraver, S. Jandaa, P. Bace, R. and Zenahlikova, J. (2010). Natural development and regeneration of a Central European montane spruce forest. *Forest Ecology and Management*, 260, 707-714.
- Teketay, D. and Granström, A. (1995). Soil seed banks in dry Afromontane forests of Ethiopia. *Journal of Vegetation Science*, 6, 777-786.
- Teketay, D. (1997). Seedling populations and regeneration of woody species in dry Afromontane forests of Ethiopia. *Forest Ecology and Management*, 98, 149-165.
- Teketay, D. (2005a). Seed and regeneration ecology in dry Afromontane forests of Ethiopia: I. Seed production-population structures. *Tropical Ecology*, 46(1), 29-44.
- Teketay, D. (2005b). Seed and regeneration ecology in dry Afromontane forests of Ethiopia: II. Forest Disturbance and Succession. *Tropical Ecology*, 46, 45-64
- ter Braak, C. J. F. & Šmilauer, P (2012). Canoco Reference Manual and Users Guide: Software for Ordination, Version 5.0. Microcomputer Power, Ithaca, New York.
- Tesfaye, G. Teketay, D. and Fetene, M. (2002). Regeneration of fourteen tree species in Hareenna forest, southeastern Ethiopia. *Flora*, 197, 461-474.
- Tesfaye, G. Teketay, D. Fetene, M. and Beck, E. (2010). Regeneration of seven indigenous tree species in a dry Afromontane forest, southern Ethiopia. *Flora*, 205, 135-143.
- Velazquez, J. Allen. R. B. Coomes, D. A. and Eichhorn, M. P. (2016) Asymmetric competition causes multimodal size distributions in spatially structured populations. *Proceedings of Royal Society B*, 283. 20152404. Doi: 10.1098/rspb.2015.2404.
- Vlam, M. Van Der Sleen, P. Groenendijk, P. and Zuidema, P. A. (2017). Tree Age Distributions Reveal Large-Scale Disturbance-Recovery Cycles in Three Tropical Forests. *Frontiers in Plant Science*, 7, 1-12. Doi: 10.3389/fpls.2016.01984.
- Wale, H.A. (2006). Study on Indigenous Tree and Shrub Species of Churches, and Monasteries of Wag-Lasta districts. Proceedings of the 1st Annual Regional Conference on Completed Research Activities on Natural Resources Management. 14-17 August 2006, Amhara Regional Agricultural Research Institute, Bahir Dar, Ethiopia.

- Wale, H. A. Bekele, T. and Dalle, G. (2012). Floristic Diversity, Regeneration Status and Vegetation Structure of the Woodland Vegetation in Metema Area, Amhara National Regional State, Northwestern Ethiopia. *Journal of Forestry Research*, 23(3), 391-398.
- Wang, H. Wan, P. Wang, Q. Liu, L. Zhang, G and Hui, G. (2017). Prevalence of Inter-Tree Competition and Its Role in Shaping the Community Structure of a Natural Mongolian Scots Pine (*Pinus sylvestris* var. *mongolica*) Forest. *Forests*, 8, 84. Doi: 10.3390/f8030084.
- Wassie, A. Sterck, F. J. & Bongers, F. (2010). Species and structural diversity of church forests in a fragmented Ethiopian Highland landscape. *Journal of Vegetation Science*, 21, 938-948. DOI: 10.1002/9781118445112.stat07684.
- Whitmore, T. C. (1978). Gaps in the forest canopy. pp. 639-655. In: P.B. Tomlinson & M.H. Zimmermann (eds.) *Tropical Trees as Living Systems*. Cambridge University Press, London & New York.
- Yamamoto, S. I. (2000). Forest Gap Dynamics and Tree Regeneration. *Journal of Forest Research*, 5(4), 223-229.
- Zagidullina, A. and Tikhodeyeva, Marina. (2006). Spatial patterns of tree regeneration and ground cover in dry Scots pine forest in Russian Karelia. *Écoscience*, 13(2), 203-218.
- Zegeye, H., Teketay, D. and Kelbessa, E. (2011). Diversity and regeneration status of woody species in Tara Gedam and Abebaye forests, Northeastern Ethiopia. *Journal of Forestry Research*, 22(3), 5-328.
- Zywiec, M. Holeksa, J. Wesółowska, M. Szewczyk, J. Zwijacz-Kozica, T and Kapusta, P. (2013). *Sorbus aucuparia* regeneration in a coarse-grained spruce forest-a landscape scale. *Journal of Vegetation Science*, 24, 735-743.

Appendices

Appendix 4.1 Stem diameter distributions of all canopy tree species across all communities and sub-communities*.

		Upper limit of DBH class, cm											
		5	10	15	20	25	30	35	40	45	50	55	60+
*		Number of stems per ha											
<i>Afrocarpus falcatus</i>	1.12	-	6	6	6	6	-	-	-	-	-	-	-
<i>Albizia schimperiana</i>	1.12	-	6	-	-	-	-	-	-	-	-	-	-
	1.211	-	-	-	7	-	7	7	-	7	-	-	-
	1.22	13	25	25	13	-	-	-	-	-	-	25	-
	2.11	-	33	-	-	-	-	-	-	-	-	-	-
	2.2	-	-	-	17	17	-	-	-	-	17	-	-
	3.11	17	-	33	17	-	-	-	-	-	-	-	-
	3.122	53	59	6	24	6	6	-	6	-	-	-	-
	3.211	10	20	-	10	-	-	20	-	-	-	-	10
	3.212	-	-	-	8	8	-	8	-	-	-	-	-
	3.222	-	-	-	-	5	-	-	-	-	-	-	-
	4	33	-	-	-	-	-	-	-	-	-	-	-
<i>Albizia sp.</i>	4	-	-	17	-	-	-	-	-	-	-	-	-
<i>Allophylus abyssinicus</i>	2.11	-	17	-	-	-	-	-	-	-	-	-	-
	2.2	-	-	17	17	33	-	-	-	-	-	-	-
	3.11	-	-	33	-	-	17	-	-	-	-	-	-
	3.121	133	133	233	33	33	-	-	-	-	-	-	-
	3.122	-	18	18	-	-	6	12	-	-	-	-	-
	3.211	-	20	-	-	-	-	-	-	-	-	-	-
	3.222	5	18	-	-	-	-	-	-	-	-	-	-
	4	50	50	-	-	-	-	-	-	-	-	-	-
<i>Apodytes dimidiata</i>	1.211	-	-	-	-	-	-	-	7	-	-	7	-
	1.22	-	-	-	-	-	-	-	13	-	-	-	-
	2.11	-	-	-	17	-	-	-	-	17	-	-	-
	3.122	12	18	-	-	-	-	-	-	-	-	-	-
<i>Celtis africana</i>	2.11	17	-	-	-	-	-	-	-	-	-	-	-
	3.211	10	-	-	-	-	-	-	-	-	-	-	-
<i>Combretum molle</i>	1.12	6	-	-	-	-	-	-	-	-	-	-	-
	3.222	-	14	9	5	5	-	9	5	-	-	-	-
	4	67	17	-	-	-	-	-	-	-	-	-	-

