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DIVERSITY AND ECOLOGICAL ANALYSIS OF VASCULAR EPIPHYTES IN GERA WILD COFFEE FOREST, JIMMA ZONE OF OROMIA REGIONAL STATE, ETHIOPIA

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ABSTRACT: Vascular epiphyte diversity as well as ecology of epiphytes was studied in Gera Forest in southwestern Ethiopia at altitudes between 1600 and 2400 m a.s.l. Fifty sampling plots of 30 m x 30 m (4.5 ha) were surveyed in coffee and non-coffee forest for the purpose of data collection. Out of these, sixteen plots were recorded from non-coffee forest. A total of 59 species of vascular epiphytes were recorded. Out of these, 34 (59%) were holo-epiphytes, two (4%) were hemi-epiphytes, and 22 (37%) were vascular epiphytes. The dominant families on the basis of species numbers were Orchidaceae (12 species), Aspleniaceae (8 species) and Polypodiaceae (7 species). In order to evaluate altitudinal factor limiting distribution of species, diversity of vascular epiphytes was studied along an altitudinal gradient from 1600–2400 m a.s.l. According to Shannon-Weiner biodiversity index (H′ = 3.41), the vascular epiphytic diversity was found to be high. The following host traits i.e., diameter, height and host bark textures, were analyzed to find out their relation to epiphytic distribution and abundance. A higher richness of epiphyte species occurred on rough bark (38%) followed by corky (26%), flack, (25%), and very low epiphyte species were found on smooth bark (1%). These results indicate that diameter size, bark texture of host tree, horizontal stems and branches had the greatest influence on epiphytic composition and abundance in the study area. A very high accumulation of humus and thus, the ability to hold water for long time, creates a suitable condition for seedling attachment and growth of vascular epiphytes. Host tree preference of vascular epiphytes was recorded only for *Vittaria volkensii* species which was hosted on *Syzygium guineense* trees. The result of similarity analysis indicated that Gera Forest showed the highest vascular epiphytic similarity (0.35) to Yayu Forest, and the least vascular epiphytic species overlap (0.295) with Harenna Forest.

Key words/phrases: Epiphytes, Gera Forest, Phorophyte, Vascular epiphytes.

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INTRODUCTION

Epiphytes are those species which normally germinate on the surface of another living plant and pass the entire life cycle without becoming connected to the ground (Kress, 1989). They derive their nourishment from atmospheric sources. In forest ecosystem, epiphytes play useful roles in nutrient cycles, provide shelter and nesting materials for some insects and bird species, and are important sources of food for some foraging animals (Coxson and Nadkarni, 1995; Stuntz *et al.*, 2002). Epiphytes constitute an important bio-indicator group of species that can be monitored to provide useful information on overall ecosystem health and productivity, because of their arboreal lifestyle and sensitivity to environmental stress (Fattland, 1996; McCune, 2000). Since they are useful climatic indicators, they can be used as a warning system for changing conditions in microclimate and even as indicators of global climatic change (Benzing, 1998). Epiphytes are extremely important elements of the flora representing about 10% of all plant species globally (Neider and Barthlott, 2001).

Vascular epiphytes are an essential component of the forest vegetation, in terms of both species diversity and their role in forest ecosystem functions (Gentry and Dodson, 1987; Benzing, 1990). Epiphytes contribute greatly to global plant diversity, as they represent between 8% and 10% of all known vascular plant species and 25–50% of plant species richness in tropical forests (Gentry and Dodson, 1987; Benzing, 1995; 2004).

The diversity and distribution of vascular epiphytes are determined by many factors. The biophysical environment of phorophytes (such as host size, bark texture and vertical stratification) and elevation above sea level, disturbance, and climatic factors are among the major factors (Barthlott *et al.*, 2001).

In forests, the distribution pattern of vascular epiphyte diversity is affected by two major processes: dispersal and establishment (Migenis and Ackerman, 1993). Host trees provide the substrate for epiphytes, so establishment seems to be affected by host tree traits, including area available for establishment, physical and chemical characteristics of bark, and architecture, e.g., canopy structure. Seedlings growing on rough, porous, and/or water-retaining bark have greater drought resistance than seedlings growing on smooth bark unable to retain adequate surface moisture, and water scarcity continues as a threat for the mature epiphyte (Benzing, 1990).

Many studies have shown that epiphytes in general are vulnerable to human disturbances (Hietz and Hietz-Seifert, 1995; Barthlott *et al*., 2001). Epiphytes can be used as indicators of forest disturbance but they also provide resources and niche possibilities for canopy-dependent fauna (Benzing, 1990).

There are some studies carried on vascular epiphytes in Ethiopian forests (e.g., Tesfa Alemayehu, 2006; Hylander and Sileshi Nemomissa, 2008; Abuna Tafa, 2010). Most of the research carried out on Ethiopian forests dealt with identifying the species diversity and analysis of vegetation structure. Epiphytes are highly important for the provision of ecological services such as water and nutrient cycling, slow down of high rainfall to the ground and regulating the humidity of the forest. However, the local communities often think of epiphytes as parasites harming the coffee plant, and decreasing the productivity of the coffee. Similarly, the studies of Matthias (2011) and Hylander and Sileshi Nemomissa (2008) indicated that farmers are concerned about epiphytes due to their possible contribution to yield decline. Due to this misconception, they remove the vascular epiphytes from the coffee plant and other shrubs at the coffee cultivation area. This will be a challenge to maintaining future diversity and richness of the vascular epiphytes in the study area.

This study was intended to assess the composition, diversity, and ecology of epiphytes in Gera Forest. Along with these, the impact of altitude, host tree DBH and height, nature of host bark and host plant species on the distribution of vascular epiphytes were assessed.

MATERIALS AND METHODS

The study area

The study was conducted in Gera District, Jimma Zone of Oromia National Regional State, southwest Ethiopia (Fig. 1). The study forest is located at about 380 km from Addis Ababa and covers a total area of 80830.4 ha. The altitudinal range of the study forest varies from 1600 to 2400 m a.s.l. The mean annual temperature of the area is about 18.4°C with mean minimum and maximum temperatures of 11.7°C and 26.5°C, respectively. The mean annual rainfall of the study area is 1805 mm. To obtain an impression of the site conditions, a reconnaissance survey was made on November 15, 2012; and the actual data collection took place between November 16–December 13, 2012.

