Current Research in Agricultural Sciences
2020 Vol. 7, No. 2, pp. 64-83.
ISSN(e): 2312-6418
ISSN(p): 2313-3716
DOI: 10.18488/journal.68.2020.72.64.83

PLANT DIVERSITY AND REGENERATION POTENTIALS IN PROTECTED AREA FORESTS OF SIERRA LEONE

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Article History
Received: 15 September 2020
Revised: 8 October 2020
Accepted: 30 October 2020
Published: 18 November 2020

Keywords
Protected areas
Regeneration
Sierra Leone
Flora biodiversity
Seedlings
Saplings & Trees.

ABSTRACT

Protected areas (PAs) around the globe are considered a reservoir for biodiversity conservation and an engine for ecosystem function and services. The regeneration potential of tropical forests in (PAs) is crucial to plant diversity survival and conservation, amid climate change in the 21st century. The PAs conservation and management status of Sierra Leone is uncertain. This study assessed the seedlings, saplings, and trees species diversity, abundance, richness and regeneration status of tropical forests in four PAs across Sierra Leone. We sampled 60 quadrats in total with each having a dimension of 20m × 20m. We found only a few new species with good regeneration potential in all the forest PAs were assessed, indicating that the resilience of these forests is quite low in the face of anthropogenic activities especially shifting cultivation and logging. Plant diversity index and soil factors were positively correlated, indicating that a decrease or increase in soil physical and chemical properties could affect speciation. The results show that diameter class distribution mainly falls within the 0-30cm category. Furthermore, abiotic factors (like precipitation and temperature), species richness, ecosystem complexity and over story were predicted to have influenced the regeneration and flora diversity of the PAs forests significantly. The results imply that PAs in Sierra Leone are going through serious exploitation and as such, plant diversity and richness is low and the regeneration ability is poor due to weak conservation strategies and approaches. It recommended that strategic planning and forest enrichment policies be instituted to mitigate future PAs forest exploitation.

Contribution/Originality: This study is one of the few studies that investigate plant diversity, regeneration and soil properties across PAs in Sierra Leone. The research contributes to the existing literatures in PAs and their ecosystem characteristics. The article concludes that; PAs in Sierra Leone plant diversity and richness and regeneration ability is low.

1. INTRODUCTION

Sierra Leone is a small country with a land area of 72,180 (sq. km), situated in the Upper Guinean, which is dominated by a lowland forest ecosystem with supposing rich biodiversity and biotic uniqueness in terms of endemic and threatened species [1-3]. The coordinates of Sierra Leone (60°55'-100°14'N and 100°14'-120°17'W) are reported to be the ultimate reasons that determine the vegetation and biodiversity of Sierra Leone [2]. The tropics of Sierra Leone are among the global tropics that play host to more plant species as compared to any other terrestrial ecosystem on earth [4]. Nonetheless, climate change and anthropogenic actions have had great impacts on forest resources across PAs in Sierra Leone [5]. Theories have proven that climate change and anthropogenic actions, especially in developing countries, affects virtually all aspects of plant diversity, regeneration and growth [5, 6]. Climatic factors and anthropogenic activities have resulted in continuous wild species transformations and their distribution on a broad scale across the globe due to precipitation regimes, increased accumulation of CO_2 in the atmosphere, flooding and warm climate [5].

According to the FAO [7] report, only 5% of Sierra Leone is covered with high forest. The decline in forest cover is primarily a result of climate change, anthropogenic actions, weak forest resources protection policy, and the 11 years civil war period, where in the total forest cover per chiefdoms in Sierra Leone declined from 67.5% to 57.9% [6, 8]. Although a few studies on plant diversity have been conducted, primarily in Gola Rain Forest National Park a well-protected park in the eastern part of the country, the extensive literature on plant diversity, and regeneration status of plant species in Sierra Leone is grossly scanty and most times unavailable. As noted by Norden, et al. [9] the human-impacted tropics face a critical shortage of ecosystem dynamics understanding and information. The availability of forest resources information and ecosystem dynamics understanding will give a platform for sustainable planning and management of PAs forests in Sierra Leone. The most comprehensive inventory of vegetation study of Sierra Leone, titled *Tress of Sierra Leone* by Savill and Fox [10] is dated back to 1967. Reports from comprehensive research done by different authorities [2, 11, 12] affirmed that plant diversity information of Sierra Leone is incomplete with no reliable data on species status of PAs except Gola Forest National Park.

Wadsworth and Lebbie [13] recently posed a question of what happened to the forests of Sierra Leone?. Numerous researchers reported the impacts of natural drivers such as climate change and human drivers such as war and land-use change as degradation culprits on forest resources and diversity decline in Sierra Leone [8, 14, 15]. Jones, et al. [16] recently employed a strategy to detect rule-breaking using optimal monitoring approach on the Gola Forest National Park Sierra Leone using field data. This approach gives an insight on changes occurring in the protected area over time due mainly to hunting. Similarly, Wilebore, et al. [17] adopted a randomized control trial to assess the influence of unconditional livelihood payment to indigenous communities on land use situated outside of Gola Forest National Park in Sierra Leone.

A comprehensive review done by Mascia and Pailler [18] uncovered massive PAs downsizing, downgrading and degazettement in 89 instances across 27 countries from 1900. PAs are generally believed to be the bedrocks of international and national biodiversity protection and conservation strategies [19] especially in Africa. Mascia and Pailler [18] referred to PAs as the *"foundation of global efforts to conserve biological diversity"*. They are the backbones for biodiversity conservation and at the same time supporting people's livelihood. Most notably at the local level [20] PAs are places of natural development that deserve ecological restoration [19]. An estimate of PAs by IUCN and UNEP [21]; Mascia and Pailler [18] and United Nations [22] suggested that there are more 122, 000 designated PAs occupying around 12% of the global land surface.

Biodiversity in the PAs worldwide is under severe anthropogenic stresses [23-27] and climate change threats [28, 29] with developing countries being more prone to threats than developed nations. The continuous growth in population coupled with rapid economic development, as well as the escalating per-capital impacts in the previous century have led to massive degradation of the PAs [30, 31]. Even though the destruction of natural resources in the PAs is minimal as compared to nearby unprotected forests, many protected areas remain mere 'paper parks'. Most of the world's flagship protected (World heritage sites) areas are being threatened increasingly by anthropogenic activities due to the lack of adequate protection [19, 32].

In the context of Sierra Leone, population growth, unemployment, mining, shifting cultivation and other forms of land use activities have contributed significantly to the degradation and loss of biodiversity in PAs with such activities threatening the planet's life support system [33] potentially affecting ecosystem health [34]. There are 48 designated PAs, in Sierra Leone including forest reserves, wildlife sanctuaries, national parks and conservation sites, covering 284, 592ha or 4% of Sierra Leone's territory [11, 35, 36] relatively less than the global average of 6.2% and Africa's average of 5.9% respectively [37]. However, only 29 of Sierra Leone PAs are under strategic management [2]. From 1967 to date, much biodiversity in Sierra Leone has been lost, leading to many plant species becoming extinct or on the verge of extinction [2]. In the policy dimension, biodiversity and tropical forests of Sierra Leone are protected by the country's Biodiversity Strategy and Action Plan [11]. However, the overlap of the mandate by other ministries renders the efficient protection of PAs areas in Sierra Leone challenging and uncertain [38].

Natural regeneration of any forest is the biological and reproductive process that facilitates the replacement and sustainable growth of that forest over time [6, 39-42]. The abundance of seedlings, saplings and trees greatly determine the regeneration potential of a forest [6]. The assessment of life stages of plant species helps in determining the relative importance of their niche as well as their community assembly neutral processes [9, 41].

