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Diversity and distribution of pteridophytes in the flora of Ethiopia and Eritrea

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ABSTRACT

This paper reports the diversity and distribution of pteridophytes in the flora of Ethiopia and Eritrea. The data available in the published accounts were used. Each of the families was recorded for its constituent taxa. Each of the species described was also recorded for habitat, floristic region, altitude and vegetation of occurrence. Taxa diversity, habitat specificity, floristic similarity, distribution patterns were analyzed. A total of 192 species representing 78 genera in 36 families are known from the flora area. The families diverse in species are Aspleniacea (36spp), Sinopteridaceae (17spp), Dryopteridaceae (14spp), Thelypteridaceae (11spp) and Polypodiaceae (10spp). These families account nearly 46% of the species of the flora area. Majority of the species (123spp, 64%) are terrestrials as compared to epiphytic, aquatic, and epilithic members. Among the floristic regions, Kefa (KF) has the highest species record (187spp, 97.4%) whereas Welo Upland (WU) (10spp) and Afar (AF) (10spp) have the lowest. More than half of the species are known only from one or two to three floristic regions and classified as “rare” and “occasional” respectively. Six major clusters of floristic regions were detected with varying levels of species similarity ranging from 25% to 52% shared species. Species are quite rich in two specific altitudinal zones: between 1500 to 2000 m (132spp) and between 2000 to 2500 m (112spp); and are mainly confined to forests (45.8%) and woodlands (13.5%). Endemism (2.1%) is found to be lower than other vascular plants indicating that most of the species also occur outside the flora area. The distribution of species diversity seems to have influenced by both altitude and vegetation. Based on the findings from this preliminary analyses, it is possible to suggest that pteridophyte diversity can be conserved mainly by focusing on the forests and woodlands between 1500-2500 m in the ‘hot spots’ identified in the flora area.

Key words: Pteridophyte, diversity, distribution, endemism, floristic regions, Ethiopia, Eritrea

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INTRODUCTION

Pteridophytes, ferns and fern-allies, are one of the most abundant and diverse non-woody plant groups, including primarily terrestrial and epiphytic herbs, in addition to some tree ferns (e.g. genus *Cyathea*)[19]. The continent of Africa is relatively poor in the pteridophyte species diversity when compared to other tropical parts of the world [22]. For example, South and Central America have c. 3 000 species, South-Eastern Asia and adjacent islands have c. 4 500 species whereas mainland Africa and the adjacent Madagascar island have c. 1300 species [11]. Though most of these African pteridophyte species are closely related to taxa both in Tropical America and South-East Asia, about $_{2/3}^{rd}$ are limited in their distribution to the continent. Various analyses on distribution pattern of pteridophytes [12, 16]; indicated that species richness shows a hump-shaped distribution in relation to elevation, with maxima between 500 m and 2000 m.

Ethiopia and Eritrea are countries on the Horn of Africa, having fairly rich wild plant species as compared with other tropical African countries. In tropical Africa, Cameroon and Gabon have the highest species richness (4,000- 5,000/10,000 km²). The average species richness in Ethiopia and Eritrea is 1,500-2,000/10,000 km² which is comparatively higher than average richness in countries west of Ethiopia, the Sudanian zone (500-1,000/10,000 km²) and the Sahel zone (200-500/10,000 km²) [6]. Sixteen floristic regions have been recognized in the flora of Ethiopia and Eritrea (figure 1). According to analysis reported by [4], species richness is not evenly distributed in these floristic regions. The highest richness (3,000-4,000/10,000 km²) is found in the Sidamo (SD), Shewa Upland (SU) and Kafa (KF) floristic regions; whereas the Eritrean Eastern coastal zone (EE) has a richness of only 2,000/10,000 km² and Afar (AF) only 400/10,000 km². Variations in species richness among the floristic regions were explained by the prevailing diverse ecological features characterized by topography, soil types, and climatic variables such as rainfall intensity and pattern. Consequently, there exist different types of natural vegetation ranging from Afro-Alpine and sub Afro-Alpine in the top of the high mountains to forests, woodlands, grasslands, wetlands to semi-desert and deserts in the lowlands of the flora area [5].