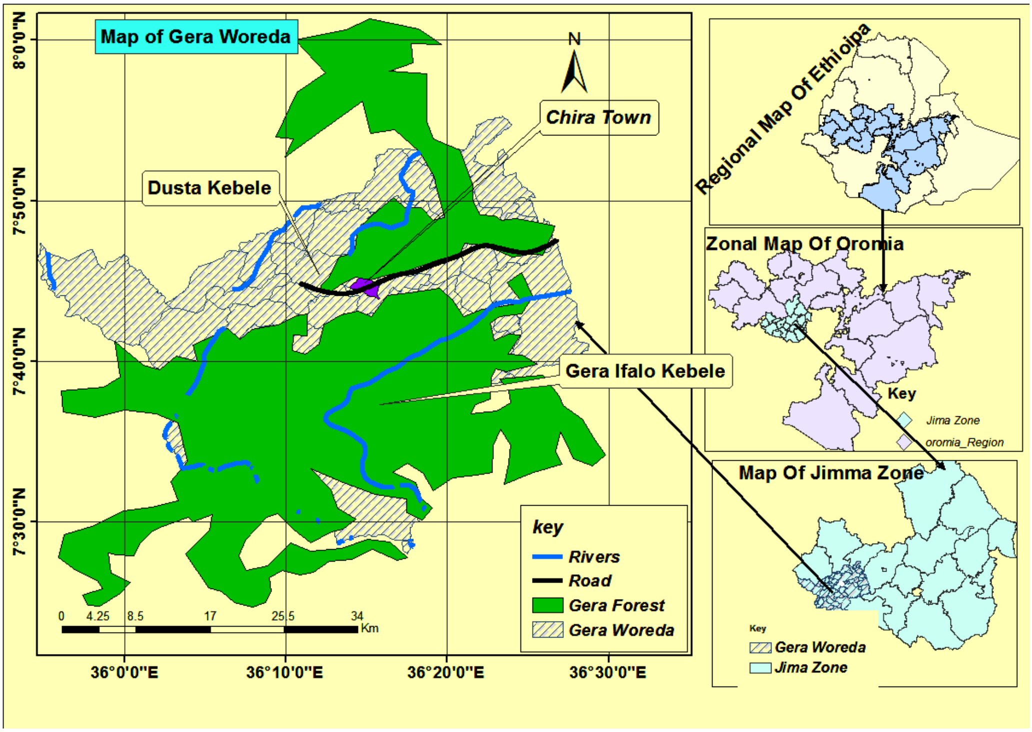

Fig. 1. Map of Ethiopia and Jimma Zone showing the location of Gera Forest.

Methods

To collect field data, line transects were laid along an altitudinal gradient between 1600 to 2400 m a.s.l. Sampling sites were arranged along transects in three directions. The first transect was laid from Chira town to Anfallo. The second transect was laid from Chira town to non-coffee forest of Gera. The third transect was laid from Chira town to Beshasha town, on the way to Agaro. The size of each quadrat was 30 m x 30 m (900 m^2). The plots were arranged at distances of 100 m from each other along the transect. To avoid edge effect, sampling plots were kept >200 m away from forest edge. In each quadrat, the number of individual species of epiphytes occurring on the phorophytes were counted. Tree height, DBH (diameter at breast height) and bark texture of the phorophytes, attachment direction of epiphytes, and the exact position of the epiphytes on the phorophytes were recorded. However, texture, colour, hardness and softness of bark were noted by visual observation and feel during data collection. The bark samples of host porophytes were collected for physical analysis. The area around the plot and along the transect line was searched systematically for additional epiphyte species in order to complete the inventory. A total of fifty (50) quadrats were analyzed. Those epiphytes occurring in dense stands were counted as one individual following Barthlott *et al*. (2001) and Johansson (1974).

To study the altitudinal distribution of vascular epiphytes, the altitudes were arbitrarily classified into lower (1600–1800 m), middle (1800–2000 m), and higher (2000–2400 m) altitudes. Access to tree crowns was achieved using the single rope technique (Perry, 1978). Epiphytes vertical distribution and samples were recorded in each of 4 vertical tree zones following a zonation scheme slightly modified after Johansson (1974) as depicted in Fig. 2:

(i) Johansson-zone 1 stretches from 0 m above ground level; (ii) Johansson-zone 2 stretches from 2 m to below first branch; (iii) Johansson-zone 3 stretches from first branch to below third branch (intermediate crown); (iv) Johansson-zone 4 stretches from third branch and above (upper crown). Trees, which are found dangerous to climb, were not selected.

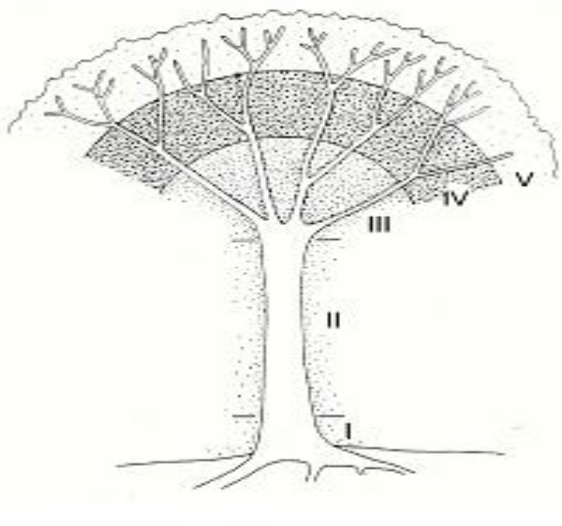

Fig. 2. Johansson zonation (Johansson,1974).

Vascular epiphytes sampled were grouped following Benzing (1990): holo-epiphytes, hemi-epiphytes, and accidental epiphytes. Holo-epiphytes are plants that spend much or all of their lives attached to other plants (Putz and

Holbrook, 1986; Benzing, 1987). These species normally germinate on the surface of other living plants and spend their entire life cycle without being connected to the ground (Madison, 1977). Accidental epiphytes are predominantly terrestrial plants that accidentally germinate in the tree trunk crevices. Hemi-epiphytes are those species whose germination occurs in the tree top but the development of roots and stems occur down to the forest floor (Fernanda and Talita, 2002).

Size of host trees was classified as follows: small phorophytes with diameter at breast height of 2.5 to 20 cm; medium phorophytes of DBH 21 to 50 cm, and larger phorophytes with DBH >51 cm.

Data analysis

The relationship between the size of host trees and the number of epiphyte species per host trees was analyzed by using Spearman rank-correlation test, and the influence of bark texture of the phorophyte on the diversity and richness of epiphyte species per tree was analyzed by using SPSS version 20.

The diversity of vascular epiphytes in Gera Forest was analyzed by using Shannon-Weiner diversity index. Sorensen's similarity was calculated to compare the epiphytic community of the study area with those of Gera, Harenna, and Yayu forests. The epiphytic data for Harenna and Yayu were obtained from the studies of Tesfa Alemayehu (2006) and Abuna Tafa (2010), respectively.

Epiphytes were collected following standard herbarium techniques and identified at the National Herbarium of Ethiopia, Department of Plant Biology and Biodiversity Management, Addis Ababa University using the Flora of Ethiopia and Eritrea, and comparison with herbarium specimens housed at ETH.

RESULTS

A total of 59 vascular epiphyte species belonging to 37 genera and 26 families were recorded. Of these, holo-epiphytes constituted 59%, hemi-epiphytes 4% and accidental epiphytes about 37% (Fig. 4). Orchidaceae was the most dominant family with twelve species (20%) belonging to six genera, while Aspleniaceae was the second dominant family with eight species (13.3%) representing one genera. The third species rich family was Polypodiaceae with seven species (11.7) belonging to four genera. The fourth species rich family were Piperaceae and Asteraceae with four species (6.7%) each (Fig. 3). The remaining 18 families contained only one species each (Fig. 3). The species diversity of the vascular epiphytes for the study area is calculated to be H' = 3.5.

