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Human disturbance upsets the ecosystem resilience and species diversity in Dinder Biosphere Reserve, Sudan

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ABSTRACT

Background: This research analyzed the effects of human disturbances, particularly harvesting of tree products and livestock grazing, on pollinators, soil nutrients, and tree diversity and composition in Dinder Biosphere Reserve, Sudan.

Methods: The research was carried-out in 150 randomly selected sample plots (1000m₂) across the three zones of DBR. Additionally, 210 key informant interviews and questionnaires were purposively conducted in six villages surrounding the reserve. A two-way analysis of variance, linear regression, descriptive statistics, and Shapiro-Wilk and Tukey's Post Hoc tests at 0.05 were used for data analysis.

Results: Outcomes show that tree species diversity, insect pollinators, and natural regeneration in transition zone were half that of core zone ($F_{2, 147}$ = 127.3 and P < 0.001; $F_{2, 147}$ = 142.4 and P = 0.001; $F_{2, 147}$ = 138.2 and P = 0.021, respectively).
($F_{2,147}$ = 92.8 and P = 0.001; $F_{2,147}$ = 91.3 and P < 0.001; $F_{2,147}$ = 101.2 and P < 0.001, respectively), with a positive relationship with mean tree crown diameter (R^2 = 0.78, β = 0.55, P < 0.001). Moreover, the fruit production was significantly varied across the three zones.

Conclusion: We concluded that illegal harvesting of forest tree products and the intensive livestock grazing negatively impacted the provisioning, regulatory, and nutrient cycling services of DBR ecosystem and deteriorated the species diversity and food security of local peoples within and around the reserve.

KEYWORDS

Anthropogenic disturbances; Food production; Pollination; Recreation; Soil health

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Introduction

Nature-reserved sites like biosphere reserves, natural forests, national parks, and sanctuaries frequently support human needs through ecosystem services provisioning [1], biodiversity preservation [2], resource sustainability [3], and utilization needs satisfaction [4,5]. These services and functions are of great importance for Sahel area and similar dryland sites with marginalized areas and nature-dependent communities [6,7]. However, unmanaged human disturbances like unpermitted livestock grazing, harvesting of tree products, and farming expansion can interrupt the flow of these services and eliminate their sustainability, particularly for vulnerable peoples within and neighboring Dinder Biosphere Reserve (DBR).

DBR accommodates significant plant and animal populations randomly distributed across the three zones of the reserve. Tree species like *Acacia seyal* and *Balanites aegyptiaca* form pure stands in the transition and buffer zones of the biosphere and scattered patches in the core zone [8]. Moreover, *Adansonia digitata*, *Tamarindus indica*, and *Ziziphus spina-christi* are frequently found along the Rahad River at the northern part of the reserve and Kadalo area at the southern borders [9]. While the core zone of DBR exhibited no permanent human settlement [10], the transition one documented an inverse status with > 20 villages and intensive movement of pastoralists [8].

The change-driving human disturbances within and around the biosphere reserves and natural forests in Sudan are illegal harvesting [9,11,12] and overgrazing [13–15]. Accordingly, the study hypothesis suggests that tree diversity and ecosystem-provisioning services in the core zone are slightly affected by illegal harvesting and livestock grazing compared to buffer and transition zones. Therefore, this study analyzed the effects of illegal harvesting and grazing on fruit production, soil nutrients (organic carbon, nitrogen, and phosphorus), pollinators, and tree species diversity in the transition, buffer, and core zones of DBR. Accordingly, the study outcomes will form a key approach for maintaining biological diversity in natural and plantation forests in Sudan and similar ecosystems in Sahel and other arid lands across the continent.

Materials and Methods

Study area

This study was carried out in DBR that covers an area of 10,290 Km2 and posed between latitudes 11°- 21′ N and 13°- 00′ N, and longitudes 34°- 28′ E and 35°- 46′ E (Figure 1). Administratively, the reserve is divided into transition zone (TZ), buffer zone (BZ), and core zone (CZ). The TZ locates at the reserve boundary with unambiguously observed human

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settlement and manmade disturbances [10], CZ at the reserve center with no presence of villages or anthropogenic interferences [14], and BZ between TZ and CZ with limited mankind snooping [8]. While the minimum temperature can reach 17 °C, the maximum temperature and rainfall reach 43 °C and 1200 mm, respectively [8,9]. The reserve topography is flat to semi-flat with clay-sand mixed soil, randomly found across the three zones [9,16,17].