Research conducted and hence published works on pteridophyte flora of Ethiopia and Eritrea are scant when compared to other vascular plant taxa. Earlier taxonomic surveys were published by [15, 21]. Subsequent analysis on these available data by [1] reported 76 species, 40 genera and 23 families of ferns from Ethiopia. Only 1% the species is endemic indicating that most fern species are widespread in their distribution range. Relatively complete taxonomic treatment, including both ferns and fern allies, from Ethiopia and Eritrea was an account in the recently published flora [7]. These accounts qualitatively present data on pteridophytes of the two countries.

Biodiversity analysis has become an increasingly important field as 'hotspots' of diversity are now becoming a targeted priority for conservation planning and preservation of natural areas. However, the diversity and distribution pattern of the group has not yet been analyzed. This paper thus reports the overall species diversity and also how this diversity is distributed in relation to floristic regions, altitude and vegetation types recognized in the flora area.

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MATERIALS AND METHODS

Data on pteridophyte flora have been retrieved from accounts in Flora of Ethiopia and Eritrea [7]. The family concept in the accounts follows mainly [15]. All the families of pteridophytes were recorded for their constituent genera and species. Each of the species described was also recorded for habitat, floristic region, altitude and vegetation of occurrence. The distribution areas of widespread species, outside Ethiopia and Eritrea, were further noted.

DATA ANALYSIS

Taxa diversity

Family diversity was quantified as absolute numbers of genera and species scored. This measure allowed comparison of diversity at familial and genus levels in terms of its constituent species (table 1).

Habitat specificity

All the species in the flora area were investigated for habitats of occurrence categorizing each species as either terrestrial, aquatic, epiphytic or epilithic. Species growing in two or more habitats (e.g. as epiphyte and terrestrial) were classified as species occurring in multiple habitats (figure 2).

Distribution of diversity

Floristic regions were assessed for their species diversity as measured by abundance (A) = total number of species in the region; and as relative abundance (RA) = abundance of species in the region divided by the total species in the flora area times 100 (figure 3). The species were also analyzed for frequency of distribution in the sixteen floristic regions in the flora area. Five distinct frequency classes were defined. Accordingly, those occurring in 10 or more floristic regions are considered to be “very common”. Species present in 7-9 floristic regions are regarded as “common’’. Those occurring in 4-6 floristic regions are “frequent”. Species found in 2-3 floristic regions are rather “occasional” and species occurring only in one floristic region are classified to be “rare”. How the total number of species distributed over these five distinct frequency classes is shown in figure 4.

Floristic similarity among floristic regions

The similarity of floristic regions in their pteridophyte flora was assessed. Species were scored for absence (0) or presence (1) in the sixteen floristic regions. Data matrix was constructed with 16 floristic regions as columns and 192 species as raw. The floristic region-species matrix was analyzed to extract the *Jaccard’s* similarity coefficients. The species similarity based on the number of common taxa among floristic regions was analyzed by clustering method and performed with NTSYS-pc 1.7 software package [18]; the resulting tree is presented in figure 5.

Distribution patterns

The distribution patterns of species in the flora area were analyzed for two environmental variables: altitude and vegetation types; because previous studies have

shown them to be relevant for pteridophytes [11, 14]. For analysis of gradient in species diversity, altitudinal zones were arbitrarily defined with a width of 500 m. The frequency of the species was quantified by recording the presence or absence of the species along altitudinal zones defined (figure 6). Similarly, the relative frequency distribution of species in the five major natural vegetation types: forests, woodlands & bush lands, grasslands and wooded grasslands, wetlands & seasonal water bodies; and Afro-Alpine & sub Afro-Alpine was investigated (figure 7). The distribution patterns of species outside the flora area were further assessed and presented as percentage of widespread species extending ws_1: Mainland Africa & Madagascar, ws_2: Africa & Asia, ws_3: Africa & America, ws_4: Africa, Asia & Europe, ws_5: Africa, Asia, & America, and ws_6: Africa, Asia, America &Europe (table 2).

