The role of agroforestry intensification in biodiversity conservation in western Ethiopia

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Abstract

Background

Human mismanagement of natural habitats caused the great loss of biodiversity and ecosystem because of their conversion into modified landscapes. On the other hand, agroecosystems are playing vital role in terms of retaining and conserving certain overstorey trees and associated perennial crops in addition to the small fauna. The main objective of this study was to assess the diversity of woody species and vegetation structure in three coffee systems across an increasing farmers' management intensity in selected research areas of western Wollega, Ethiopia. A total of 72 samples (24 per each management systems) were purposively selected from three districts based on the dominant coffee production system and the level of coffee production, which supposed to affect the diversity of tree species for collecting data on woody species. Plant specimens were collected following standard herbarium technique and identified in the field and at national herbarium.

Results

A total of 50 woody species were identified. The most abundant shade tree in coffee agroecosystems was Cordia africana. The nonmetric multidimensional scaling (NMDS) ordination and Sorensen distance-based ordination demonstrated that plots of the same coffee system were almost maintained similar species composition and abundance. However, no similar pattern was observed between the coffee systems, except the small overlap in species composition between plantation coffee and garden coffee systems. Diversity of woody species was significantly different among the coffee management systems ($P < .0001$). Similarly, some of the structural parameters like density, basal area, and shade significantly reduced along the increased coffee management intensity.

Conclusions

The study found evidence that the intensification of coffee management was not always the source of biodiversity loss; rather, it is an opportunity for conservation of the locally threatened higher plants. Incorporation of coffee shrubs in the degraded lands or remnant forest patches, integrating coffee in the massive afforestation/tree planting programs, and using multipurpose trees in afforestation can be used as an alternative strategy for overstorey plant conservation

Background

Forest resources provide the ecological and economic services spanning from local to the global, such as ecosystem functioning, biodiversity, carbon dynamics, and climate change mitigation (Duguma et al 2019). Tropical forests are the most hosts of the plenty plant biodiversity through retaining about two-thirds of the global flora (Semper-pascular et al 2019). However, as forest fragmentations continue, the provision of valuable goods and ecosystem services from forest resources are highly declining in the world, particularly in the developing nations (Aerts et al 2011; Hundera et al 2013; Oke & Jamala, 2013; Tadesse et al 2014). In particular, deforestation is the main cause of forest resource loss in Ethiopia following the alarming human population pressure and lack of the appropriate sustainable forest management approaches.

Conversion of natural forest to widespread commercial crop production resulted in a high loss of biodiversity (Agidie et al 2013) and even structural complexity reduction including shade tree diversity under the increasingly intensive management of agroforestry system (Boreux et al 2016). Likewise, intensification of coffee management systems in Ethiopia results in structural degradation (Hundera et al 2013). Coffee agroecosystems are widely seen as the means that can reduce the impacts of deforestation through by providing eco-agricultural solutions (Gobena et al 2013; Tadesse et al 2014). Particularly, it plays a significant role in harboring various tree species, especially those locally threatened from natural habitats. However, the expansion of plantation coffee system results in the dramatic loss of Afromontane rain forest species in Ethiopia along with the increasing intensive management.

Several studies of biodiversity in the past had been focused mainly on natural ecosystems, while less emphasis was paid to biodiversity conserving in the managed ecosystem in general and agroecosystems in particular. More recently, human-altered landscapes like traditional agroforestry have increasingly gained attention for their potential to conserve biodiversity (Perfecto et al 2014; Tadesse et al 2014), mainly in tropical and temperate regions (Oke & Jamala, 2013). Despite the information on the ecosystem services of the coffee agroecosystems, there is a gap in the effect of intensive silvicultural activities and certain agronomic management practices on the plant diversity in the coffee agroecosystems in Western Ethiopia. Therefore, still, there is a knowledge gap on the ecological importance of human-induced land-use systems or modified natural ecosystems in general, traditional coffee production systems of East Africa or Ethiopia in particular. Lack of ecological importance knowledge would result in loss of the locally threatened indigenous higher plant species in the natural habitats and in coffee landscapes following the increasing management intensity to satisfy the market coffee demands.

We hypothesized that as coffee management intensity increases, the diversity of woody species decreases. The structure of woody species found in the intensively managed coffee system is more disturbed than the traditionally managed coffee system. Therefore, the two subjects were well addressed that (i) which coffee management system can negatively influence the plant biodiversity; (i) which vegetation structure can be more affected by changes in coffee landscape management practices. In this study, we aimed to assess the diversity of woody species in the coffee agroecosystems across the increasing management intensity. Moreover, we aimed to evaluate the structure of woody species among the three coffee management systems.