Knowing the regeneration status of flora biodiversity of any PAs helps in the design of effective interventions and adaptive management, improving conservation communication and management strategies. In order to narrow the decades-long knowledge gap of plant diversity and regeneration status, we conducted surveys in four protected areas with aims to address the following research questions: what is the regeneration status of plant diversity in protected areas of Sierra Leone? Could the current plant diversity in Sierra Leone be sustained for another decade? Does the soil type affect plant diversity and regeneration across protected areas in Sierra Leone? What are the driving factors of poor species regeneration? The answers to these research hypotheses can provide vital information about the flora biodiversity, plant regeneration status, and the relationship between plant diversity and soil properties of the protected areas.

2. MATERIALS AND METHOD

2.1. Study Location

The research was carried out in four forest PAs including forest reserves and national parks, which are Western Area Peninsular National Park (17,800ha) in the West; Kangari Hills forest reserve (8,537ha) in Central North; Kambui forest reserve (21,213ha) in the East and Kasewe forest reserve (2,333ha) in the South of the country respectively Figure 1.

These four PAs were selected based on their strategic geographical locations, vegetation and protected area status as well as their biotic activity and settlement proximity characteristics. The elevation of these protected areas ranges from 100m to 700m Table 1. All four PAs fall under category IV of the International Union for the Conservation of Nature (IUCN) designation [43] and cover five major ecosystems in Sierra Leone, i.e., low land tropical rain forests; montane forests; coastal marine; savanna woodlands, and freshwater & wetlands [3]. Sierra Leone's climate is tropical humid with two pronounced seasons, i.e., the dry season from November to April and the wet season from May to October.

Species and family dominance are report in Table 1 together with the region and elevation of each study location Tables describes. Additionally, the geographical location of each study area is recorded in Table 1.

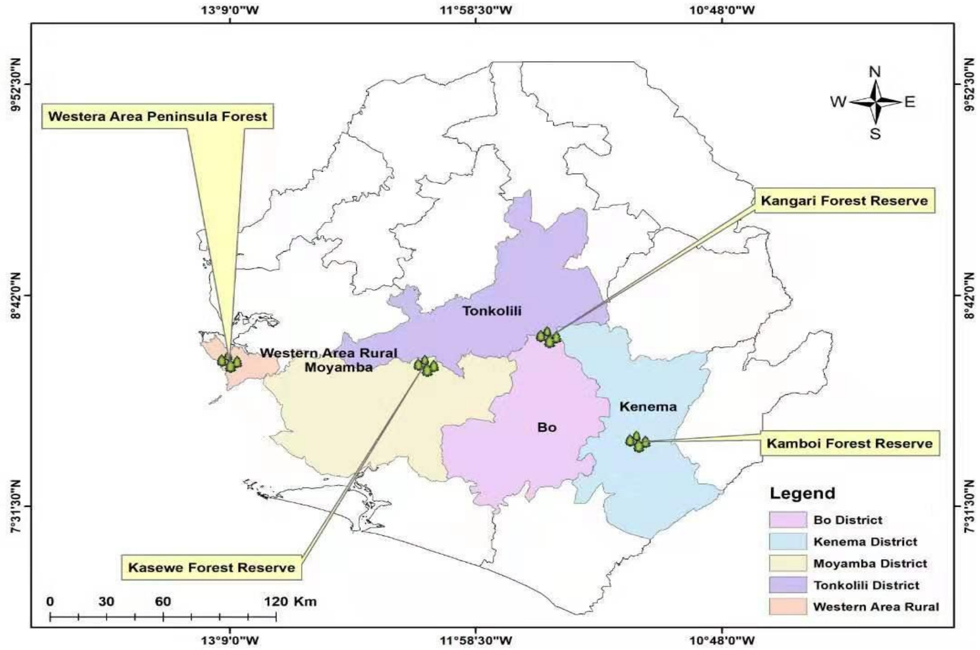

Figure-1. Map of Sierra Leone showing Districts and sampling sites (forest reserves).

Table-1. Location and dominant species in study areas.

Name	St	Geographic location	Al (asl)	Dominate species	Dominate. family	Region
WAF	NP	N 08^0 07' 08.7"- W 012^0 04'23.1' N 08^0 20' 55.7"- W013^0 10' 40.2"	50-300m	*Phyllocosmus africanus*	Euphorbiaceae	West
Kangari F	FR	N 08^0 20' 55.5" -W013^0 10' 40.2" N08^0 31' 40.2" - W011^0 40' 10.4"	55-550m	*Heriteria utilis*	Euphorbiaceae	Central/North
Kambui F	FR	N 07^0 31' 40.1" -W011^0 40' 01.6" N07^0 54' 48.8"- W011^0 13' 45.8"	132-600m	*Diospyros cooperi*	Ebanaceae	East
Kasewe F	FR	N 08^0 07' 09.1"- W012^0 04' 22.9" N08^0 19' 24.8" - W012^0 10' 28.4"	100-300m	*Guibourtia copallifera*	Euphor piaceae	South

Note: F= Forest; NP= National Park; FR= forest reserves; Al= Altitude; D= Dominant; St= Stat. Source: Researcher, 2019.

Table-2. Temperature and precipitation in Sierra Leone.

Climate	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Anu
Av Max Tem	29.9	30.3	30.9	31.2	30.9	30.1	28.7	28.4	29	29.9	30.1	29.7	29.9
Av Min Tem	23.8	27.6	24.4	24.8	24.4	23.6	23.1	23	23.1	23.4	24	24.1	23.8
Av Prep mm	3.4	3.6	12.5	46.9	177.2	323	734.3	791.1	484.1	265.8	87.9	15.9	2945.3

Note: Av= Average, Max= Maximum, Min=Minimum and Prep= Precipitation.
Source: ClimTemp.com (http://www.freetown.climatemps.com/temperatures.php).

2.2. Vegetation Sampling and Analysis

The vegetation was sampled from four protected forests in Sierra Leone from December 2018 to March 2019. Random sampling was carried out as per [44, 45]. Sixty quadrats the sizes of 20 m × 20 m^2 were laid randomly in the forests, with 15 quadrats from each PAs. In each quadrat, two subplots the size of 3 m × 3 m and 1 m × 1 m^2

were nested to enlist the saplings and seedlings. In each quadrat, plant individuals were considered as trees when their diameter at breast height (Dbh) was >10cm Dbh, as saplings when their Dbh was ≤ 10 cm and as seedlings, when their DBH was ≤ 3m [46]. The flora vegetation and analysis followed acceptable global flora biodiversity assessment in tropical forests protocols as per [45, 47-49]. A checklist of trees species was prepared using the "Trees of Sierra Leone" [10]. The diameter at breast height =1.3m was recorded for each tree above 10cm for the determination of basal area and cover by extension r^2 (the radius). Importance value index (IVI), density, frequency, and the basal area was calculated based on Mishra. [45] formulae and regeneration, as described by Singh, et al. [50] and Shankar [51].

2.3. Soil Sampling and Analysis

The soil in the study areas was moderately acidic with a loamy, sandy texture Table 3. Samples of soil were collected from three points within the quadrats *viz a vice two* opposite corners and in the Centre at a 0-15cm depth, mixed and placed in a soil sample polythene bag. The combined samples from each quadrat in each site were thoroughly mixed to form one composite soil sample. The samples were analyzed in the laboratory as per [52, 53] for both physical chemical soil parameters as seen in Table 3.

2.4. Formula of Different Diversity Indices used to Analyze Data

I. Simpson Diversity index: *Eq1*

$$D = 1 - \frac{\Sigma (n-1)}{(N-1)}$$

where,

n = refers to the number of each individual species.

N = refers to a total number of all individual species.

II. Shannon Diversity index: *Eq2*

$$SHDI = -\sum_{i=1}^{S}(P_i \times \ln P_i)$$

Where:

H= refers to Shannon-Wiener Index of diversity, Pi = the individual proportion of a species, S = Species number in the community, Σ = summation symbol, In = Natural logarithm to the base e.