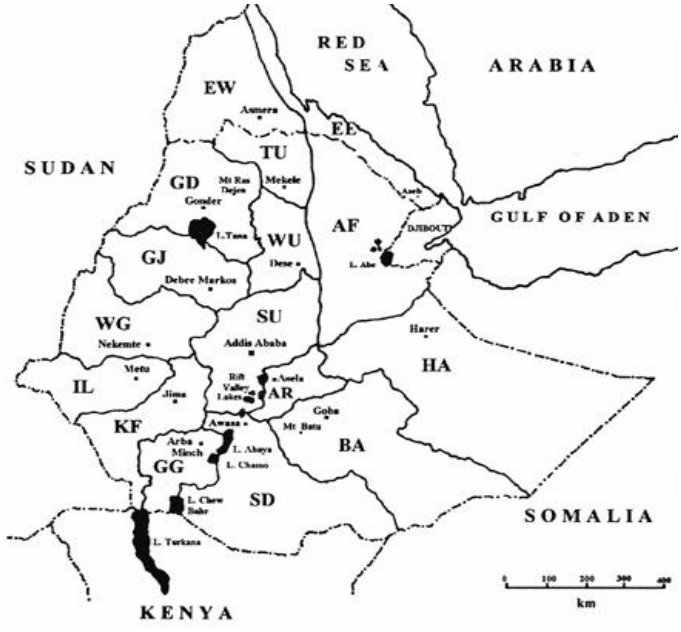

Figure 1 Map showing the sixteen floristic regions recognized in Ethiopia and Eritrea (*Abbreviations:* EE-Eritrea East, EW-Eritrea West, AF-Afar, TU-Tigray Upland, GD-Gonder, GJ-Gojam, WU-Welo Upland, SU-Shewa Upland, AR-Arsi, WG-Welega, IL-Illubabor, KF-Kefa, GG-GamoGofa, SD-Sidamo, BA-Bale, and HA-Harerge).

RESULTS

Taxa diversity

The Flora of Ethiopia and Eritrea (volume1) includes accounts of 36 families of fern allies and ferns in 78 genera and 192 species. Among these taxa, 3 families (Lycopodiaceae, Selaginellaceae, and Isoetaceae), 5 genera, and 17 species are fern allies whereas the remaining 33 families, 73 genera and 175 species are fern taxa. Table 1 shows familial diversity accounted by the number of constituent genera and species. The five most diverse families are subsequently, Aspleniacea (36spp), Sinopteridaceae (17spp), Dryopteridaceae (14spp), Thelypteridaceae (11spp) and Polypodiaceae (10spp). These five families comprise nearly 46% of the total described species in the flora area. However, twelve of the families are represented by only one species (e.g. Azollaceae, Cyatheaceae, Equisetaceae etc.). The

most diverse genera with the highest species records are, *Asplenium* (Aspleniacea, 36spp) followed by *Pteris* (Pteridaceae, 9sp), *Dryopteris* (Dryopteridaceae, 8spp), *Cheilanthes* (Sinopteridaceae, 8spp), *Ophioglossum* (Ophioglossaceae, 8spp) and *Selaginella* (Selaginellaceae, 8spp).Fifty four genera (69.2%), however, are mono specific genera, i.e. consisting of only a single species.

Habitat specificity

Habitat specificity for 192 species of pteridophytes was evaluated. Of these, 123 (64%) species are terrestrial, 17 are epiphytic, 11 are aquatic, and 5 are epilithic indicating that there are more terrestrials than others. The remaining 36 (18.8%) species grow in multiple habitats.

Of these, 27 species are found to grow both on the ground as terrestrials and on the trees as epiphytes most which are in genus *Asplenium*(e.g. *A. dalhousiac, A. stuhlmannii, A. sandersonii, A. semedsii* etc.). There was lower degree of overlap between aquatic and terrestrial habitats with 9 species being shared by these habitats. Apart from this species, there was no species shared between other habitat classes (figure 2).

Distribution of diversity

Figure 3 shows pteridophyte species diversity in the sixteen floristic regions of the flora area (see figure 1 for abbreviations). Among the floristic regions: Kefa (KF) have the highest records of species (187spp, 97.4%) followed by Sidamo (SD) (144spp, 75%), Bale (BA) (132spp, 68.8%), Shewa Upland (SU) (126spp, 65.6%) and Illubabor (IL) (119spp, 62%). Welo Upland (WU) (10spp, 5.2%) and Afar (AF) (10spp, 5.2%) have the least species records. The distribution frequency of species analyzed showed that species regarded as “very common” and hence with relatively wider distribution in the flora area are few (12spp, 6.3%). Some examples of the species that occur in ten or more floristic regions are *Selaginella goudotiana, Equisetum ramosissimum, Loxogramme abyssinica, Pleopeltis macrocarpa, Cheilanthes farinose, Doryopteris concolor, Actiniopteris semiflabellata* etc.). Largest proportions (58spp, 30.2%) of the species, on the other hand, are “occasional” and occur in two or three floristic regions. Still significant proportions, (49spp, 25.5%) are “rare” indicating that they have limited distribution area and restricted to specific floristic region (figure 4). These rare species are found in most of the genera but mainly concentrated in aquatic genus *Marsilea*: *M. aegyptiaca, M. coromandelina, M. farinose, M. minuta* etc.