		Upper limit of DBH class, cm											
		5	10	15	20	25	30	35	40	45	50	55	60+
*		Number of stems per ha											
<i>Croton macrostachyus</i>	1.12	6	6	11	6	-	-	-	-	-	-	-	-
	1.211	-	7	7	-	-	-	-	-	-	-	-	-
	1.212	-	13	-	13	-	-	13	-	13	-	-	-
	1.22	-	-	-	13	13	13	-	-	-	-	-	13
	2.11	-	-	-	-	17	-	-	-	-	-	-	-
	2.12	-	-	-	25	-	-	-	-	-	-	-	-
	3.122	-	6	18	6	12	6	6	-	-	6	-	-
	3.211	-	-	20	20	10	-	-	-	-	-	-	-
	3.212	17	17	8	17	33	8	8	-	-	-	-	-
	3.221	-	29	14	29	-	-	14	-	-	-	-	-
	3.222	-	5	-	-	5	-	-	-	-	-	-	-
<i>Dombeya torrida</i>	1.12	11	-	-	-	6	-	-	-	-	-	-	-
	1.211	13	7	-	-	-	-	7	-	-	-	-	-
	1.212	-	25	13	-	-	-	-	-	13	-	-	13
	1.22	-	13	-	-	-	-	-	-	-	-	-	-
	2.11	-	-	-	-	-	-	-	-	-	-	-	17
	3.11	-	-	-	17	-	-	-	-	-	-	-	-
	3.121	-	33	-	-	-	-	-	-	-	-	-	-
	3.122	-	12	-	6	-	-	-	-	-	-	-	-
<i>Ekebergia capensis</i>	1.12	-	-	-	6	6	-	-	-	6	-	-	-
	1.211	-	7	-	-	-	-	7	-	-	-	-	-
	1.212	-	-	-	-	-	-	-	13	-	-	-	38
	1.22	-	25	-	-	-	-	-	-	13	-	-	-
	3.122	-	12	12	-	-	-	-	-	-	-	-	6
<i>Ficus sur</i>	1.12	-	6	-	-	-	-	-	-	-	-	6	-
	1.211	-	7	-	-	-	-	-	-	-	-	7	-
	1.212	-	-	-	-	-	-	-	-	25	-	13	-
	2.11	-	-	-	17	-	-	17	-	17	-	-	-
<i>Ficus sycomorus</i>	1.11	-	-	-	-	33	33	-	-	33	-	-	-
	1.212	-	-	-	-	-	-	-	13	-	-	-	-
	1.22	-	-	-	-	-	-	-	13	-	-	-	-
	2.12	-	-	-	-	-	-	25	-	-	-	-	-
<i>Galiniera saxifraga</i>	2.2	50	50	-	-	-	-	-	-	-	-	-	-
	2.11	-	-	33	-	-	-	-	-	-	-	-	-

	Upper limit of DBH class, cm												
	5	10	15	20	25	30	35	40	45	50	55	60+	
	* Number of stems per ha												
	2.12	25	-	-	-	-	-	-	-	-	-	-	-
	3.122	53	53	6	-	-	-	-	-	-	-	-	-
	3.212	8	-	-	-	-	-	-	-	-	-	-	-
<i>Juniperus procera</i>	2.11	-	-	-	-	-	-	-	-	-	-	-	17
	2.12	-	-	25	-	-	-	50	-	-	-	25	-
	3.221	-	-	-	29	-	-	-	-	-	-	-	14
<i>Mimusops kummel</i>	3.122	-	-	-	-	-	-	6	-	-	-	-	-
<i>Myrica salicifolia</i>	3.222	-	5	-	-	-	-	-	-	5	5	-	-
<i>Nuxia congesta</i>	1.12	-	-	6	-	-	-	-	-	-	-	-	-
	1.22	-	-	-	-	13	-	-	-	-	-	-	-
	2.11	-	17	-	-	-	-	17	-	-	-	-	-
	2.2	-	17	-	-	-	-	17	17	-	-	-	-
	3.11	-	17	50	17	17	-	-	-	-	-	-	-
	3.121	-	33	-	-	-	-	-	-	-	-	-	-
	3.122	12	41	53	6	6	-	-	12	-	-	-	-
	3.211	-	-	60	-	-	-	-	-	-	-	-	-
	3.212	8	67	100	67	17	-	-	-	-	-	8	-
	3.221	-	29	14	-	14	-	-	-	-	-	-	-
	3.222	-	-	-	-	5	-	-	-	-	-	-	-
	4	33	17	17	-	-	-	-	-	-	-	-	-
<i>Olea capensis</i> subsp. <i>macrocarpa</i>	1.11	-	-	-	-	-	-	-	33	33	67	-	-
	1.12	-	6	-	-	-	-	11	22	33	89	-	-
	1.211	-	-	-	-	13	-	20	7	-	113	-	-
	1.212	13	-	-	-	-	-	13	-	13	50	-	-
	1.22	-	-	-	-	-	-	-	-	25	13	-	-
<i>Olea europaea</i> <i>cuspidata</i>	1.22	-	-	-	-	-	-	-	-	-	-	13	13
	2.11	-	-	-	-	-	-	-	-	-	-	-	17
	2.12	-	-	-	-	-	-	-	-	-	-	-	50
	2.2	-	17	-	-	-	-	-	-	-	-	-	33
	3.11	-	-	-	-	-	-	-	-	-	-	-	17
	3.121	-	33	33	-	-	-	-	-	-	-	-	-
	3.122	18	12	12	-	-	-	-	-	-	-	-	6

	Upper limit of DBH class, cm												
	5	10	15	20	25	30	35	40	45	50	55	60+	
	* Number of stems per ha												
	3.211	-	10	-	-	-	-	-	-	-	-	-	-
	3.212	17	-	-	-	-	-	-	-	-	-	-	-
	3.221	29	29	-	-	-	-	14	-	-	-	-	-
	3.222	5	5	9	5	-	-	-	-	-	-	-	-
	4	-	-	17	17	17	-	-	-	-	-	-	-
<i>Olinia rochetiana</i>	1.22	-	13	-	-	-	-	-	-	-	-	-	-
	3.122	-	-	6	-	-	-	-	-	-	-	-	-
	3.211	-	-	-	-	-	-	-	-	-	-	-	-
	3.212	-	25	17	-	-	-	-	-	-	-	-	-
<i>Piliostigma thonningii</i>	3.221	-	-	-	14	-	-	-	-	-	-	-	-
<i>Prunus africana</i>	1.12	-	6	-	-	-	-	-	-	-	-	-	-
	1.211	-	13	-	-	7	-	-	-	40	-	-	-
	1.22	-	-	-	-	-	-	13	-	-	25	-	-
<i>Prunus persica</i>	1.211	-	7	20	-	7	7	-	-	-	-	-	-
	1.212	-	-	-	13	25	-	-	-	-	-	-	-
	1.22	13	-	25	25	-	-	-	-	-	-	-	-
	3.122	-	-	-	-	6	-	-	-	-	-	-	-
	3.211	-	10	-	-	-	-	-	-	-	-	-	-
<i>Schefflera abyssinica</i>	1.12	-	-	-	-	-	-	-	-	-	-	-	17
	2.12	-	25	-	-	-	-	-	-	-	-	-	-
	2.2	-	-	33	-	-	-	-	-	-	-	-	-
	3.212	-	8	-	-	-	-	-	-	-	-	-	-
	3.221	-	-	-	-	-	-	-	-	-	-	-	14
<i>Schrebera alata</i>	2.2	-	-	-	-	-	17	-	-	-	-	-	-
	3.121	-	33	-	-	-	-	-	-	-	-	-	-
	3.122	6	6	6	12	-	6	-	-	-	-	-	-
	3.211	-	10	-	10	-	-	-	-	-	-	-	-
	3.222	-	5	5	-	-	-	-	-	-	-	-	-
	4	-	33	17	-	-	-	-	-	-	-	-	-
<i>Scolopia theifolia</i>	1.12	-	6	-	-	-	-	-	-	-	-	-	-
	1.211	7	7	20	-	-	-	-	-	-	-	-	-
	1.212	-	13	-	-	-	-	-	-	-	-	-	-
	1.22	-	-	13	-	-	-	-	-	-	-	-	-
	2.11	167	117	117	50	-	-	17	-	-	-	-	-

	Upper limit of DBH class, cm												
	5	10	15	20	25	30	35	40	45	50	55	60+	
*	Number of stems per ha												
	2.12	25	25	50	50	-	-	-	-	-	-	-	-
	2.2	17	100	33	17	-	-	-	-	-	-	-	-
	3.11	100	83	-	-	-	-	-	-	-	-	-	-
	3.121	-	33	-	-	33	-	-	-	-	-	-	-
	3.122	76	88	6	-	-	-	-	-	-	-	-	-
<i>Terminalia schimperiana</i>	1.11	33	133	67	67	-	-	-	-	-	-	-	-
	1.12	28	56	-	-	-	-	-	-	-	-	-	-
	1.211	93	493	133	40	27	-	-	-	-	-	-	-
	1.212	13	113	63	-	-	-	-	-	-	-	-	-
	1.22	38	25	25	-	-	-	-	-	-	-	-	-
<i>Vachellia abyssinica</i>	3.212	-	-	-	-	-	-	-	-	-	-	8	-
	3.221	-	14	-	-	-	-	-	-	-	-	-	-
<i>Vachellia etbaica</i>	3.211	-	-	-	10	-	-	-	-	-	-	-	-
	3.212	-	-	8	-	-	-	-	-	-	-	-	-
	3.221	-	14	14	-	-	-	-	-	-	-	-	-
	3.222	-	9	9	-	5	-	-	-	-	-	-	-
<i>Vachellia seyal</i>	3.222	-	5	-	-	5	5	-	-	-	-	-	-

Appendix 4.2 Stem diameter distributions of all sub-canopy tree species across all communities and sub-communities*.