Material And Methods

Description of the study area

The study was conducted in three districts, namely, Gimbi, Haru, and Lalo Asabi of West Wollega zone, in Oromia regional national state, Western Ethiopia (Fig. 1). The Zone has 21 districts. Gimbi town, which is the capital of the zone, is located at a distance of 441 km West of Addis Ababa (the capital of the country). The Zone is bordered by Benishangul-Gumuz regional state in the North, East, and West; Qellem Wollega Zone in Southwest; and Illubabor and East Wollega zones in Southeast. The land area of the Zone is estimated to be 14,160.29 km^2. In general, the Zone has a tropical climate with annual temperatures ranging between 15°C and 25°C. The annual rainfall pattern in the zone decreases from East to West following the physiographic nature of the Zone; where the Eastern highlands are characterized by highest ranges of rainfall from 1800-2000 mm; the central plateaus with an intermediate range of 1600-1800 mm at mid highlands and the remaining lowlands have rainfall ranging from 1200-1600 mm. The farming system in the Zone is mixed (livestock production integrated with crop production).

Sampling design

The reconnaissance survey was conducted in December 2019 to collect information about the study area. The purposive sampling design was used to select districts, Peasant Association (PA), and Households (HH) from the selected administrative Zone. Accordingly, three districts were purposively selected based on the presence of several coffee management systems and being among the potential districts chosen for the advanced level of coffee production, which is supposed to affect the diversity of woody plant species. Similarly, within the selected district, a potential PA was selected based on the above-set criteria for the selection of the district. Coffee farming HHs intentionally selected whose coffee land spanning 400 m^2 or more and fulfill the criteria set for one of the coffee management systems.

Three coffee management systems (semi-plantation coffee, garden coffee, and shade plantation coffee) were identified depending on the intensity of coffee management in the Zone since the area is not the origin of coffee there is no forest coffee or semi-forest coffee systems. The semi-plantation coffee (SPC) system represents the systematic modification of the forest through planting coffee seedlings under the naturally existing overstorey trees (Hundera et al 2013; Worku et al 2015). The garden coffee (GC) system refers to the practice of coffee planting in association with the exotic and retained indigenous canopy trees around homestead on a small plot of land (Worku et al 2015). The shade plantation coffee (PC) system represents planting the improved varieties of coffee seedlings in combination with only a few indigenous large canopy trees and rarely incorporation of fast-growing exotic tree species (De Beenhouwer et al 2016). Sample plots were equally selected from all coffee management systems, in that, 72 samples from all coffee systems or 24 samples per coffee management system were selected for the study.

Inventory on the floristic composition and vegetation structure was conducted within a 400 m^2 sample plot per coffee land. All woody plant species having a diameter at breast height (DBH) ≥ 2.5 cm and height ≥ 1.5 m were measured for the population structural characterization. Caliper or diameter tape and Hypsometer were used to measure DBH and total height, respectively. Similarly, tree crown diameter on the ground from perpendicular crown edges using a measuring tape. The height was classified into ten classes, while the diameter was categorized into fifteen classes. The geographical location in degrees and elevation of each sample plot was taken from the plot center using Garmin 72 GPS receiver. Plant identification was carried out both in the field using local informants and in the national herbarium of Ethiopia.

Statistical analysis

Nonmetric multidimensional scaling (NMDS) ordination, which relies on rank orders of distances, was used to represent graphically the similarity/dissimilarity of plots. Sample plots were arranged along poles using polar ordination according to a distance matrix. Data from the vegetation survey was analyzed for species diversity and vegetation/population structure. Species richness, Shannon diversity index(H'), Shannon Evenness (E), Jaccard’s similarity index, frequency, importance value index, and stand structure such as density, basal area, percent shade cover, diameter, and height were computed and compared among coffee systems. Descriptive statistics such as mean, percentage, and standard deviation were used to present the results. The data were subjected to One-Way ANOVA to compare the mean difference and separated at least significant differences ($p < 0.05$). All statistical analyses were performed using R software.

Results

Species composition and Ordination

Fifty woody plant species belonging to 46 genera and 28 families were recorded in the coffee management systems, of which 45 were native and five were exotic species. Fabaceae was the most species-rich family with eight (16%) species; followed by Euphorbiaceae, which contain four (8%) species, and Bignoniaceae, Moraceae, and Rutaceae had accommodated three (6%) species each. Five families, Asteraceae, Celastraceae, Combretaceae, Meliaceae, and Myrtaceae had contained two (4%) species each. Moreover, the remaining fifteen families had one species each in the overall coffee management systems. The number of species composition decreased from 37 to 26 and 19, which belonged to 22, 17, and 13 families across the increased coffee management gradients in SPC, GC, and PC systems, respectively.

The NMDS ordination and Sorensen distance-based ordination demonstrated that sites of the same coffee system almost maintained similar species composition. On the other hand, sites of SPC and PC systems were different in terms of their species composition and respective abundance, whereas a small overlap was observed between SPC and GC systems, and PC and GC systems. Five sites of the SPC system clustered with that of the GC system or five of the latter system grouped with that of the PC system (Fig. 2).

