Science for Sustainable Societies

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Strategies for Building Resilience against Climate and Ecosystem Changes in Sub-Saharan Africa

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Preface

This book is the product of over 5 years of collaborative and interdisciplinary research work by scientists and researchers from Ghana and Japan, farmers in local communities in the Tolon and Wa West Districts in the Northern and Upper West Regions of Ghana, and policy agents under the Enhancing Resilience to Climate and Ecosystem Changes in Semi-Arid Africa: An Integrated Approach (CECAR-Africa) project initiated in 2012. CECAR stands for Climate and Ecosystem Changes Adaptation Research. To be more specific, this edited book is a compilation of selected presentations from the first "International Conference on Enhancing Resilience to Climate and Ecosystem Changes in Semi-Arid Africa" under the theme "Adaptation strategies for mitigating impacts of climate and ecosystem changes on developing societies" at the University for Development Studies, Tamale, Ghana, on 6–7 August 2014. The conference was attended by over 140 participants made up of project members, researchers and scientists from academe, and development practitioners and business sectors, government agencies, departments, and ministries from Ghana and over 20 countries across the world to present and discuss research findings. The contributed papers include research findings from both CECAR-Africa project members and non-project members.

The CECAR-Africa project locally operationalized the sustainability science approach by integrating the needs and traditional knowledge of local communities and the use of various quantitative and qualitative research techniques and methods such as field surveys, questionnaires, focal group discussions, land use and cover change analysis, climate downscaling, hydrological model, and crop modeling. Each chapter in the book contributes to understanding and appreciating the effects of climate and ecosystem changes with sub-Saharan Africa (SSA) which is considered to be one of the most vulnerable regions to climate and ecosystem changes. The case studies also provide useful knowledge of collective responses and coping adaptive capacity to enhance overall resilience across scales from local, to regional, to national scales.

This book is designed to be useful for both academics and professionals including policy makers in various government agencies and international organizations, natural resource managers, and local leaders and practitioners. Also, we envision that the book contributes to raising awareness and effective implementation for achieving Sustainable Development Goals (SDGs) in sub-Saharan Africa. This book can be used in both undergraduate and postgraduate courses concerning topics such as localized application of sustainability science, climate change adaptation, resilience, natural resource management, and governance and capacity building.

We also believe that the case studies presented in this book are highly relevant as they show research conducted at a local, national, and regional scale. They will also serve as useful data for consideration in international research and policy activities such as the climate change adaptation research of the Intergovernmental Panel on Climate Change (IPCC) and the regional and subregional assessments of Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES).

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The dedication and diligence of project scientists and researchers from Ghana (University of Ghana, University for Development Studies, Ghana Meteorological Agency, and United Nations University Institute for Natural Resources in Africa) and Japan (the University of Tokyo, Kyoto University, and United Nations University Institute for the Advanced Study of Sustainability) was instrumental in the conceptualization and implementation of the project.

To all the authors who contributed to this book, we say a big thank you for their efforts. We are also grateful to the anonymous reviewers for their valuable and constructive comments which helped improve initial drafts of authors' manuscript.

Above all, we are profoundly grateful to the community members in the project sites in the Tolon district (Yoggu, Cheshagu, Fihini, Daboshe, Zagua, and Kpalgun) and Wa West district (Baleufili, Bankpama, Chietanga, and Zowayeli) of the Northern and Upper West Regions, respectively. Farmers and other community members whose knowledge and information forms the basis for this book were very receptive to researchers and scientists during numerous field visits and community workshops.

