The spatial patterns of taxonomic and phylogenetic diversity of seed plants with the climate factors across Ethiopia and Eritrea

Biyansa H. Boru

Wuhan Botanical Garden, CAS

Shengwei Wang

Wuhan Botanical Garden, CAS

Anne C. Ochola

Wuhan Botanical Garden

Antony W. Njogu

Wuhan Botanical Garden, CAS

Haiping Xin

Wuhan Botanical Garden, CAS

Qingfeng Wang

Wuhan Botanical Garden, CAS

Yadong Zhou (✉ zhouyd@wbgcas.cn)

Wuhan Botanical Garden, CAS

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Abstract

Background Biodiversity is the basic units and measures of the health of ecosystems that provide diverse goods and services for the well-being of human societies and other life forms. However, in this era due to the threats from climatic change and other human-driven environmental changes the earth's biodiversity is in a grave danger in the world wide. Here, we explored and mapped how the patterns of plant taxonomic diversity, phylogenetic diversity and structures vary across the geographical regions and with respect to climatic factors in Ethiopia and Eritrea in the horn of Africa by using different analyzing methods and diversity measuring indices for the same reasons. Results Our analysis showed varied spatial distribution patterns of plant diversity across the region and with the gradients of climatic factors. While the central and southern highland parts of Ethiopia were found to be the primary centres of taxonomic diversity, the centres with higher evolutionary diversity were found scattered in the region. The phylogenetic community structures also vary greatly. About 70% of the plant communities in the region showed phylogenetically clustering patterns. Significant and different relationships were observed between the climatic variables and plant diversity and phylogenetic structures. Generally mean annual temperature and precipitation were respectively found to negatively and positively impact the patterns of plant diversity in the region while variable patterns were observed among different plant life forms. The phylogenetic structure patterns of woody and herbaceous plant groups in terms of NRI were found to be differently impacted by climatic factors. Conclusions The patterns of plant diversity both from taxonomic and evolutionary perspectives vary greatly across the geographic and with climatic gradients in Ethiopia and Eritrea. Phylogenetic clustering patterns dominate the plant community assembly in the region though considerable areas were found with communities of phylogenetically overdispersing patterns. The patterns observed from evolutionary perspectives can provide more crucial information for conservation plans. It provide insights that enable the areas with high evolutionary diversity and phylogenetically overdispersing community assemblages to gain as much conservation attention as that of areas with high taxonomic diversity, given their species richness.

Background

Biodiversity is the basic unit and measure of the health of ecosystems. It plays an important roles in ecosystem functioning that provide supporting, provisioning, regulatory, and cultural services essential for the well-being of human society and other life forms [1, 2]. However in recent decades due to the threats from climatic change and other human-driven environmental changes mainly habitat loss, fragmentations and degradations, in worldwide the earth's biodiversity is in a grave danger. To address such problems it needs a comprehensive study and clear understanding of the patterns of biodiversity in a given region. As a result a concern for biodiversity resources become a core topic for research and conservation programs [3, 4, 5].

The patterns of plant biodiversity in different regions have long been well studied using traditional biodiversity assessment measures such as taxonomic diversity (TD) [5, 6]. Nonetheless, the use of such measures alone may not provide complete pictures of diversity in a given region as these may fail to

account for the evolutionary or lineage diversity of communities in a given region [5, 7]. A number of previous studies [4, 5, 8, 9] showed that the information of evolutionary diversity is very crucial in identifying and preserving communities with greater traits and functions to maintain ecosystems with better potentials that could respond to different changes and be able to provide sustainable services. As a result of these facts, considering such evolutionary based criteria in biodiversity becomes an area of interest both for ecologists who are interested in understanding the underlying driving factors shaping the diversity patterns at multiple spatial scales and for the conservation biologists who need to prioritize conservation plans to preserve communities with such greater potentials. So for a better understanding of the patterns of plant diversity in a given region along with the underlying factors that shaped these patterns, the integration of the genetic and evolutionary diversity measuring metrics with the taxonomic diversity measuring indices is paramount [4, 8].