Diversity of woody species

Woody species richness of coffee agroecosystems was found to be significantly different across the intensified management gradients ($P<.0001$). The SPC system accommodated the highest mean richness ($S = 7.75 \pm 2.35$) compared with GC and PC systems (Table 1). Species richness varied from 4 to 12 per plot of SPC and 2 to 6 per plot of PC and GC systems. The diversity of woody species (mean H') was significantly highest ($P<.0001$) in the SPC system and declined along the increased coffee management gradients (Table 9). However, the species distribution showed decreasing pattern across the increasing management intensity even though the difference was not statistically significant ($P = 0.2275$). A strong positive correlation found between woody species richness and Shannon diversity index ($S_S = 0.94$, $P <.0001$) and species distribution ($S_S = 0.25$, $P = 0.25$).

Table 1
Summary of woody species diversity indices (mean ± SD) in coffee agroecosystems in the studies area

	Diversity among the management systems		
Management system	S	H'	E
SPC	$7.75(\pm 2.35)^a$	$1.87(\pm 0.33)^a$	$0.93(\pm 0.07)^a$
GC	$4.04(\pm 1.27)^b$	$1.22(\pm 0.38)^b$	$0.91(\pm 0.08)^a$
PC	$3.08(\pm 1.35)^b$	$0.94(\pm 0.37)^c$	$0.89(\pm 0.10)^a$
P>F	<.0001	<.0001	0.2275
Means with the same letter in the column were not significantly different at P=0.05			
Where: S-richness; H'- Shannon diversity index; E- Shannon evenness, SPC, GC, and PC as defined above			

Density and frequency of woody plants in coffee agroecosystems

Mean stem density was not significantly different between the coffee management systems, where the figure gradually decreased from the SPC system (8683.3 stem density ha^{-1}) to the GC system (7891.7 stem density ha^{-1}) and PC system (7806.2 stem density ha^{-1}) across the increased management intensity. On the other hand, shade trees were found significantly highest (350 stem density ha^{-1}) in the SPC system, while the lowest (139.6 stem density ha^{-1}) in the PC system. Similarly, coffee shrub density, reduced along with the increased management intensification from the SPC system (8333.3 stem density ha^{-1}) to the GC system and PC system (Table 2).

Table 2
Woody plant structural variables (mean ± SD) at coffee management systems

Structural variables	Coffee management systems			
	SPC	GC	PC	P>F
Tree density	350.0(±113)[a]	141.7(±73)[b]	139.6(±30)[b]	<.0001
Coffee density	8333.3(±2839)	7750.0(±2448)	7666.7(±3084)	0.6698
Total density	8683.3(±2877)	7891.7(±2439)	7806.2(±3089)	0.4961
Tree BA	35.4(±0.59)[a]	17.7(±0.52)[b]	12.5(±0.48)[b]	<.0001
Coffee BA	1.25(±0.02)[b]	1.56(±0.05)[b]	2.75(±0.08)[a]	<.0001
Total BA	36.25(±0.60)[a]	19.75(±0.53)[b]	16.26(±0.49)[b]	<.0001
Shade %	83.9(±15.3)[a]	67.2(±45.4)[b]	48.1(±36.7)[b]	0.003
DBH	34.39(±22.10)[a]	29.60(±18.91)[b]	28.39(±21.9)[b]	0.029
Height	12.14(±5.8)	11.44(±4.7)	11.18(±3.8)	0.101
Means with the same letter in the row were not significantly different at P=0.05				
Where: BA = Basal area; DBH = diameter at breast height; SPC, GC, and PC as defined above				

The woody species were not uniformly distributed along the increased coffee management gradients. A small proportion of the identified species had a higher relative frequency; while the remaining species were rare, showed the inverted J shape (Fig. 3). The result revealed that *Albizia gummifera* was the most frequently distributed species (61.1%), followed by *Cordia africana* (52.8%), *Croton macrostachyus* (51.4%), and *Acacia abyssinica* (37.5%). On the contrary, about 44 woody species were rarely distributed in the coffee agroecosystems.

In the SPC system, the most abundant tree species was *C. macrostachyus* followed by *A. gummifera* and *C. africana*. Similarly, *A. abyssinica* followed by *A. gummifera* and *C. macrostachyus* were the top highly distributed tree species in the PC system, while the rest 15 species were rarely distributed. In the GC system, *C. africana* was found to be the most frequently distributed tree species (Fig. 3).

Basal area and importance value index (IVI)

The mean basal area was significantly different between the coffee management systems. Accordingly, the tree mean basal (BA = 35.4 m^2 ha^{-1}) was significantly higher in the SPC compared with GC and PC systems. Inversely, coffee shrubs BA increased significantly along the intensified coffee management gradients, despite that the difference was insignificant between the latter two coffee systems (Table 2). Some species were more dominant or important than those highly abundant or densely populated in coffee farms. *A. gummifera* (IVI=46), *C. africana* (IVI=37), *A. abyssinica* (IVI=28), and *C. macrostachyus* (IVI=27) were found to be the four most important species having greater than 20 IVI. The dominant species were not found uniform throughout all coffee systems. Accordingly, *A. gummifera* (IVI = 38), *C. africana* (IVI=52), and *A. abyssinica* (IVI = 86) were found the dominant species from SPC, GC, and PC systems, respectively (Appendix 1).