Chapter 8
Diversity and Dispersion Patterns of Tree Species Within Household Farmlands and Open Parklands in the Talensi Area of Northern Ghana

Francis Azumah Chimsah, Joseph Saa Dittoh, and Israel Kwame Dzomeku

Abstract Ghana is bedeviled with issues related to dwindling natural resources, particularly tree populations. One of the most fundamental problems faced by community ecologists is how to measure the population sizes and distributions of plant species. In the northern Savanna region, the survival of tree species is being threatened by changes in climate and human activities. This chapter examines the diversity of woody tree species in terms of the size of the population and pattern of dispersion in household farmlands and open parklands in the Talensi area of the Upper East Region of Ghana. In total, 839 individual woody trees (652 in household farmlands and 187 in open parklands) belonging to 78 species were identified. The commonly identified species were *Adansonia digitata* L., *Azadirachta indica* A. Juss., *Ceiba pentandra* (L.) Gaertn, *Diospyros mespiliformis* Hochst. ex A. Rich, *Ficus trichopoda* Baker, *Lannea acida* A. Rich, and *Mangifera indica* L. The variance-to-mean ratios determined for household farmlands and open parklands were 8.97 and 8.99 respectively, indicating clumped dispersion patterns for these tree species in both land types. The findings of this chapter provide a good foundation for ecologists, foresters, developers, and others who are trying to understand the state of tree resources in Ghana in this era of changing climate in order to develop appropriate mitigation strategies.

Keywords Biodiversity • Northern Ghana • Tree species • Dispersion pattern • Tree diversity • Species richness • Species abundance • Species evenness • Climate change

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8.1 Introduction

Ghana's natural resources, particularly tree populations, are in a general state of decline. This problem is more pronounced in the parts of the country that are experiencing the impacts of desertification and climate change. Climate is a key factor that shapes the forest environment; changes in the Earth's climate greatly affect forest ecosystems that are primarily made up of woody tree species by altering the physiology, growth, reproduction, and mortality rates of the trees. Climate change also affects the interactions between trees and pathogens and, most importantly, greatly impacts disturbance regimes (e.g., winds, wildfires, and insect/pest attacks).

Different scientists have attempted to define climate change in different ways. Herein, we refer to two definitions from the Climate Change report (2007), in which the Intergovernmental Panel on Climate Change defines climate change as "a change in the state of the climate that can be identified (for example, using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer." This definition refers to any change in climate over time, whether resulting from natural variability or human activity. The second defines climate change as "a change in climate attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods."

Biological diversity or biodiversity refers to the variety of life on earth. Biodiversity is also defined as the types and numbers of organisms and their patterns of distribution (Barnes et al. 1998). As defined by the United Nations Convention on Biological Diversity, biodiversity includes the diversity of ecosystems, biological species and genes, and the ecological processes that support them. Natural diversity in ecosystems provides essential economic benefits and services to human society, including food, clothing, shelter, energy, fuel, and medicine, along with ecological, recreational, cultural, and esthetic value. Therefore, natural diversity plays a key role in sustainable development. The global state of biodiversity is under threat in many parts of the world. The conservation of biodiversity relies heavily on understanding how plant resources are distributed across complex landscapes, and they can be properly utilized for human livelihood (Cunningham 2001). For example, in their designations of biodiversity hotspots, most conservation agencies recognize the uneven geographic distributions of species rich and rare endemic plants (Myers 2003).

Global biodiversity loss has emerged as a prominent and widespread public issue. In order to conserve biodiversity, thorough understandings of plant vegetation dynamics at the spatiotemporal scale and successional trends are required (Adler and Lauenroth 2003). Furthermore, as indicated by Millar (2003), almost all household incomes in the northern Savanna region of Ghana are obtained directly or indirectly from natural resources, largely those emanating from woodlands.

When addressing the above environmental issues, it is critical to measure the population sizes and distributions of species and consider the differences among communities and species at all levels. Such measurements are necessary for impact assessments (i.e., measuring the effects of disturbances) and restoration ecology (i.e., restoring ecological systems). Ecologists are often interested in the spatial distributions of populations because they provide information about the social behaviors and/or ecological requirements of species.