III. Evenness diversity *Eq3*

$$J = H' / \ln S$$

Where H represents the Shannon diversity index.

S means the number of species.

N= the total number of individuals in a given community.

ni= the number of individual species in the ith species.

IV. Equitability J: *Eq4*

E= H/Ins

Where H= Shannon diversity index was divided by the logarithm of the number of given taxa.

3. RESULTS

3.1. Floral Composition in Different PAs

Across the four protected areas, a total of 129 species from 53 families were recorded Appendix A. Specifically, there were 68 species (trees, saplings, and seedlings) from 38 families of vascular plants in Kangari forest; 69 species from 34 families in Kambui forest reserve; 46 species from 27 families in Kasewe reserve, and 50 species from 31 families in Western Area reserve Table 4. The dominant tree species in the four PAs were *Diospyros cooperi* in Kambui, *Phyllocomos africanus* in Kangari, *Heriteria. Utilis* in Kasewe and *Guibourtia copallifera* in Western Area forest national park, respectively Table 1. The pH of the four sites ranged from 4.11 to 4.99, with a mean of 4.64 pH. Soil Electrical Conductivity ranges from 11.35 to 30.00, with a mean value of 19.34 (μS/cm). The highest total Nitrogen value was (1.19 %) while the Western Area Forest recorded the least (0.35%). Total P was the highest in the Western Area Forest (119.00 mg/kg) and the lowest (99.00 mg/kg) in Kasewe forest.

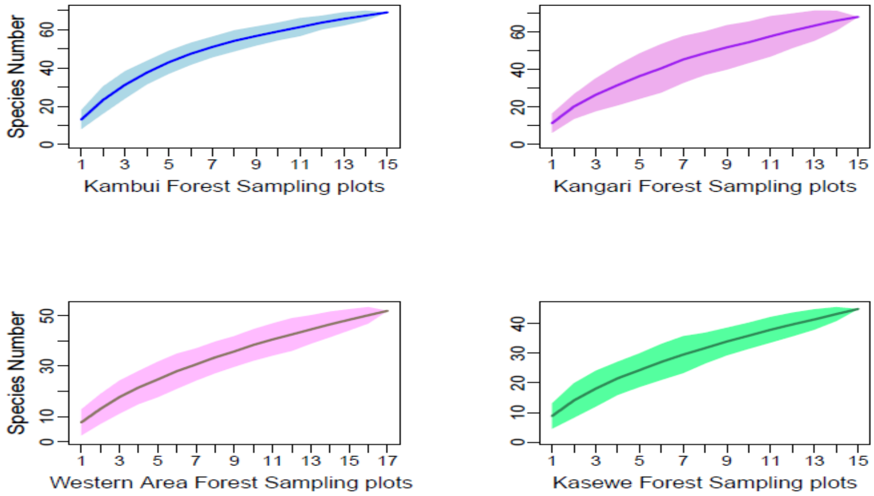

Figure-2. Total number of species per sampling plot in the four PAs.

Kambui and Kangari forest recorded the highest number of species while Kasewe recorded the lowest Figure 2. Both Western area and Kasewe forest reserve recorded 50 individual trees species.

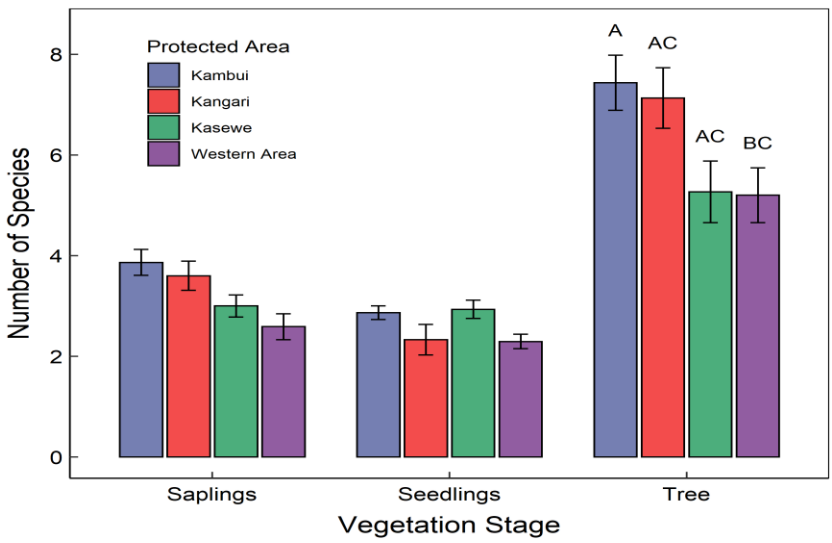

Figure-3. Average number of species diversity per PAs vegetation stages.

Trees had the highest number of species followed by sapling and seedlings. Western area forest however recorded the lowest number of species in all vegetation stages Figure 3.

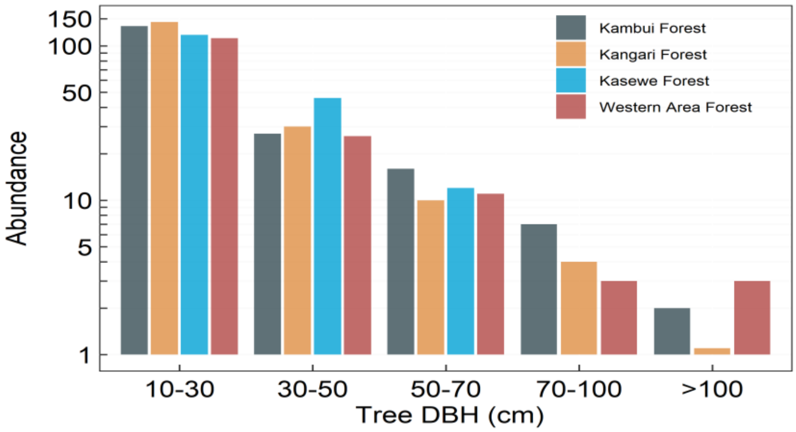

Figure-4. Species abundance as per trees diameter at breast height (DBH).

Kangari forest recorded the highest number of trees species within 10-30cm diameter at breast height range Figure 4. In all four study sites, the highest densities of species were observed in the lower class of DBH (0-30cm)

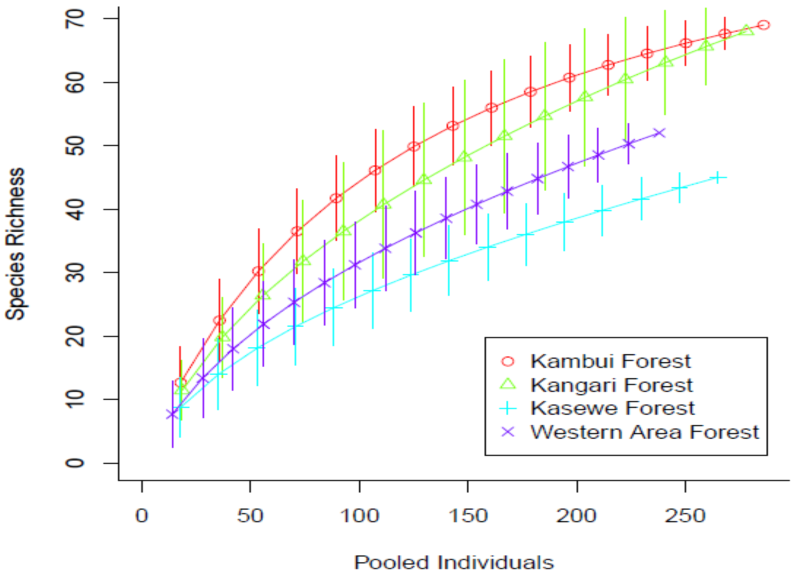

Figure-5. Species richness per individual species in protected areas.