Shade

Mean shade cover over coffee farms decreased significantly among the coffee management systems across the intensified management gradients that the highest mean shade cover (83.88%) was that of from semi-plantation coffee system followed by 67.24% and 48.11% in GC and PC systems, respectively. On the other hand, shade cover percent did not vary significantly among age groups (Table 2).

Population structure

The diameter classes of woody plants in the coffee agroecosystems almost created an inverted J shape as expected. About 25% of the plants had DBH range between 10.1 cm and 20 cm, comparatively the most abundant class, while only a single plant had DBH greater than >140 cm diameter. The highest diameter (DBH = 144 cm) was occupied by the *Ficus vasta* found in the SPC system. About 83% of the identified woody species had DBH of ≤ 50 cm, while the rest (17%) was found in higher diameter classes ranging from 50.1 cm to 144 cm (Figure 4a).

The result showed that the height of woody plants found in coffee agroecosystems had height ranged between 3 m and 30 m. The most abundant height class was 6.1-9 m class with 173 stocks, whereas the 27.1-30 m class had only a single tree. The measured maximum height (30 m) was offered by *Eucalyptus camaldulensis* found in the PC system. Three plants (*C. africana*, *C. macrostachyus*, and *Entada abyssinica*) were identified with the lowest height (3 m). A greater proportion of woody plants (77%) had ≤15 m height, while the rest (23%) belonged to high classes ranged between 15.1 and 30 m (Figure 4b). A higher proportion of woody plants had lower to an intermediate diameter and height. Inversely, higher diameter and height classes accommodated a small number or even a single plant; this indicated that higher class was species-specific like of the buttress *Ficus vasta* or an exceptional tallest *E. camaldulensis* than any other.

Species similarity among the coffee management systems

Eighteen percent of recorded species were commonly available in all the coffee management systems. The Jaccard's similarity index showed 40.6% (13 of 32 woody species recorded in both systems) of species commonly belonged to GC and PC systems. The species similarity between SPC and GC systems was 40% (16 of 40 species of both coffee systems). The lowest species similarity, 27.3% (12 of 44 species of both coffee systems) was observed between SPC and PC systems. On the other hand, nineteen (51.3%), six (23.1%), and three (15.8%) species were only identified from SPC, GC, and PC systems, respectively.

Discussion

Coffee agroecosystems species diversity

Conversion of adjacent disturbed remnant forest patches to the intensively managed coffee farms could be the source of change in species composition and dominance of very few shade trees. Accordingly, this study depicted that *A. gummifera* was the most commonly available shade tree in coffee farms. On the other hand, earlier reports showed that *C. africana* was the most abundant and frequent in smallholder coffee farms of western Ethiopia (Likassa & Gure, 2017), in the Enset coffee agroforestry system of southern Ethiopia (Molla & Asfaw, 2014), and coffee farms of Uganda (Negawo & Beyene, 2017). According to Tefera et al (2016), *Millettia ferruginea* was found the most abundant and frequent in the coffee-based agroforest of southern Ethiopia. Whereas, *C. macrostachyus* and *A. gummifera* were reported as the most dominant and important species in SPC and PC systems from southwest Ethiopia (Aerts et al 2011; Hundera et al 2013; Worku et al 2015).

There was a change of species occurrence along the increasing gradients of coffee management intensity. Very few shade tree species were frequently available in each coffee system as the result of different factors. Accordingly, the most frequent shade tree species in the SPC system could be discussed from the high natural regeneration potential characteristics, while the deliberate planting of ecologically important species (e.g., N-fixation to improve soil property and balanced shade provision) influenced that of the PC system since productivity improvement is the management goal. Therefore, *A. abyssinica* deserves the right place for this goal and become the most frequent species. On the other hand, *C. africana*, the most frequent in the GC system was influenced by the economic value, although ecologically less important in coffee systems (Likassa 2014; Evizal et al 2016). The result indicates the farmer preference of *C. africana*, A. *abyssinica*, and *C.macrostachyus* based on the plant characteristics. These species have been reported as the most dominant in the coffee landscape of Ethiopia (Hundera et al 2013; Likassa 2014; Molla and Asfaw 2014; Worku et al 2015; Denu et al 2016; Likassa and Gure 2017). Similarly, Negawo & Beyene (2017) have reported that the quality timber which highly demanded in the local market made *C. africana* to be the most dominant species in coffee farms of Uganda.