It is difficult or simply not possible to count all the individual tree species in a target area. The only way around this problem is to estimate population size using some form of sampling. To date, in many parts of the world, few attempts have been made to analyze plant species diversity in human-dominated landscapes, particularly in relation to time scale (Carey et al. 2007; White et al. 2006).

Studies on diversity that employ the appropriate measurement indices would provide important information about the rarity/commonness of different species. The ability to quantify diversity in this way is an important tool for biologists, foresters, developers, and others trying to understand community structure, quantify diversity with calculated indices, and describe an ecosystem numerically.

Different levels of disturbance have different effects on tree species diversity. All conservationists aim to preserve biodiversity within any given area. Thus, there is a need to understand how diversity is affected by different management strategies, because diversity indices go further to provide more details than just the number of species present in a given ecosystem.

This study aimed to measure the richness and abundance of woody tree species within the Talensi area and to determine the dispersion patterns of these species in both household farmlands and open parklands.

In Ghana, the most extensive vegetation type is the Guinea Savanna, which covers approximately 60.8% of the total land area of Ghana (NSBCP 2000). The Talensi area of Northern Ghana falls within the Talensi District of the Upper East Region of Ghana. The Talensi area lies between latitudes 10.15° and 10.60° N and longitudes 0.31° and 10.5° W. The annual rainfall in the area ranges between 645 and 1250 mm with an average of 921 mm. The maximum temperature is 45°C in March and April, and the minimum is 16°C in December. The vegetation is Guinea Savanna woodland and consists of short, widely spread deciduous trees and ground flora (grasses), which are easily burnt by the rampant bush fires. The ecological conditions have given rise to an overreliance on natural resources such as woodlots, forest and forest products, and agricultural land for survival (Map 8.1).

Map 8.1 Map of Northern Ghana (*red region* is the study area) (Source: Google Earth 2016)

8.2 Materials and Methods

8.2.1 Sampling Procedure

Stratified random sampling was employed to select communities, household farmlands, and open parklands. Fifteen communities were randomly selected for the study: Digare, Kolpeliga, Gaare-jogre, Kpatia, Buug, Woog, Yameriga, Tongo-Beo, Puliera, Tongo-wakii, Yinduri, Gorogo, Winkogo-Awaaradone, Balungu-Abienbisi, and Pwalugu. These study communities were further divided into four strata covering the entire geographical coordinates of the area: Talensi Far East (TFE), Talensi Middle East (TME), Talensi Central (TC), and Talensi West (TW). Within each community, data were collected from five household farmlands and two open parklands with square land quadrats of 10,000 m^2. Thus, a total of 105 quadrats were sampled for the study.

8.2.2 Measuring Species Diversity

Species richness and abundance were used to estimate population size, whereas the Shannon-Weiner index of diversity (*H*) was used as a measure of diversity. This index measures the order (or disorder) observed within a particular system (i.e., how a species is distributed in an ecosystem). In most ecological studies, this type of order is characterized by the number of individuals observed for each species in that population. To calculate H, sample populations were selected, and the species in the sampled populations were counted and assessed for abundance.

Mathematically, H is defined as

$$H = -Sum\left(P_i \log\left[P_i\right]\right),$$

where P_i is the proportion of species i. For each tree species considered, P_i was calculated by dividing the number of individuals (species richness) by the total number of individuals (species abundance) for each land type. Species abundance, which indicates the total number of individual species, is important in determining species diversity, which was determined from P_i.

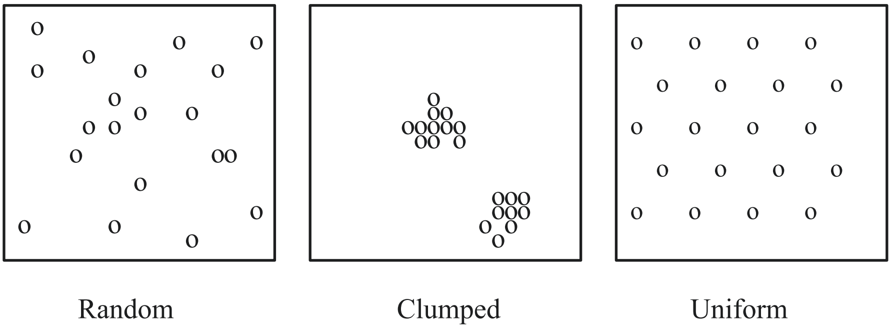
A measure of evenness E was then computed as

