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Endangered vegetation ecosystems are rich in unique woody species and hold significant conservation potential before reaching a critical ecological tipping point

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ABSTRACT: In most cases, the patterns of species assemblies in vegetation ecosystems are shaped by socio-ecological processes. However, the relationship between unique species and threat statuses of vegetation ecosystems remains unexplored. This study assessed how both overall and unique woody species in adjoining vegetation ecosystems are associated with their threat statuses. For this, woody species assessment was undertaken by laying out a line transect (620 m in length) on the adjoining four vegetation ecosystem types to the interior direction at nine sites. Six sample plots (size: 20 × 20 m each) were arranged on transects with a 100 m interval. In total, 18 transects and 108 plots were used for data collection. The list of species and number of stems of mature trees and shrubs, saplings and seedlings were recorded. The dataset was organized into three sub-datasets: mature trees and shrubs, saplings, and seedlings. These ecosystems were sorted into four threat categories based on the IUCN threat categories of vegetation ecosystems. The variations in compositions of the overall and the unique woody species between adjoining vegetation ecosystem types having threat categories were tested using *Adonis2* function within *vegan* package. Similarly, the differences in species richness and number of stems were analyzed using one-way ANOVA. The multivariate analysis of variance indicated that the species compositions of all growth stages significantly vary between the ecosystem threat categories ($P<0.003$). Similarly, both the overall and unique woody species richness is significantly higher in a critically endangered vegetation ecosystems than the adjoining ecosystems with either least concern, near threatened or vulnerable threat categories ($P<0.004$). These results suggest that the vegetation ecosystems, which were previously floristically diverse but are currently critically endangered, are comprised of higher unique woody species. Hence, this potential needs to be restored before the tipping point triggered by the continuing socio-ecological disturbances.

Keywords/phrases: Biodiversity, Disturbance, Ecosystems, Ethiopia, IUCN

INTRODUCTION

Species diversity and endemism are critical concepts in vegetation ecology, reflecting the richness and uniqueness of plant life across ecosystems. Species diversity encompasses the variety and abundance of species in a given area, often categorized into alpha diversity (within-site diversity), beta diversity (variation between sites), and gamma diversity (regional diversity). High species diversity contributes to ecosystem functions such as productivity, resilience, and stability, making it a cornerstone of biodiversity conservation (Tilman *et al.*, 1997). Ecological processes like competition, disturbance, and environmental gradients such as climate and soil type drive species diversity patterns, with diverse ecosystems often exhibiting greater capacity to adapt to changes or disturbances (MacArthur and Wilson, 1967).

Endemism, on the other hand, highlights species that are confined to specific geographic locations. Endemic species face heightened vulnerability due to restricted ranges and specific habitat requirements, often overlapping with areas of high biodiversity. Thus, regions with both high diversity and endemism, such as tropical rainforests and Mediterranean ecosystems, are global conservation priorities. Preserving these ecosystems safeguards not only their vast species richness but also the unique evolutionary and ecological roles of endemic species (Mittermeier *et al.*, 1998).

In ecology, the effects of disturbances-whether natural, anthropogenic, or composite-on ecosystems and their biodiversity have long been recognized (Huston, 1994; Dornelas, 2010). Understanding these effects is critical for land management and conservation, especially in the context of climate change (Turner, 2010). Pickett and White (1985) defined disturbance as "any relatively discrete event that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment." Earlier studies suggest that disturbances can have both positive and negative impacts on biodiversity (Huston, 1994; Holt, 2008). In this regard, Dial and Roughgarden (1988) introduced the Intermediate Disturbance Hypothesis (IDH), which posits that species diversity is maximized in areas with intermediate levels of disturbance, compared to ecosystems experiencing either low or high levels of disturbance. This hypothesis suggests a hump-shaped relationship between species diversity and disturbance (Grime, 1973; Connell, 1978), showing that disturbances influence the structure, composition, and function of ecosystems. Understanding these impacts is therefore essential for managing ecosystems (Rees et al., 2001; Forrestel, 2013).

The IUCN (International Union for Conservation of Nature) ecosystem threat categories provide a framework for assessing the conservation status of ecosystems based on their degree of degradation and the likelihood of their continued existence. These categories are designed to reflect the degree of threat posed to ecosystems from human activities, climate change, and other disturbances. Ecosystem status is classified into five main categories: Least Concern, Near Threatened, Vulnerable, Endangered, and Critically Endangered, with ecosystems at the higher threat categories facing an increased risk of collapse or irreversible change. This system helps prioritize conservation efforts and inform management strategies to prevent further degradation and loss of ecosystem services (Keith *et al*., 2013). Correspondingly, IUCN has recently developed guidelines for assessing ecosystem disturbance and criteria for identifying categories in the Red List of Ecosystems. The IUCN approach emphasizes that ecosystem threats are determined by species, their interactions, and ecological processes, which can be used as proxies for biodiversity assessments (SANBI and UNEP-WCMC, 2016; Bland *et al*., 2017). However, the relationships between disturbance types, thresholds, tipping points, and changes in biodiversity or species assemblages-both qualitative and quantitative-remain unclear (Łaska, 2001). Although this study does not fully address these gaps, it aims to assess the status of unique woody species in adjoining vegetation ecosystems in Ethiopia, categorized according to IUCN Red List criteria as critically endangered, vulnerable, near threatened, or least concern (Bland *et al*., 2017). Here, unique species refer to woody species that are specific to each adjoining ecosystem (Debissa Lemessa *et al*., 2023).