Phylogenetic diversity (PD) or its derivatives such as standardized effect size phylogenetic diversity (SES_PD) which is defined as the sum of all the branch lengths connecting taxa in a defined region [10], is among such genetic and evolutionary diversity measuring metrics used to quantify the phylogenetic composition (evolutionary relationships) of floristic assemblages in a given region similar to that of taxonomic diversity which measures the species composition of a given flora [11]. In addition to these phylogenetic diversity metrics, there are also phylogenetic structure measuring metrics like net relatedness index (NRI) and nearest taxon index (NTI) that are used to quantify the phylogenetic relatedness among coexisting species in regional plant assemblages and help to identify whether communities are composed of distinctly related species or closely related ones and then provide good insights for decision making in biodiversity conservation planning [12, 13]. Although some studies [4, 5, 9] showed a strong correlation between TD and PD, some others [eg. 8, 14] reported inconsistent relationships between them. As a result for decision making in conservation, both metrics are recommended to be estimated.

Numerous factors can be responsible for the variations in TD, PD and phylogenetic structures of plant community assemblages across the space and along environmental gradients of a given region [5, 15]. Biogeographically and evolutionary histories, habitat heterogeneities, edaphic heterogeneities, climatic variability and the influences of biotic factors such as interspecific interactions among the species in the community have been reported as some of these factors [5, 9, 16, 17]. The associations among plant diversity and climatic factors have been observed by several researchers [e.g. 7, 9, 18] Temperature and precipitation are the two most commonly considered climatic variables in the studies concerned with understanding how climate factors shape the diversity and distribution patterns of plant community at the global scale [19, 20]. The results of these studies have shown different relationships among the patterns of plant diversity, phylogenetic structure and the climatic variables. Their findings have also shown that these relationships vary between different plant life forms, i.e., herbaceous and woody plants have been found to be differentially influenced by climatic factors [9, 21]. However, the findings about the influence of climatic and other environmental factors on the patterns of plant diversity and phylogenetic structures are inconsistent, especially among different life forms [e.g., 7, 9, 16, 18, 20, 22], this has also received little attention in our study area and thus calls for scientific investigation.

Ethiopia and Eritrea are among the East African countries located in the horn of Africa, possessing the richest biodiversity in the continent that hosts 2 of the 35 world's biodiversity hot spots [6]. But the most threatened one due to the combined effects of destructive human activities and climatic changes [6, 23-25]. Despite these facts, the studies that have been done in this region to understand the patterns of plant diversity along with the factors driving them were not comprehensive, mainly from the evolutionary perspective. The previous studies have only focused on TD aspects [26], while PD is more inclusive and imperative in conservation biology for the preservation of communities with greater evolutionary diversity that maximize the potential of the local flora to respond to future changes and provide sustainable services [4, 9, 16]. Therefore, there are gaps in this region in understanding the patterns of plant diversity from the evolutionary perspectives and in considering this dimension in conservation plans.

Thus, in this study, our aim was to investigate how the patterns of plant TD, PD and phylogenetic structures vary across the geographical regions and with respect to variations in climatic factors in Ethiopia and Eritrea, in the horn of Africa mainly so as to gain insights of evolutionary diversity into the flora of the region. Specifically, we aimed to answer the following questions: (1) how spatial patterns of seed plants' phylogenetic diversity vary across Ethiopia and Eritrea and related with the patterns of their taxonomic diversity? (2) How the plant community phylogenetic structures assembled across the region? (3) How climatic factors influenced the patterns of plants' taxonomic diversity, phylogenetic diversity and community phylogenetic structures in the region and how these influences of climate factors vary between woody and herbaceous plant groups?

Methods

Study area and climate data

The study was conducted in Ethiopia and Eritrea, which are located in the Horn of Africa between 3° to 18° N and 33° to 48° E, covering a total area of ca. 1.251 million km², and characterized with a wide variety of landscapes, diverse geological formations and topographic features with marked contrasts in relief where the altitude ranges from about 125 m below sea level to 4,620 m above sea level [Fig. 1; 26, 27, 28]. Due to these diverse topographic features and wide elevational ranges the region is also known to have very variable macro and micro-climatic conditions and experience large spatial variations in temperature and precipitations [25, 29]. The mean annual precipitations across the region vary from 500 mm to 2200 mm while the mean annual temperature ranges from below 10 °C to 30 °C with very high local variability. The transition between lowlands and highlands is commonly very sharp, resulting in a variety of climates that vary from very arid to very humid typical of equatorial mountains. Moreover, precipitation varies with latitude, generally decreasing from south to north. As the result of these physiographic and climatic features the region is endowed with a complex mosaic of habitats and ecological zones ranging from desert scrubland vegetation to alpine vegetations in high mountain areas that are inhabited with rich diversity of plants, animals and microbial life forms [28]. To analyze the spatial patterns of plant diversity in this region in terms of the proposed parameters, we used uniform grid cells of 0.5° latitudes × 0.5° longitudes as units of analyses (Fig. 1).