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Table 1 Names of families, and the numbers of genera and species in each family

Family	Number of Genera	Number of Species
Azollaceae	1	1
Blechnacaeae	1	2
Davalliaceae	1	1
Oleandraceae	2	3
Nephrolepidaceae	1	1
Lomariopsidaceae	2	6
Tectariaceae	3	3
Dryopteridaceae	5	14
Woodsiaceae	4	5
Aspleniaceae	1	36
Thelypteridaceae	7	11
Hypolepidaceae	4	5
Dennstaeditiaceae	1	1
Cyatheaceae	1	1
Hymenophyllaceae	4	6
Marsileaceae	2	8
Parkeriaceae	1	1
Vittariaceae	2	3
Hemionitidaceae	2	2
Adiantaceae	1	7
Pteridaceae	1	9
Actiniopteridaceae	1	3
Cryptogrammaceae	1	1
Sinopteridaceae	5	17
Negripteridaceae	1	2
Anemiaceae	1	1
Polypodiaceae	9	10
Grammitidaceae	2	2
Gleicheniaceae	1	1
Osmundaceae	1	1
Marattiaceae	1	1
Ophioglossaceae	2	9
Equisetaceae	1	1
Isoetaceae	1	3
Selaginellaceae	1	8
Lycopodiaceae	3	6
TOTAL	**78**	**192**

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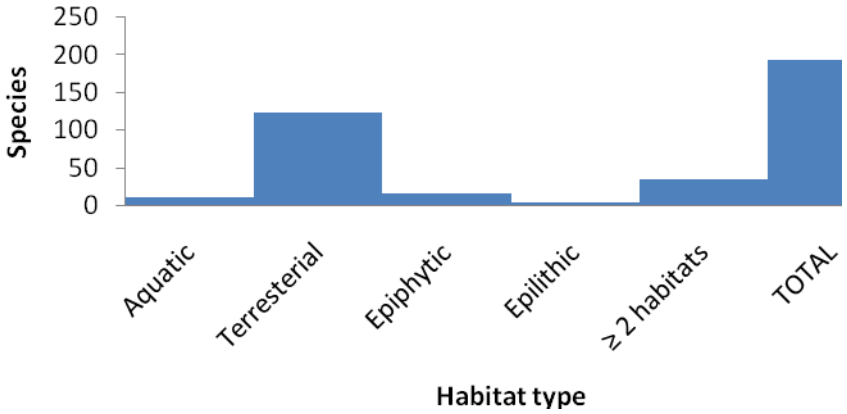
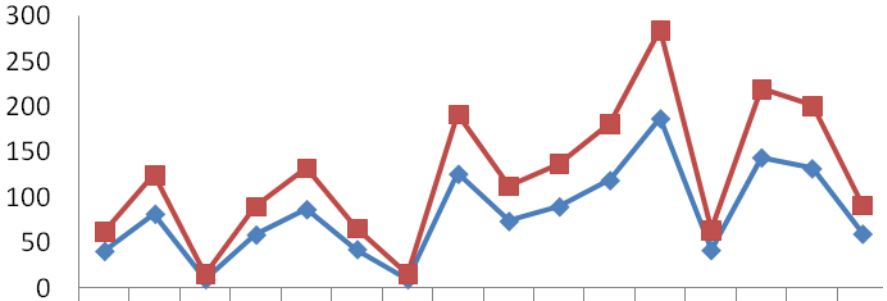


Figure 2 Species in the four specific habitat types: aquatic, terrestrials, epiphytic, epilithic; and those growing in multiple habitats.