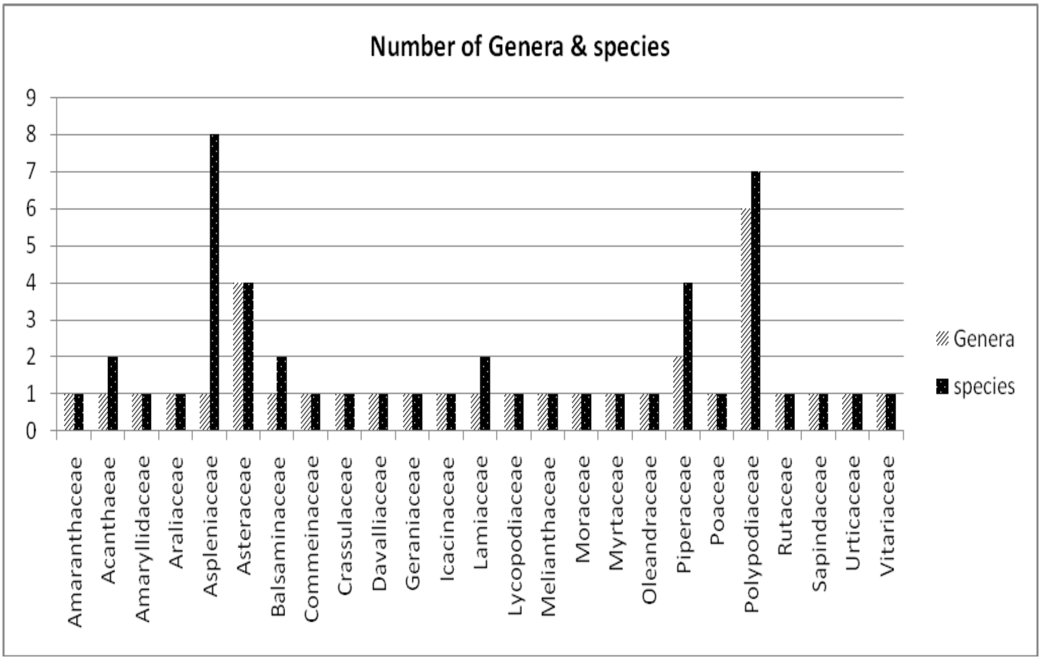

Fig. 3. The species richness of the families of holo, hemi and accidental epiphytes.

Host specific and life forms of vascular epiphytes

In the study area, most of the vascular epiphyte species (98.33%) were not host specific. They were recorded from more than two species of host phorophytes. Only one (1.66%) species of vascular epiphyte was recorded from a specific host tree species. The most abundant life form of the epiphytic species in Gera Forest was buds close to one another (Reptata densa upright). Buds close to one another, densely tufted, and pendulus life form was the second common life form of epiphytic species. Buds far apart, shoots or leaves scattered (Reptata remota) and Rosette forms (Fasicularis) was relatively the least in abundance. Buds on basal portion of plants and upright shoots tufted (Caespitosa) were life form which were rare in Gera Forest (Table 1).

Altitudinal distribution of vascular epiphytes

The altitudinal distribution of holo and hemi vascular epiphyte species in Gera Forest showed variation in pattern. Thirty per cent (30%) of holo and hemi vascular epiphytes were recorded at altitudes between 1600 m to 2400 m, while 52% were concentrated in the middle altitudinal range of 1800 m to 2000 m.

Table 1. Patterns of altitudinal distribution of holo and hemi vascular epiphytes in Gera Forest. Legend: A = 2400–2300, B = 2300–2200, C = 2200–2100, D = 2100–2000, E = 2000–1900, F = 1900–1800, G = 1800–1700, H = 1700–1600.

Species	**Family**	**Altitudinal range**							
		A	B	C	D	E	F	G	H
Aerangis thomsonii (Rolfe) Schltr	Orchidaceae	+	+	+	+	+	+	+	+
Aerangis brachycarpa (A.Rich.) Th.Dur.& Schinz	Orchidaceae	+	+	+	+	+	+	+	+
Allophylus macrobotrys Gilg	Sapindaceae	+	+	+	−	−	−	−	−
Apodytes dimidiata E. Mey.ex Arn	Icacinaceae	−	+	+	−	−	−	−	−
Arthropteris monocarpa Cordem.) C.Chr	Oleandraceae	+	+	+	+	+	+	+	+
Arthropteris orientalis (Gmel.) Posth	Davalliaceae	−	−	−	+	+	+	+	
Asplenium anisophyllum		−	−	−	−	+	+	+	−
Asplenium erectum Bory ex Willd.	Aspleniaceae	+	+	+	+	+	+	+	+
Asplenium protensum Schrad.	Aspleniaceae	+	+	+	+	+	+	+	+
Asplenium sandersonii Hook	Aspleniaceae	−	−	−	−	+	+	+	−
Asplenium abyssinicum Fée	Aspleniaceae	−	−	−	+	+	+	+	+
Asplenium aethiopcum (Burm.f.) Bech.	Aspleniaceae	+	+	+	+	+	+	+	+
Asplenium linkii Kuhn.	Aspleniaceae	−	−	−	−	+	+	+	+
Asplenium theciferum (HBK.) Mett.	Aspleniaceae	−	−	+	+	+	+	+	−
Cyrtorchis arcuata (Lindl.) Schltr.	Orchidaceae	−	−	−	−	+	+	+	+
Diaphananthe adoxa Rasm.	Orchidaceae	+	+	+	+	+	+	+	+
Diaphananthe tenuicalcar. Summerh.	Orchidaceae	+	+	+	+	+	+	+	+
Drynaria volkensii Hieron.	Polypodiaceae	+	+	+	+	+	+	+	+
Ficus thonningii Blume	Moraceae	−	−	−	+	+	+	−	−
Huperzia ophioglossoides (Lam.) Rothm.	Lycopodiaceae	+	+	+	+	−	−	−	−
Lepisorus excavatus (Willd.) Ching	Polypodiaceae	+	+	+	+	+	+	+	+
Lepisorus schraderi (Mett.) Ching	Polypodiaceae	+	+	+	+	+	+	+	+
Loxogramme abyssinica (Baker) M.G.Price	Polypodiaceae	+	+	+	+	+	+	+	+
Microcoelia globulosa (Hochst.) L. Jonsson	Orchidaceae	−	−	−	+	+	+	+	+
Peperomia molleri C.DC.	Piperaceae	−	−	−	−	−	+	+	+
Peperomia abyssinica Miq.	Piperaceae	+	+	+	+	+	+	+	+
Peperomia tetraphylla (Forster) Hook. & Arn.	Piperaceae	+	+	+	+	+	+	+	+
Phymatosorus scolopendria (Burm.f.) Ching	Polypodiaceae	−	−	−	−	−	−	−	+
Pleopeltis excavata (Willd.) Sledge	Polypodiaceae	+	+	+	+	+	+	+	−
Pleopeltis macrocarpa (Wild.) Kaulf	Polypodiaceae	+	+	+	+	+	+	+	+
Polystachya rivae Schweinf.	Orchidaceae	+	+	+	+	+	+	+	+
Polystachya bennettiana Rchb.f.	Orchidaceae	−	−	−	−	+	+	+	+
Polystachya cultriformis (Thouars) Spreng.	Orchidaceae	−	−	−	−	−	+	+	+
Polystachya tessellata Lindl.	Orchidaceae	−	−	−	+	+	+	+	+
Polystachya lindblomii Schltr.	Orchidaceae	−	−	−	−	+	+	+	+
Scadoxus nutans (Friis & I.Bjørnstad) Friis & Nordal	Amaryllidaceae	−	+	+	−	−	−	−	−
Schefflera abyssinica (Hochst ex A. Rich.) Harms	Araliaceae	−	−	+	+	+	+	−	−
Vittaria volkensii Hieron.	Vittariaceae	−	+	−	−	−	−	−	−
Indet. fern sp.		−	−	−	−	+	+	−	−

At altitudes above 2000 m, 13% of the holo-epiphytes were recorded while at lower altitudinal ranges (i.e., 1600 m to 1800 m) 5% of the hemi vascular epiphytic species were recorded (Fig. 4). Species of the families Orchidaceae and Aspleniaceae were mostly distributed at the middle (1800 m–2000 m) altitudinal ranges followed by a decline at lower and upper altitudinal ranges. Although most species of the family Piperaceae are distributed at all altitudinal ranges, some of the species are noted to be restricted within the lower (1600 m–1800 m) and middle (1800 m–2000 m) altitudinal ranges.