	*	Upper limit of DBH class, cm					
		5	10	15	20	25	30+
		Number of stems per ha					
<i>Bersama abyssinica</i>	1.11	167	-	-	-	-	-
	1.12	33	28	6	-	-	6
	1.211	40	13	-	-	-	13
	1.212	25	13	-	13	-	-
	1.22	25	13	-	-	-	-
	2.11	33	17	-	-	-	-
	2.12	125	50	-	-	-	-
	2.2	33	-	-	-	-	-
	3.11	50	-	83	33	33	-
	3.121	-	33	-	-	-	-
	3.122	6	41	-	12	-	-
	3.211	40	50	10	10	-	-
	3.212	8	17	-	-	-	-
	3.221	-	14	-	-	-	-
	3.222	-	-	5	-	-	-
<i>Bridelia micrantha</i>	1.12	6	6	-	-	-	-
	1.211	7	40	7	-	-	-
	1.212	-	25	-	-	-	-
	1.22	-	-	13	-	-	-
	3.211	-	10	-	-	-	-
	3.212	-	8	-	-	-	-
<i>Brucea antidysenterica</i>	3.211	-	10	-	-	-	-
	3.212	17	-	-	-	-	-
<i>Buddleja polystachya</i>	3.122	-	6	12	-	6	3
	3.211	-	10	-	10	-	-
	3.212	-	8	-	-	-	3
	3.221	-	-	-	-	-	-
	3.222	5	-	-	-	-	-
<i>Calpurnia aurea</i>	1.11	33	-	67	-	-	-
	1.12	278	667	78	-	-	-
	1.211	27	20	-	-	-	-
	1.22	38	100	-	13	-	-
	2.11	33	17	-	-	-	-
	2.12	75	25	-	-	-	-
	3.11	17	50	17	-	-	-
	3.121	-	33	-	-	-	-
	3.122	171	241	24	-	-	-
	3.211	20	-	-	-	-	-
	3.212	8	8	17	-	-	-
	3.221	200	186	29	-	-	-
	4	33	17	-	-	-	-

	*	Upper limit of DBH class, cm						
		5	10	15	20	25	30+	
		Number of stems per ha						
<i>Clausena anisata</i>	1.11	67	-	33	-	-	-	
	1.12	11	17	-	-	-	-	
	1.211	7	-	7	-	-	-	
	1.212	13	38	13	-	-	-	
	1.22	50	88	13	-	-	-	
	2.11	-	17	-	-	-	-	
	2.12	25	25	-	-	-	-	
	2.2	83	100	-	-	-	-	
	3.11	467	-	-	-	-	-	
	3.122	-	171	6	-	-	6	
	3.211	30	30	10	-	-	-	
	3.222	-	5	-	-	-	-	
	4	17	-	-	-	-	-	
	<i>Dovyalis abyssinica</i>	1.11	67	-	-	-	-	33
1.12		6	39	17	17	-	6	
1.211		13	27	13	13	20	14	
1.212		-	-	13	-	-	25	
1.22		13	63	25	13	-	-	
2.11		17	-	-	-	-	-	
3.122		-	-	6	-	-	-	
<i>Dregea schimperi</i>	1.12	6	-	-	-	-	-	
<i>Entada abyssinica</i>	1.211	-	-	5	5	-	-	
<i>Euphorbia abyssinica</i>	1.11	67	167	133	200	133	132	
	1.12	17	39	22	28	17	40	
	1.211	-	40	13	7	-	21	
	1.212	-	13	13	-	-	26	
	1.22	-	25	-	-	-	-	
	2.12	-	-	25	-	-	-	
	3.122	-	-	6	-	-	-	
<i>Flacourtia indica</i>	3.122	-	-	6	-	-	-	
<i>Gnidia glauca</i>	1.11	-	40	-	-	-	-	
<i>Grewia ferruginea</i>	2.2	-	-	17	-	-	-	
	3.121	-	67	100	67	33	-	
	3.122	6	12	29	29	-	6	
	3.211	-	10	20	-	10	-	
	3.212	-	33	8	-	-	-	
	3.221	14	14	14	-	-	-	
	3.222	-	9	14	-	-	-	
	4	-	33	-	-	-	-	
	<i>Hypericum quartinianum</i>	3.11	-	17	-	-	-	-
		3.122	6	-	-	-	-	-
3.211		10	-	-	-	-	-	
3.212		8	25	-	-	-	-	
3.221		14	14	14	-	-	-	
3.222		5	9	-	-	-	-	
4		-	33	-	-	-	-	
<i>Maesa lanceolata</i>	1.12	-	6	17	-	-	-	
	1.211	-	-	7	-	7	-	

	*	Upper limit of DBH class, cm					
		5	10	15	20	25	30+
		Number of stems per ha					
	1.212	-	-	13	-	-	-
	2.11	-	17	-	-	-	-
	2.12	50	100	50	-	-	-
	2.2	-	-	-	-	-	-
	3.11	-	-	17	-	-	-
	3.212	-	8	17	8	-	-
	3.221	-	14	14	-	-	-
<i>Maytenus arbutifolia</i>	2.2	-	-	-	-	-	34
	3.11	-	-	-	33	-	-
<i>Maytenus gracilipes</i>	1.11	300	-	-	-	-	-
	1.12	94	-	-	-	-	-
	1.211	353	-	-	-	-	-
	1.212	413	38	-	-	-	13
	1.22	25	25	-	-	-	-
	2.11	117	133	33	33	-	-
	2.12	50	-	-	-	-	-
	2.2	67	167	-	-	-	-
	3.11	17	50	-	-	-	-
	3.122	24	41	12	-	-	-
	3.211	20	20	10	-	-	-
	3.212	33	33	8	-	-	-
	3.221	71	86	-	-	-	-
	3.222	14	14	-	-	-	-
<i>Maytenus senegalensis</i>	2.11	-	-	33	-	-	-
	2.2	17	33	17	-	-	-
	3.11	-	-	17	-	-	-
	3.122	-	6	6	12	-	6
<i>Maytenus undata</i>	2.11	-	133	50	-	-	-
	2.12	25	75	-	-	-	-
	2.2	-	50	17	-	-	-
	3.11	-	67	-	-	-	-
	3.121	-	33	-	-	-	-
	3.122	-	-	6	-	-	-
<i>Myrsine africana</i>	2.11	17	-	-	-	-	-
	3.11	17	-	-	-	-	-
	3.121	-	-	-	-	-	-
	3.122	24	-	-	-	-	-
	3.211	-	-	-	-	-	-
	3.212	-	-	-	-	-	-
	3.221	-	-	-	-	-	-
	3.222	5	-	-	-	-	-
<i>Osyris quadripartita</i>	1.11	-	17	-	-	-	-
	1.211	33	-	-	33	-	-
	1.212	6	18	-	6	-	-
	1.22	10	10	-	-	-	-