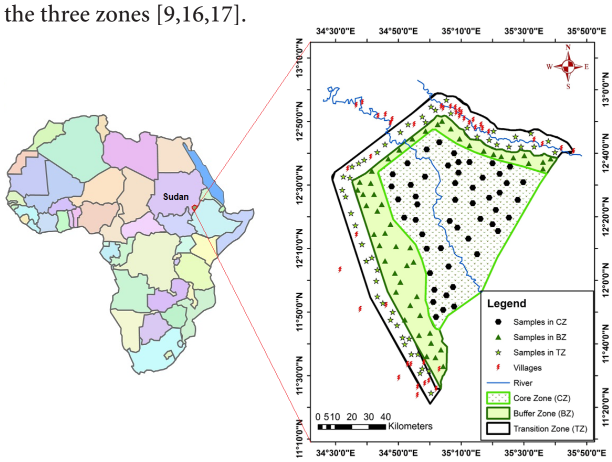

Figure 1. The Dinder Biosphere Reserve map showing the sites of the cruised sample plots as drawn using ArcGIS.

Data collection

The inventory data were collected from 150 sample plots (1000 m²) randomly chosen across the reserve's three stratified zones (50 samples per zone). The diameter (at breast height), height (total), and crown width of all cruised tree species were measured. Regeneration, insect pollinators, illegal harvesting signs, and grazing areas were reported throughout the sampled area. Moreover, ten mature trees with healthy and affected fruit-bearing branches were counted per surveyed sample plots. Five soil samples were collected at a depth of 15 cm (four at the corners and one centralized) in each inventory sample plot.

Additionally, for the social survey and based on purposive selection, the research questionnaires and key informant interviews were respectively distributed to 180 and 30 respondents found in six villages lying within and around the biosphere summing a total of 210 respondents. The selection of participants based on their income generation activities and experience with non-timber forest products trade. The questionnaire involved 20 aspects, covering the demographic characteristics of the participants, their socio-economic activities, their experience in uses, markets, and selling of non-timber forest products, the history of tree species in the area and their benefits, common pollinators, and the consequences of the species decline on their life.

Data analysis

The chemical analysis for soil nitrogen, organic carbon, and phosphorous took place at the University of Gezira following the recommended international procedures as adopted by [18–20]. Nitrogen and Organic Carbon were measured using a CN-analyzer as recommended by [21], while Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) with nitric and perchloric acid was used for Phosphorous [19]. The Shapiro-Wilk test to check for normality, linear regression for correlations, two-way analysis of variance for within and between sites comparison, and Tukey's Post Hoc test at 0.05 for significant differences [22–24] were carried out. Descriptive statistics and cross-tabulation with Chi-square were performed for the socio-economic data [25,26]. The importance value index (IVI) was computed as a sum total of relative abundance, relative dominance, and relative frequency [10,27,28]. All statistical analysis were executed in JAMOVI and SPSS softwares.

Results

Regeneration pattern, tree diversity, and pollinators

Results show that the reserve hosts more than thirty-five tree species, with the majority belonging to Fabaceae and Combretaceae families (Tables 1, 2, and 3). Based on the importance value index analysis, *Acacia seyal*, *Balanites aegyptiaca*, and *Combretum hartmannianum* are dominant tree species in the three zones with IVI values above thirty (Tables 1, 2, and 3). While most trees with excellent regeneration patterns come from Combretaceae family, the majority of poor and none regenerated trees are from Fabaceae family (Tables 1, 2, and 3). Moreover, the tree species diversity and insect pollinator richness at the transition zone were half that of core ones with unblemished significant differences between zones ($F_{2,\ 147}$ = 127.3 and P < 0.001; $F_{2,\ 147}$ = 142.4 and P = 0.001, respectively, figure 2).

Though *Tamarindus indica* and *Terminalia brownii* displayed none and poor regeneration trends in the core and transition zones, Acacia leata and *Acacia mellifera* appeared in the transition zone only (Tables 1, 2, and 3). The buffer zone attained the same intermediate status between core and transition zones for the species richness of both insect pollinators and tree species assessed in the study sites (Figure 2).

Table 1. Tree species, importance value index (IVI), and regeneration pattern in core zone.