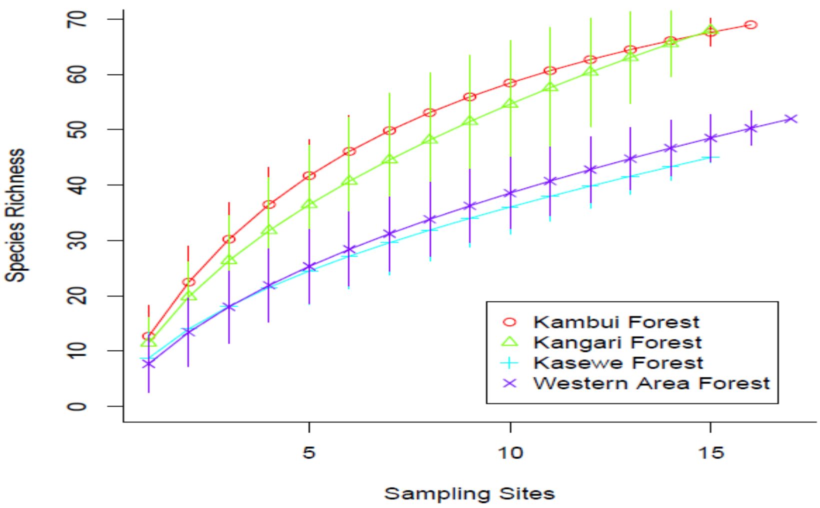

Figure-6. Species richness per sampling sites.

The richness of species per individual and sampling sites is demonstrated in Figures 5 & 6. Kambui forest recorded high species richness as compared to the other forests. Alternately, Kasewe forest reserve recorded the lowest species per site and individual pool.

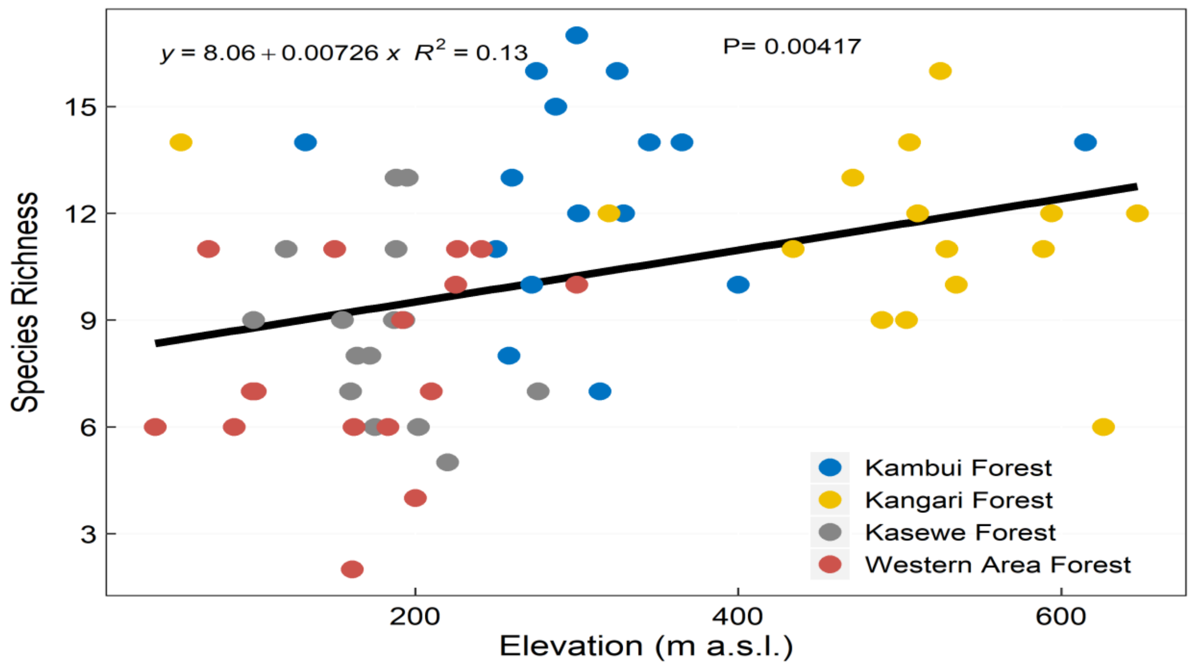

Figure-7. Species richness against elevation.

A statistical significance at (< 0.05) was detected between species richness and altitude Figure 7. The figure demonstrates that Kangari and Kambui forest had higher species richness and elevation.

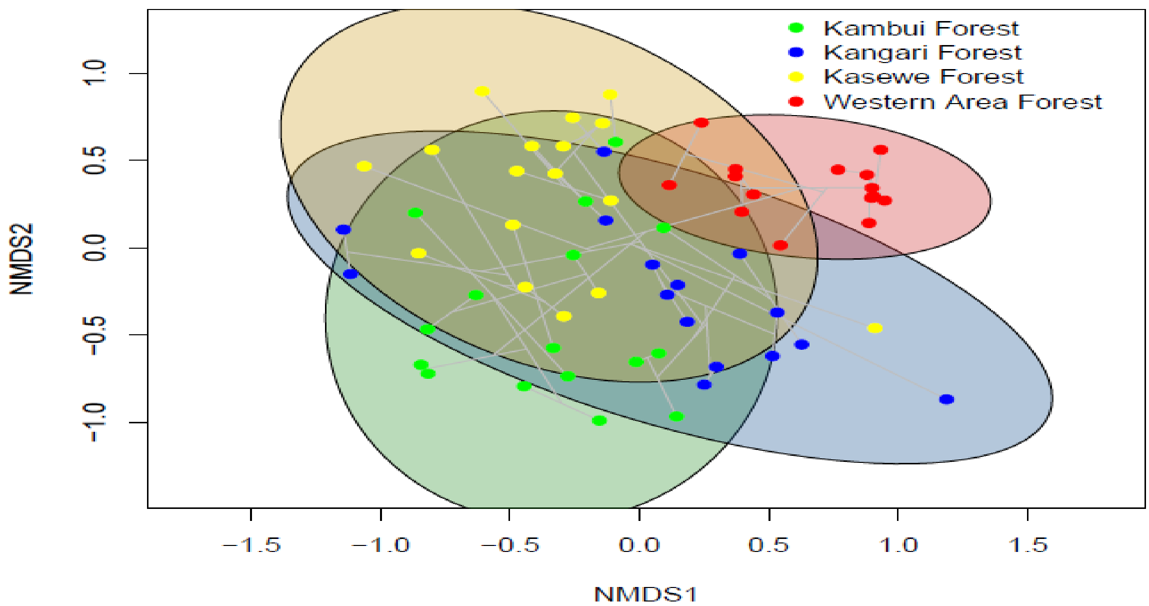

Figure-8. Relatioship between sampling sites and quadrats.

The relationship between sampling sites and quadrats is shown in Figure, 8. The figure shows the distribution of sampling quadrat per forest reserve. The figure clearly explain the sampling sites and how randomly the quadrats were laid in each site Figure, 8.