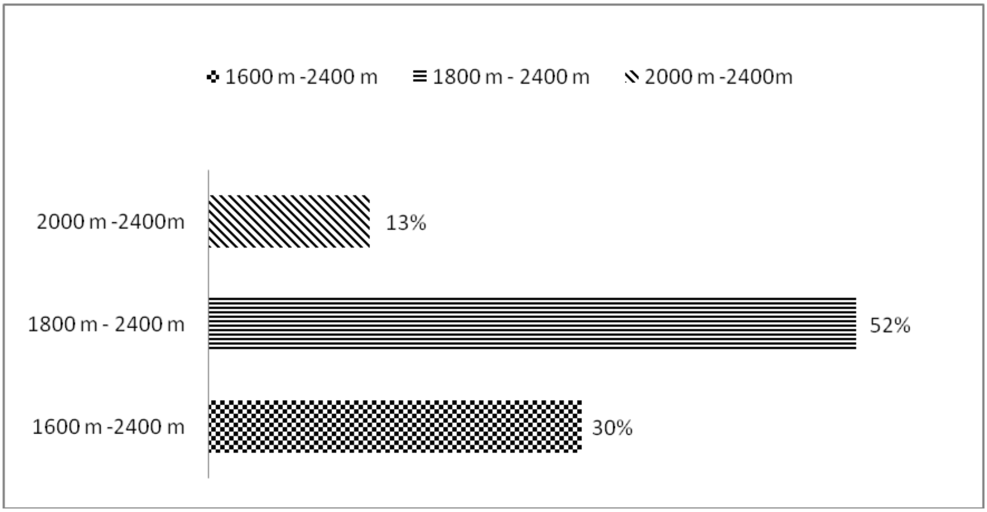

Fig. 4. Altitudinal distributions of holo and hemi epiphytic vascular epiphyte species in Gera Forest.

Attachment position

The attachment direction of vascular epiphytic species in Gera Forest showed different patterns (Table 2). Most of the species were recorded from west and east face of the phorophytes. However, species such as *Drynaria volkensii*, *Asplenium anisophyllum*, *Asplenium theciferum*, *Microcoelia globulosa* and *Peperomia tetraphylla* were collected from north and south faces of the phorophytes as well. Overall, high epiphyte diversity and richness was recorded from the west and east faces of the phorophytes.

Table 2. Attachment direction of holo and hemi vascular epiphytes on phorophytes in Gera Forest.

Species	**Family**	**Attachment direction on phorophytes**			
		East	**West**	**North**	**South**
Asplenium abyssinicum Fée	Aspleniaceae	+	+	−	−
Aerangis brachycarpa (*A.Rich.*) Th.Dur.& Schinz	Orchidaceae	+	+	−	−
Arthropteris monocarpa (Cordem.) C.Chr	Orchidaceae	−	+	−	−
Arthropteris orientalis (Gmel.) Posth	Davalliaceae	+	+	−	−
Aerangis thomsonii (Rolfe) Schltr	Orchidaceae	+	+	−	−
Asplenium aethiopcum (Burm.f.) Bech.	Aspleniaceae	+	+	−	−
Asplenium linkii Kuhn.	Aspleniaceae	+	+	−	−
Asplenium smedsii		+	+	−	+
Asplenium protensum Schrad.	Aspleniaceae	+	+	−	+
Asplenium sandersonii Hook	Aspleniaceae	−	+	−	−
Asplenium theciferum (HBK.) Mett.	Aspleniaceae	+	+	+	−
Cyrtorchis arcuata (Lindl.) Schltr.	Orchidaceae	+	−	+	−
Diaphananthe adoxa Rasm.	Orchidaceae	+	+	−	−
Diaphananthe tenuicalcar. Summerh.	Orchidaceae	+	+	−	+
Drynaria volkensii Hieron.	Polypodiaceae	+	+	+	+
Huperzia ophioglossoides (Lam.) Rothm.	Lycopodiaceae	+	+	−	−
Lepisorus excavatus (Willd.) Ching	Polypodiaceae	+	+	−	−
Asplenium erectum Bory ex Willd.	Aspleniaceae	+	+	+	−
Lepisorus schraderi (Mett.) Ching	Polypodiaceae	−	+	−	−
Loxogramme abyssinica (Baker) M.G.Price	Polypodiaceae	+	+	−	+
Microcoelia globulosa (Hochst.) L. Jonsson	Orchidaceae	+	+	+	+
Peperomia abyssinica Miq.	Piperaceae	+	+	−	−
Peperomia fernandopoiana		+	−	−	−
Peperomia molleri C.DC.	Piperaceae	+	+	−	−
Peperomia tetraphylla (Forster) Hook. & Arn.	Piperaceae	+	+	+	+
Phymatosorus scolopendria (Burm.f.) Ching	Polypodiaceae	+	+	−	−
Pleopeltis excavata (Willd.) Sledge	Polypodiaceae	−	+	−	−
Pleopeltis macrocarpa (Willd.) Kaulf	Polypodiaceae	−	+	−	−
Polystachya bennettiana Rchb.f.	Orchidaceae	+	+	+	−
Polystachya cultriformis (Thouars) Spreng.	Orchidaceae	+	+	−	−
Polystachya rivae Schweinf.	Orchidaceae	+	+	+	−
Polystachya lindblomii Schltr.	Orchidaceae	+	−	−	−
Rhipidoglossum adoxum		+	+	+	−
Scadoxus nutans (Friis & I.Bjørnstad) Friis & Nordal	Amaryllidaceae	+	−	−	−
Vittaria volkensii Hieron.	Vittariaceae	−	+	−	−
Indet. fern sp.		+	−	−	−
Ficus thonningii Blume	Moraceae	−	−	+	−
Schefflera abyssinica (Hochst ex A. Rich.) Harms	Araliaceae	−	+	−	−

Vertical distribution of epiphytes on phorophytes

The vertical distribution patterns of vascular epiphytes, from the basal part to the top of most crowns of the phorophytes, showed variation. The number of epiphytic species increased from the tree base to the middle branches and then declined towards the top branch region (Table 3).

Table 3. List of species of vascular epiphytes (holo, hemi and accidental epiphytes) distributed in different zones of the host tree. Legend: Class A = base area (0–2 m above ground), Class B = 2 m - first branches, Class C = middle crown (first branches to below third branches), Class D = upper crown third branches).