	EE	EW	AF	TU	GD	GJ	WU	SU	AR	WG	IL	KF	GG	SD	BA	HA
Relative abundance (RA)	21.	42.	5.2	30.	45.	22.	5.2	65.	38.	46.	62	97.	21.	75	68.	31.
Abundance (A)	41	82	10	59	87	43	10	126	74	90	119	187	42	144	132	60

Figure 3 Species diversity expressed as abundance (A) and relative abundance (RA) in the sixteen floristic regions.

Floristic similarity among floristic regions

The similarity of floristic regions in their pteridophyte flora is shown in figure 5. It can be observed from the tree that six major pairs of floristic regions were clustered at different levels of similarity; the highest being between Kefa (KF) and Illubabor (IL) that have 52% shared species. The second highest pairs of floristic regions are SD, Sidamo (SD) and Bale (BA), (47%) followed by Gonder (GD) and Shewa (SU) (46%); Eritrea West (EW) and Tigray Upland (TU) (45%); Gojam (GJ) and Welega (WG) (25%). A pair of the floristic regions having lowest level of similarity is Welo Upland (WU) and Afar (AF) (12%, mutual species); which are also less diverse for their pteridophyte taxa.

Distribution patterns

The altitudinal distribution of species in Ethiopia and Eritrea is wide ranging between 150 m to 4300 m. Five species, namely *Marsilea coromandelina, Adiantum balfouri, Onychium divaricatum, Selaginella caffrorum,* and *Selaginella imbricate* were recorded between 150-500 m, though only *M. coromandelina* is restricted to this lower altitudinal

zone. Species diversity gradually increases with altitude reaching maximum between 1500-2000 m (132spp). The species are also quite diverse at altitudinal zone between 2000 to 2500 m (112spp). Diversity declines from these two specific altitudinal zones in direction towards the highlands. Thirty one species (16%) are recorded in the altitudes above 3000 m, out of which only six species: *Dryopteris rodolfii, Asplenium adamsii, Asplenium demerkense, Asplenium baleens, Huperzia incise,* and *Huperziagoetzei*, are restricted to this highest altitudinal zone (figure 6).

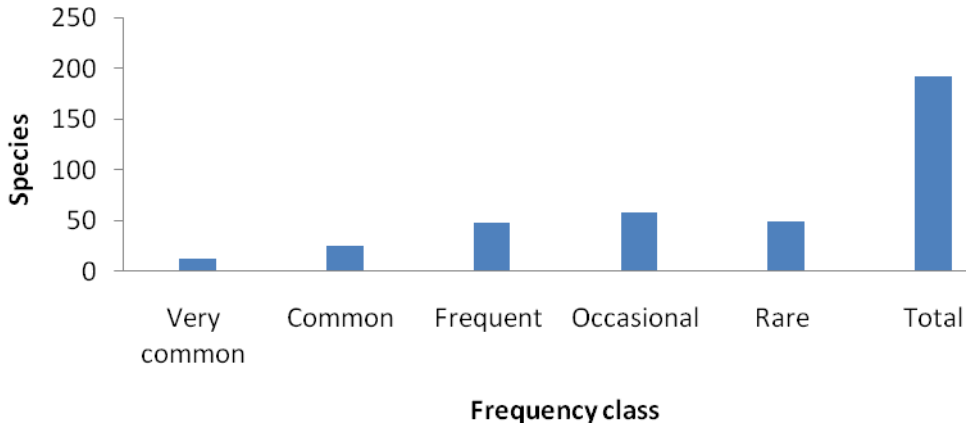


Figure 4 Distribution of species in the five frequency classes defined. The total number of species in the flora area is 192

Figure7 shows relative frequency of species restricted in their distribution to five major vegetation types: forests, woodlands& bushlands, grasslands & wooded-grasslands, wetlands & seasonal water bodies, Afro-Alpine and sub Afro-Alpine; and also those inhabiting in multiple vegetation types. It was found that species are mainly distributed in two major vegetation types: forests and woodlands. Majority of the species (88spp, 45.8%), however, occur in the shady forests. Those species restricted to grasslands, wetlands, and Afro-Alpine & sub Afro-Alpine vegetation types each accounted < 10% of species. Some other members (44spp, 23%) inhabit in multiple vegetation types mainly in forests & woodlands or widely occur in forests, sub Afro-Alpine & Afro-Alpine.