The result of the current study indicated that the diversity of woody species changed, as coffee management transformed from an extensive to a more intensified system. This implies that a change in management activities caused a loss of species diversity. Therefore, the coffee system with less management intervention was found with greater woody species composition, while the most intensively managed system had harbored few species and low diversity. Similarly, earlier studies concluded that increased coffee management gradients have been observed with high change over species and the species loss in Ethiopian (Aerts et al 2011; Hundera et al 2013; Tadesse et al 2014; Worku et al 2015; De Beenhouwer et al 2016; Mengistu and Asfaw, 2016). The intensity of management is mostly designed with selective removal of certain tree species that are less suitable for coffee shrubs or have negative tree-crop interaction. Our result is congruent with the report of Tadesse et al (2014) and De Beenhouwer et al (2016) that the highest diversity in the SPC system mimics the complex nature of the natural forest. On the other hand, the careful selection criteria and tedious silvicultural practices mainly thinning and slashing reduced the species diversity in the PC system.

Vegetation structure of coffee agroecosystems

Removal of understorey vegetation and selective thinning of shade trees, as the result of improving coffee management system, appears a negative effect on the density of woody species. The regular application of silvicultural practices to create free space for coffee plant growth and development resulted in the lower density of other woody plants (Worku et al 2015; Nigatu et al 2017). The strategy of reducing shade cover makes the canopy trees to be eliminated from the PC system. The density of woody plants varies among the different size classes (Kumsa et al 2016). There is an inverse relationship between thickness and the density of available plants. It is not surprising that plants having a lower diameter to be densely populated in the coffee landscape as the result of maintaining the woody plant regeneration for the future shade over in case of the old canopy tree failed. Accordingly, distributions of stem density skewed towards a small DBH class followed inverted J shape curves, indicative of continuous removal of the big trees for coffee management or construction and fuelwood (Tadesse et al 2014; Worku et al 2015; Denu et al 2016; Nigatu et al 2017). This implies as the clearing of undergrowth vegetation continues, the structure, as well as the regeneration capacity of the coffee agroecosystems, is affected negatively (Aerts et al 2011; Hundera et al 2013; Denu et al 2016; Nigatu et al 2017).

The basal area of the woody plants in the coffee agroecosystems decreased inversely along with the increased management intensity gradients from SPC to GC and PC. Our result is similar to the report of Hundera et al (2013), Worku et al (2015), and Cerda et al (2017). Shade reduction across the increased coffee management gradients appears that there is a negative relationship between shade cover and production intensification. Similarly, studies from southwest Ethiopia (Tadesse et al 2014) and Costa Rica (Cerda et al 2017) showed that mean canopy cover declined significantly along the increased coffee management gradients. There is the highest shade cover in the SPC system because of the densely populated early successional shade tree than the rest coffee systems where most of the late-successional shade trees are raised with an intermediate or lower cover as in the PC system. Likassa and Gure (2017) investigated that the presence of dominant larger trees in coffee farms may be the cause for greater shade cover rather than a higher density of woody species.

Conclusions

Increased human management intensity to maximize coffee products can be perceived as the negative factor for plant biodiversity conservation in the coffee agroecosystems of western Ethiopia. Although plant biodiversity conservation is usually more promising in the natural ecosystem, coffee agroecosystems deserve an important role for *in-situ* and *ex-situ* conservation of woody species including the locally endangered higher plants as alternative modified land-use systems. The study found evidence of *C. africana* one of the locally destructing Ethiopian higher plants from the wild is abundantly conserved in the coffee agroecosystems; it is possible to determine that traditional coffee management systems caused better plant biodiversity conservation. Therefore, it is possible to conclude that the intensively managed coffee systems are not always the source of plant biodiversity loss, but also an opportunity to conserve some woody species based on coffee growers' knowledge on the compatibility with coffee shrubs and use value they have.

Woody species composition has a high similarity among the coffee systems, indicating the conservation role being played as the result of farmers' preference associated with coffee and the origin of plants maintained on the farm. There was an inverse relationship between woody species diversity and coffee management intensity; it is possible to conclude that diversity is highly influenced by the intensity of management efforts applied insight of collecting coffee cherries. In general, the intensification of coffee management systems resulted in the degradation of vegetation structure.

Incorporation of coffee shrubs in the degraded lands or remnant forest patches, integrating coffee in the massive afforestation/tree planting programs, and using multipurpose trees in afforestation can be used as an alternative strategy for overstorey plant conservation. To make the ecosystem services sustainable, conservationists, as well as policymakers, should recognize and acknowledge the traditional coffee management systems either through incentives or through ecological seal certification programs. We recommended the national and regional governments include coffee agroecosystems in the design of agricultural climate change adaptation and mitigation strategies.

Abbreviations

ANOVA	Analysis of Variance
DBH	Diameter at Breast Height
GC	Garden Coffee system
ha	Hectare
HH	Household
IVI	Importance Value Index
mm	Millimeter
PA	Peasant Association
PC	Plantation Coffee system
SPC	Semi-plantation coffee system

Declarations

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Authors' contributions

Ebisa Likassa designed the experiment, collected the samples, analyzed data, and prepared the writing original draft.Tamrat Bekele and Sileshi Nemomissareviewed andrevised the manuscript. All authors read and approved the final manuscript.

Availability of data and materials

The data used and analyzed in this study can be provided from the corresponding author for scientific, non-profit purpose.