The vegetation ecosystems in Ethiopia are largely characterized by topography, climate, geology, and soil conditions. As a result, they vary along environmental gradients such as altitude, edaphic factors, precipitation, temperature, and topographic features (Mengesha Asefa *et al*., 2020). These factors exert cumulative direct or indirect effects on the spatial distribution of flora. The variations in floristic composition among these ecosystems are driven by spatial differences in ecological filters (Muñoz *et al*., 2013; Mittelbach and Schemske, 2015). For example, species-specific traits such as dispersal range, population structure, adaptive variation, and competitive ability, as well as historical ecological processes, climatic filters, and anthropogenic influences, shape the distribution of plant species and endemism (Kessler, 2002; Nogué *et al*., 2013).

Recently, the vegetation ecosystems of Ethiopia were categorized using IUCN ecosystem threat criteria, and a map was produced in 2022 (EBI, 2022). Of the 12 vegetation ecosystems in Ethiopia, approximately 13% of the Dry Evergreen Afromontane Forest and Grassland Complex (DAF) was classified as critically endangered, 26.33% of the Combretum-Terminalia Woodland and Wooded Grassland (CTW) as vulnerable, 0.75% of the Moist Evergreen Afromontane Forest (MAF) as near threatened, and 52% of the Vachellia-Commiphora Woodland and Bushland (VCB) as least concern. These four vegetation ecosystems occur adjacently but differ in their topographic and climatic characteristics (Friis *et al*., 2010; Debissa Lemessa and Yayehyirad Teka, 2017). In a nutshell, this study explored the relationship between woody species diversity (overall and unique species) and the threat status of adjoining vegetation ecosystems, with a specific focus on identifying patterns in species composition, richness, and abundance across growth stages (mature trees and shrubs, saplings, and seedlings) and assessing the conservation potential of critically endangered ecosystems before they reach ecological tipping points. Accordingly, the key findings from this study calls for pre-ecological tipping point restoration of critically endangered ecosystems and unique woody species.

MATERIALS AND METHODS

Study areas

Ethiopia is located in east Africa extending between the geographical coordinates of 3°–15°N latitudes and 33° – 48°E longitudes south of the Sahara Desert. Ethiopia is a country of high topographical contrast where the elevational range lies between 126m below sea level in the Danakil Depression and 4533 m a.s.l. at Ras Dashen Mountain. The sampling sites are located in southeast, central and northwest parts of the country (Fig. 1). From the 12 vegetation ecosystem map of Ethiopia (Friis *et al*., 2010), four vegetation ecosystem types which are found adjacent to each other and considered as forests were identified at nine sites (Fig. 1), namely: (1) Moist evergreen Afromontane forest (MAF) which is characterized by closed strata that may reach the height of 30 to 40 m and found within the altitudinal range of between 1500-3000 m a.s.l. and in areas receiving an annual rainfall between 700-2000 mm, (2) Dry evergreen Afromontane forest and grassland complex (DAF) which represents the largest and most complex ecosystem and is found in different regions of the country between the altitudes of 1800-3000m; (3) Combretum-Terminalia woodland and wooded grassland (CTW):which represents fairly large-sized deciduous trees and is found in lowland areas and western escarpments located between the altitudes of 500-1900 m; and (4) Vachellia-Commiphora woodland and bush land (VCB) which is found in dry lowland areas of the eastern, southern part of Ethiopia and to the east of the highlands in the Rift Valley within the altitudinal range of 900-1900 m (Friis *et al.,* 2010).