Climatic data

In order to examine the relationships between the climatic factors and the diversity and structures of plant communities across the geographical regions of Ethiopia and Eritrea, we considered the mean annual temperature and precipitation as important ecological drivers of plant taxa distributions. The mean annual temperature and precipitation data as climate variables for each of the grid cells were extracted from global climate model Worldclim [30, available: <http://www.worldclim.org/>] using ArcGIS 10.5 [31].

Data sources

The plant data sets used in this study were extracted from the published Flora volumes of Ethiopia and Eritrea (FEE) [32] and from the global biodiversity information facility (GBIF, <https://www.gbif.org/>). Based on our sources, we compiled a comprehensive checklist of seed plants belonging to Ethiopia and Eritrea. The database consisted of species names, family names, life forms, altitudinal and geographical distribution information's of each of the species. Then, to ensure a standard taxonomy in the analyses we adjusted the family and genera of these plants as per the Plant List version 1.1 (available at <http://www.theplantlist.org>), using the R package "plantlist" [33], where the circumscription of the angiosperm family is generally consistent with APG III [34]

Taxonomic metrics

We extracted the minimum and maximum elevations of each of these grids using ArcGIS, and then the plant data records in each of these cells were obtained based on the altitudinal and geographical distribution range information of each plant as described in the sources (FEE). To assess the spatial taxonomic diversity patterns of seed plant distributions for total, woody and herbaceous plant groups across the geographic regions of these countries we calculated and mapped the genus richness of these plants at the 0.5° grid cell levels. The uniform size grid cells were used to eliminate the effect of the differences in area of the spatial units of analysis [35].

Phylogeny construction

We constructed a phylogenetic tree for all the seed plants we compiled for analysis and also for the woody and herbaceous plant groups separately at genus level using the online program Phylomatic version 3 [36]. The Phylomatic tree version R20120829.new was used as a backbone of the super tree and the BLADJ algorithm with PHYLOCOM version 4.2 was used to obtain phylogeny including the branch lengths in millions of years (Ma) based on Wikstrom [37, 38].

Phylogenetic metrics

To examine the variation in evolutionary diversity of plant communities across the space and with respect to climatic factors in Ethiopia and Eritrea, we quantified the standardized effect size phylogenetic diversity (SES_PD) as standardized PD metrics because PD is strongly and positively correlated with TD

[4]. For this PD was standardized to the observed taxa richness by using the null model randomization method by shuffling the taxa labels across the phylogeny 999 times. Then SES_PD was computed as equation below [5, 38]

$$SES_PD = (PD_{observed} - \text{mean } PD_{randomized}) / sdPD_{randomized} \quad (1)$$

$PD_{observed}$ is the metric value of the communities under the study; the $PD_{randomized}$ is the mean metric value of the null communities and $sdPD_{randomized}$ is the standard deviation for the metric value of the null communities.

To examine the phylogenetic structures of community assemblages that quantify the degree of phylogenetic relatedness among plant communities in each unit, we calculated the net relatedness index (NRI) and the nearest taxon index (NTI) using the following models [12]:

$$NRI = -1 \times (MPD_{observed} - MPD_{randomized}) / sdMPD_{randomized} \quad (2)$$

$$NTI = -1 \times (MNTD_{observed} - MNTD_{randomized}) / sdMNTD_{randomized} \quad (3)$$

Where, MPD is a diversity metrics measuring mean phylogenetic distance among all pair of taxa in the assemblage, $MPD_{observed}$ is the MPD metric values of the community under the study, $MPD_{randomized}$ is the mean value of MPD for the null communities, and $sdMPD_{randomized}$ is the standard deviation of the phylogenetic distances in the null communities [12]. MNTD represents the mean phylogenetic relatedness between each taxon and its nearest relative in the assemblage. $MNTD_{observed}$ is the MNTD metric values of the community under the study, $MNTD_{randomized}$ is the metric value for the null communities, and $sdMNTD_{randomized}$ is the standard deviation of phylogenetic distances in the null communities [39]. To maintain the statistical significance of the observed patterns, the randomization process for each of the null communities were repeated 999 times. Positive values of NRI and NTI indicate phylogenetically clustering communities while their negative values reveal phylogenetically overdispersing communities.