Species		**Class of phorophytes/host tree**			
	Family	**A**	**B**	**C**	**D**
Achyranthus aspera L.	Amaranthaceae	+	−	−	−
Adenostema mauritianum DC.	Asteraceae	+	−	−	−
Aerangis brachycarpa (A.Rich.)Th.Dur.& Schinz	Orchidaceae	+	+	+	−
Aerangis thomsonii (Rolfe) Schltr	Orchidaceae	−	+	−	−
Allophylus macrobotrys Gilg	Sapindaceae	+	+	−	−
Apodytes dimidiata E. Mey.ex Arn.	Icacinaceae	+	+	+	−
Arthropteris monocarpa (Cordem.) C.Chr.	Oleandraceae	+	+	−	−
Asplenium abyssinicum Fée	Aspleniaceae	+	+	−	−
Asplenium aethiopicum (Burm.f.) Bech.	Aspleniaceae	+	+	+	+
Asplenium smedsii Pic.Serm.	Aspleniaceae	+	+	+	−
Asplenium erectum Bory ex Willd.	Aspleniaceae	+	+	+	+
Asplenium linkii Kuhn.	Aspleniaceae	−	+	+	
Asplenium protensum Schrad.	Aspleniaceae	+	+	+	−
Asplenium sandersonii Hook.	Aspleniaceae	+	+	+	+
Asplenium theciferum (HBK.)Mett.	Aspleniaceae	+	+	−	−
Bersama abyssinica Fresen.	Melianthaceae	+	−	−	−
Bidens pilosa L.	Asteraceae	+	−	−	−
Clausena anisata (Willd.) Benth.	Rutaceae	+	−	−	−
Commelina diffusa Burm.f	Commeinaceae	+	−	−	−
Crassocephalum crepidioides (Benth.) S.Moore.	Asteraceae	+	+	+	−
Cyrtorchis arcuata (Lindl.) Schltr.	Orchidaceae	−	+	−	−
Diaphanante adoxa Rasm.	Orchidaceae	−	−	+	+
Diaphananthe tenuicalcar Summerh.	Orchidaceae	−	+	−	−
Drynaria volkensii Hieron.	Polypodiaceae	−	+	+	+
Ficus thonningii Blume	Moraceae	−	+	+	
Geranium arabicum Forssk.	Geraniaceae	+	−	−	−
Huperzia ophioglossoides (Lam.) Rothm.	Lycopodiaceae	−	+	+	+
Hypoestes forskaolii (Vahl) Rom. & Schultes	Acanthaeae	+	−	−	−
Hypoestes triflora (Forssk.) Roem & Schultes	Acanthaeae	+	−	−	−
Impatiens hochstetteri Warb.	Balsaminaceae	+	+	−	−
Impatiens rothii Hook.f.	Balsaminaceae	+	−	−	−
Kalanchoe petitiana A.Rich.	Crassulaceae	+	+	−	−
Lepisorus excavatus (Willd.) Ching	Polypodiaceae	+	+	−	−
Lepisorus schraderi (Mett.) Ching	Polypodiaceae	+	+	+	−
Loxogramme abyssinica (Baker) M.G.Price	Polypodiaceae	+	+	+	−
Microcoelia globulosa (Hochst.) L.Jonsson	Orchidaceae	−	+	−	−
Oplismenus hirtellus (L.) P. Beauv	Poaceae	+	−	−	−
Peperomia abyssinica Miq.	Piperaceae	+	+	+	+
Peperoma molleri C.DC.	Piperaceae	+	+	+	+
Peperomia tetraphylla (Forster) Hook.& Arn.	Piperaceae	+	+	+	+
Phymatosorus scolopendria (Burm.f.) Ching	Polypodiaceae	+	+	−	−

Species	**Family**	**Class of phorophytes/host tree**			
		A	**B**	**C**	**D**
Pilea rivuaris Wedd.	Urticaceae	+	+	−	−
Pleopeltis excavata (Willd.) Sledge	Polypodiaceae	−	+	+	+
Pleopeltis macrocarpa (Willd.) Kaulf	Polypodiaceae	+	+	+	−
Polystachya rivae Schweinf.	Orchidaceae	−	+	+	+
Polystachya bennettiana Rchb.f.	Orchidaceae	−	+	+	+
Polystachya cultriformis (Thouars) Spreng.	Orchidaceae	−	+	−	−
Polystachya lindblomii Schltr.	Orchidaceae	−	−	+	+
Polystachya tessellata Lindl.	Orchidaceae	−	+		
Pycnostachys abyssinica Fresn.	Lamiaceae	+	−	−	−
Pycnostachys eminii Gürke.	Lamiaceae	+	−	−	−
Scadoxus nutans (Friis & I.Bjørnstad) Friis & Nordal	Amaryllidaceae	+	−	−	−
Schefflera abyssinica (Hochst ex A. Rich.) Harms	Araliaceae	−	+	+	−
Syzygium guineense (Willd.) DC.	Myrtaceae	+	−	−	−
Urera hypselodendron (A.Rich.) Wedd.	Urticaceae	+	+	−	−
Vernonia auriculifera Hiern	Asteraceae	+	−	−	−
Vittaria volkensii Hieron.	Vittariaceae	−	−	+	−
Indet. fern sp.		−	+	+	−

Accidental epiphytes were mostly confined to the lower class of the host plant (Class A). Species such as *Impatiens hochstetteri* and *Kalanchoe petitiana* rarely reached up to Class B and C, respectively. *Polystachya cultriformis* species was restricted to classes A and B of the phorophyte, while *Scadoxus nutans* was restricted to the lower Class A usually growing between branches. On the other hand, hemi-epiphytes such as *Ficus thonningii*, and *Schefflera abyssinica* extended up to Class C (Fig. 5). The leafless orchid *Microcoelia globulosa* mostly grew on the top most outer branches and twigs of trees. Epiphytic species such as *Drynaria volkensii*, *Peperomia tetraphylla*, *Peperomia abyssinica*, *Asplenium aethiopicum*, *Asplenium sandersonii* and *Peperomia molleri* were distributed in all sections of the phorophytes. *Drynaria volkensii* was probably the most common epiphyte in the study area growing abundantly under sunny conditions, mostly in the crowns. Three vascular epiphytic species, *Microcoelia globulosa*, *Aerangis brachycarpa*, *Diaphananthe tenuicalcar* and *Diaphanante adoxa*, grew mainly restricted within 2 m to 3rd branches of the phorophytes.

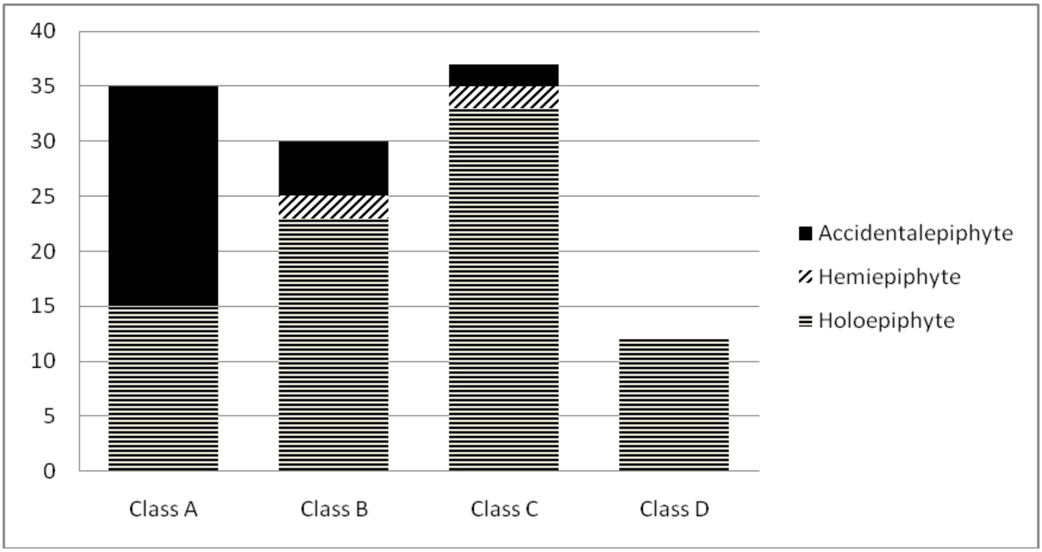

Fig. 5. Types of vascular epiphytes distributed on different class of host trees.