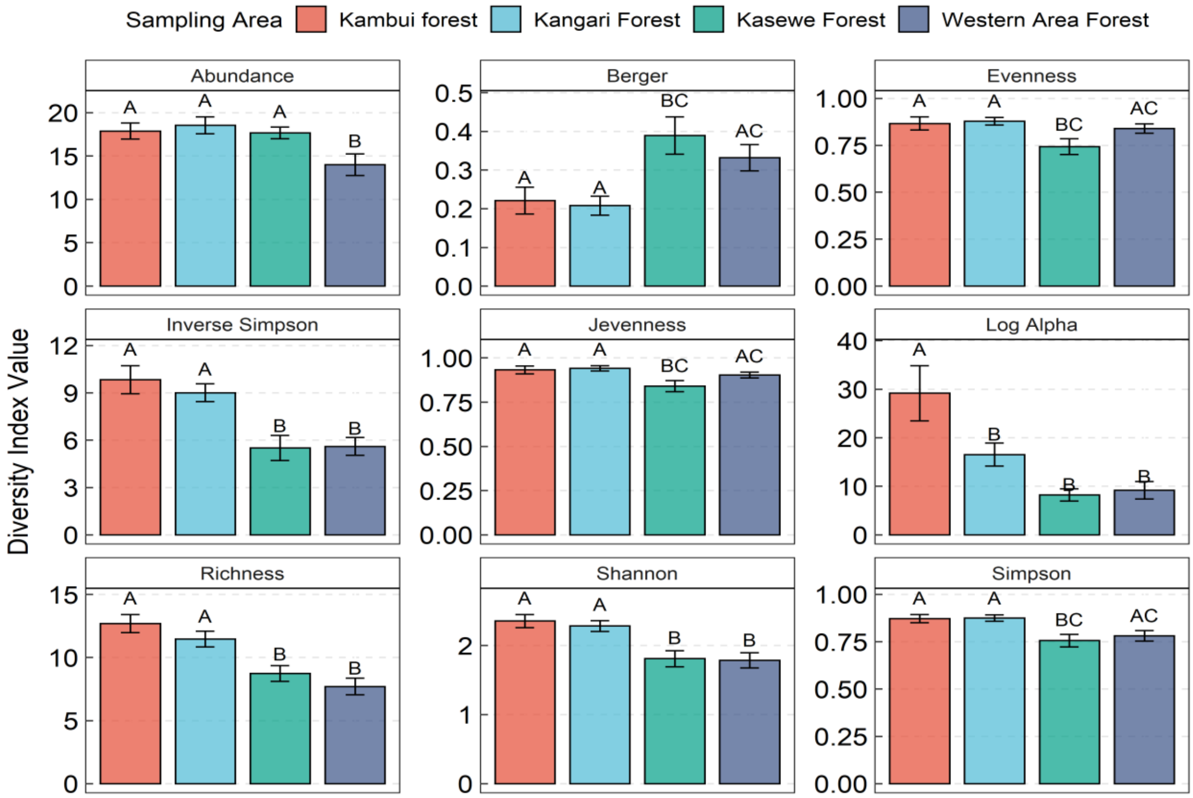

Figure-9. Plant multi-diversity indices of plants.

The Shannon and Simpson diversity was higher in Kangari and Kambui forest at a (<0.05) significance level Figure 9. However, the trend was different with species evenness index, Berger index, and J evenness.

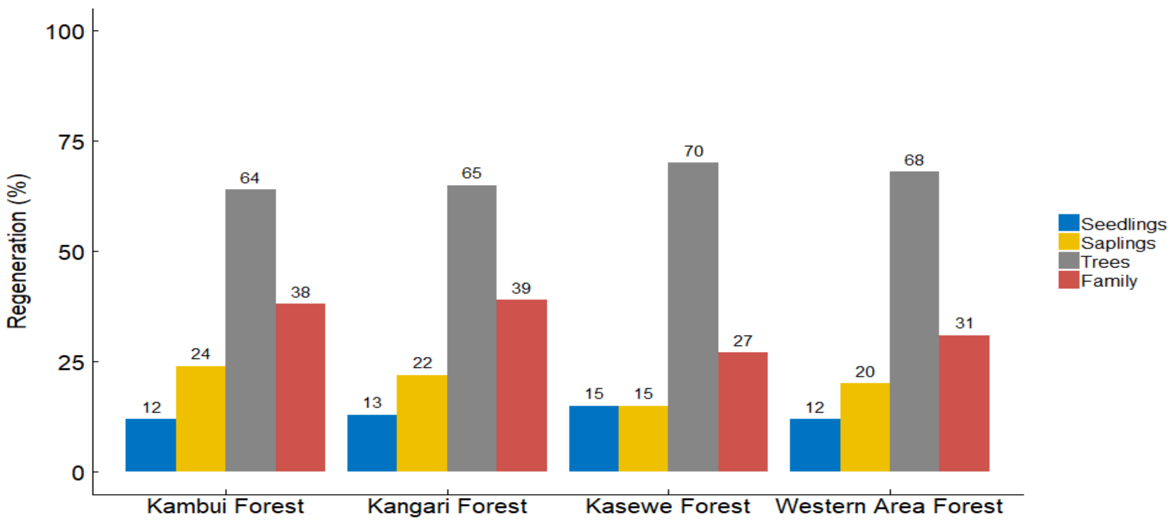

Figure-10. Regeneration status of seedlings, saplings and trees.

Majority of plants were seen in the tree stage while only few were observed in the seedling stage Figure 10. The mature trees species dominates in all four protected areas. Only 12-15% of trees showed a good regeneration potential across the four study sites Figure 10.

Table-3. Physicochemical parameters of the soil in the study sites.

Sample	Kambui Forest	Kangari Forest	Kasewe Forest	Western Area Forest
pH	4.11	4.94	4.51	4.99
EC (µS/cm)	20.00	11.35	30.00	16.00
% OC	4.20	3.40	2.20	4.70
% N	0.11	0.16	0.12	0.23
Ava. P (mg/kg)	8.10	6.30	5.50	4.00
Exc. K (mg/kg)	103.5	94.8	94.8	77.4
Exc. Ca (mg/kg)	25.00	50.00	25.00	25.00
Exc. Mg (mg/kg)	10.00	80.00	100.00	25.00
Total P (mg/kg)	102.00	118	99.00	119.00
Total N %	1.19	0.56	0.77	0.35

Note: EC= Electrical conductivity; OC= Organic carbon; N= Nitrogen; Ava= Available; P= phosphorus; K= potassium; Ca= Calcium; Mg= Magnesium; Exc= Exchangeable.

The soil pH for the four study site was found to be moderately acidic with a loamy sand texture. The exchangeable elements displayed low values in all the forests. The EC ranged from 11.35 to 30.00 µS/cm.

Table-4. Correlations between plant diversity and soil chemical and physical factors.

Diversity parameters		Shannon diversity			Soil chemical and physical factors							
	Richness	Trees	Sap	Seed	TP	TN	OC	Ca	K	Mg	pH	EC
Richness	1											
Shannon, Trees	.823	1										
Shannon, Sapling	.950	.695	1									
Shannon, Seedling	.835	.999**	.722	1								
Total P (TP)	.140	.493	-.169	.450	1							
Total N (TN)	.490	.148	.738	.195	-.778	1						
Organic Carbon	.322	.795	.207	.788	.553	-.146	1					
Calcium (Ca)	.544	.334	.322	.309	.541	-.254	-.138	1				
Potassium (K)	.604	.107	.789	.146	-.670	.908	-.383	.132	1			
Magnesium (Mg)	-.352	-.721	-.370	-.734	-.153	-.241	-.907	.406	.085	1		
pH	-.275	-.004	-.562	-.054	.866	-.967*	.140	.489	-.792	.281	1	
EC	-.610	-.825	-.342	-.797	-.868	.369	-.641	-.669	.246	.344	-.539	1

Note: **. The correlation is significant at the 0.01 level * significant at 0.05 level (2-tailed). EC= Electrical conductivity; T.P= Total Phosphorus; T.N=Total Nitrogen; O.C= Organic Carbon; Ca=Calcium K= Potassium; Mg= Magnesium; Sap= Saplings; Seed= Seedlings.

Plant richness and diversity of the four sites were positively correlated with soil factors such as total P, total N, OC, and exchangeable K, but negatively correlated with exchangeable Magnesium respectively at a significant level of P< 0.05 Table 4.

Table-5. Jaccard Similarity index of seedling, sapling and tree among all the study sites.