The analysis of PD and phylogenetic structures were performed in R software, using 'picante' package [40]. The spatial patterns of diversity and phylogenetic structure were analyzed and mapped with ArcGIS 10.5 [31]. To assess the relationships among plant diversity indices, phylogenetic structure attributes and climatic factors, we performed simple linear regression analysis and fitted the model for each plant group in R software [41].

Results

Seed plants data composition

The total plant data compiled from the whole study areas (485 grid cells) and used for this analysis was composed of 1401 genera belonging to 172 families of seed plants. From these, 380 genera belonging to

101 families were woody seed plants while the remaining 1021 genera from 139 families were herbaceous seed plants. In this data set, Fabaceae, Poaceae, Asteraceae, cypraceae, Malvaceae, Acanthaceae and Lamiaceae were the top rich families each represented by more than 200 species per family while *Euphorbia*, *Cyperus*, *Crotalaria*, *Indigofera*, *Commiphora*, *Ipomoea* and *Habenaria* were the most speciose genera in the data set containing more than 50 species per genus.

Spatial patterns of plant diversity and phylogenetic structures

Very variable spatial distribution patterns of taxonomic and phylogenetic diversity of seed plants were observed across the geographic regions of Ethiopia and Eritrea. The genera richness were found to range from 48 to 837 for the total, 14 to 248 for woody and 34 to 591 for herbaceous plant groups per grid cells (Fig. 2a–c). The highest genera richness of the total, woody and herbaceous plant groups were all found in montane areas of the central and southern parts of Ethiopia and the lowest were all found in lowland areas of Ethiopia and Eritrea (Fig. 1; Fig. 2a–c). The evolutionary diversity patterns of these plants in terms of SES_PD were found to range from -3.378 to 2.296 for total, -1.838 to 1.740 for woody and -3.851 to 1.980 for herbaceous plants (Fig. 2d–f). The highest SES_PD were also found in montane areas of Ethiopia and Eritrea, though different for the woody plant groups (Fig. 2d–f, grid cells with red colors). There were clear variations between the patterns of woody and herbaceous diversity, especially for the patterns of SES_PD.

The phylogenetic structures (NRI and NTI) of the plant communities were also found to be varied across the region (Fig. 2g–i). The majorities of the communities (grid cells) across the region showed phylogenetic clustering (positive values of NRI and NTI) implying that the co-occurring species of the communities in most areas of the region are more closely related than those that are expected from null model communities. Still communities in considerable areas of the region have also shown phylogenetic overdispersion patterns (negative values of NRI and NTI) with some variations among different plant groups in which relatively higher communities of woody plant groups showed overdispersion patterns.

Patterns of plant diversity and phylogenetic structures with respect to climatic factors

The result of linear regression model showed various association patterns among climatic variables and plant diversity and phylogenetic structures. According to the result of this analysis highly significant and negative relationships were found between the mean annual temperature and the TD (Fig. 3a) and SES_PD (Fig. 3c) of total plant groups ($P < 0.001$; $R^2 = 0.463$ for TD and 0.212 for SES_PD) while mean annual precipitation and TD (Fig. 3b) and SES_PD (Fig. 3d) of these plant groups were found to be significantly and positively related ($P < 0.001$; $R^2 = 0.230$ for TD and 0.559 for SES_PD).

The relationships between the mean annual temperature and the TD (Fig. 4a) and SES_PD (Fig. 4c) of woody plant groups were also found to be highly significant and negative ($P < 0.001$; $R^2 = 0.408$ for a TD and 0.165 for SES_PD) while these relationships were significant and positive between the mean annual precipitation and TD (Fig. 4b) and SES_PD (Fig. 4d) of these plant groups ($P < 0.001$; $R^2 = 0.216$ for a TD and 0.379 for SES_PD). In a similar way, both TD (Fig. 5a) and SES_PD (Fig. 5c) have shown a

significantly negative correlation with the mean annual temperature while the correlation of TD (Fig. 5b) and SES_PD (Fig. 5d) with mean annual precipitation was found to be significantly positive ($P < 0.001$; $R^2 = 0.231$ for a TD and 0.487 for SES_PD).