	*	Upper limit of DBH class, cm					
		5	10	15	20	25	30+
		Number of stems per ha					
	2.11	-	17	-	-	-	-
	2.12	29	-	-	-	-	-
	2.2	5	5	-	-	-	-
	3.11	17	17	-	-	-	-
<i>Pittosporum abyssinicum</i>	1.12	-	-	-	-	-	6
<i>Premna schimperi</i>	2.2	-	-	17	-	-	-
	3.121	-	33	-	-	-	-
	3.122	6	65	12	6	6	-
	3.211	-	10	20	10	-	-
	3.212	17	17	-	-	-	-
	3.221	-	71	14	-	-	-
	3.222	14	55	-	-	-	-
<i>Rhamnus staddo</i>	3.121	33	100	-	-	-	-
	3.122	18	47	-	-	6	-
	3.212	-	8	-	-	-	-
	4	17	33	-	17	-	-
<i>Ritchiea albersii</i>	1.11	17	-	-	-	-	-
	1.12	25	-	-	-	-	-
	1.211	-	-	-	-	7	-
	1.212	-	13	-	-	-	38
	1.22	-	13	-	-	-	-
	2.12	-	25	25	-	-	-
	2.2	-	-	17	-	-	-
	3.122	-	6	12	-	-	-
	3.222	5	14	-	-	-	-
<i>Searsia pyroides</i>	1.11	-	-	17	-	-	-
	2.11	-	17	-	-	-	-
	3.11	-	-	17	-	-	-
	3.121	-	167	33	-	-	-
	3.122	24	59	65	-	-	-
	3.211	20	10	20	10	-	-
	3.212	8	-	25	-	-	-
	3.221	14	29	-	-	-	-
	3.222	14	50	5	-	-	-
	4	33	83	17	-	-	-
<i>Steganotaenia araliacea</i>	2.11	-	17	-	-	-	-
	3.11	50	33	-	-	-	-
	3.121	33	-	-	-	-	-
	4	-	-	17	-	-	-
<i>Stereospermum kunthianum</i>	3.211	-	-	10	-	-	-
<i>Teclea nobilis</i>	1.11	-	-	-	-	33	33
	1.12	6	6	11	33	-	-
	1.211	-	47	7	13	7	7
	1.212	-	-	-	13	13	13
	1.22	-	50	50	13	25	-

	*	Upper limit of DBH class, cm					
		5	10	15	20	25	30+
		Number of stems per ha					
	2.11	-	33	33	-	-	-
	2.12	-	-	25	25	-	-
	2.2	100	83	50	67	50	33
	3.122	-	29	6	-	-	-
<i>Vernonia amygdalina</i>	1.211	-	13	-	-	-	-
	3.122	-	-	18	6	-	-
<i>Vernonia myriantha</i>	1.11	33	267	-	33	-	-
	1.12	44	17	6	-	-	-
	1.211	13	13	7	-	-	-
	1.212	13	138	25	13	-	-
	2.12	50	-	-	-	-	-
	3.211	-	60	10	-	-	-
	3.212	25	-	-	-	-	-
	3.221	-	29	-	-	-	-
<i>Vachellia lahai</i>	1.22	-	-	13	-	-	-
	3.122	-	-	6	-	6	12
	3.211	-	-	10	10	10	50
	3.212	-	8	8	-	-	33

Chapter 5: Synthesis: Ecological basis for sustainable management of three remnant Afromontane forests in Northwestern Ethiopia

Appropriate resource management is the key to sustain the biodiversity, productivity and resource value of natural forests, and thereby conserve them into perpetuity. There are different approaches to sustain these attributes of natural forests. It is often thought that by protecting such forests would serve the purpose of their conservation. However, many people are directly and indirectly dependent on the products, services and values of such forests. By merely protecting the forests could mean that people directly dependent on those forests for their daily livelihood needs could be denied such benefits. It could also mean that certain ecological processes that underlie the maintenance of their biodiversity and productivity cannot function properly. The question then is what basic information is required to manage such forests effectively to sustain their biodiversity, productivity and use value.

The main aim of resource use management is to match the resource use needs with the available resources (Geldenhuys, 2005, 2011). It is important to understand what resources people use from the specific forests of focus. The kind of product required determines the likely harvesting technique and eventual impact on the resource. For example, there is a difference in impact from harvesting of bark for traditional medicine, harvesting poles of different size for construction needs, harvesting of firewood for energy needs. All the products relate to specific forest species, and the species relate to specific forest ecosystems. Available forest resources include diversity of species, species associations, and stand structures, and rates of disturbance-recovery processes (stand dynamics), including their constraints and potentials. This is the basis of sustainable forest management policies, strategies and practices and thus sustainable forest resource use. Geldenhuys (2010) presented the concept of using the basic disturbance-recovery processes, with recovery development via stand development stages, as the basis for the development of silvicultural systems suitable for maintenance of forest complexity (mixed species - mixed age forests). He used grain analysis and stem diameter distributions, analysed from resource inventories, to determine the specific shade- or fire-tolerance characteristics of key economical and ecological tree species. The gained knowledge of the ecosystem and species characteristics (including modes of regeneration, i.e. from seed or vegetative regrowth) and processes was used to simulate the ecological disturbance-recovery processes through the development of mixed silvicultural systems, such as a single-tree selection system, a group felling system and a coppice management system in the same forest to accommodate the diverse species characteristics.

The overall objective of this study was to use different analytical tools to assess and explain the causal ecological drivers of three remnant Afromontane forests in Northwestern Ethiopia at species,

community and ecosystem level as basis for sustainable resource use management systems at different levels (Chapter 1). This general objective of the dissertation was addressed through pursuing three overarching specific objectives to assess, explain and develop an understanding of the main causal ecological drivers of three remnant Afromontane forests in Northwestern Ethiopia. These objectives were:

1. To assess the floristic composition of three Afromontane forests in Northwestern Ethiopia (Chapter 2)
2. To assess the floristic-structural composition of the associations of plants and their relationships with physical site factors (Chapter 3)
3. To assess the scale of ecological processes of disturbance and recovery and how these affect the population structure and regeneration status of canopy tree species across forest communities (Chapter 4).

This focus of this synthesis chapter is to extract the relevant information from these information-gathering studies to develop a conceptual framework for the sustainable management of the three Northwestern Ethiopian forests.

5.1 Floristic composition, floral similarity and biogeographical relationships

This component of the overall study showed the potential of the studied forests in terms of the range of species recorded, the ecological characteristics in terms of their growth form, regeneration strategies (fruit/seed types) and ecological breadth based on their biogeographical affinities. It also indicated which species require specific attention to ensure their survival.

This study encountered 209 vascular plant species belonging to 75 families. The three most species-rich families contributing about 28% of species, were Asteraceae, Fabaceae and Poaceae. Similar dominance of these families has been reported elsewhere in Afromontane forests of African countries (Brand *et al.*, 2010; Gehrke and Linder, 2014; Lötter *et al.*, 2014; Grieve and Downs, 2015; Kikoti and Mligo, 2015). The 11 liana species represented about 10% of the total woody species recorded in the study area. The observation of liana species in the area may indicate the presence of non-disturbed parts in the studied forests, as this study observed some fine-grained sub-communities (Addo-Fordjour *et al.*, 2008). Liana species abundance are higher in forest ecosystems with nutrient-rich soils (Laurance *et al.*, 2001; Suganuma and Durigan, 2015). High liana species diversity along with other palm and tree species had been reported from non-disturbed forest parts of the Amazon as

compared to disturbed ones due to seasonal flooding (Barnett *et al.*, 2015). Such species were reported as high as 44% of the total woody species, from Amazon Basin (Bolivia) (Pérez-Salicrup and Sork, 2001).

Evenness index refers to the degree to which individuals are shared among species. Its low values indicate the domination of one or a few species in a given forest landscape, while its high values referring to relatively equal numbers of individuals belonging to each species (Morris *et al.*, 2014). Although this study area has shown high Shannon diversity values, its evenness value was very low (0.26) as compared to other Afromontane forest of Southwestern Ethiopia, where the relatively intact high forests of Ethiopia are considered to be found. Tadesse *et al.* (2016) reported about 0.79 Shannon evenness value from this biogeographical area.