Species	Family	Habit	IVI	Regeneration
Acacia polyacantha	Fabaceae	Tree	4.3	Fair
Acacia senegal	Fabaceae	Tree	12.9	Excellent
Acacia seyal	Fabaceae	Tree	30.7	Excellent
Anogeissus leiocarpus	Combretaceae	Tree	18.4	Excellent
Balanites aegyptiaca	Balanitaceae	Tree	36.9	Excellent
Boscia senegalensis	Capparaceae	Shrub	3.8	Poor
Boswellia papyrifera	Burseraceae	Tree	11.2	Excellent

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Combretum aculeatum	Combretaceae	Shrub	2.7	None
Combretum ghasalense	Combretaceae	Tree	6.9	Good
Combretum glutinosum	Combretaceae	Tree	9.5	Good
Combretum hartmannianum	Combretaceae	Tree	32.2	Excellent
Commiphora africana	Burseraceae	Shrub	3.2	Poor
Dalbergia melanoxylon	Fabaceae	Tree	4.8	Fair
Dichrostachys cinerea	Fabaceae	Shrub	2.8	None
Diospyros mespiliformis	Ebenaceae	Tree	4.6	Fair
Gardenia lutea	Rubiaceae	Shrub	4.1	Fair
Hyphaena thebiaca	Palmae	Tree	6.4	Good
Lannea fruticosa	Anacardiaceae	Tree	18.8	Excellent
Lannea nigritana	Anacardiaceae	Tree	9.4	Good
Lannea schimperi	Anacardiaceae	Tree	4.4	Fair
Maerua angolensis	Capparaceae	Shrub	2.8	None
Piliostigma reticulatum	Fabaceae	Tree	2.3	None
Pseudocedreca kotschyi	Meliaceae	Tree	7.4	Good
Pterocarpus lucens	Fabaceae	Tree	6.1	Good
Sclerocarya birrea	Anacardiaceae	Tree	5.9	Fair
Sterculia setigera	Malvaceae	Tree	10.7	Excellent
Stereospermum kunthianum	Bignoniaceae	Tree	2.2	None
Strychos innocua	Loganiaceae	Shrub	3.1	Poor
Tamarindus indica	Fabaceae	Tree	2.2	None
Terminalia brownii	Combretaceae	Tree	1.6	None
Terminalia macroptera	Combretaceae	Tree	6.5	Good
Xeromphis nilotica	Rubiaceae	Shrub	2.9	None
Ximenia americana	Olacaceae	Shrub	4.7	Fair
Ziziphus spina-christi	Rhamnaceae	Tree	13.4	Excellent

Table 2. Tree species, importance value index (IVI), and regeneration pattern in buffer zone.

Species	Family	Habit	IVI	Regeneration
Acacia polyacantha	Fabaceae	Tree	8.4	Good
Acacia senegal	Fabaceae	Tree	3.1	Poor
Acacia seyal	Fabaceae	Tree	58.1	Excellent
Anogeissus leiocarpus	Combretaceae	Tree	14.1	Excellent
Balanites aegyptiaca	Balanitaceae	Tree	58.5	Excellent
Boscia senegalensis	Capparaceae	Shrub	4.1	Fair
Combretum aculeatum	Combretaceae	Shrub	7.1	Good
Combretum ghasalense	Combretaceae	Tree	4.8	Fair
Combretum glutinosum	Combretaceae	Tree	12.8	Excellent
Combretum hartmannianum	Combretaceae	Tree	21.5	Excellent
Commiphora africana	Burseraceae	Shrub	5.9	Fair
Dalbergia melanoxylon	Fabaceae	Tree	11.5	Excellent

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Gardenia lutea	Rubiaceae	Shrub	3.5	Poor
Hyphaena thebiaca	Palmae	Tree	7.2	Good
Lannea fruticosa	Anacardiaceae	Tree	13.5	Excellent
Pterocarpus lucens	Fabaceae	Tree	8.9	Good
Sclerocarya birrea	Anacardiaceae	Tree	8.5	Good
Sterculia setigera	Malvaceae	Tree	7.6	Good
Tamarindus indica	Fabaceae	Tree	11.9	Excellent
Terminalia laxiflora	Combretaceae	Tree	9.3	Good
Terminalia macroptera	Combretaceae	Tree	7.4	Good
Ziziphus spina-christi	Rhamnaceae	Tree	12.3	Excellent

Table 3. . Tree species, importance value index (IVI), and regeneration pattern in transition zone.

Species	Family	Habit	IVI	Regeneration
Acacia leata	Fabaceae	Shrub	6.3	Good
Acacia mellifera	Fabaceae	Shrub	9.2	Good
Acacia polyacantha	Fabaceae	Tree	6.5	Good
Acacia senegal	Fabaceae	Tree	21.8	Excellent
Acacia seyal	Fabaceae	Tree	89.9	Excellent
Adansonia digitata	Malvaceae	Tree	3.2	Poor
Anogeissus leiocarpus	Combretaceae	Tree	14.2	Excellent
Balanites aegyptiaca	Balanitaceae	Tree	36.4	Excellent
Combretum hartmannianum	Combretaceae	Tree	38.1	Excellent
Dichrostachys cinerea	Fabaceae	Shrub	7.4	Good
Lannea fruticosa	Anacardiaceae	Tree	7.1	Good
Lonchocarpus laxiflorus	Fabaceae	Tree	19.4	Excellent
Sterculia setigera	Malvaceae	Tree	6.8	Good
Tamarindus indica	Fabaceae	Tree	4.4	Poor
Terminalia brownii	Combretaceae	Tree	4.1	Poor
Ziziphus spina-christi	Rhamnaceae	Tree	24.9	Excellent