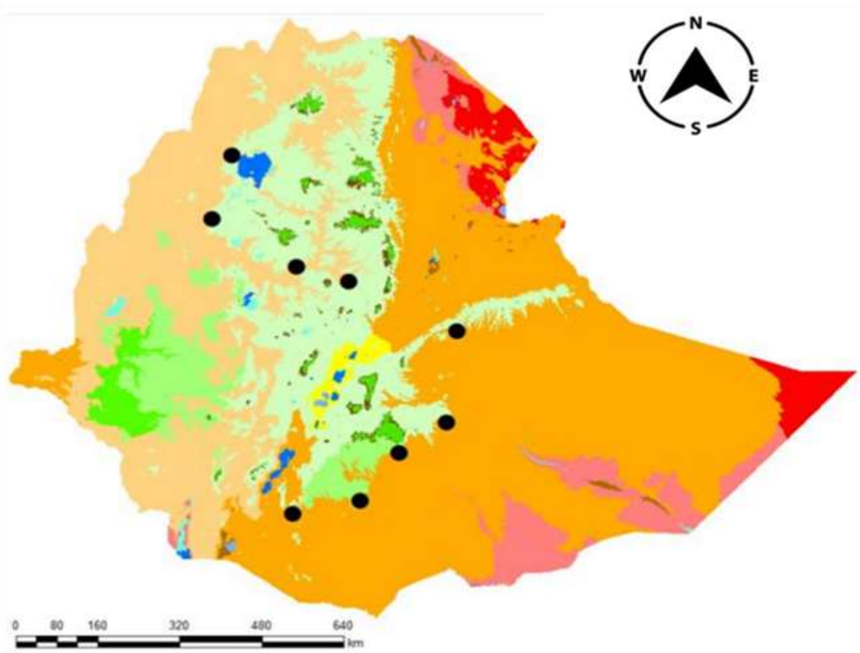

Figure 1. The locations of data collection areas from the adjoining vegetation ecosystems (dark circular dots) in relation to the ecosystems map of Ethiopia (MAF with Pale green colour, DAF light green colour, CTW light brown colour, and VCB yellow colour). The shapefile of the vegetation map was adopted from Friis et al. (2010) with online permission.

Study design

Before the actual woody species assessment, a ground truthing was performed during the scoping survey for the adjoining vegetation ecosystem types identified from the shape file of the vegetation map of Ethiopia. The geographical coordinates (locations) of the adjoining vegetation ecosystem types were first collected from the shapefile of the vegetation map and transferred to GPS (Garmin GPSMAP 60CSx). On the ground, the vegetation ecosystem types are clearly identifiable from the contrasts in species composition and dominant tree species.

Data collection

A systematic sampling procedure was employed to collect the vegetational data. Firstly, woody species assessment was undertaken by laying out line transect (620 m in length) on the adjoining vegetation ecosystem types to the interior directions at nine sites. Secondly, six sample plots (size: 20 × 20 m each) were arranged on each transect with a 100 m interval. The GPS points were taken at the center of each plot.

At each of the nine sites, two transects and six plots; in total, 18 transects and 108 plots were used for the woody species assessment during 2018 to 2019. Subsequently, from each plot, the lists and the numbers of stems of mature trees and shrubs were counted and recorded. Moreover, a complete count was carried out for saplings (DBH<2cm and height <1.3 m) and seedlings in each plot, and plant specimens were collected and identified at the Herbarium of Ethiopian Biodiversity Institute.

Data analysis

First, the overall woody species composition and species richness were organized with respect to the vegetation ecosystem types. In the next, the data of unique woody species (i.e. woody species that are specific to each adjoining ecosystem) to each vegetation ecosystem were organized into three growth structure datasets: mature trees and shrubs, saplings, and seedlings with respect to the four vegetation ecosystem types. Moreover, these ecosystems were sorted into four IUCN threat categories based on the already characterized ecosystems of Ethiopia according to their threat statuses (EBI, 2022). In this respect, (1) Moist evergreen Afromontane Forest (MAF) is a near threatened (NT) vegetation ecosystem; (2) Dry evergreen Afromontane Forest and grassland complex (DAF) is critically endangered (CR); (3) Combretum-Terminalia woodland and wooded grassland (CTW) is vulnerable (VUL); and (4) Vachellia-Commiphora woodland and bush land (VCB) was described as least concern (LC) vegetation ecosystem.

The compositions of the overall and unique woody species

The differences in woody compositions of the different growth structures between the ecosystem threat categories were tested using *Adonis2* function with 999 number of permutations. *Adonis2* is a permutational multivariate analysis of variance (MNOVA) used for partitioning distance matrices among sources of variations among samples by measuring the dissimilarity with Bray-Curtis's distance method.

The species richness and number of stems of the overall and the unique woody species

The difference in species richness of the overall woody species between the ecosystem threat categories were tested. Moreover, the unique woody species richness and number of stems of mature trees and shrubs, saplings, and seedlings were first organized into three datasets to test for the differences between the ecosystem threats categories. Since these datasets are count data, contain zero scores and showed skewed patterns, I performed square-root transformation by adding 0.1 to each data value to convert to continuous data and attain the assumptions of the normal distribution- homoscedasticity of the variances to apply ANOVA. Here, I added 0.1 to each data value since the square root of zero is just zero and thus to complete the transformation for the dataset. In the next, one-way ANOVA was employed to test the differences in species richness and number of stems of different growth structures (trees and shrubs, sapling and seedlings) between the adjoining vegetation ecosystems with different IUCN threat categories. Finally, after I found significant differences, I performed multiple comparisons of the means with the Tukey Honest Significance Difference (Tukey's HSD) with Bonferroni adjusted p-values within the *multcomp* package. All statistical analyses were performed using R statistical computing environment (version: 4.3.1., R Core Team, 2023).