The result of the simple linear regression model analysis also indicated that the gradients of mean annual temperature and precipitations have differently influenced the phylogenetic structures of these plant communities across the geographical regions of Ethiopia and Eritrea. The model identified significant negative relationships between the mean annual temperature and NRI of total plant groups (Fig. 3e) and herbaceous plant groups (Fig. 5e) while positive relationships were found between the mean annual precipitation and NRI of total plant groups (Fig. 3f) and herbaceous plant groups (Fig. 5f). However, remarkably, different patterns were observed between woody and herbaceous plant groups with respect to the association between their phylogenetic structure (NRI) and climatic variables. While woody NRI showed a positive relationship with increasing mean annual temperature (Fig. 4e) and negative relationship with increasing mean annual precipitations (Fig. 4f), inverse relationships were observed between the herbaceous NRI and these climatic factors; i.e. negative relationship was observed between NRI of herbaceous plants and the mean annual temperature (Fig. 5e) while these plant groups showed a positive relationship with respect to mean annual precipitation (Fig. 5f). In terms of NTI the relationships between the phylogenetic structures of all plant groups, i.e., total (Fig 3g), woody (Fig. 4g) and herbaceous (Fig. 5g) and the mean annual temperature were found to be significantly positive while NTI of total plant groups (Fig. 3h), NTI of woody plant groups (Fig. 4h) and NTI of herbaceous plant groups (Fig. 5h) were found to be significantly and negatively related with the mean annual precipitation.

Discussion

In this study, we analyzed the patterns of taxonomic and phylogenetic diversity as well as the phylogenetic structures of seed plants as a whole and for woody and herbaceous plant groups separately across the geographical regions of Ethiopia and Eritrea. We also examined how these patterns vary with respect to variation in climatic factors. All indices of diversity and phylogenetic structures of these plant communities were found to be variable from region to region. Areas of high TD were found from the central and southern parts of the region. This could be because of the existence of complex topographic features and relatively high precipitations in these parts of the region. Moreover, this could also be associated with the relatively high intensity of plant collection and scientific investigation made in these parts of the region than other parts [27, 42]. We used standardized effect size phylogenetic diversity (SES_PD) to examine the spatial variations in evolutionary diversity of seed plants across this region because this metric reflects the actual variations by controlling the effect of variations in species richness among communities [5, 8]. While this metric was used, we found the areas of high evolutionary diversity apart from the areas of high taxonomic diversity distributed in different parts of the region. Across the region the highest level of PD was found in the western, southwestern, north central highlands of Ethiopia and from central highlands of Eritrea with some variations for different life forms (Fig. 2d–f). This indicates the importance of considering the evolutionary diversity perspectives of plant communities in

biodiversity assessment to specify the potential areas for conservation planning in a given region given their species richness [4, 5, 8]

The phylogenetic structure of the flora of Ethiopia and Eritrea showed strong variations across the region. The majority (in average > 70%) of communities (grid cells) in the region showed phylogenetic clustering patterns (positive values of NRI and NTI) while only communities in < 30% of the areas were found to have phylogenetic overdispersion patterns (negative values of NRI and NTI). These patterns were found to be different for different plant groups. Relatively more communities of woody plant groups showed phylogenetic over dispersion (negative values of NRI and NTI) than others. For woody plants out of the 485 grid cells across the region about 150 (31%) of them had negative values of NRI and 50% of them had negative values of NTI while only 18.6% and 29% of the communities had negative values of NRI and NTI respectively for herbaceous assemblages. It seems that the observed patterns are likely the results of evolutionary processes and environmental heterogeneities in the region. The complex ecosystems, topographic features and climatic changes resulting from the past complex geological events [27, 43] may have shaped the various phylogenetic structures across the region by facilitating the species assemblages in the community.