The seven endemic plant species (to Ethiopia) encountered in this study, namely *Acanthus sennii* (Acanthaceae), *Lippia adoensis* (Verbenaceae), *Aeollanthus abyssinicus* (Lamiaceae), *Bidens ghedoensis* (Asteraceae), *Mikaniopsis clematoides* (Asteraceae), *Solanecio gigas* (Asteraceae), and *Impatiens rothii* (Balsaminaceae), were encountered either solely to or shared among the three studied forests. This has the implication that, no matter the size of the forest where these endemic species are present, all the studied forests are conservationally important in particular and implying the biogeographical significance of Northwest Ethiopia in general. Many Afromontane species are endemic to a single mountain or mountain system (Popp *et al.*, 2008). The observation of some particular species limited to one forest, might indicate their limited ecological breadth. About 53 (25%) vascular plant species were observed to be limited to the Northwest Ethiopian biogeographical area. Fifteen woody species and 38 herbaceous species were not reported in any of the other Afromontane forests and woodlands of Ethiopia and parts of Africa. Such observation may indicate the narrow ecological breadth of the species and the need for conservation efforts of these particular species and their habitats. Some of these woody species are *Discopodium penninervium*, *Flacourtia indica*, *Pittosporum abyssinicum*, *Rhamnus staddo*, *Rhynchosia resinosa*, *Stephania cyanantha*, *Terminalia schimperiana* and *Triumfetta tomentosa*. Herbaceous species included *Bartsia trixago*, *Bidens ghedoensis*, *Crotalaria glauca*, *Digitaria abyssinica*, *Chlorophytum tetraphyllum*, *Plectranthus lactiflorus*, *Plectranthus longipes*, *Australina flascida*, *Canarina abyssinica*, *Chrysopogon aucheri*, *Cyphostemma adenocaulis*, *Kosteletzkya adoensis* and *Lactuca inermis*. The relatively many species limited in their distribution to this study area, may indicate the biogeographical significance of Northwest Ethiopia and the need to attend to their conservation status (Chapter 2, Appendix 2.1 and 2.2).

Despite their geographical vicinity, each of the three studied Afromontane forests harboured particular species limited only to one of the three forests, suggesting that conservation efforts are equally important to all studied forests in this particular biogeographical area. Woody species *Cadia purpurea*, *Myrica salicifolia*, *Stephania cyanantha* were observed only in Alem Saga forest, while *Pittosporum abyssinicum* and *Rhynchosia resinosa* were confined to Gelawudiwos forest. Similarly, *Albizia sp.*, *Flacourtia indica*, *Rhamnus staddo*, *Triumfetta tomentosa* and *Vernonia sp.* were observed only in Tara Gedam forest. This also further indicates the biogeographical significance of Northwest Ethiopian forests in general, that every fragment of forest in this biogeographical area, regardless of their size, could possibly harbour some particular species that need due conservation attention (Chapter 2, Appendix 2.1 and 2.2).

Afromontane forests of Northwest Ethiopia in general showed high shared species (75% shared vascular plant species) and floral similarity with Afromontane forests of Wondo Genet, Gendo and Denkoro, respectively located in Southcentral, West and Northcentral Ethiopia (Chapter 2). Such a high shared species and similarity percentages maybe due to their geographical vicinity, the prevailing wind patterns and their historical landmass connectivity. The seed characteristics of the individual species, such as its size and palatability, may play significant role in harnessing seed dispersal and the observed floral similarity (Leslie *et al.* 2017). Observing *Ficus sur* and *Ficus thonningii*, in most of the reported Afromontane forests could possibly be attributed to their fruits' palatability by various fruit-eating birds, bats and other fauna. Tree species *Afrocarpus falcatus*, *Bersama abyssinica*, *Celtis africana*, *Croton macrostachyus*, *Ficus sur*, *Ficus thonningii*, *Grewia ferruginea*, *Maesa lanceolata*, *Maytenus undata*, *Prunus africana*, *Syzygium guineense* and *Teclea nobilis*; shrub species *Asparagus africanus*, *Carissa spinarum* and *Rubus steudneri*; and forbs including *Achyranthes aspera*, *Commelina africana*, *Hypoestes forskaolii*, *Thalictrum rhynchocarpum* and *Zehneria scabra*, were the topmost species observed in most of Afromontane forests and woodlands in Ethiopia and parts of Africa. This may indicate their relatively better survival strategies, connecting as metapopulations in the continent (Chapter 2, Table 2.6-2.9, Appendix 2.1 and 2.2).

Though Wondo Genet is located relatively far away from this study area, such similarity could possibly be attributed to long-distance dispersal and/or vicariance biogeography (Mairal *et al.*, 2015). In the formation of the East African Rift System (EARS), land masses of this particular region disconnected and moved towards the Eastern and Western flanks of the rift system (Sepulchre *et al.*, 2006; Ring 2014; de Gouveia *et al.*, 2018). This study area and Wondo Genet currently respectively located in the Western and Eastern flanks of EARS. In EARS evolution, Chorowicz (2005) reported that the plume that first formed at around 30 Million years (Ma), was likely in Lake Tana Region,

where the current study area is located. This may possibly indicate the point of historical disconnection between this study area and other remnant Afromontane forests in the Eastern flank of the rift, including Wondo Genet, Bale Mountains National Park, Kimphe Lafa, Mana Angetu and Delo Mena (Chapter 2, Table 2.6-2.9, Appendix 2.1 and 2.2).

5.2 Plant communities, environmental variables, spatial regeneration scales and population status

The plant associations identified in this study show that the forests represent different habitat types for the different forest species, and that the forest is composed is a variety of recovery stages of the vegetation. The key species also show definite characteristics that relate to requirements for their successful regeneration. This suggest that these forests need to be zoned into several homogenous vegetation units as a basis for more foscused resource use management.

Four communities and 16 sub-communities for woody plant species, and two communities and eight sub-communities for herbaceous species were identified. The identified communities and sub-communities have shown relationships to different environmental variables. Nitrogen and radiation index were, statistically, the two highly significant variables at $p < 0.01$, in explaining the total occurrence and distribution pattern of woody species in the study area, but altitude, CEC, litter, phosphorus and soil moisture were also statistically significant at $p < 0.01$. This indicates that most woody species have shown to occur towards the warmer conditions (towards Southwest orientation) and high level of nitrogen whereby their shoot and root growth possibly be influenced by the availability of nitrogen. Community 1 related to high levels of radiation index, altitude, litter, nitrogen and organic carbon, while community 2 to high levels of pH, slope, CEC and clay. Sub-communities 3.11, 3.121 and 3.122 related to high levels of clay, pH and slope, while sub-communities 3.211, 3.212, 3.221 and 3.222 to high available phosphorus. Community 4 related to high clay content of the soil. When compared to community 1, which occur towards the warmer conditions, community 2, sub-communities 3.11, 3.121, 3.122 and community 4 occur towards the cooler conditions (towards Northeastrly and steeper slopes) (Chapter 3, Figure 3.6 and Table 3.3).

Moisture, radiation index, altitude and phosphorus were highly statistically significant environmental variables at $p < 0.01$ in explaining the total composition and distribution of herbaceous species in this study area. CEC, clay, EC, slope, organic carbon, silt, sand, pH, and litters, were statistically non-significant to do so. Herbaceous sub-communities 1.11, 1.12 and 1.211 related to high gradients of radiation index, altitude, available phosphorus, litter, EC and nitrogen, while sub-community 1.212 to high gradients of soil moisture, EC, CEC, nitrogen and organic carbon. Sub-communities 1.221

and 1.222 related to high gradients of slope, pH, clay and CEC. Sub-community 2.1 related to high gradients of available phosphorus, clay and altitude, while sub-community 2.2 related to high gradients of available Phosphorus, altitude and radiation index. In both woody and herbaceous communities, radiation index was statistically a highly significant environmental variable, that would affect the temperature conditions of the air and substrate, which in turn may affect the wind, air humidity and evapotranspiration regimes of these forest ecosystems, i.e. causing physiologically drier conditions (Piedallu and G'égout, 2008; Košir *et al.*, 2013; Paudel and Vetaas, 2014; Måren *et al.*, 2015). (Chapter 3, Figure 3.9 and Table 3.6). Indicator and preferentially dominant species for each community and sub-community were presented and discussed in chapter 3. See in sections 3.3.5 and 3.3.6 in chapter 3, respectively for herbaceous and woody indicator species.