RESULTS

The compositions of the overall and unique woody species in relation to the vegetation ecosystem threat categories

The total number of woody species is 63 that belongs to 34 families in MAF (NT), 92 species and 44 families in DAF(CR), 70 species and 29 families in VCB (LC), 34 species and 22 families in CTW (VUL). In total, 164 woody species that belong to 57 families were recorded from adjoining four vegetation types. The multivariate analysis of variance indicated that the overall species compositions is dissimilar between the threat categories of the vegetation ecosystem (Adonis2, $F_{(3, 21)}$ = 8.29, P=0.001).

The number of woody species and the families recorded from the adjoining four vegetation ecosystems were indicated in Table 1. The higher number of unique woody species (55) that belong to 35 families were recorded from the critically endangered DAF vegetation ecosystem followed by the near threatened MAF vegetation ecosystem that comprised 40 unique woody species belonging to 25 families. The multivariate analysis of variance indicated that the species compositions of mature trees and shrubs significantly differ between the adjoining vegetation ecosystems (Adonis2, $F_{(3, 19)}$ = 1.26, P=0.001). Similarly, the species composition between vegetation ecosystems is different for saplings ($F_{(3, 18)}$ = 1.94, P=0.001) and seedlings ($F_{(3, 14)}$ = 1.26, P=0.003).

Table 1. The number of unique woody species and families in relation to the ecosystem threat categories.

No	Vegetation ecosystems	IUCN Ecosystem threat categories	Number of species		Proportion from the overall four ecosystems (%)
			Total	Mean ± SD	
1	*Vachellia-Commiphora* woodland and bushland proper (VCB)	Least concern (LC)	38	8.50 ± 3.99	23.17
2	*Combretum-Terminalia* woodland (CTW)	Vulnerable (VUL)	12	2.60 ± 0.89	7.32
3	Dry evergreen Afromontane Forest and grassland complex (DAF)	Critically endangered (CR)	55	10.83 ± 2.32	33.54
4	Moist evergreen Afromontane Forest (MAF)	Near Threatened (NT)	40	7.83 ± 2.93	24.39

Species richness and number of stems

The results of the one-way ANOVA showed that the species richness of the overall woody species is significantly higher in critically endangered DAF ecosystem when compared with the other threat categories ($F_{(3, 20)}$, =46.18, P<0.001, Fig. 2).

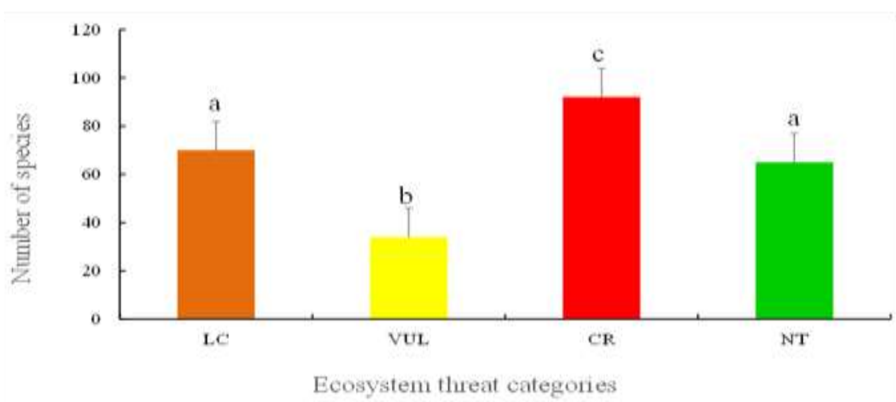

Figure 2. The bar graph showing the species richness of woody species by IUCN ecosystem threat categories. The different lower-case letters on the error bars show significant differences.

The unique woody species richness of mature trees and shrubs is significantly higher in a critically endangered DAF ecosystem than the adjoining vulnerable CTW ecosystem ($F_{(3, 20)}$, =12.5, P<0.001, Fig. 3 A), but there is no significant difference when compared with the other vegetation under the threat categories of least concern (VCB) and near threatened (MAF) ecosystems (P>0.41, Fig. 3 A). At the sapling growth stage, the unique species richness in a critically endangered DAF ecosystem is higher than the vulnerable and near threatened ecosystems ($F_{(3, 20)}$, =15.3, P<0.001, Fig. 3 B), but does not significantly differ from the least concern ecosystem threat category (P=0.91). Similarly, at the seedling growth stage, the unique species richness is higher in a critically endangered DAF ecosystem than the ecosystem under vulnerable threat category ($F_{(3, 20)}$, =6.02, P=0.004, Fig. 3 C), but not with the other ecosystems (P>0.097). The results clearly indicated that unique woody species richness in in DAF vegetation ecosystem that is categorized as critically endangered is higher when compared with other ecosystems.