Table 2 shows distribution pattern of pteridophyte species investigated. Only four species are endemic, confined only to the flora area. The rest majority of the species (188spp, 97.9%) are widespread in their distribution extending to other continents of the globe. Hence, endemism (2.1%) of ferns and fern-allies is found to be very low. Detailed analysis on the distribution of species having wider distribution range revealed six major distribution areas outside the flora area. Accordingly, pteridophyte species in Ethiopia and Eritrea are shared with one to four continents in different combinations. Most of the widespread species (70.3%) are shared with mainland Africa & Madagascar, followed by Africa & Asia with (15.1%) shared species. Note that the sixth category ($ws_{6)}$ comprises six species which are nearly cosmopolitan; shared with four continents.

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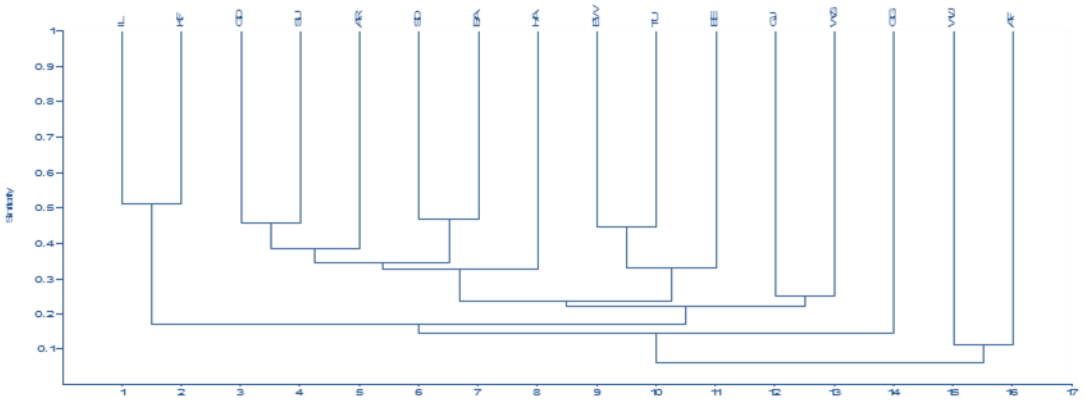

Figure 5 Tree showing similarities of floristic regions by their pteridophyte flora.

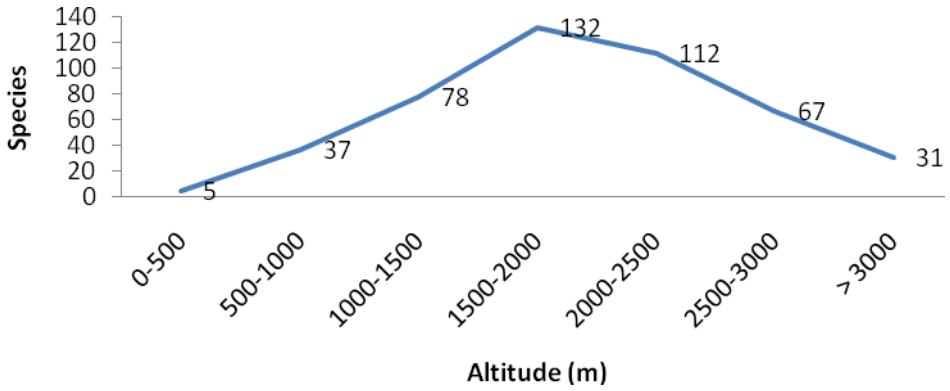

Figure 6 Altitudinal distributions of species in the flora area.