Various spatial scales in canopy gaps (disturbance gradients) ranging from relatively fine grain (small gaps) in community 2, intermediate grain (intermediate gaps) in community 1 and 4, and coarse grain (large gaps) in community 3 were observed. Such variability in spatial scales of disturbance (gap size) relates to the regeneration requirements of canopy tree species, and this was also observed in the identified tree sub-communities. Tree community 2 showed a in a relatively small regeneration gap, which implies that this particular community has fine grain with high representation of both canopy and regeneration species in its stands (Zywiec *et al.*, 2013; Nieto-Lugilde *et al.*, 2015). Some tree species were present in both regeneration and canopy composition of some fine-grained sub-communities, indicating their relative higher shade-tolerance, as with *Olea europaea* subsp. *cuspidata* and *Scolopia theifolia*. Some tree species, such as *Croton macrostachyus* and *Ekebergia capensis*, were present in both regeneration and canopy composition of some coarse-grained sub-communities, indicating their relative lower shade-tolerance. A species' grain refers to whether that particular species regenerates within its own canopy shadow (fine-grained) or over a larger spatial scale (coarse-grained) (Lawes *et al.*, 2007; Geldenhuys, 2010). The observation of communities and sub-communities with various regeneration gaps, ranging from relatively fine to coarse spatial scales, might possibly be due to the relative disturbance heterogeneity of the stands (Garbarino *et al.*, 2012) (Chapter 3, Appendix 3.2 and Chapter 4, Figure 4.3 and 4.4).

The presence of very few stems of some Afromontane species, such as *Celtis africana* in the studied forest, suggests the need for due conservation efforts for such species. Only few stems of this particular species were recorded in sub-community 2.11. Similarly, though *Afrocarpus falcatus* reflected its theoretical spatial regeneration scale as a shade-tolerant species (Tadesse and Nigatu, 1996; Teketay, 2005; Geldenhuys, 2010), it was only observed in a coarse-grained forest sub-community 1.12 as an early successional species. In some cases, this species can be observed as a forest edge species where there is some form of disturbance like fire (Adie *et al.*, 2017). This

particular species lacked stems in its medium-higher diameter classes as early successional tree species (Fetene and Feleke, 2001; von Gadow *et al.*, 2016). This also suggests for consideration, in the future conservation endeavours. *Teclea nobilis* was observed in most fine-grained forest sub-communities. This species is considered a typical shade-tolerant species with a seed-dispersal limitation (Kiama and Kiyiapi, 2001).

Albizia schimperiana was observed with relatively fair numbers of stems across all spatial grains, both in regeneration and canopy strata, as compared to other canopy tree species. This might be possibly due to the fact that this species is one of the potential nitrogen-fixer plant species that can regenerate in nutrient-poor soils (Anthofer *et al.*, 1997; Mkonda and He, 2017). Most of recorded stems accumulated in the lower DBH classes, as compared to the middle and higher DBH classes. Conversely, some of the observed canopy and sub-canopy tree species showed a tendency towards the bell-shaped stem diameter distribution. This may indicate the presence of light-demanding species, which need moderate disturbance and canopy gaps for their successful regeneration, such as *Ekebergia capensis*, *Croton macrostachyus*, *Juniperus procera*, *Nuxia congesta*, *Olea capensis* subsp. *macrocarpa*, *Prunus africana*, *Schefflera abyssinica* and *Terminalia schimperiana* (Chapter 4, Figure 4.7 and 4.8, and Appendix 4.1 and 4.2).

Variability in stand dynamics across the identified tree communities was observed. Such variability may suggest the need for different forest management approaches according to the observed stand variability. Community 1 showed wide ranges in stem diameters, but sub-communities 3.11, 3.121, 3.222 and community 4 showed narrower ranges in stem diameters. The narrower ranges of stem diameter in these tree communities may indicate their earlier stage of development, recovering from diverse natural/anthropogenic disturbances (Chapter 4, Figure 4.6). The lowest mean number of woody species per plot, stem density/ha and basal area/ha and the most coarse-grained regeneration gap, were observed in sub-community 3.222, suggesting the need for silvicultural intervention to optimize the gap size. The observation of the highest density/ha with a coarse regeneration gap at community 4, with relatively small mean number of species per plot, also suggests the need for silvicultural intervention. Sub-community 1.211, a fine-grained regeneration gap with small mean number of species, diversity and evenness and the highest basal area/ha; indicating the need for selective thinning to maximize diversity and stability. Such similar stand conditions were also observed in 1.12 and 1.212 (Chapter 3, Table 3.2 and Chapter 4, Figure 4.4). Variability in their dynamics might be due to differences in age, competitive status, growth rate, genetic properties, and the variability of disturbances and available resources (Rouvinena and Kuuluvainen, 2005; Svoboda *et al.*, 2010; Panayotov *et al.*, 2015).

5.3 Conclusions and recommendations

The observation of high floristic diversity, and with some limited range or endemic species to study area, indicates the biogeographical significance of Northwest Ethiopia in conserving Afromontane plant species. Despite the area showing a high floristic diversity, this study observed a low level of endemism in the area. The shared floristic similarity with other Afromontane forests and woodlands in the country and parts of Africa, could be attributed to the ongoing seed dispersal by wind, birds, wild mammals, and their historical landmass connectivity. The observed shared similarity reflects on the ongoing inter-connectivity of Afromontane forest species as mega-populations in the continent, through the dynamic interplay of dispersal and vicariance.

Various plant communities were characterized by different gradients and spatial regeneration scales, indicating the need for different ecological/silvicultural interventions. Several environmental variables were found to be important in determining the composition and distribution of the woody and herbaceous vegetation units, and their associated species. Radiation index, altitude, nitrogen, available phosphorus and soil moisture were found to be of particular significance. This study recommends to consider the identified plant communities (plant to plant relationships) and their relationships to different environmental variables (plant to environment relationships), as a baseline information in the future forest management activities of the area. The identified variation in spatial regeneration gaps indicate the level of canopy openings across the identified communities, which maybe used as baseline information in optimizing and sustaining the positive effects of canopy openings (gap disturbances). This positive effect of canopy gaps was observed in some identified forest communities. For instance, in community 4 with small number of plots, the highest stem density was observed which indicate the early regrowth stage, and also the dominance of *Dodonaea angustifolia*, a pioneer species.

Stem diameter distributions of canopy and sub-canopy tree species were characterized by different regeneration or recruitment trends, suggesting different management strategies for each species. The observation of some tree species with Bell-shaped stem diameter distribution, may indicate their light-demanding characteristics and suggest the need to have larger-scale disturbances. This study recommends to develop resource harvesting system that would allow larger gaps for regeneration of light demanding species and small gaps for regeneration of shade tolerant species. For example, *Olea europaea* subsp. *cuspidata* is shade tolerant does not need large gaps to regenerate. By contrast, *Croton macrostachyus* is a light demanding species that needs large gaps to regenerate. Although relatively high diversity was observed in Tara Gedam forest, plots of community 4 and all fine-grained sub-communities of community 2 were observed in this particular forest. Plots of fine to

coarse-grained sub-communities of community 1 and 3 were observed, respectively in Gelawudiwos and Alem Saga forests. This indicates the need for diversified management interventions according to observed spatial regeneration scales. In addition to the prevailing local climate (such as rainfall and temperature) and the landscape physiography, both natural and anthropogenic disturbances may play role in shaping the observed plant composition and distribution patterns. However, the question about to what extent the natural and/or anthropogenic disturbances contributed in shaping the observed patterns over the prevailing natural environment needs further in-depth investigation. For sustainable management of the forests, this study recommends adaptive management approaches, in line with grain gradient (fine to coarse) and light response characteristics of canopy tree species (Figure 5.1).