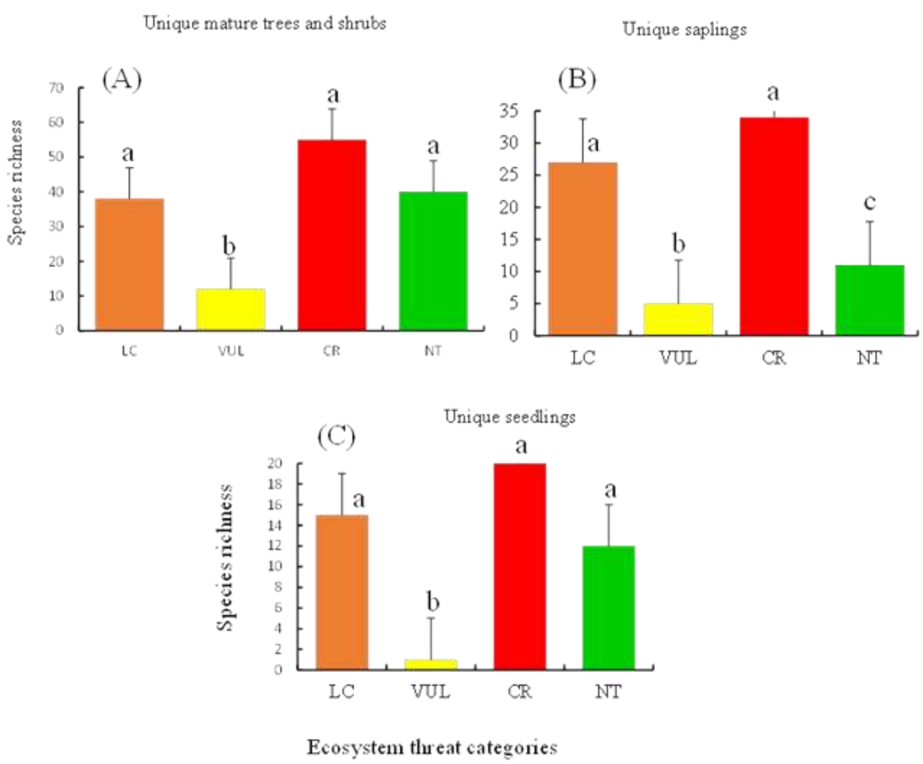

Figure 3. The bar graphs showing the species richness of unique mature trees and shrubs, saplings and seedlings in relation to the IUCN ecosystem threat categories. The different lower-case letters on the error bars show significant differences.

The results of the one-way ANOVA showed that the number of stems of the unique species of mature trees and shrubs is significantly higher in a critically endangered DAF ecosystem than the vulnerable CTW ecosystem ($F_{(3, 20)}$, =5.15, P=0.008, Fig. 4 A), but there is no such difference from other ecosystems with different threat categories (Fig. 4 A). At the sapling growth stage, the number of stems is higher in a critically endangered DAF ecosystem than the least concern and vulnerable ecosystems ($F_{(3, 20)}$, =5.56, P=0.006, Fig. 4 B). Similarly, at the seedling growth stage, the number of stems is higher in a critically endangered DAF ecosystem than the vulnerable ecosystem ($F_{(3, 20)}$, =6.78, P=0.002, Fig. 4 C), but it is not significant from the least concern and near threatened ecosystems (Fig. 4 C).