Concerning the association between climatic variables and plant diversity patterns, our results revealed that both taxonomic diversity and evolutionary diversity had the same tendency in which they showed significant and positive relationships with the mean annual precipitation and significant and negative relations with the mean annual temperature regardless of the plant life forms ($p < 0.001$, Fig.3a–d, 4a–d and 5a–d). These were in accordance with other findings from other regions [18, 20, 44, 45]. The influences of climatic factors on the phylogenetic structure in terms of NTI showed similar trends for all plant groups (i.e. clustering and overdispersing patterns with increasing mean temperature and precipitations respectively). But, in terms of NRI, the influence of the climate factors showed different patterns on phylogenetic structures of woody and herbaceous plant groups. While the NRI of woody assemblages showed clustering patterns with the mean annual temperature (Fig. 4e) and overdispersing patterns with the mean annual precipitation (Fig. 4f), these patterns were found to be the inverse for herbaceous assemblages (Fig. 5gh). Previous studies have reported that generally the diversity and structures of plant communities in a given region are regulated by the combined effects of ecological interactions, environmental filtering and evolutionary processes [9, 45]. So, here, we also proposed that the possible underlying reasons for the patterns we observed could primarily be attributed to these deterministic processes. We especially support that the underlying reasons for the different patterns observed between woody and herbaceous groups in their phylogenetic structure (NRI) could be attributed to the environmental filtering processes.

The clustering pattern of woody assemblages due to the increase in temperature might have resulted from its filtering effects, because, since temperature is relatively warmer in the tropics, its increase may have effects that restrict the species present in the woody community assemblages only to certain individuals having typical ecological traits that can withstand the situation. Such species will be close relatives because it is believed that closely related species share similar ecological traits and strategies to

adapt to different environments [9, 17, 46]. For instance, the increase in temperature may cause moisture stress problems, mainly in the dry regions through increasing evapotranspirations that could be a potential constraint for woody plants as they have long life cycles and this may result in restricting the species present in wood assemblages only to certain closely related individuals having similar ecological traits to tolerate such stresses. One of the reasons for phylogenetically clustering in herbaceous assemblages with declining temperature could be due to the limitation in competitive exclusion, because in colder regions like in higher elevation zone plants are usually less populated and this may result in less interspecific competition [47]. The cold temperature could also act as a filter to sort only related species having special ecological strategies to tolerate such cold environments.

The justifications for the phylogenetic overdispersion (negative NRI) of woody plants with increasing precipitation could be the result of interspecific interactions (competitive exclusion). That is, as moisture deficit is the most limiting factor in the tropics, especially for higher plants like woody assemblages with larger structures and longer life cycle, the increase in precipitations may improve such constraints and promote the growth and survival of abundant individuals. This may lead to an increase in interspecific competition and exclusion among close relatives because close relatives are believed to have ecological niche overlaps where they strongly compete for similar resources. This may give a chance for the co-occurrence of distantly related species having different ecological niches resulting in phylogenetically overdispersed community assemblages [17, 44]. Moreover, the increase in precipitation could create diverse habitats that can support the co-existence of many distantly related woody species which lead to phylogenetically overdispersed communities [48]. On the other hand, the phylogenetic clustering pattern (positive NRI) in herbaceous assemblages with increasing precipitation might be due to the negative effects of increase in the diversity of the woody assemblages. That is, the increase in woody diversity with increasing precipitation may have indirect effects on the growth and survival of different herbaceous species. The increase in woody diversity not only increase their density, but also diversifies their traits and these could pose adverse effects such as allelopathy and shading effects on herbaceous assemblages and restrict their species to only close relatives that can survive such effects. This is in accordance with other findings [e.g., 49, 50] reporting that woody plants facilitate the growth of understory grasses in low rainfall areas, but compete with them under higher rainfall conditions. Based on the facts we discussed so far, it is possible to support that the patterns of woody assemblages are more influenced by macro-climatic factors than those of herbaceous assemblages which seems to be more affected by micro-climatic conditions and edaphic factors.

Conclusions

In conclusion, the results of our study found that the patterns of plant diversity, both in the taxonomic and phylogenetic perspective vary greatly across the geographic regions of Ethiopia and Eritrea. While the central and southern parts of the region were found to be the center of taxonomic diversity, centers of high phylogenetic diversity were found scattered in the region. Phylogenetic clustering patterns dominate the plant community assembly in the region though considerable areas were found with phylogenetically overdispersed communities. Significant and different relationships between the plant diversity and