The holo-epiphytes gradually increased from Class A to Class C, followed by decline in Class D (Fig. 5). High holo-epiphytes (39%) occurred in the middle class of the phorophytes from below the first branch to the third branches, most of these epiphytes were orchid species, followed by Class B (27%) occurred from 2 m to below third branches. The least holo vascular epiphytes were recorded from Class D (15%) and Class A (19%) of phorophytes. However, accidental epiphytes gradually decreased from Class A to Class C, and were totally absent on upper crown (Class D) (Fig. 5). In Gera Forest, high accidental vascular epiphytes were recorded at Class A (75%) followed by Class B (21%). Only 4% of accidental vascular epiphytes reached up to Class C of phorophytes (Fig. 3). Hemi-epiphytes were totally absent in the lower Class A and upper crown (Class D); they were only restricted to Class B and C (Fig. 5).

Epiphytes and characteristics of phorophytes

In Gera Forest, host species such as *Croton macrostachys*, *Millettia ferruginea* and *Polyscias fulva* harboured a small number of epiphyte species. Only a small number of the epiphyte species *Polystachya bennettiana* occurred on the branches of these host species. Host species such as *Albizia gummifera* and *Pouteria adolfi-friederici* have large DBH sizes and heights. However, the number of epiphytic species they harboured were very low. Host species such as *Flacourtia indica*, *Grewia ferruginea*, *Macaranga capensis*, *Maesa lanceolata*, *Maytenus arbutifolia*, *Vernonia* *auriculifera* and *Coffea arabica* were suitable for the growth of epiphytes like *Polystachya cultriformis*, *Diaphanante adoxa*, *Microcoelia globulosa* and *Aerangis brachycarpa*.

Table 4. List of host species (phorophytes) harbouring the vascular epiphytes.

List of host species (Phorophytes)	**Family**
Albizia gummifera (J.F.Gmel.) C.A.Sim.	Fabaceae
Allophylus abyssinicus (Hochst.) Radlk.	Sapindaceae
Apodytes dimidiata E. Mey.ex Am.	Icacinaceae
Bersama abyssinica Fresen.	Melianthaceae
Coffea arabica L.	Rubiaceae
Cordia africana Lam.	Boraginaceae
Croton macrostachyus Del.	Euphorbiaceae
Dracaena steudneri Scw.ex Engl.	Dracaenaceae
Ficus sur Forssk.	Moraceae
Flacourtia indica Burm.f. Merr.	Flacourtaceae
Grewia ferruginea Hochst. ex A.Rich	Tiliaceae
Macaranga capensis (Bail.) Sim.	Euphorbiaceae
Maesa lanceolata Forssk.	Myrsinaceae
Maytenus arbutifolia (A .Rich) Wilczek	Celastraceae
Millettia ferruginea (Hochst.) Bak.	Fabaceae
Olea capensis L.	Oleaceae
Olea welwitschii (Knobl.) Gilg & Schellenb	Oleaceae
Pittosporum viridiflorum Sims.	Pittosporaceae
Podocarpus falcatus (Thunb.) R.B. ex Mirb.	Podocarpaceae
Polyscias fulva (Hiern) Harms	Araliaceae
Pouteria adolfi-friederici (Engl.) Baehni	Sapotaceae
Prunus africana (Hook.f.) Kalkm	Rosaceae
Psychotria orophila Petit	Rubiaceae
Sapium ellipticum (Krauss) Pax	Euphorbiaceae
Schefflera abyssinica (Hochst.ex A.Rich.) Harms	Araliaceae
Syzygium guineense (Willd.) DC. subsp. *afromontanum* F.White	Myrtaceae
Teclea nobilis Del.	Rutaceae
Vernonia auriculifera Hiern.	Asteraceae

In Gera Forest, *Croton macrostachyus* being the most abundant species, however, harboured a small number of epiphyte species. The epiphyte *Huperzia ophioglossoides* was abundant on *Syzygium guineense*, which is a medium sized tree with dense crown and a flacky bark texture. Host tree characteristics such as taxonomic identity or size have an important effect on species richness and composition of epiphytes (Zotz and Schultz, 2003).

Cordia africana, *Syzygium guineense*, *Sapium ellipticum* and *Olea capensis* harboured a large number of epiphyte species. Coffee shrubs are highly important for the attachment of vascular epiphytes, especially for *Polystachya cultriformis*. On the other hand, the epiphyte species *Diaphanante adoxa* was frequently observed and recorded on old and branched coffee hosts.

Relation of types of host barks, DBH, height, and canopy architecture with epiphytic richness and diversity

In Gera Forest, epiphytic species diversity and richness showed significant differences between host bark types. Epiphytic species were recorded from smooth, rough, flacky and corky host bark textures. The mean number of epiphyte species recorded from smooth bark texture was 3.5, from rough bark 13.4, from flacky bark, 11.7 and from corky bark, 10.3.

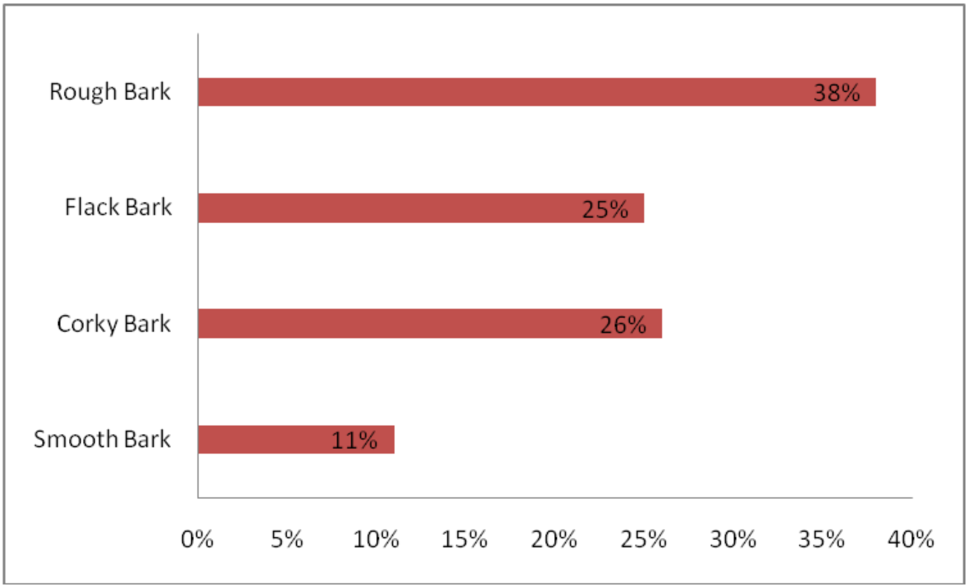

Fig. 6. Host bark textures and epiphyte species richness.