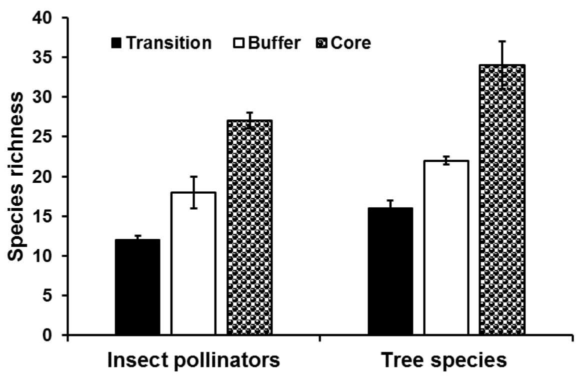

Figure 2. Species richness for identified insect pollinators and trees in the transition, buffer, and core zones of the study area.

Tree crown diameter, height, and fruit production

The crown height and total height of mature trees in the core zone of DBR were double that of the transition ones and significantly differ with the buffer zone ($F_{2,\ 147}$ = 87.6 and $P < 0.01$; $F_{2,\ 147}$ = 92.1 and $P = 0.001$; $F_{2,\ 147}$ = 76.8 and $P = 0.021$, respectively, figure 3). Similarly, the fruit production in a core zone was three times and twice that of a transition zone and buffer zone, respectively, with significant differences across zones ($F_{2,\ 147}$ = 102.7 and $P < 0.001$; $F_{2,\ 147}$ = 118.6 and $P = 0.001$, respectively, figure 4). Moreover, fruit production increases with an increase in the tree crown diameter and fruiting branches (R2 = 0.89, β = 0.53, P < 0.01; R2 = 0.92, β = 0.34, P = 0.01; R2 = 0.91, β = 0.46, P = 0.01, respectively, figure 5).

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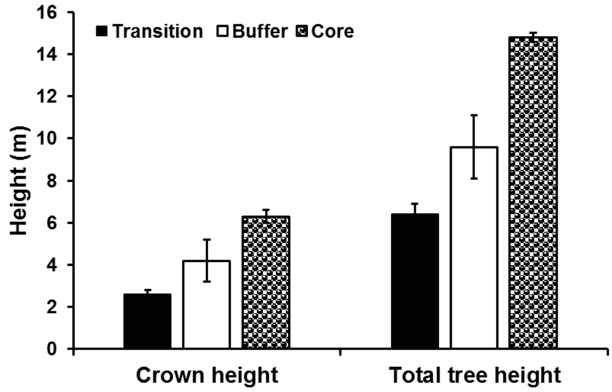

Figure 3. The mean crown and total tree height for tree species inventoried in the transition, buffer, and core zone of the study area.

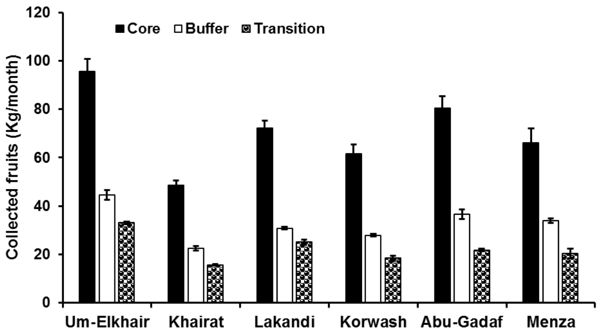

Figure 4. Average collected fruits amount in kilogram for the interviewed people of Um-Elkhair, Khairat, Lakandi, Korwash, Abu-Gadaf, and Menza villages.

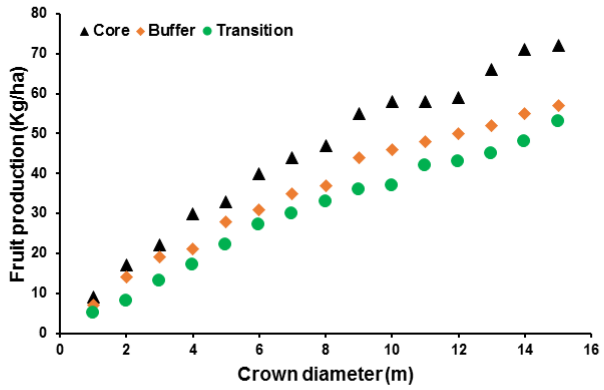

Figure 5. The crown diameter-fruit production correlations for tree species cruised in the transition, buffer, and core zone of the study area.