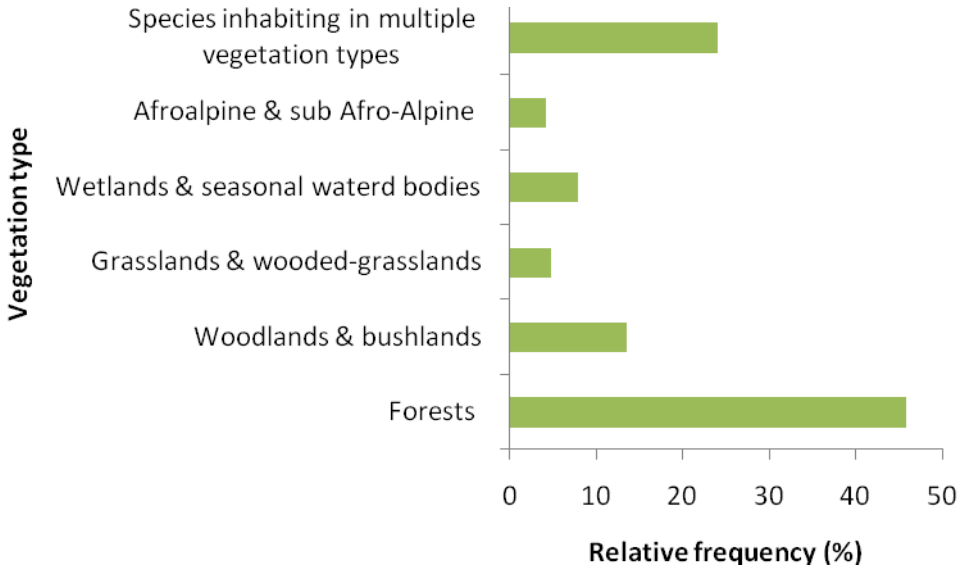

Figure 7 Distributions of species in five specific and also multiple vegetation types. The total number of species in the flora area is 192

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Table 2 Distribution pattern of species: E = Endemic, WS = Widespread species extending ws_1: Mainland Africa & Madagascar, ws_2: Africa & Asia, ws_3: Africa & America, ws_4: Africa, Asia & Europe, ws_5: Africa, Asia, & America, and ws_6: Africa, Asia, America & Europe.

Distribution range	Distribution area	Number of species (% shared)
Endemic	Species confined only to the flora area: *Asplenium baleens* *Aspleniumstipicellatum* *Aspleniumerythraeum* *Nigripteristricholepifera*	4
Widespread	ws_1: Mainland Africa & Madagascar	135 (70.3)
	ws_2: Africa & Asia	29 (15.1)
	ws_3: Africa & America	6 (3.1)
	ws_4: Africa, Asia & Europe	7 (3.6)
	ws_5 : Africa, Asia, & America	5 (2.6)
	ws_6: Africa, Asia, America & Europe; that are nearly cosmopolitan: *Selaginellacaffrorum* *Osmundaregalis* *Adiantumcapillus* *Cheristella dentate* *Cystopterisfragilis* *Anogrammaleptophylla*	6 (3.1)
TOTAL		**192**

DISCUSSION

Hundred ninety-two species representing 78 genera and 36 families are recorded from Ethiopia & Eritrea. Only 2.1% of these species are endemic indicating that most of the species have wider geographical distribution range outside the flora area. Consequently, endemism of ferns and fern-allies are lower than the total vascular plant flora, estimated at 10 to 12% [4]. Endemism of pteridophytes is generally found to be lower than that of seed plants which might be explained by the higher dispersal ability of their spores [13]. Fern species diversity and endemism of the flora area, the most abundant and diverse group among pteridophytes, (175spp, 2.1% endemic) is found to be less when compared to countries in the flora of Tropical East Africa such as Kenya (258spp, 3% endemic), Uganda (252spp, 4% endemic) and Tanzania (371spp, 15% endemic)[3]. These might be due to differences on the availability of suitable niches and isolated mountain complexes for species to evolve.

The most diverse pteridophyte families are Aspleniacea (36spp), Sinopteridaceae (17spp), Dryopteridaceae (14spp), Thelypteridaceae (11spp) and Polypodiaceae (10spp). These families are also diverse by their constituent taxa in the floras of South and East Africa [10]. However, 12 (33.3%) of the families; and 54 (69.2%) of the genera being mono specific,

i.e. consisting of only a single species, indicates low species diversity in these higher taxa. The five floristic regions identified as centers of pteridophyte species diversity or "hotspots" are subsequently, Keffa (KF) (187spp, 97.4%), Sidamo (SD) (144spp, 75%), Bale (BA) (132spp, 68.8%), Shewa Upland (SU) (126spp, 65.6%) and Illubabor (IL) (119spp, 62%). These floristic regions are also recognized for the diversity of the entire vascular plant species. They are also regions harboring the existing remnant forests and woodlands [9]. The pteridophyte flora similarity among the sixteen floristic regions revealed variations with regard to shared species. Six pairs of floristic regions are identified by the degree of mutual species ranging from 25% to 52%. This finding corroborate with the report for the entire flora by [4]; stating that floristic regions geographically adjacent and having relatively similar topographic, and associated climatic conditions and also vegetation, show highest floristic similarity. For example, greater similarity between Kefa (KF) and Illubabor (IL) is due to the reason that they share forest belt of the western Ethiopia and are wetter than other regions in the flora area.