The minimum and maximum species recorded per tree was significantly different between smooth and other host bark texture. Minimum and maximum species recorded from smooth bark was (1 and 10), rough bark (5 and 15) flacky bark (3 and 21) and corky (12 and 28) species, respectively. There was a statistically significant difference between bark type and epiphyte abundance as determined by one-way ANOVA ($F(3, 91) = 21.833$, $p<0.001$), with rough host bark hosting the highest epiphyte diversity and abundance. The post-hoc test showed a significant difference in vascular epiphyte richness between the smooth bole substrate and rough, flack and corky bark types ($p<0.001$). Similarly, the test showed a significant difference between rough and cork bark ($p<0.05$). However, there was no significant difference in epiphyte between rough, flack and corky bole substrate ($p>0.05$).

In this study, species richness showed that 38% of epiphyte species were found on rough bark, 26% on flack, 25% on corky and 11% on smooth bark substrates (Fig. 6). This result showed that smooth bark textures are less suitable for seedling establishment and anchoring of epiphytes. On the other hand, rough bark types are more suitable for epiphyte attachment.

The results of the study revealed a positive relationship between host tree DBH and epiphyte abundance (Fig. 7). In Gera Forest, host species having large DBH harboured high numbers of vascular epiphytic species. For instance, a large number of epiphyte species of Aspleniaceae and Piperaceae families were recorded from large-sized host trees. Similar to this study, Laube and Zotz (2006) found positive correlation between host tree size and epiphyte richness. They also detected higher colonization rates of epiphytes per surface area on larger trees.

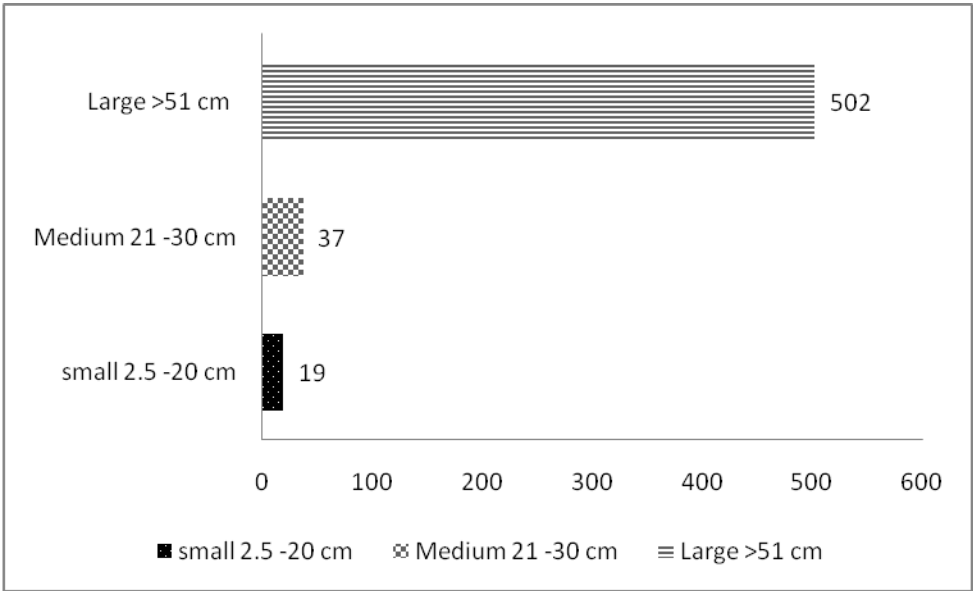

Fig. 7. Host DBH classification and epiphytic abundance.

The regression correlation test showed that the number of species of vascular epiphytes and the size of host tree are positively correlated ($R^2 = 0.773$, $p<0.01$). Not only DBH but also height of host tree had positive correlation with epiphytes abundance and richness. The regression correlation test ($R^2 = 0.28$, $p = 0.0001 < 0.05$), showed that the epiphyte species richness increased with increase in host tree height. This may be due to increasing light availability as the tree trunk height increases. This condition is more suitable for the colonization of solar radiation-tolerant epiphytes such as Orchidaceae family than shade-tolerant epiphytes. However, as the host tree grows above the forest canopy, it becomes a huge challenge for the survival of shade-tolerant epiphytes such as Aspleniaceae and Piperaceae families.

Phytogeographical comparison of vascular epiphytes

A comparison of Gera Forest with 2 forests in the country was made to evaluate the similarity of vascular epiphyte species in the forests (Table 5). Gera Forest is relatively more diverse compared to other moist montane forests in Ethiopia. In Harenna Forest, southeastern Ethiopia, 55 vascular epiphytes were recorded between an altitude of 2000 m and 3000 m (Tesfa Alemayehu, 2006), while 36 vascular epiphytes were recorded in Yayu Forest, southwestern Ethiopia, at altitudes between 1300 and 1700 m (Abuna Tafa, 2010).

Table 5. Comparison of Gera Forest vascular epiphytes with two other forests in Ethiopia based on their similarity and difference.

Forest	**Altitude (m)**	**a**	**b**	**c**	**Ss**	**References**
Yayu	1300−1700	17	43	19	0.354	Abuna Tafa (2010)
Harenna	2000−3000	17	43	38	0.295	Tesfa Alemayehu (2006)

Result of similarity analysis (Table 5) showed that Gera Forest to be more similar to Yayu Forest than Harenna Forest. The result showed that Gera Forest had more holo vascular epiphytic similarity with Yayu Forest than Harenna Forest. The most common epiphytic species between Gera and Harenna forests are accidental vascular epiphytes. Orchidaceae are more abundant in Yayu Forest than in Gera Forest. However, Aspleniaceae, Piperaceae and Polypodiaceae are more abundant in Gera Forest than the other two forests.

Table 6. List of common epiphytic species between Gera, Harenna and Yayu Forest.

Gera vs. Harenna Forest	**Gera vs. Yayu Forest**	**Common species within the three forests**
Asplenium smedsii	*Asplenium sandersonii*	*Asplenium theciferum*
Pleopeltis macrocarpa	*Polystachya bennettiana*	*Aerangis brachycarpa*
Achyranthes aspera	*Aerangis brachycarpa*	*Arthropteris monocarpa*
Aerangis brachycarpa	*Asplenium theciferum*	*Drynaria volkensii*
Arthropteris monocarpa	*Peperomia tetraphylla*	*Peperomia abyssinica*
Asplenium aethiopicum	*Cyrtorchis arcuata*	
Asplenium theciferum	*Peperoma molleri*	
Asplenium protensum	*Loxogramme abyssinica*	
Bersama abyssinica	*Drynaria volkensii*	
Diaphananthe tenuicalar	*Lepisorus excavatus*	
Drynaria volkensii	*Vittaria volkensii*	
Huperzia ophioglossoides	*Peperomia abyssinica*	
Kalanchoe petitiana	*Arthropteris monocarpa*	
Peperomia abyssinica	*Pleopeltis macrocarpa*	
Pleopeltis excavata	*Polystachya cultriformis*	
Schefflera abyssinica	*Polystachya tessellata*	
Urera hypselodendron	*Diaphananthe tenuicalcar*	
Vernonia auriculifera		

DISCUSSION

Epiphyte composition

The number of vascular epiphyte species recorded from Gera Forest is very low compared to the number reported from different tropical forests. Barthlott *et al*. (2001) reported 178 and 81 epiphytic species from primary and secondary rainforests, respectively from Venezuela. Bussmann *et al*. (2000) reported 223 species from Estacion Cientifica Forest, San Francisco. This could be related to the forest disturbances caused by human activities. The deforestation activities performed by local people (for agriculture, fuel, and timber) and logging activities were some of the disturbances observed in Gera Forest. Coffee farmers and investors remove shrub plants leaving behind only selected tree species for coffee shade purpose. Most of the coffee shade plants have smooth bark textures which are not suitable for seedling establishment of vascular epiphytes. This could be due to low accumulation of litter and low water-retaining capacity. The disturbance activities mentioned above resulted in the removal of forest trees on which the epiphytes could have been hosted, thus resulting in the decrease of epiphytic species diversity.