Soil organic carbon, nitrogen, and phosphorus contents

The soil analysis revealed that the transition zone sequestrates less carbon compared to buffer and core zones (Figure 6). The soil organic carbon, nitrogen, and phosphorus contents at the core zone were double and three times equal to that of the transition ones ($F_{2,147}$ = 92.8 and P = 0.001; $F_{2,147}$ = 91.3 and *P* < 0.001; $F_{2,147}$ = 101.2 and *P* < 0.001, respectively, figure 6). Furthermore, the findings illustrate a positive relationship linking the mean tree crown diameter with soil phosphorus contents (R^2 = 0.78, β = 0.55, *P* < 0.001, Figure 7).

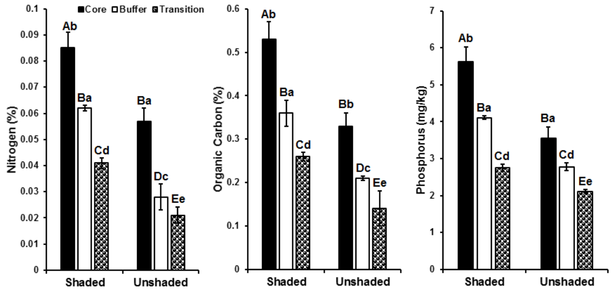

Figure 6. Mean nitrogen, organic carbon, and phosphorus content assessed in shaded and unshaded areas of the core, buffer, and transition zone of the study area.

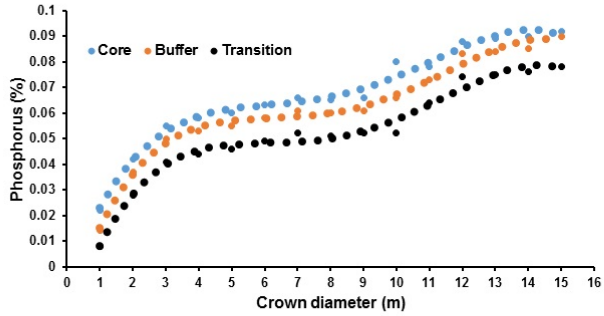

Figure 7. The crown diameter-soil phosphorus correlations for the collected soil samples and tree species cruised in the transition, buffer, and core zone of the study area.

Discussion

Regeneration pattern, tree diversity, and pollinators

The study results illustrated that the core zone had better regeneration patterns, tree species diversity, and insect pollinators compared to buffer and transition zones. The transition and buffer zones of DBR are frequently subjected to intensive grazing by livestock and severe illegal harvesting for domestic and commercial utilization [10,29]. However, due to the high adaptability of *Acacia seyal*, *Balanites aegyptiaca*, and *Combretum hartmannianum* to various soil types and climatic conditions [30–32], most open space that resulted from anthropogenic disturbance is occupied by these species and form pure stands.

Furthermore, the exploitation of *Adansonia digitata*, *Tamarindus indica*, and *Terminalia brownii* for food production, livestock foraging, timber production, and medicinal extracts has reduced their species population and disrupted their regeneration. These outcomes are consistent with [33–35]. The large spaces between adult trees and low species richness in the transition zone of DBR explicate that most vulnerable tree species with poor regeneration disappeared from the site and call for quick interventions for further conservation and management of the remaining species and the ecological functions of the biosphere.

Tree crown diameter, height, and fruit production

Findings documented that the transition zone encompasses trees with small crown diameters, low crown and total tree heights, and fruit production. This can be directly associated with the locals' income generation activities and the types of domestic animals that are reared. During summer and the

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extended dry seasons, the only source of fodder for animals is DBR. However, among the livestock keepers settling within and around the reserve, the herds of goats and sheep are dominant compared to cows and camels, resulting in more pressure on natural regeneration due to overgrazing and small crowns due to the removal of branches and twigs for feeding purposes. Moreover, rigorous cutting of crown branches reduces the number of flowering twigs, fruiting branches, and hence fruit production [36,37]. Similar results were reported by [38–41]. Additionally, Um-Elkhair, Abu-Gadaf, and Lakandi showed high amounts of collected fruits among all surveyed villages, which might result from the considerable numbers of non-timber forest products collectors, traders, and markets as well as indigenous knowledge and healing skills of their residents.