The distribution pattern of specie revealed that forests are the main vegetation type of occurrence for pteridophytes. About 45.8% of the total species of the flora area inhabit the wet and dry forests mainly along mountain slopes and dry lowland forests. This can be explained by their requirement of shady places, moistures, nutrients and low light levels. The more shade trees exist in a habitat, the more niches will be available for ferns to grow [8]. Shade is also important to mitigate the effects of temperature and light intensity [3]. Some of the species are not restricted to specific vegetation types but occur in multiple habitats. They occur widely stretching from forests at around 3000 m (dominated by both conifers and olive-trees on the dry leeward side and large-leaved plants such as *Dracaena* and *Milletia* species on the wetter windward side of the plateaus& mountains. Higher up found in sub Afro-Alpine low scrubs with a wealth of woody species such as *Rhus, Carissa, Dodonea* spices to Afro Alpine vegetation on the highest altitude, above 3,500 meters, inhabited by flower bushes, moor-lands with briars, alpine meadows strewn with clovers, as well as giant *Kniphofia* species. Still others are occurring in the woodlands of *Acacia-Commiphora*, and *Combretum-Terminalia* and extending to dry forests in rift valleys and lowlands at around 1000-1500 m. Diversityis low in many unstable lowland environments, below 500 m, in regions such as Afar, Welo and Ogaden in eastern and north eastern part of the flora area [6]. This lower altitudinal zone is known for erratic and highly irregular precipitation pattern; and therefore, have relatively less number of niches and suitable microhabitats for pteridophytes to evolve [20].Analysis on the relationship between altitude and number of species indicated that species diversity gradually increases from lower altitude, with highest being at the middle of the altitudinal zones, between 1500-2000 m. The pattern of distribution then continued decreasing in diversity towards higher altitudes. It was found that species restricted to extremes of low and high altitudinal zones are few. This finding might be explained by the existing diverse ecological features prevailing along various altitudinal zones in the flora area.[17] found common distribution pattern in 80% of the 204studies he examined. Although, detailed analysis is required to augment this finding in combination with other environmental parameters of rainfall, humidity, temperature and human activities, it seems that both altitude and vegetation might have influenced species distribution patterns in the flora area.

Endemic species that are restricted in their distribution to flora area occur in different floristic regions at various altitudes. Accordingly, *Asplenium baleens* is found in mountains of Arsi (AR) Bale (BA) at altitude between 3150 to 4100 m; *Asplenium stipicellatum* in forests of Kefa (KF) and Sidamo (SD) between 1900 to 2000 m; *Asplenium erythraeum* among rocks in western Eritrea (EW) between 2800 to 3000 m, and *Nigripteris tricholepifera* in scrubs of Bale (BA) between 1500 to 2000 m. The distribution patterns outside flora area of the non-endemic species revealed that they are shared with other parts of the globe; a strong floristic affinity (70%) being to other parts of African main land and Madagascar and few of the species are nearly cosmopolitan. The paradox is that a quarter of pteridophyte species shared with other continents are "rare" in the flora area and known only from one floristic region. These endemic and rare species; and their habitats need to be conserved.

CONCLUSION

The diversity and endemism of pteridophytes in the flora of Ethiopia and Eritrea is low when compared to countries in the flora of Tropical East Africa (TEA) such as Kenya, Tanzania and Uganda.The floristic regions detected as centers of species diversity or "hotspots" are also regions recognized for the diversity of the entire vascular plant species. Six major components of floristic regions were detected in their pteridophyte flora similarities. These clusters of floristic regions are geographically adjacent and share relatively similar topography and associated climatic and vegetation features. The distribution of species seems to be influenced by both altitude and vegetation in the flora area. However, detailed analysis of species diversity to these and other environmental variables has to be further conducted to fully understand factors that determine distribution patterns. The low degree of endemism indicates that most of the species also occur outside the flora area. Based on the findings from this analyses, it is possible to suggest that pteridophyte diversity can be conserved mainly by focusing on the forests and woodlands between 1500-2500 m in the 'hot spots' identified. It is also hoped that this piece of work will stimulate future ecological and conservation research of the group.

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