Plant code	K1Sa	K1 Se	K1Tr	K2Sa	K2 Se	K2Tr	K3 Sa	K3 Se	K3 Tr	W1Sa	W1Se
K1 Sa	1.00										
K1 Se	0.41	1.00									
K1 Tr	0.23	0.13	1.00								
K2 Sa	0.26	0.26	0.16	1.00							
K2 Se	0.20	0.26	0.15	0.32	1.00						
K2 Tr	0.21	0.12	0.29	0.17	0.21	1.00					
K3 Sa	0.24	0.18	0.12	0.24	0.17	0.14	1.00				
K3 Se	0.24	0.24	0.10	0.24	0.17	0.08	0.39	1.00			
K3 Tr	0.12	0.09	0.19	0.16	0.15	0.21	0.28	0.18	1.00		
W1 Sa	0.26	0.19	0.11	0.19	0.18	0.14	0.24	0.19	0.09	1.00	
W1 Se	0.21	0.18	0.16	0.31	0.21	0.14	0.23	0.18	0.13	0.33	1.00
W1 Tr	0.20	0.06	0.32	0.08	0.09	0.28	0.11	0.11	0.20	0.16	0.16

Note: K1= Kambui; K2= Kangari; K3 =Kasewe; W1 = Western area; Se=Seedling; Sa=Sapling; Tr=Trees.

The Jaccard similarity index showed that Western Areas shared 30% similarity with trees of Kambui forest, and 31% similarity with saplings of Kangari forest. Similarly, Kambui forest shared 26% sapling and seedling similarity with Kangari forest Table 5.

4. DISCUSSIONS

Understanding the species composition, biodiversity, and regeneration status of vegetation in PAs is imperative in order to implement an effective conservation strategy for any protected forest [41]. Similarly, knowledge of the regeneration, composition, structure and function of species diversity and pattern is essential for the conservation of undisturbed area is critical for forest ecosystems [54]. This information is a pre-condition for other ecological studies [55]. According to FAO [7] estimation only 5% of Sierra Leone is covered with natural forest while the rest is either categorized as farm bush or secondary forest. However, Wadsworth and Lebbie [13] refuted this and other recent estimate done by various environmental organizations as well as government reports. Also the current study is the first in four decades that attempts to assess the flora biodiversity status, regeneration status and potential, and distribution of species, as well as soil factors across the four protected areas in Sierra Leone.

4.1. Species Composition in Forest PAs of Sierra Leone

The density of trees in the four forest PAs in Sierra Leone ranged from 676 to 820 plants per hectare (ha). For a protected tropical forest reserve, these figures depict a decline in vegetation due to deforestation and degradation [56]. Climatic factors such as precipitation and temperature, and species richness, ecosystem complexity, and over story were believed to have influenced the regeneration and flora diversity of the protected area forests significantly [5, 6]. Although Sierra Leone experiences only two pronounced seasons, the rainfall, sunshine and temperature distributional patterns vary across the four regions. For example, the intensity of rain that fall in the southeast is far more than the north. Additionally, anthropogenic activities undertaken across the four PAs contribute greatly to the current status of these PAs. However, the frequency of seedlings and saplings in the studied PAs were relatively high. The species richness and diversity of plants in these four PAs denoted that these forests are degraded when compared to floral biodiversity in the Gola Forest National Park located in the east of Sierra Leone. Laurin, et al. [56] at the Gola Forest in East Sierra Leone recorded 133 plant species in a single forest. While Kargbo [57] and Bendu [58] recorded 1,320 individuals and 42 plant species in the South East, respectively. Comparing the species abundance in the sub-Western African region, Pereki, et al. [59] recorded 258 plant species belonging 63 families in Togo. Appiah [60] recorded 40 species from 32 families in a 40ha forest in Ghana. Therefore, less than 70 species recorded in the four PAs in this study suggest that these PAs are under high biotic and climatic stress. The variation in species richness across the four PAs is believed to be linked with their proximity to urban setting, anthropogenic pressure and the little or no adequate forest protection measures and policies [2, 61, 62]. Each forest displayed a unique dominance in term of species. Our findings were similar with the result of Bendu [58] who recorded *Guibouria copallifera* (45) as the dominant species in Kasewe forest; Fayiah, et al. [63] also recorded *Nosogodonia papaverifera and Guibourtia copallifera* as the dominant species in Kambui forest eastern Sierra Leone. Similarly, Mattia, et al. [64] and Bangura [65] recorded *Octhnocosmus africanus* and *Nosogordonia papaverifera* as the dominant species within Moyamba District in Southern Sierra Leone. The absolute dominance of a single species in any given forest showed the attribute of lesser diversity [60, 66].

4.2. Plant Diversity in the Forest PAs of Sierra Leone

The increase in diversity can increase the regeneration of forests (Malik and Bhatt, 2016). In this study, the Shannon diversity ranged from (0-2.8) in the four PAs. These values were comparable to previous studies within Sierra Leone and the sub-region. Laurin, et al. [56]; Bangura [65] and Fayiah, et al. [63] recorded Shannon diversity ranging from 0- 3.24 for the plants in forest reserves in the East and South of Sierra Leone. However, Bendu [58] and Fayiah. and Koroma [67] reported lower Shannon diversity index of 0.75 and 0.96 from a study within Moyamba District Southern Sierra Leone. In the sub-region, Aigbe, et al. [68] reported Shannon values of 3.827 and 3.795 for plants in two forest reserves in Nigeria. Appiah [60] recorded a mean Shannon index of 4.52 for the plants in different forest PAs, while Gatti, et al. [66] recorded Shannon values of 4.23; 4.26 and 4.35 for the plants in three different forests PAs in Ghana. The plant diversity in the forest PAs in Sierra Leone is generally low as compared to countries with similar vegetation in the subcontinent. This may be attributed to the nature of anthropogenic activities, ecological degradation and climate change [60, 63]. Moreover, the changes in soil properties may also significantly affect tree species richness and abundance [12, 69].

4.3. Similarity and Difference of Saplings, Seedlings and Trees in the Forest PAs of Sierra Leone

The Jaccard similarity index showed that most sites had common species. The Western area contained 30% similar trees species with Kambui forest and 31% similar sapling species with Kangari forest. Kangari showed 26% of similar sapling and seedlings with Kambui forest species. These findings were in agreement with Fayiah.., et al. [70] results that recorded 26% similarity between species from Kasewe forest and that of a community riparian forest in Moyamba District. The similarity of species among sites could be connected with soil type, soil pH, soil texture, soil nutrients and climatic patterns [71] as well as the climatic condition. The correspondence analysis showed that there was no congruence among tree species and the saplings and seedlings among all the study sites. There was an even distribution with high evenness from 0.5 to 0.7 in all the study sites except Kasewe reserve, which recorded lower evenness value.

The proportion of trees with various diameters at breast height classes can predict the growth and stem volume status of any given forest. The diameter distributions of the tree species in all the sites in the present study were not unique, although the majority of the sizes fell within the range of 0-30cm, which was supported by the Rocky and Mligo [72] findings in Tanzania. The diameter class displayed different patterns and exhibited a decrease in diameter as the richness of plant species increased [40]. The dominance of smaller class diameter at breast height suggested that these forests are undergoing natural regeneration after stresses, as the forests with high density in lower size class have the potential to regenerate if proper measures are provided to curb pressures [41].

4.4. Regeneration Status and Potential of Forest PAs in Sierra Leone

The wealth of any given forest depends much on the regeneration potential of the component species of that forest in space and time [73]. Typically, good regeneration potential of a forests is determines by a good number of species in all categories, i.e. seedlings> saplings > trees [40, 72]. Similarly, the number of different categories of life stages such as trees, saplings and seedlings of diverse species can help in forecasting future changes, regeneration, and status of flora biodiversity in any forest [41].