Soil organic carbon, nitrogen, and phosphorus contents

Outcomes exhibited that shaded areas have higher soil nutrients than unshaded ones, with noteworthy variations between the three zones. Various studies have concluded that leaf litter improves soil properties and health by increasing soil aeration, nitrogen, organic carbon, phosphorus, and decomposers [18,42,43]. The illegal logging of trees negatively affects soil fertility by increasing soil erodibility and nutrient loss [19,44]. Therefore, sites with high tree density and shade, like the core zone of DBR, attained more soil nutrients than less stocked and open ones (transition zone). Such reduction in soil nutrients indicates the need for urgent conservation programs to better manage the DBR, this can restore the degraded areas and sustain the ecological and socio-economic roles of the reserve.

Conclusions

The study concludes that illegal harvesting of forest products has influenced the provisioning, regulatory, and nutrient cycling services of the DBR ecosystem, deteriorated species diversity, and affected food security of the local peoples within and around the reserve. The low regeneration status and soil nutrients in the transition and buffer zones of DBR can directly refer to observed anthropogenic disturbances that are governed by overgrazing and harvesting activities. Moreover, as the core zone comprises species with healthy trees and good fruit production, it forms an excellent source for restoration and afforestation of the degraded areas in the transition and buffer zone. We recommended an introduction of community forests in the bare lands outside the reserve for local community needs satisfaction, an intensive awareness-raising program for conservation purposes, and mobile guards to reduce the grazing activities in the newly regenerated sites.

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Disclosure statement

No potential conflict of interest was reported by the authors.

References

1. Dimobe K, Kuyah S, Dabré Z, Ouédraogo A, Thiombiano A. Diversity-carbon stock relationship across vegetation types in W National park in Burkina Faso. For Ecol Manage. 2019;438:243-254. https://doi.org/10.1016/j.foreco.2019.02.027
2. Gorgens EB, Nunes MH, Jackson T, Coomes D, Keller M, Reis CR, et al. Resource availability and disturbance shape maximum tree height across the Amazon. Glob Chang Biol. 2021;27(1):177-189. https://doi.org/10.1111/gcb.15423
3. Mohammed EM, Hassan TT, Idris EA, Abdel-Magid TD. Tree population structure, diversity, regeneration status, and potential disturbances in Abu Gadaf natural reserved forest, Sudan. Environ Challenges. 2021;5:100366. https://doi.org/10.1016/j.envc.2021.100366
4. Beltrán-Rodríguez L, Valdez-Hernández JI, Saynes-Vásquez A, Blancas J, Sierra-Huelsz JA, Cristians S, et al. Sustaining medicinal barks: Survival and bark regeneration of *amphipterygium adstringens* (anacardiaceae), a tropical tree under experimental debarking. Sustain. 2021;13(5):1-19. https://doi.org/10.3390/su13052860
5. Gurashi NA, Mohammed EMI, Mohammed EMI. Modeling carbon stock-dendrometric parameters relationship and tree species diversity in Abu-Gadaf Natural Forest Reserve, Sudan. J Agric For Res. 2023;2(6):1-10.
6. Marone D, Poirier V, Coyea M, Olivier A, Munson AD. Carbon storage in agroforestry systems in the semi-arid zone of Niayes, Senegal. Agrofor Syst. 2017;91:941-954. https://doi.org/10.1007/s10457-016-9969-0
7. Neya T, Neya O, Abunyewa AA. Agroforestry parkland profiles in three climatic zones of Burkina Faso. Int J Biol Chem Sci. 2019;12(5):2119. https://doi.org/10.4314/ijbcs.v12i5.14
8. Mohammed EM, Hamid EA, Ndakidemi PA, Treydte AC. The stocking density and regeneration status of Balanites aegyptiaca in Dinder Biosphere Reserve, Sudan. Trees For People. 2022;8:100259. https://doi.org/10.1016/j.tfp.2022.100259
9. Hassan TT, Mohammed EMI, Magid TDA. Exploring the current status of forest stock in the areas bordering Dinder Biosphere Reserve, Sudan. J For Nat Resour. 2022;1(1):11-25.
10. Mohammed EM, Elhag AM, Ndakidemi PA, Treydte AC. Anthropogenic pressure on tree species diversity, composition, and growth of *Balanites aegyptiaca* in Dinder Biosphere Reserve, Sudan. Plants. 2021;10(3):1-18. https://doi.org/10.3390/plants10030483
11. Mohammed EM, Mohammed EM, Gerbeel BA. Intensive harvesting menaces trees producing fodder, edible fruit, and gum in Abu Gadaf natural reserved forest. J Ecol Conserv. 2023;1:32-34. https://doi.org/10.61577/jec.2023.100002
12. Abdelkarim HA, Ahmed DA, Yagoub YE, Siddig AA. Composition, structure and regeneration status of *Hyphaene thebaica* (L.) Mart. natural forests in dry lands of Sudan. Agric For J. 2021;5(2):82-88. https://journals.univ-tlemcen.dz/AFJ/index.php/AFJ/article/view/19
13. Alzubair MAH, Hamdan SAM. Deterioration of Blue Nile forests and its ecological effects in the Gezira State– Sudan. MOJ Ecol Environ Sci. 2020;5:34-40.
14. Mohammed EMI, Hammed AME, Minnick TJ, Ndakidemi PA, Treydte AC. Livestock browsing threatens the survival of *Balanites aegyptiaca* seedlings and saplings in Dinder Biosphere Reserve, Sudan. J Sustain For. 202;41(10):1046-1063. https://doi.org/10.1080/10549811.2021.1935279
15. Mohammed EMI, Harouna DV, Osman EH, Mohammed EMI, Fadlelmola SAA. Causes and consequences of mother tree population decline in Fazara Natural Forest Reserve, Sudan. J Biodivers Environ Sci. 2023;23(1):189-209.
16. Hassaballah K, Mohamed YA, Uhlenbrook S. The Mayas wetlands of the Dinder and Rahad: tributaries of the Blue Nile Basin (Sudan). The Wetland Book; Springer: Dordrecht, The Netherland. 2016:1-13.
17. Hassaballah K, Mohamed Y, Omer A, Uhlenbrook S. Modelling the Inundation and Morphology of the Seasonally Flooded Mayas Wetlands in the Dinder National Park-Sudan. Environ Process. 2020;7(3):723-747. https://doi.org/10.1007/s40710-020-00444-5
18. Dai Z, Birdsey RA, Johnson KD, Dupuy JM, Hernandez-Stefanoni JL, Richardson K. Modeling carbon stocks in a secondary tropical dry forest in the Yucatan Peninsula, Mexico. Water Air Soil Pollut.