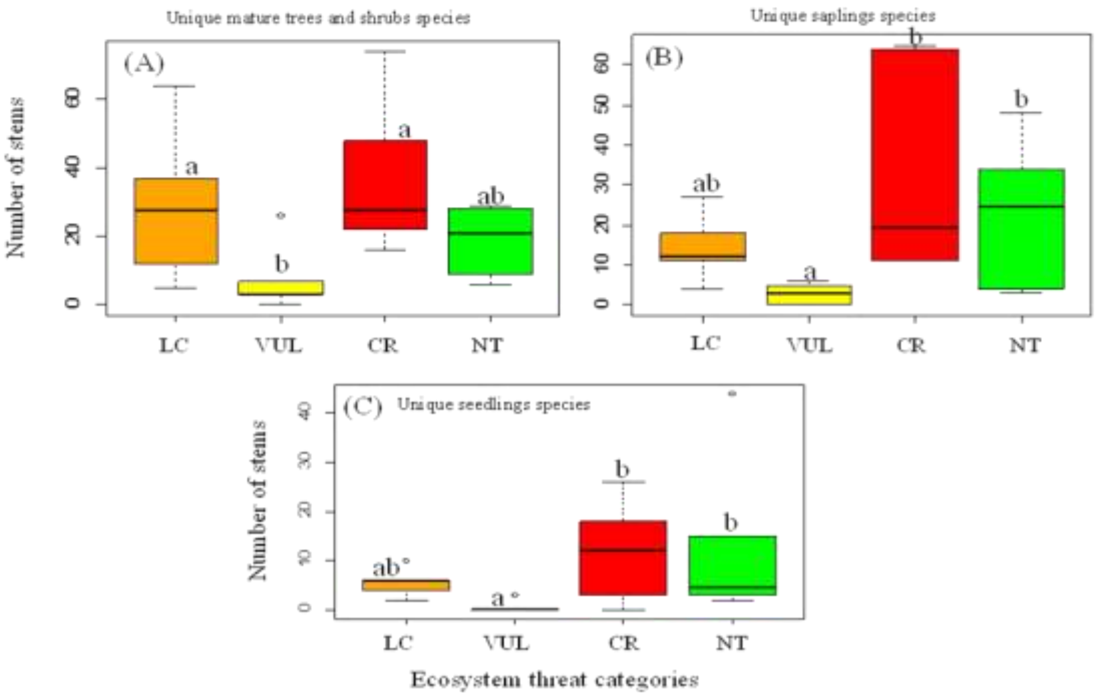

Figure 4. The boxplot showing the number of stems of unique species of mature trees and shrubs, saplings and seedlings in relation to the IUCN ecosystem threat categories. The different lower-case letters on the error bars show significant differences.

The results generally clearly depicted that number of stems of unique woody species at different growth stages is either higher in a critically endangered DAF vegetation ecosystem or not different from the other ecosystems. From the growth habits perspectives, the overall number of stems of saplings and trees are higher in critically endangered ecosystems than in other threat categories despite the fact that the pattern is similar across the ecosystem threat categories (Fig. 5). However, for unique species, the number of stems is higher for trees and saplings while it is lower for shrubs across the ecosystem threat categories (Fig. 6).

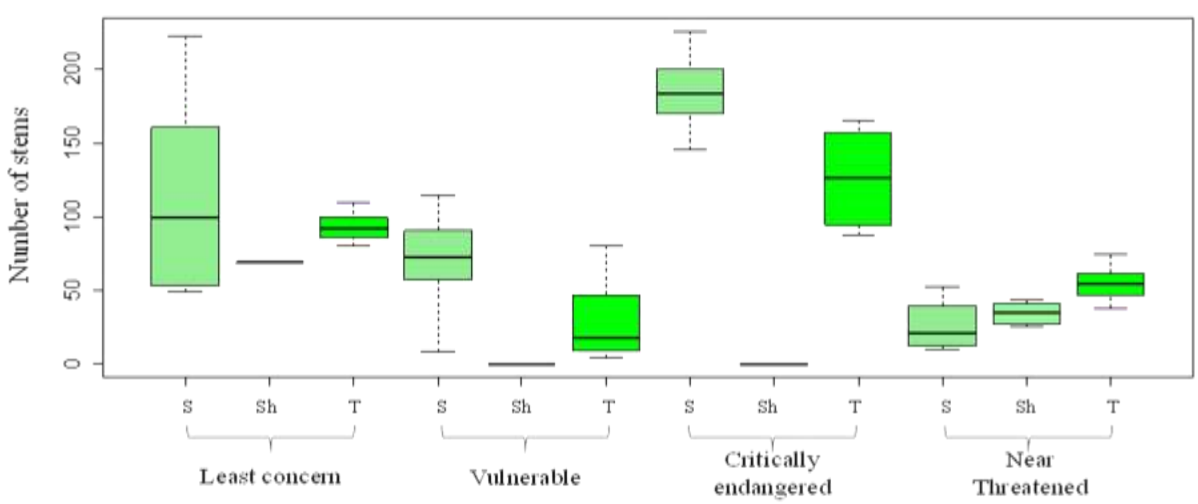

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Figure 5. The boxplot showing the number of stems of the overall woody species in relation to the growth habits (i.e., T: Tree, S: Seedling, Sh: shrubs) and the IUCN ecosystem threat categories.