Ethics approval and consent to participate

Not applicable, the study involves no human participants.

Consent for publication

Not applicable.

Competing Interests

There is no conflict of interest in this manuscript. It is part of my Ph.D. dissertation work. Both of my supervisors were acknowledged and deserve the position of co-authors.

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Figures

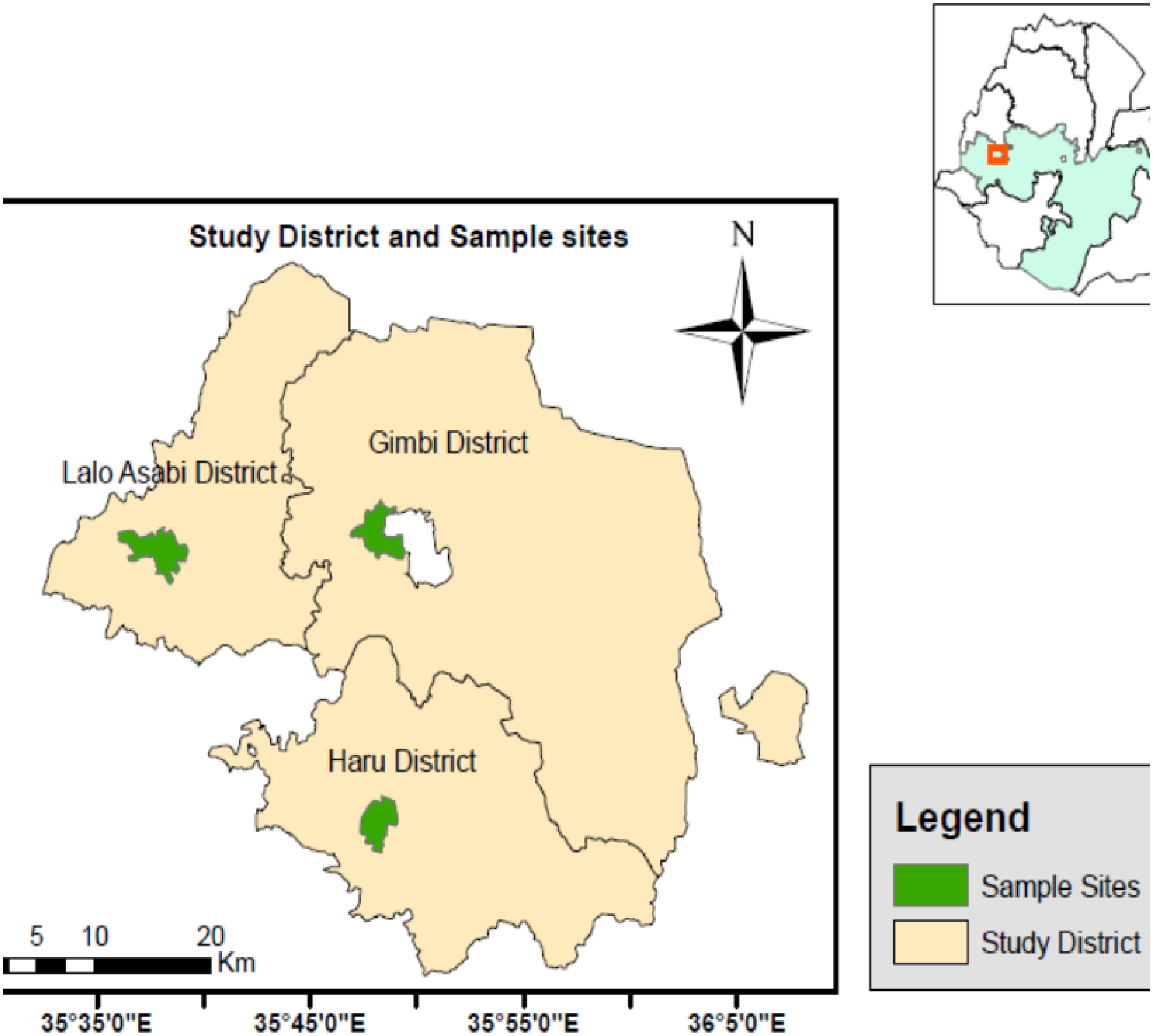

Figure 1

Map of the study area

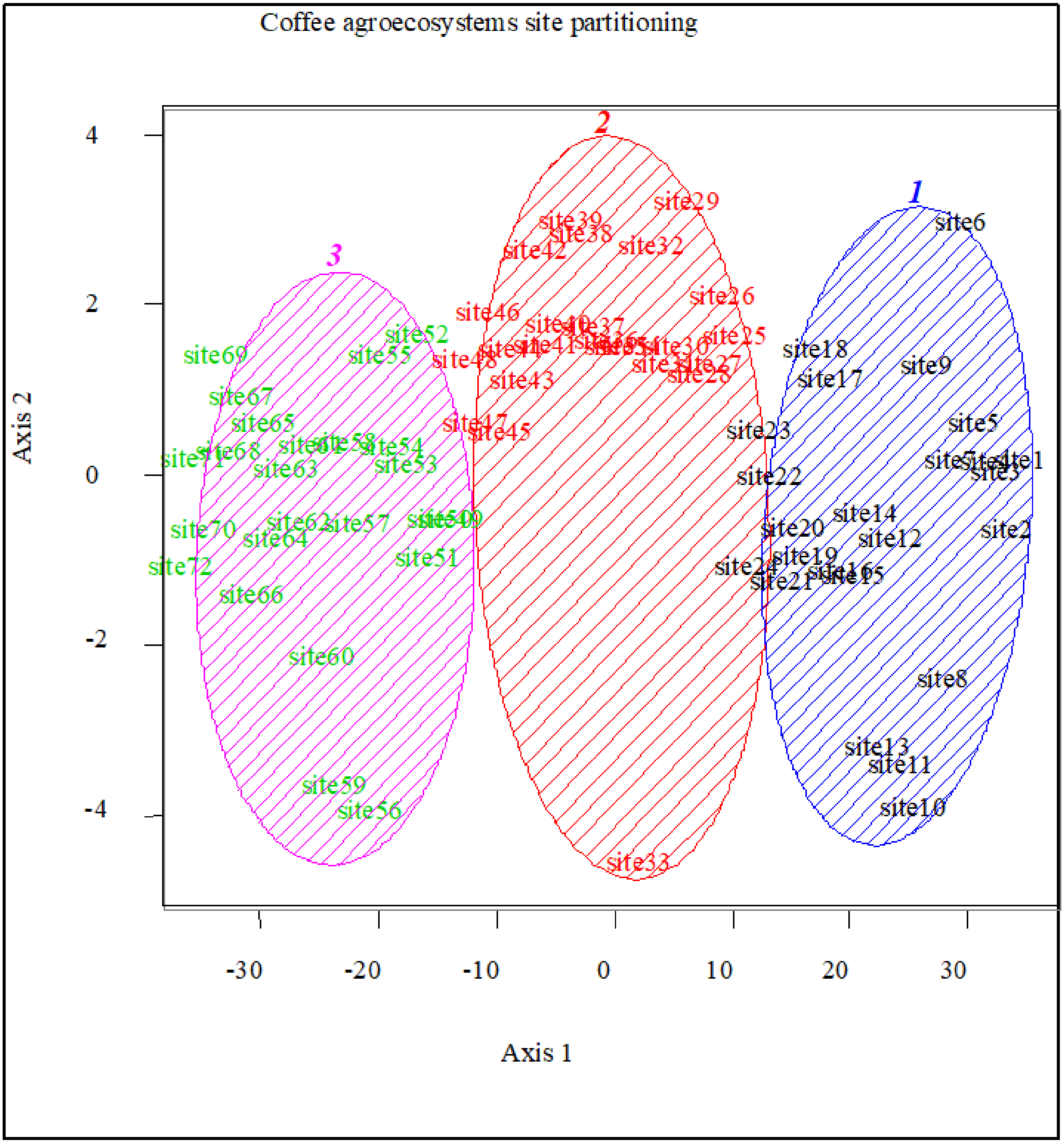

Figure 2

NMDS ordination of 72 sample sites in 3 coffee systems (1=semi-plantation coffee, 2=garden coffee, and 3= plantation coffee) based on species composition and abundance using Bray and Curtis method