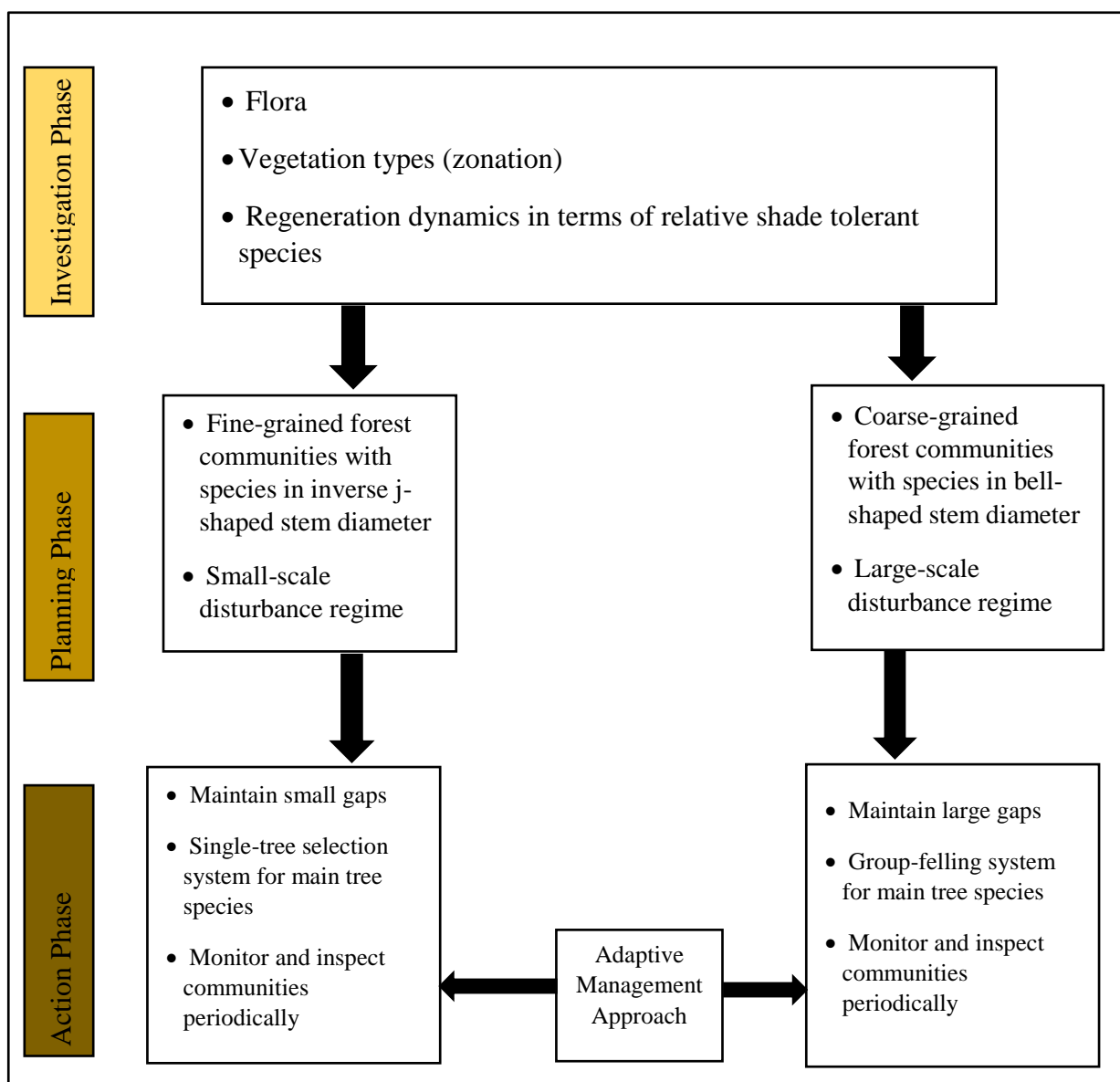


Figure 5.1 General conceptual framework for a management plan to deal with different forest communities with various scales of disturbance

Further studies are recommended about what natural disturbance factors (such as fire, drought, landslide and windfalls) influence Afromontane Forests in Northwest Ethiopia, resource use practices in the area (anthropogenic factors), and how do species and the communities respond to both natural and anthropogenic disturbances of different scales. Studies about the determination of the optimum spatial and temporal extent of disturbances are also recommended, to keep the structural diversity and productivity of the forest ecosystem on sustainable basis.

References

- Addo-Fordjour, P. Obeng, S. Addo, M. G. and Akyeampong, S. (2009). Effects of human disturbances and plant invasion on liana community structure and relationship with trees in the Tinte Bepo forest reserve, Ghana. *Forest Ecology and Management*, 258, 728-734.
- Adie, H. D. Kotze, J. and Lawes, M. J. (2017). Small fire refugia in the grassy matrix and the persistence of Afrotropical forest in the Drakensberg mountains. *Scientific Reports*, 1-7: 6549. DOI:10.1038/s41598-017-06747-2
- Anthofer, J. Hanson, J. and Jutzi, S. C. (1997). Nitrogen Mineralization Pattern of Agroforestry Tree Leaves under Tropical Highland Conditions. *J. Agronomy & Crop Science*, 179, 139-147.
- Barnett, A. A. Silva, W.S. Shaw, P. J. A. and Rams, P.M. (2015). Inundation duration and vertical vegetation zonation: a preliminary description of the vegetation and structuring factors in borokotóh (hummock igapó), an overlooked, high-diversity, Amazonian vegetation association. *Nordic Journal of Botany*, 33, 601-614.
- Brand, R. F. Brown, L.R. du Preez, P. J. (2010). A floristic analysis of the vegetation of Platberg, eastern Free State, South Africa, *Koedoe*, 52(1), 1- 11, DOI: 10.4102/koedoe. v52i1.710
- Chorowicz, J. (2005). The East African rift system. *Journal of African Earth Sciences*, 43, 379-410.
- de Gouveia, S. V. Besse, J. de Lamotte, D. F. Greff-Lefftz, M. Lescanne, M. Gueydan, F. and Leparmentier, F. (2018). Evidence of hotspot paths below Arabia and the Horn of Africa and consequences on the Red Sea opening. *Earth and Planetary Science Letters*, 487, 210-220.
- Fetene, M. and Feleke, Y. (2001). Growth and photosynthesis of seedlings of four tree species from a dry tropical Afrotropical forest. *Journal of Tropical Ecology*, 17(2), 269-283.
- Garbarino, M. Mondino, E. B. Lingua, E. Nagel, T. A. Dukić, V. Govedar, Z. and Motta, R. (2012). Gap disturbances and regeneration patterns in a Bosnian old-growth forest: a multispectral remote sensing and ground-based approach. *Annals of Forest Science*, 69, 617- 625.
- Gehrke, B. and Linder, H. P. (2014). Species richness, endemism and species composition in the tropical Afroalpine flora. *Alp Botany*, 124,165-177.
- Geldenhuys, C. J. (2011). Disturbance and recovery in natural forests and woodlands in Africa: Some concepts for the design of sustainable forest management and rehabilitation practices. In: Geldenhuys C. J, Ham, C and Ham, H (eds.). *Sustainable Forest Management in Africa: Some*

Solutions to Natural Forest Management Problems in Africa. Proceedings of the Sustainable Forest Management in Africa Symposium. Stellenbosch, 3 - 7 November 2008, 61-70.