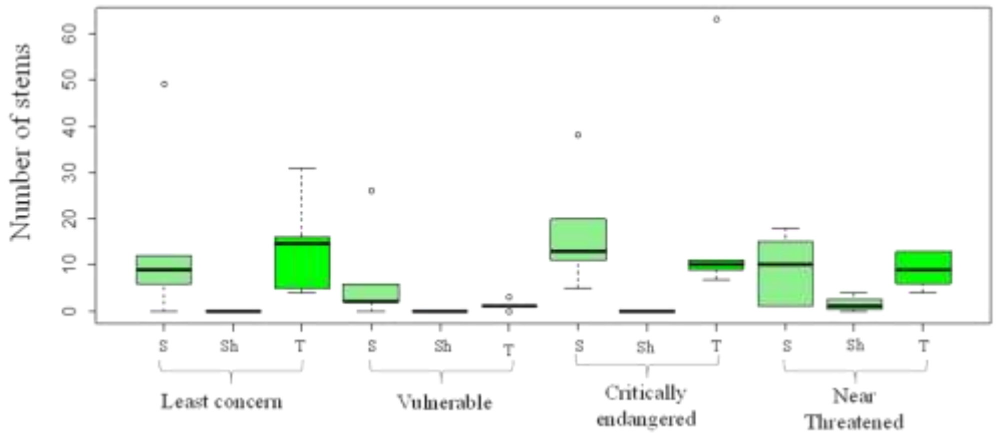

Figure 6. The boxplot showing the number of stems of unique woody species in relation to the growth habits (i.e., T: Tree, S: Seedling, Sh: shrubs) and the IUCN ecosystem threat categories.

DISCUSSION

The present study highlights that species assemblages in vegetation ecosystems do not consistently align with the ecosystem threat statuses. While the critically endangered DAF vegetation ecosystem exhibits a higher overall woody species richness, the pattern is inconsistent for unique woody species at different growth stages (Fig. 2 and 3A). At the sapling and seedling stages, species richness of unique or endemic woody species is either higher or comparable to ecosystems under different IUCN threat categories, such as vulnerable, least concern, and near threatened. However, woody species composition consistently differs across all growth stages among ecosystems with different threat categories.

From the overall species composition, the critically endangered DAF ecosystem hosts the highest proportion of unique species (33.54%), followed by the MAF near threatened ecosystem (24.39%), with the CTW vulnerable ecosystem having the lowest (7.32%) (Table 1). This suggests that ecosystems rich in floristic diversity before disturbances also tend to contain a higher number of unique species, even if they are now critically endangered, compared to ecosystems with lower floristic diversity. This finding aligns with previous research indicating that species-rich ecosystems are more resilient to disturbances compared to ecosystems with lower diversity (Holling, 1973; Peterson *et al*., 1998; Mori *et al*., 2013). Vegetation ecosystems, and the species within them, do not respond uniformly to disturbances; their resilience varies depending on ecological processes (Kessel, 2002; Nogué *et al*., 2013).

While moderate levels of disturbance can promote species diversity (Singh, 2021), severe disturbances often create gaps or new habitats that eventually increase species numbers (Derroire *et al*., 2016). This can be seen as species turnover over time. However, my findings contradict Kutnar *et al*. (2019), who observed that species richness declines after disturbance in temperate forest ecosystems due to the replacement of habitat specialists by generalist species.

Interestingly, the critically endangered DAF ecosystem also shows a healthy recruitment structure, as indicated by the higher number of saplings and tree stems compared to other ecosystems (Fig. 5). Unique species follow a similar pattern, with a higher number of sapling and tree stems, though lower for shrubs, across the ecosystem threat categories (Fig. 6). This suggests that previously floristically rich ecosystems, even when critically endangered, continue to support a higher diversity of unique species compared to ecosystems that are less disturbed but lower in species richness.

The DAF ecosystem exemplifies this trend, historically rich in species diversity but now critically endangered due to centuries of sedentary agriculture and high human population density (Friis *et al*., 2010). The high species diversity observed in critically endangered ecosystems supports the Intermediate Disturbance Hypothesis (IDH), which posits that species diversity peaks in ecosystems experiencing intermediate levels of disturbance (Dial and Roughgarden, 1988). This raises a key question: How congruent is the IUCN ecosystem threat classification with the IDH? The IUCN Red List of Ecosystems suggests that ecosystem threat status is a function of species interactions and the ecological processes that sustain them (SANBI and UNEP-WCMC, 2016; Bland *et al*., 2017). However, it may be challenging to align the IUCN ecosystem categories with the IDH levels of disturbance. My findings suggest that critically endangered ecosystems, like the DAF, may still harbor a higher diversity of unique and endemic species compared to other ecosystems, consistent with the region's status as part of the Eastern Afromontane biodiversity hotspot (Myers *et al.*, 2000; Friis *et al*., 2010; Debissa Lemessa *et al*., 2023). However, the extinction risk for many taxa in Ethiopia's ecosystems remains under-assessed (Mengesha Asefa et al., 2020), and continued ecosystem degradation could disrupt ecological processes and biodiversity function (De Groot, 1992; Dunster and Dunster, 1996).

Although it is difficult to fully capture how different disturbance types affect species composition (Dinkissa Beche *et al*., 2022), my results serve as a foundation for future research on key questions, such as: How do ecological disturbances impact biodiversity? What is the threshold of disturbance that favors or harms biodiversity? How do anthropogenic disturbances influence biodiversity, and at what threshold? What are the cumulative impacts of climate change and disturbances on biodiversity, and how do these impacts vary across spatial scales?