Altitudinal distribution of vascular epiphytes

In Gera Forest, most of the vascular epiphytes were recorded from middle altitudinal range. Similar to this study, Wolf and Alejandro (2003) in a study in Mexico, recorded the highest species richness in Chiapas Forest at mid-elevation between 500 and 2000 m. A mid-elevation species richness bulge has been suggested for vascular epiphytes in general (Schimper, 1888; Madison, 1977; Nieder *et al*., 2001).

The families Orchidaceae and Aspleniaceae were abundantly distributed at middle elevations between 1750 and 2000 m (Fig. 4). Similarly, Cardelus *et al*. (2006) recorded orchid richness at elevations between 1600 and 2000 m in old-growth forest of Costa Rica. However, in Gera Forest, species of Piperaceae and Polypodiaceae were distributed at all altitudinal ranges. However, the species *Peperomia molleri* (Piperaceae) and *Phymatosorus scolopendria* (Polypodiaceae) were restricted to lower elevation.

Attachment direction

The abundance of epiphyte attachments on phorophytes along the west and east face of the phorophytes could be due to the abundance of flux of light to the forest during sunrise in the east and sunset in the west. While the nest forming *Drynaria volkensii* epiphytic species occurred in all faces of the phorophytes, however, more abundance was observed in east and west face of the vertical trunk. Successful establishment of epiphytes on their host depends on several host tree traits such as size, age, branch quality and bark texture (Callaway *et al*., 2002). In addition to these, the deposition of humus, host tree architecture and wind direction affect the attachment of epiphytes in the studied forest.

Vertical distribution of epiphytes on phorophytes

Vertical stratification of epiphytes on forest trees in relation to changes in microclimatic conditions along the tree has been described often (Johansson, 1974; Ter Steege and Cornelissen, 1989). The vertical distribution of vascular epiphytes in the study area depicted differences in epiphytic species diversity and abundance from the base of the host tree up to its crown. This may be due to differences in microclimate in the different zones of the host plants. In Gera Forest, high epiphytic diversity and richness was recorded from middle strata of the phorophytes. This finding is in agreement with studies by Freiberg (1996) and Arévalo and Betancur (2006) who recorded high epiphytic abundance in the centre of host crowns.

A significant difference of epiphytic richness on vertical and horizontal branches of host trees occurred in Gera Forest. Especially Orchidaceae, Lycopodiaceae and Piperaceae families were abundant on vertical branches than trunks. This may be due to the dead organic matter that accumulated more easily on the horizontal branches than vertical trunks. Accumulation of dead organic matter was important for the seedling establishment, colonization and survival of vascular epiphytes. Chansa *et al*. (2011) reported that more inclined or vertical branches receive less wet season rainfall and experience more rapid run off than a less inclined or horizontal branch. In Gera Forest, more epiphytic abundance was recorded from the upper layer of horizontal branches than the vertical trunk. The other reason for abundance of epiphytes in the branches is that epiphytes are light demanding species, and therefore, light availability becomes higher in the crown than in the vertical trunks.

According to Patrick (2007), the species rich community in the canopy zone may reflect an optimum balance between light and moisture requirements. The result obtained from Gera Forest demonstrated the presence of different vertical distribution patterns of vascular epiphytes along host trees starting from base to upper crown.

Epiphytes and characteristics of phorophytes

The different bark types of the host plants showed different epiphytic diversity and abundance in Gera Forest. Phorophytes such as *Croton macrostachyus*, *Millettia ferruginea* and *Polyscias fulva* harboured low epiphytic species diversity. This could be due to the openness of their crown and the smooth bark nature of the trees, which makes seedling establishment very difficult.

Some phorophytes, while having large DBH sizes and heights, however, harboured a small number of epiphyte species. This may be related to the nature of their bark which are not suitable for development of epiphytes, due to low accumulation of humus, water and unsuitable for the attachment of epiphytes.

Some host tree species such as *Cordia africana*, *Syzygium guineense*, *Sapium ellipticum* and *Olea capensis* harboured high epiphyte species richness. This may be due to their large crown, rough and corky bark texture. According to the study of Mucunguzi (2007), the physical attributes of a host tree such as a huge trunk size, rough bark, horizontal branching and numerous invaginations on the stem facilitate epiphyte establishment. In

Gera Forest, *Schefflera abyssinica*, due to its high accumulation of humus and its large trunk size, harboured a high number of accidental epiphytes.

These observed differences may be due to the water holding capacity, humus deposition and bark chemical differences of the host plant. Smooth bark texture harboured lower number of epiphyte richness. However, rough barks provide space for holding water, humus and seeds. This creates a suitable micro environment for epiphytic establishment and colonization, thereby accounting for the main reason for high epiphytic abundance recorded from rough bark types. Similar to this study, Chansa *et al*. (2011) stated that rough barks provided better surface for anchorage of epiphytes. Khullar (1981) also suggested that the bark of trees is a factor meriting considerable importance for the prevalence of epiphytic ferns.

CONCLUSION

The present study provides data on diversity and ecology of vascular epiphytes in Gera Forest. Based on the results of this study, the following conclusion and recommendations may be drawn. Size, bark types, canopy architecture, and species of host plants were the factors influencing diversity and abundance of vascular epiphytes. Large DBH and heights of tree trunks and branches of host trees provide different microclimatic conditions thereby allowing high amounts of humus deposition. These could be the reasons for high epiphytic abundance on large phorophytes. Older and rough hosts accumulate high humus and have high water holding capacity than smooth bark textures. Due to these reasons, older trees, larger trunks and rough bark types were found to be better substrates for epiphyte colonizers in the study area.

Vascular epiphytes are one of the most important components of forest ecosystems; they are home to many arthropods and birds. Reduction of epiphytic species due to human activities may have indirect effects in agro-ecosystems through its influence on pollination and other ecosystem services.

In the present study, forest disturbance due to logging of trees for timber, clearing of regenerated shrubs, and growing of selected trees for coffee shade system have been found to be major challenges for future epiphyte diversity and distribution.

Another problem in the study area is that the coffee farmers perceive vascular epiphytes as parasites that reduce the quality and yields of their coffee. They remove epiphytes from coffee shade trees and clear small shrubs from around the coffee trees/shrubs. Most of the orchid species are highly affected by this factor.

Generally, the study of vascular epiphytes is full of challenges in Ethiopia, starting from data collection to herbarium specimen identification due to insufficient field materials and experts.

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