In this study, the abundance of trees species against saplings and seedlings denoted poor or no regeneration in the four PAs. Similarly, Fayiah, et al. [70] recorded a fair regeneration for two forests reserves inventoried in southern Sierra Leone. They concluded that the regeneration potential of the two forests ranged from fair to poor and that may even worsen if urgent measures are not put in place to curb the rate of forest resource exploitation within these two forest areas. In the sub-continent, Rocky and Mligo [72] concluded that native species had better regeneration potential than exotic species in Tanzania. Poorter, et al. [74] recorded no regeneration along the Liberia and Cote d'Ivoire border in West Africa. According to numerous researchers [74, 75] these problems have been dated back decades. In this study, the majority of species were found in the tree stage depicting non-regeneration ability, while some species were found in all growth stages. Many factors such as climate change, shade tolerance, fire resistance, dormancy ability, and soil properties could be attributed to these phenomena [76, 77]. On a larger scale, the regeneration of natural forests dramatically depends on both abiotic factors such as temperature, rainfall, and soil fertility and biotic factors such as diversity, composition and richness [6].

4.5. Soil Physicochemical factors and Plant Diversity in Forest PAs of Sierra Leone

Accurate soil information is vital in achieving the sustainable development target 15.3 of eradicating land degradation/forest globally [78]. Recent discoveries has noted that accurate soil information is essential in not only forecasting climate change impacts on global food production [79] but also help in halting forest degradation and desertification. The vegetative community and soil chemical and physical factors have been proven to have a reciprocal relationship [80, 81]. In recent years, researchers have proven that the floral composition of plants, spatial and temporal distribution, and community structure were significantly controlled by the type of soil and land creation [71, 82].

Additionally, other factors influencing soil properties were topography and microclimate [80]. The average pH of 4.6 showed that the soil was moderately acidic can affect speciation [71]. This finding agree with the global gridded soil information published by Hengl, et al. [78] using machine learning approach. The Soil Grids is a global database that predicts standard and accepted numeric physical and chemical properties of soil depth ranging from 0-200cm respectively [83].

A match exist when comparing global Soil Grids information with national data in terms of physical and chemical soil properties in most cases [78]. In general; acidification of soil changes the available soil nutrients in many different ways [84]. Medinski [85] and Huston [86] concluded that soil texture, pH, and EC were essential indicators for explaining the richness of plant species in forests. The inadequacies of primary and micronutrients of soils are common in Sierra Leone, leading to low soil fertility [87]. Palpurina, et al. [71] suggested that the pH of the soil should be considered as an essential catalyst of fine-scale floral species richness in the terrestrial ecosystem. The low physicochemical property of soil in the study sites is believed to have affected species composition and richness as well [71, 78, 82, 85, 87]. In agreement with Gol, et al. [80] we predict that the physical and chemical properties of soil may have affected regeneration, density, and diversity of plants in the forest PAs of Sierra Leone.

5. IMPLICATION FOR CONSERVATION

The findings of this study provide a good insight into the current status of PAs in Sierra Leone. Our findings revealed differences between the study sites of four forest PAs in Sierra Leone in terms of species diversity, regeneration status, and soil properties. Kambui and Kangari forests protected areas showed richer plant diversity, while Kasewe and Western forest PAs showed a lower percentage of plant species in all categories. We found only a few new species and other species with good regeneration potential in all the forest PAs, indicating the resilience of these forests is quite low in the face of degradation.

Richness, plant diversity and soil factors were positively correlated, indicating that a decrease or increase in soil could affect speciation. The various phytosociological attributes and diversity indices showed that the plant diversity status of forest PAs in Sierra Leone is at a crossroad. Abiotic factors (like precipitation and temperature), species richness, ecosystem complexity and over story were believed to have influenced the regeneration and flora diversity of the protected area forests significantly. Drastic management policies and appropriate strategies are urgently needed to prevent the forest PAs from further degradation. The regeneration ability of plant diversity in the four PAs was generally poor with the majority of the species in the tree stage. The future survival of PAs in Sierra Leone is uncertain, and most tree species are at the risk of extinction. The findings on species regeneration, distribution and composition, and diversity in this study may be beneficial for sustainable management of protected areas across Sierra Leone and the subregion.

This study will help policy and decision-makers have an idea of the status of protected forests and the urgency needed in tackling their exploitation. Going forward, the timely design and implementation of strategic management approaches would save the forest from further degradation in the near future. It will be in the best interest of forest resources protection in Sierra Leone if the decades-old 1988 forest protection law is replaced with a sound policy that addresses current challenges. Forest protection institutions should be strengthened and given political support in carrying out their mandates without any fear. This article serves as a baseline for researchers and forest management practitioners in Sierra Leone.

Funding: This research was financially supported by the grants from the Second Tibetan Plateau Scientific Expedition and Research Program (2019QZKK0307), National Key R&D Program of China (2016YFC0501906), Qinghai Provincial Key R&D program (2019-SF-145 & 2018-NK-A2), Qinghai innovation platform construction project (2017-ZJ-Y20). The authors would also thank the anonymous reviewers for their helpful comments.
Competing Interests: The authors declare that they have no competing interests.
Acknowledgement: Many thanks is extended to Mr M. Swarray (Botanist) attached to the Gola Rainforest National Park in Sierra Leone for trees species identification. Many more thanks is extended to authors field researchers assistants, Mr. Mohamed Shaw, Salia P. Sannoh, Mr. Edward H. Sama and Mr. Musa M. Swarray for their support in collecting data in the field.

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SUPPLEMENTARY MATERIALS

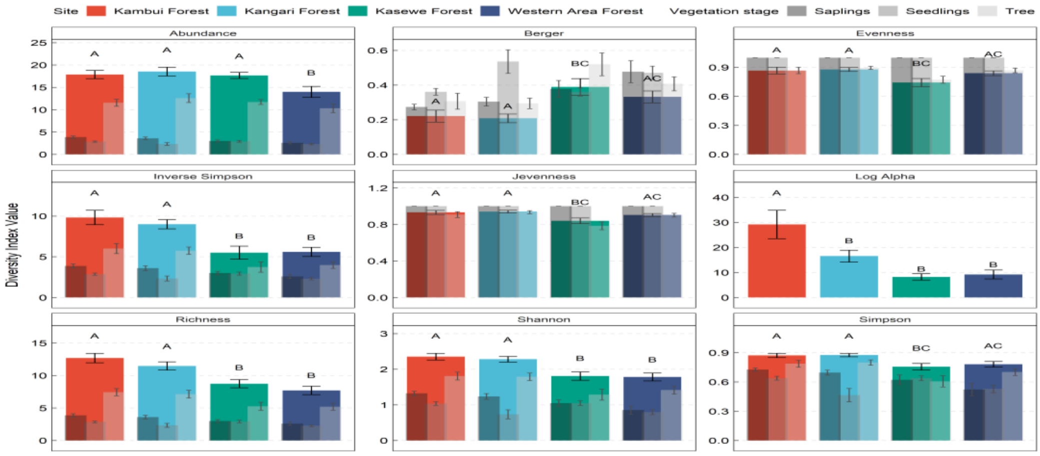

Figure-1. Diversity index of the four Study area.