Disturbance, whether natural or anthropogenic, can have both positive and negative effects on biodiversity (Huston, 1994; Holt, 2008). While disturbances can kill biomass, they can also promote species survival and increase diversity by opening up new spaces for species immigration. This supports the notion that unique woody species can be more prevalent in critically endangered ecosystems compared to stable ecosystems, such as those classified as least concern or near threatened.

The nonequilibrium theory suggests that disturbances are vital ecological processes that, at appropriate levels, contribute to long-term ecosystem sustainability and productivity. Disturbances help maintain diversity in species, genetics, and structure, essential for ecosystem health (Reice, 1994). Some species even depend on disturbances for their survival (Vogl, 1983). Therefore, before implementing conservation efforts, it is essential to assess the optimum thresholds of ecosystem disturbance and tipping points, aligned with IUCN Red List categories (Bland *et al*., 2017).

The results of this study reveal intricate relationships between ecosystem threat status, species richness, and the influence of ecological disturbances on vegetation ecosystems. Based on these findings, I propose six hypotheses that can inform future research on ecosystem resilience and the conservation of unique species, offering a foundation for advancing our understanding of biodiversity dynamics and disturbance impacts: (1)

Higher Diversity of Unique Species in Critically Endangered Ecosystems hypothesis.

Critically endangered ecosystems, such as the DAF, are hypothesized to harbor a higher diversity of unique and endemic species compared to ecosystems with lower threat statuses. This observation is consistent with the higher proportion of unique species found in the DAF ecosystem, despite its current status as critically endangered. The richness of unique species in these ecosystems may indicate that floristically diverse ecosystems before disturbances can maintain higher diversity even under ongoing threats (Myers *et al.,* 2000; Friis *et al.*, 2010); (2)

Species Richness and Composition Across Growth Stages hypothesis.

A significant difference in the richness and composition of unique woody species is expected across different growth stages (mature trees, saplings, and seedlings) among ecosystems with varying threat categories. This hypothesis aligns with my finding that the species composition in ecosystems with higher threat levels, like DAF, is distinct from that in ecosystems with lower threat categories. The growth stage dynamics observed may reflect differential resilience and recruitment patterns under disturbance regimes, (3) **Intermediate Disturbance Hypothesis in Critically Endangered Ecosystems hypothesis**. I hypothesize that the Intermediate Disturbance

Hypothesis (IDH) will hold true for critically endangered ecosystems, where moderate levels of disturbance may lead to higher species diversity, including unique species, due to the creation of new habitats and species turnover. This hypothesis is supported by my findings, where the DAF ecosystem, despite its critical status, maintains a relatively healthy recruitment structure, especially at the sapling and tree stem stages; (4) **Pre-Disturbance Floristic Diversity and Post-Disturbance Resilience hypothesis.** It is hypothesized that ecosystems with a history of high floristic diversity, even if critically endangered, will continue to support a higher diversity of unique species post-disturbance compared to ecosystems with lower pre-disturbance diversity. This is consistent with my observation that, despite the ongoing degradation, the DAF ecosystem still harbors a significant number of unique species, particularly at earlier growth stages; (5) **Impact of Anthropogenic Disturbances on Biodiversity hypothesis**. Anthropogenic disturbances, particularly those associated with sedentary agriculture and high human population density, likely exacerbate species loss and disrupt ecological processes in critically endangered ecosystems. However, these disturbances may also maintain some unique species in the short term, as seen in the higher sapling and tree stem counts in the DAF. This raises important questions about the threshold at which disturbance becomes detrimental to biodiversity, and (6) **Misalignment of IUCN Ecosystem Threat Categories with Disturbance Resilience hypothesis**. My findings suggest that the IUCN ecosystem threat status does not always align with the predictions of the Intermediate Disturbance Hypothesis (IDH). Critically endangered ecosystems, such as the DAF, may still harbor relatively high species richness and resilience to disturbances compared to ecosystems with lower threat levels, suggesting that the IUCN threat categories may not fully capture the ecological dynamics of these systems. These hypotheses offer a framework for further research on how disturbances, particularly anthropogenic ones, influence biodiversity across ecosystems with varying threat statuses. Understanding these relationships is critical for developing more effective conservation strategies, particularly for ecosystems that are critically endangered yet continue to host significant biodiversity.

CONCLUSION

We are living in an era where it is increasingly difficult to predict the impacts of natural or anthropogenic disturbances on biodiversity. This challenge calls for innovative conservation models beyond conventional methods, as ecosystems face rapid degradation and climate change. Species exhibit varying adaptability and ecological niches, and it is crucial to disentangle the thresholds and tipping points for species survival under different disturbance levels. The present study suggests that future conservation strategies should assess these processes in alignment with IUCN Red List categories, particularly in tropical vegetation ecosystems.

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