climate factors were observed. The mean annual temperature and precipitation negatively and positively influenced the diversity of plant communities in the region respectively. While the mean annual temperature and precipitation, respectively negatively and positively influenced the phylogenetic structures of all the plant groups in terms of NTI, these patterns were different among different life forms in terms of NRI. In addition to climatic factors, we also support that the other deterministic processes, mainly environmental filtering process played major roles in shaping the observed diversity and phylogenetic structure patterns in this region. Considering plant PD and phylogenetic structure in biodiversity conservation prioritizations and focusing on areas of communities with high species richness and overdispersed structures in conservation have been reported as an efficient criterion to preserve communities with greatest features and functions [4, 8]. So, in our study region, since variable diversity and phylogenetic structure patterns were found across the region, we suggest that conservation actions should focus on all parts and the areas with high evolutionary diversity and phylogenetically overdispersed community assemblages should gain as much conservation actions as areas of high TD for the maintenance of ecosystems with future diversification options and better potentials to respond to future global changes and ensure the continuous provision of associated services.

Abbreviations

TD: Taxonomic diversity

PD: Phylogenetic diversity

SES_PD: Standardized effect size phylogenetic diversity

NRI: Net relatedness index

NTI: Nearest taxon index

FEE: Flora of Ethiopia and Eritrea

Declarations

Ethics approval and consent to participate

Not applicable.

Consent to publish

Not applicable.

Availability of data and materials

The datasets used and analyzed in this study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

BHB compiled the datasets used in the study. BHB developed the study methods with valuable contributions from YZ and SW. BHB and YZ analyzed the data. BHB wrote the manuscript with contributions and modifications from YZ. WQ and XH coordinate and led the work and commented on the manuscript. ACO edited the English grammar. All the Authors contributed in reading, editing, commenting and approving the final manuscript.

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Figures

Figure 1

Location and topographic map of Ethiopia and Eritrea in the horn of Africa.

Figure 2

Spatial patterns for diversity and phylogenetic structures of total, woody and herbaceous seed plants across the geographical regions of Ethiopia and Eritrea. (a–c) taxonomic diversity (genera richness); (d–f) phylogenetic diversity (SES_PD); (g–i) phylogenetic structure (NRI) and (j–l) phylogenetic structure (NTI).

Figure 3

Relationships between climatic factors and indices of total plants diversity and phylogenetic structures. (a) genera richness and annual mean temperature ($R^2=0.463$, $P<0.001$); (b) genera richness and annual mean precipitation ($R^2=0.230$, $P<0.001$); (c) SES_PD and annual mean temperature ($R^2=0.212$, $P<0.001$); (d) SES_PD and annual mean precipitation ($R^2=0.559$, $P<0.001$); (e) NRI and annual mean temperature

($R^2=0.019$, $P<0.05$); (f) NRI and annual mean precipitation ($R^2=0.005$, $P=0.07$); (g) NTI and annual mean temperature ($R^2=0.241$, $P<0.001$); (h) NTI and annual mean precipitation ($R^2=0.572$, $P<0.001$).

Figure 4

Relationships between climatic factors and indices of woody plants diversity and phylogenetic structures. (a) genera richness and annual mean temperature ($R^2=0.408$, $P<0.001$); (b) genera richness and annual mean precipitation ($R^2=0.216$, $P<0.001$); (c) SES_PD and annual mean temperature ($R^2=0.165$, $P<0.001$);

(d) SES_PD and annual mean precipitation ($R^2=0.379$, $P<0.001$); (e) NRI and annual mean temperature ($R^2=0.034$, $P<0.001$); (f) NRI and annual mean precipitation ($R^2=0.091$, $P<0.001$); (g) NTI and annual mean temperature ($R^2=0.228$, $P<0.001$); (h) NTI and annual mean precipitation ($R^2=0.447$, $P<0.001$).

Figure 5

Relationships between climatic factors and indices of herbaceous plants diversity and phylogenetic structures. (a) genera richness and annual mean temperature ($R^2=0.475$, $P<0.001$); (b) genera richness

and annual mean precipitation ($R^2=0.231$, $P<0.001$); (c) SES_PD and annual mean temperature ($R^2=0.175$, $P<0.001$); (d) SES_PD and annual mean precipitation ($R^2=0.487$, $P<0.001$); (e) NRI and annual mean temperature ($R^2=0.076$, $P<0.001$); (f) NRI and annual mean precipitation ($R^2=0.027$, $P<0.001$); (g) NTI and annual mean temperature ($R^2=0.220$, $P<0.001$); (h) NTI and annual mean precipitation ($R^2=0.473$, $P<0.001$).