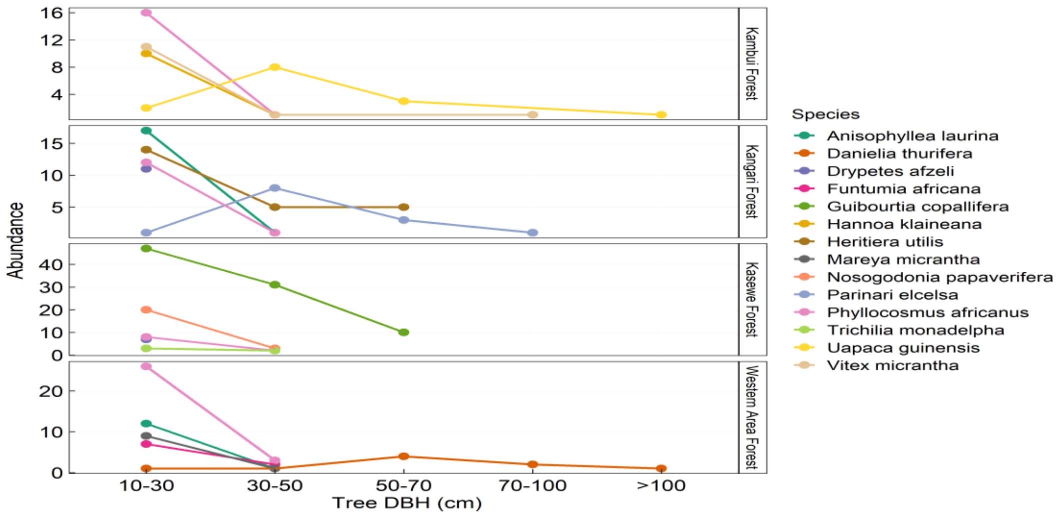

Figure-2. Trees DBH and their abundance.

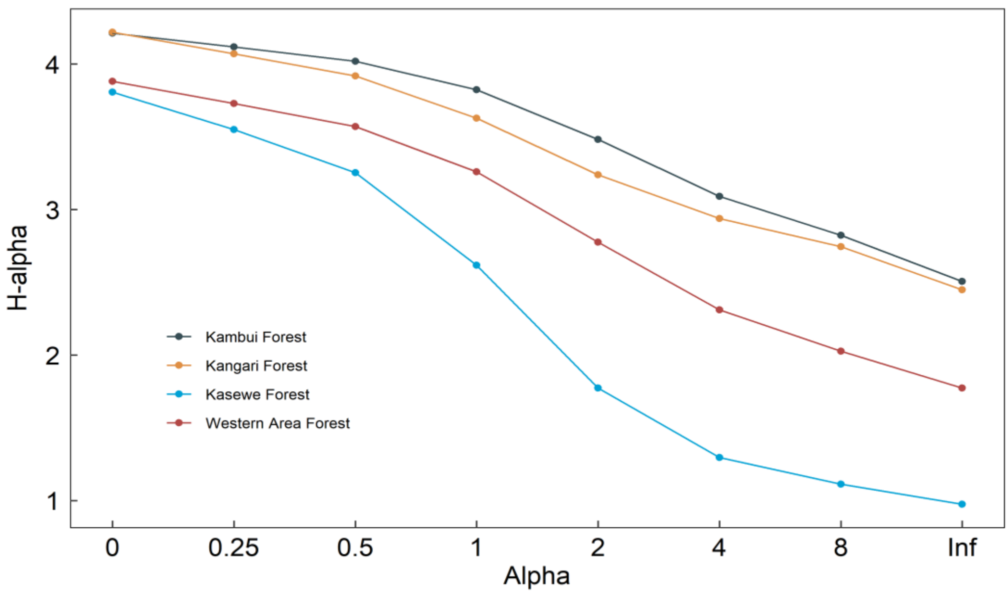

Figure-3. H Alpha diversity of the four protected areas.

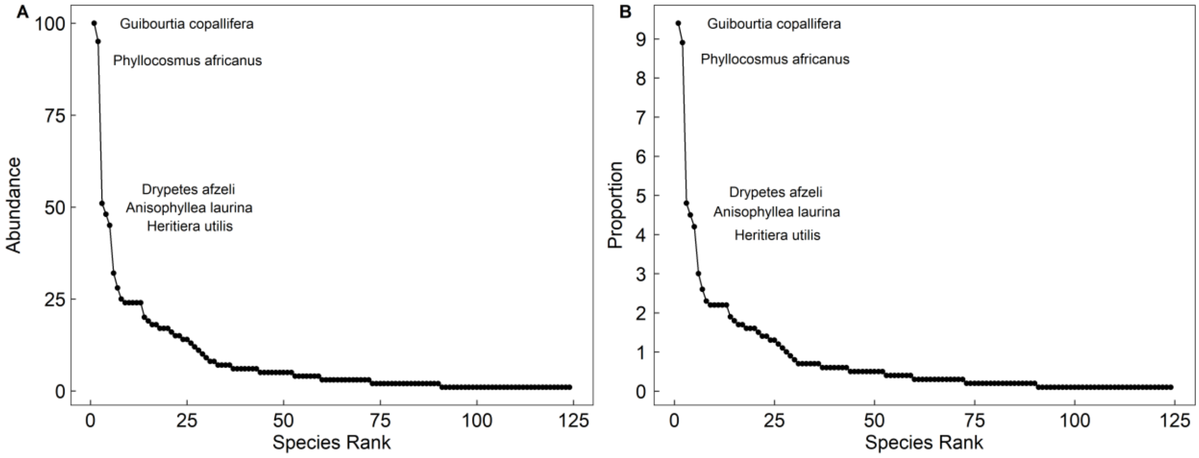

Figure-4. Species Rank and abundance of the four protected areas.

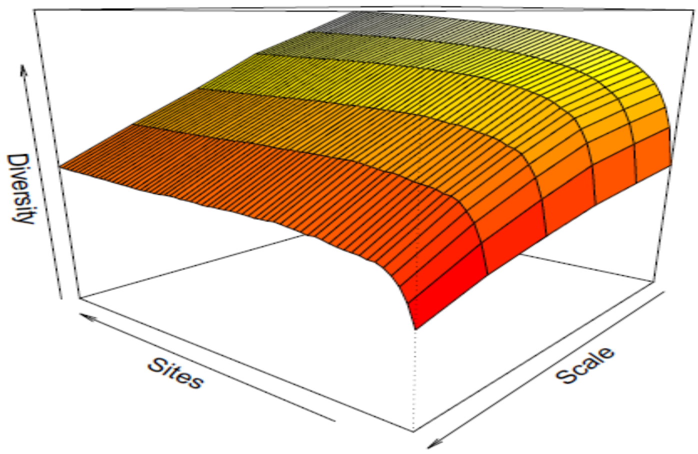

Figure-5. Diversity per site and scale.

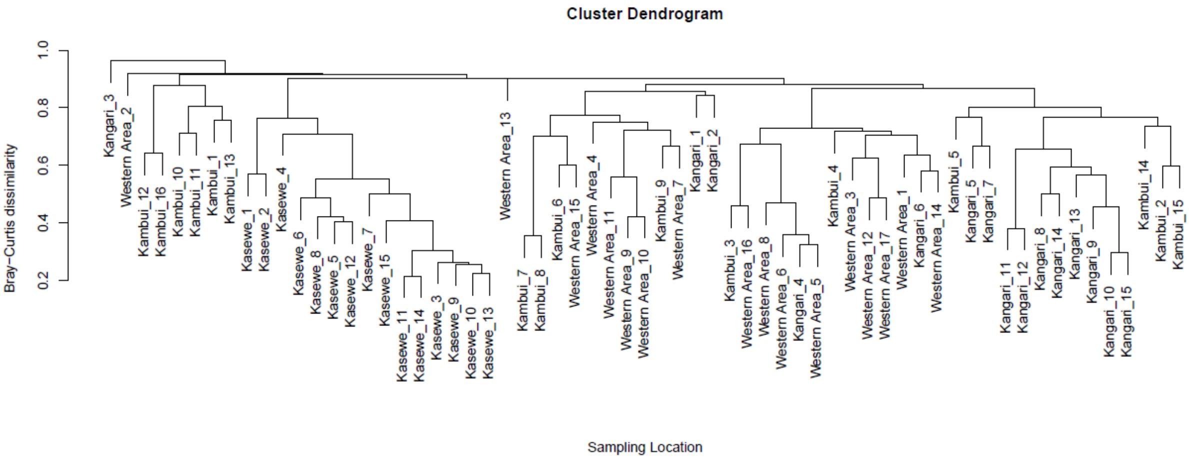

Figure-6. Cluster diagram of sampling location.