https://doi.org/10.61577/jec.2024.100005

2014;225:1-15. https://doi.org/10.1007/s11270-014-1925-x

19. Mohammed EMI, Hamed AME, Ndakidemi PA, Treydte AC. Illegal harvesting threatens fruit production and seedling recruitment of *Balanites aegyptiaca* in Dinder Biosphere Reserve, Sudan. Glob Ecol Conserv. 2021;29:e01732. https://doi.org/10.1016/j.gecco.2021.e01732
20. Ghosh M, Devi A. Assessment of crop growth, soil properties and crop yield in an upland acidic soil with inorganic fertilizer blended with organic amendments in summer rice cropping seasons. Int J Recycl Org Waste Agric. 2019;8:1-9. https://doi.org/10.1007/s40093-019-0252-z
21. Scholten T, Goebes P, Kuhn P, Seitz S, Assmann T, Bauhus J, et al. On the combined effect of soil fertility and topography on tree growth in subtropical forest ecosystems study from SE China. J Plant Ecol. 2017;10(1):111-127. https://doi.org/10.1093/jpe/rtw065
22. Moges DM, Taye AA. Determinants of farmers' perception to invest in soil and water conservation technologies in the North-Western Highlands of Ethiopia. Int Soil Water Conserv Res. 2017;5(1):56-61. https://doi.org/10.1016/j.iswcr.2017.02.003
23. Schreiber-Gregory D, Bader K. Logistic and linear regression assumptions: Violation recognition and control. Henry M Jackson Foundation. 2018;247:22.
24. Sukhbaatar G, Baatarbileg N, Battulga P, Batsaikhan G, Khishigjargal M, Batchuluun T, et al. Which selective logging intensity is most suitable for the maintenance of soil properties and the promotion of natural regeneration in highly continental scots pine forests? - Results 19 years after harvest operations in Mongolia. Forests. 2019;10(2):141. https://doi.org/10.3390/f10020141
25. Gessesse B, Bewket W, Bräuning A. Determinants of farmers' tree-planting investment decisions as a degraded landscape management strategy in the central highlands of Ethiopia. Solid Earth. 2016;7(2):639-650. https://doi.org/10.5194/se-7-639-2016
26. Regidor SCG, Arroyo RA, Aclan QAJE, Azuelo APL. Preference and constraints on outdoor recreational activities: Insights from hospitality management students. Int J Acad Ind Res. 2022;3(4):145-164. https://doi.org/10.53378/352945
27. Ghanbari S, Sefidi K, Kern CC, Álvarez-Álvarez P. Population structure and regeneration status of woody plants in relation to the human Interventions, Arasbaran Biosphere Reserve, Iran. Forests. 2021;12(2):191. https://doi.org/10.3390/f12020191
28. Asigbaase M, Sjogersten S, Lomax HB, Dawoe E. Tree diversity and its ecological importance value in organic and conventional cocoa agroforests in Ghana. PLoS One. 2019;14(1):e0210557. https://doi.org/10.1371/journal.pone.0210557
29. Mahgoub AAM. Changes in vegetation cover and impacts of human population in Dinder National Park, Sudan during the period from 1972 to 2013 [dissertation]. Sudan Academy of Science (SAS); 2014.
30. Ahmed AT, Desougi MA. The ecology of some gum tree species and their uses at Tozi Natural Forest, Sinnar State, Sudan. J Nat Resour evironmental Stud. 2014;6456:29-35.