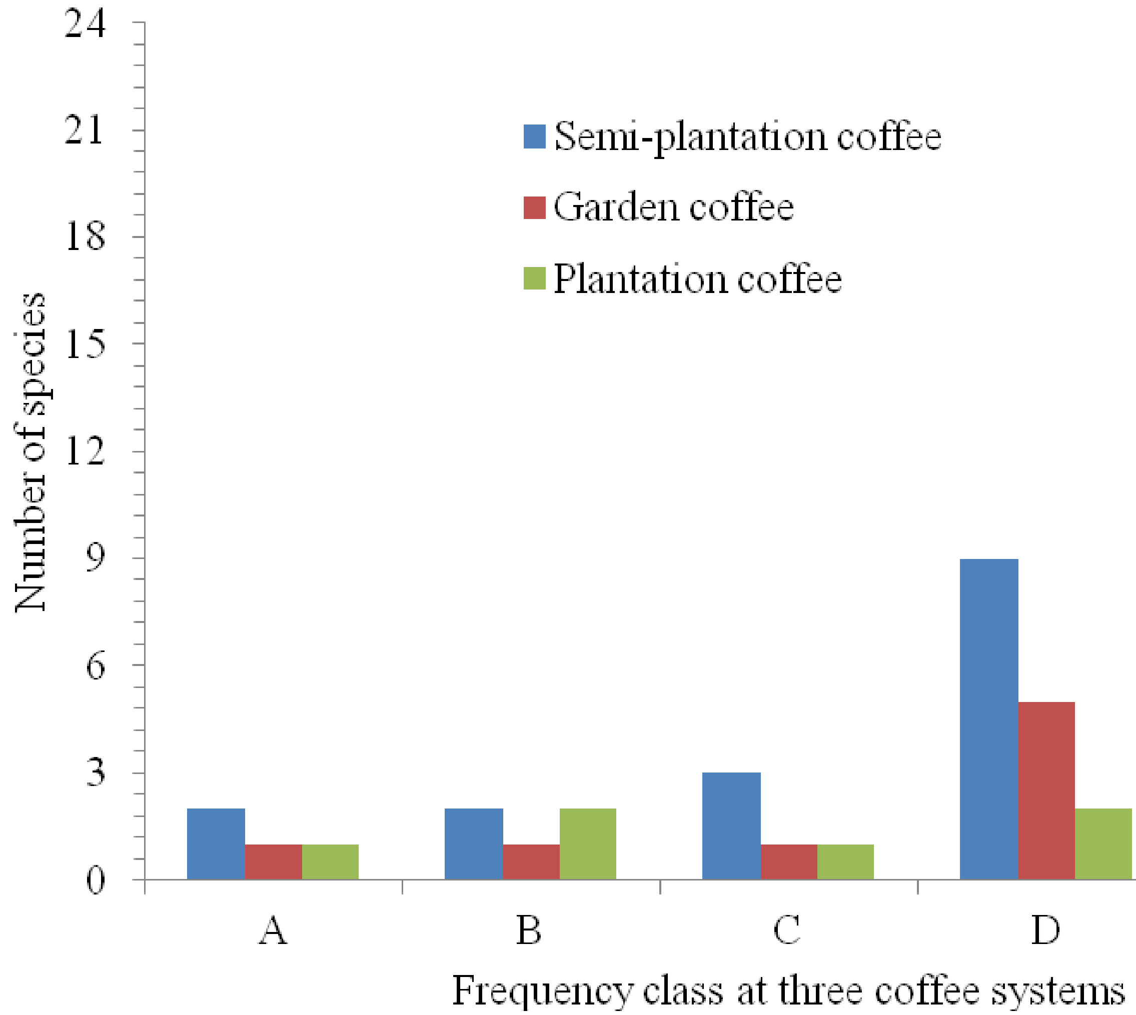

Figure 3

Frequency class of distribution of woody species at three coffee systems (A=>80%, B= 60.1-80%, C= 40.1-60%, D=20.1-40, and E= 1-20%).

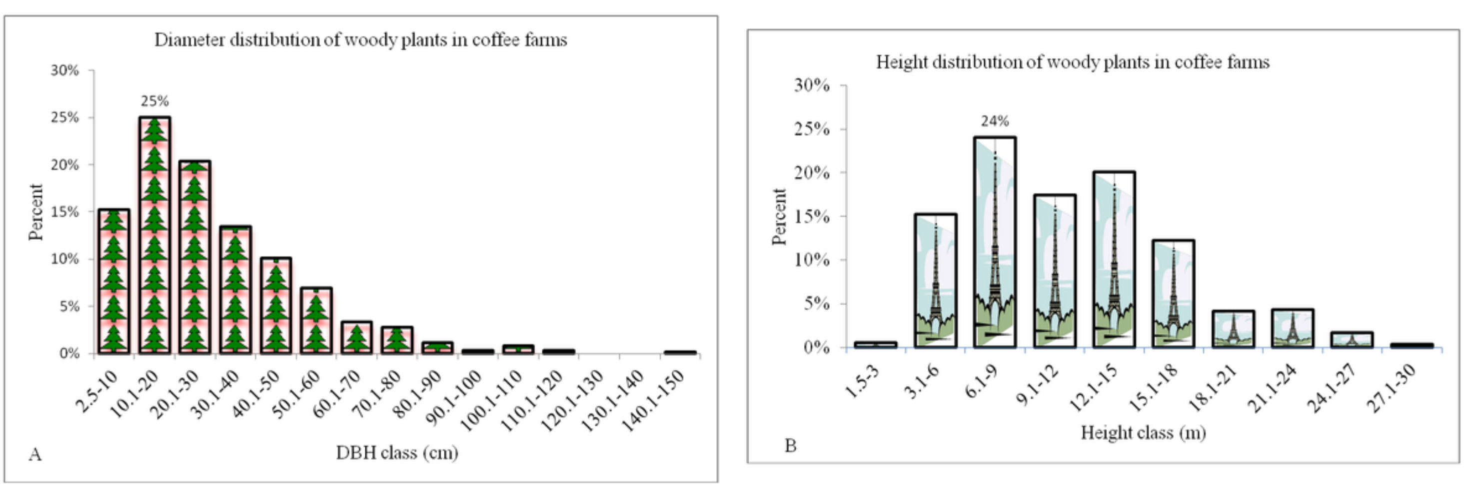

Figure 4

Distribution percent of woody plants along diameter (A) and height (B) classes in coffee agroecosystems

Supplementary Files

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- Appendix1.doc