Geldenhuys, C. J. (2010). Managing forest complexity through application of disturbance-recovery knowledge in development of silvicultural systems and ecological rehabilitation in natural forest systems in Africa. *Journal of Forest Research*, 15, 3-13. Doi: 10.1007/s10310-009-0159-z.

Geldenhuys, C. J. (2005). Basic guidelines for silvicultural and management practices in Mozambique. Report FW-04/05, FORESTWOOD cc, Pretoria.

Grieve, G. R. H. & Downs, C. T. (2015). A checklist of the plants of the forests and grasslands in the Weza district, southern KwaZuluNatal and a review of their status in the Red Data List. *Koedoe*, 57(1), 1-7. <http://dx.doi.org/10.4102/koedoe.v57i1.1237>.

Kiama, D. and Kiyiapi, J. (2001). Shade tolerance and regeneration of some tree species of a tropical rainforest in Western Kenya. *Plant Ecology*, 156, 183-191.

Kikoti, I. A. and Mligo, C. (2015) Impacts of livestock grazing on plant species composition in montane forests on the northern slope of Mount Kilimanjaro, Tanzania. *International Journal of Biodiversity Science, Ecosystem Services & Management*, 11(2), 114-127.

Košir, P. Casavecchia, S. Čarni, A. Škvorc, Ž. Zivkovic, L. & Biondi, E. (2013). Ecological and phytogeographical differentiation of oak-hornbeam forests in southeastern Europe. *Plant Biosystems*, 147(1), 84-98, DOI: 10.1080/11263504.2012.717550.

Laurance, W. F. Pérez-Salicru, D. Delamonica, P. Fearnside, P. M. D'angelo, S. Jerozolinski, A. Pohl, L. and Lovejoy, T. E. (2001). Rain forest fragmentation and the structure of Amazonian liana communities. *Ecology*, 82, 105-116.

Lawes, M. J. Joubert, R. Griffiths, M. E. Boudreau, S. and Chapman, C. A. (2007). The effect of the spatial scale of recruitment on tree diversity in Afromontane forest fragments. *Biological Conservation*, 139, 447-456.

Leslie, A. B. Beaulieu, J. M. and Mathews, S. (2017). Variation in seed size is structured by dispersal syndrome and cone morphology in conifers and other nonflowering seed plants. *New Phytologist*, 216, 429-437.

Lötter, M. C. Mucina, L. and Witkowski, E. T. F. (2014). Classification of the indigenous forests of Mpumalanga Province, South Africa. *South African Journal of Botany*, 90, 37-51.

- Mairal, M. Pokorny, L. Aldasoro, J. J. Alarcon, M. and Sanmartin, I. (2015). Ancient vicariance and climate driven extinction explain continental-wide disjunctions in Africa: the case of the Randa Flora genus *Canarina* (Campanulaceae). *Molecular Ecology*, 24, 1335-1354.
- Måren, I.E. Karki, S. Prajapati, C. Yadav, R.K. and Shrestha, B.B. (2015). Facing north or south: Does slope aspect impact forest stand characteristics and soil properties in a semiarid trans-Himalayan valley? *Journal of Arid Environments*, 121, 112-123.
- Mkonda, M. Y. and He, X. (2017). Sustainable Environmental Conservation in East Africa through Agroforestry Systems: A Case of the Eastern Arc Mountains of Tanzania. *International Journal of Sustainable and Green Energy*, 6(4), 49-56.
- Morris, E. K. Caruso, T. Buscot, F. Fischer, M. Hancock, C. Maier, T. S. Meiners, T. Muller, C. Elisabeth Obermaier, E. Prati, D. Socher, S. A. Sonnemann, I. Waschke, N. Wubet, T. Wurst, S. and Rillig, M.C. (2014). Choosing and using diversity indices: insights for ecological applications from the German Biodiversity Exploratories. *Ecology and Evolution*, 4(18), 3514-3524.
- Nieto-Lugilde, D. Lenoir, J. Abdulhak, S. Aeschmann, D. Dullinger, S. Gégout, J. C. Guisan, A. Pauli, H. Renaud, J. Theurillat, J. P. Thuiller, W. Van Es, J. Vittoz, P. Willner, W. Wohlgemuth, T. Zimmermann, N. E. and Svenning, J. C. (2015). Tree cover at fine and coarse spatial grains interacts with shade tolerance to shape plant species distributions across the Alps. *Ecography*, 2015, 38(6), 578-589. Doi:10.1111/ecog.00954.
- Panayotov, M. Bebi, P. Tsvetanov, N. Alexandrov, N. Laranjeiro, L. and Kulakowski, D. (2015). The disturbance regime of Norway spruce forests in Bulgaria. *Canadian Journal of Forest Research*, 45, 1143-1153.
- Paudel, S, and Vetaas, O. R. (2014). Effects of Topography and Land use on Woody Plant Species Composition and Beta Diversity in an Arid Trans-Himalayan Landscape, Nepal. *Journal of Mountain Science*, 11(5), 1112-1122.
- Pérez-Salicrup, D. R. and Sork, V. L. (2001) Lianas and trees in a liana forest of Amazonian Bolivia. *Biotropica*, 33, 34-47.
- Piedallu, C. and Gégout, J-C. (2008). Efficient assessment of topographic solar radiation to improve plant distribution models. *Agricultural and Forest Meteorology*, 148, 1696-1706.
- Popp, M. Gizaw, A. Nemomissa, S. Suda, J. and Brochmann, C. (2008). Colonization and diversification in the African 'sky islands' by Eurasian *Lychnis* L. (Caryophyllaceae). *Journal of Biogeography*, 35, 1016-1029.

- Ring, U. (2014). The East African Rift System. *Austrian Journal of Earth Sciences*, 107 (1), 132-146.
- Rouvinena, S. and Kuuluvainen, T. (2005). Tree diameter distributions in natural and managed old *Pinus sylvestris*-dominated forests. *Forest Ecology and Management*, 208, 45-61.
- Sepulchre, P. Ramstein, G. Fluteau, F. Schuster, M. Tiercelin, J-J and Brunet, M. (2006). Tectonic Uplift and Eastern Africa Aridification. *Science*, 313(5792), 1419-1423.
- Suganuma, M. S and Durigan, G. (2015). Indicators of restoration success in riparian tropical forests using multiple reference ecosystems. *Restoration Ecology*, 23 (3), 238-251.
- Svoboda, M. Fraver, S. Jandaa, P. Bace, R. and Zenahlikova, J. (2010). Natural development and regeneration of a Central European montane spruce forest. *Forest Ecology and Management*, 260, 707-714.
- Tadesse, M. and Nigatu, L. (1996). An ecological and ethnobotanical study of wild or spontaneous coffee, *Coffea Arabica* in Ethiopia. In: van der Maesen, L. J. G. van der Burgt, X. M., and van Medenbach de Rooy, J. M. (eds.) *The Biodiversity of African Plants*. Springer, Dordrecht.
- Tadesse, S. Woldetsadik, M. and Senbeta, F. (2016). Impacts of participatory forest management on forest conditions: Evidences from Gebradima Forest, southwest Ethiopia. *Journal of Sustainable Forestry*, 35 (8), 604-622.
- Teketay, D. (2005). Seed and Regeneration Ecology in Dry Afromontane Forests of Ethiopia: seed production-population structures. *International Society for Tropical Ecology*, 46(1), 29-44.
- von Gadow, K. Zhao, X. H. Tewari, V. P. Zhang, C. Y. Kumar, A. Rivas, J. J. C. and Kumar, R. (2016). Forest observational studies: an alternative to designed Experiments. *Eur J Forest Res*, 135, 417-431.
- White, P. S. and Jentsch, A. (2001). The search for generality in studies of disturbance and ecosystem dynamics. *Progress in Botany*, 62, 399-450.
- Zywiec, M. Holeksa, J. Wesołowska, M. Szewczyk, J. Zwijacz-Kozica, T and Kapusta, P. (2013). *Sorbus aucuparia* regeneration in a coarse-grained spruce forest-a landscape scale. *Journal of Vegetation Science*, 24, 735-743.