31. Fahmi MKM, Dafa-Alla DAM, Kanninen M, Luukkanen O. Impact of agroforestry parklands on crop yield and income generation: case study of rainfed farming in the semi-arid zone of Sudan. Agrofor Syst. 2018;92:785-800. https://doi.org/10.1007/s10457-016-0048-3
32. Hasoba AMM, Siddig AAH, Yagoub YE. Exploring tree diversity and stand structure of savanna woodlands in southeastern Sudan. J Arid Land. 2020;12(4):609-617. https://doi.org/10.1007/s40333-020-0076-8
33. Gaisberger H, Legay S, Andre C, Loo J, Azimov R, Aaliev S, et al. Diversity under threat: Connecting genetic diversity and threat mapping to set conservation priorities for Juglans regia L. populations in Central Asia. Front Ecol Evol. 2020;8:1-18. https://doi.org/10.3389/fevo.2020.00171
34. Kutnar L, Nagel TA, Kermavnar J. Effects of disturbance on understory vegetation across slovenian forest ecosystems. Forests. 2019;10(11):1048. https://doi.org/10.3390/f10111048
35. Weldemariam CE, Jakisa SE, Ahebwe AD. Implication of forest zonation on tree species composition, diversity and structure in Mabira Forest, Uganda. Environ Earth Ecol. 2017;1(1):112-122. https://doi.org/10.24051/eee/69224
36. Chaudhary A, Burivalova Z, Koh LP, Hellweg S. Impact of forest management on species richness: Global meta-analysis and economic trade-offs. Sci Rep. 2016;6(1):23954. https://doi.org/10.1038/srep23954
37. Gebru BM, Wang SW, Kim SJ, Lee WK. Socio-ecological niche and factors affecting agroforestry practice adoption in different agroecologies of southern Tigray, Ethiopia. Sustain. 2019;11(13):3729. https://doi.org/10.3390/su11133729
38. Gaoue OG, Ticktin T. Impacts of bark and foliage harvest on Khaya senegalensis (Meliaceae) reproductive performance in Benin. J Appl Ecol. 2008;45(1):34-40. https://doi.org/10.1111/j.1365-2664.2007.01381.x
39. Kochare T, Tamir B, Kechero Y. Palatability and animal preferences of plants in small and fragmented land holdings: The case of Wolayta Zone, Southern Ethiopia. Agric Res Technol Open Access J. 2018;14:55-59.
40. Ligate EJ, Wu C, Chen C. Investigation of tropical coastal forest regeneration after farming and livestock grazing exclusion. J For Res. 2019;30(5):1873-1884. https://doi.org/10.1007/s11676-018-0792-5
41. Yasin EHE, Mulyana B. Spatial distribution of tree species composition and carbon stock in Tozi tropical dry forest, Sinnar State, Sudan. Biodiversitas. 2022;23(5):2359-2368. https://doi.org/10.13057/biodiv/d230513
42. Alemu B. The role of forest and soil carbon sequestrations on climate change mitigation. Res J Agric Environ Manag. 2014;3(10):492-505.
43. Elevitch CR, Mazaroli ND, Ragone D. Agroforestry standards for regenerative agriculture. Sustain. 2018;10(9):3337. https://doi.org/10.3390/su10093337
44. Piabuo SM, Minang PA, Tieguhong CJ, Foundjem-Tita D, Nghobuoche F. Illegal logging, governance effectiveness and carbon dioxide emission in the timber-producing countries of Congo Basin and Asia. Environ Dev Sustain. 2021;14176-14196. https://doi.org/10.1007/s10668-021-01257-8

https://doi.org/10.61577/jec.2024.100005