$$E = H / \log\left(S\right),$$

where S is species richness. E is a measure of how similar the abundances of different species are. An E value of 1 indicates similar proportions of all subspecies, whereas higher values of E indicate dissimilar abundances (some rare and some common species).

8.2.3 Measuring the Dispersion Patterns of Tree Species

The distribution pattern of a tree species population can be categorized into one of three types: random, uniform, or clumped. In a random distribution pattern, the locations and distribution of all individuals are independent of each other. In a uniform distribution pattern, the occurrence of one individual reduces the likelihood of finding another individual nearby. In a clumped distribution pattern, the occurrence of one individual increases the likelihood of finding another individual nearby; in this case, individuals tend to form groups or clumps (Sokal and Rolf 1981).



Unfortunately, it is often difficult to visually assess the precise spatial distribution of a population of tree species; hence, it is useful to obtain some number (a quantitative measure) that describes the spatial distribution to compare different populations at any location. Therefore, in this study, we employed the variance-to-mean ratio as a statistical tool to describe the spatial distributions of tree species in the Talensi area.

For dispersion pattern, the ratio of variance (s^2) to mean of individuals in each strata within the study area was used as a measure of the degree to which the tree distributions were random, clumped, or uniform (s^2/mean > 1.0 indicates clumped distribution; s^2/mean = 1.0 indicates random distribution; and s^2/mean < 1.0 indicates uniform distribution). *T*-tests were used to determine whether the dispersion patterns were statistically significant based on the calculated variance-to-mean ratios (Lambshead and Hodda 1994; Rice and Lamnshead 1994). The test statistic t was calculated as $t = \{(s^2/\text{mean})–1.0\}/\{\sqrt{2/(n-1)}\}$ where n is the species size or number.

8.3 Results and Discussion

8.3.1 Identified Woody Plant Species

A total of 78 individual woody plant species were identified and studied in household farmlands and open parklands. The most abundant woody tree species (>10 plants) in household farmlands were *Adansonia digitata* L., *Azadirachta indica* A. Juss., *Diospyros mespiliformis* Hochst. ex A. Rich, *Ficus trichopoda* Baker, *Jatropha curcas* L., *Lannea acida* A. Rich, *Mangifera indica* L., *Parkia biglobosa* R.Br. ex G. Don, and *Vitellaria paradoxa* Gaerfn. F.

In the open parklands, the most abundant species (>3 plants) were *Acacia sieberiana* DC., *Anogeissus leiocarpus* (DC) Guill & Perr., *Azadirachta indica* A. Juss., *Combretum collinum* Fresen, *Diospyros mespiliformis* Hochst. ex A. Rich, *Ficus trichopoda* Baker, *Lannea acida* A. Rich, *Tamarindus indica* L., *Vitellaria paradoxa* Gaertn. F., and *Ziziphus abyssinica* Hochst. ex A. Rich.

Table 8.1 lists all of the identified woody tree species in the study area in open parklands and household farmlands. Species are indicated by botanical names and, where applicable, common English names.

Table 8.2 shows the species richness and abundance values in all study strata. Stratum 2 (TME) and Stratum 3 (TC) showed high species richness and abundance values. The analysis of variance of H for all study strata showed no significant difference at $p > 0.05$ in both household farmlands and open parklands in the Talensi area. To ecologists, this means that while household farmlands are more abundant in species than open parklands, the difference in diversity is not significantly different.

Table 8.1 List of woody plant species identified in the Talensi area

Plant code	Common name (English)	Botanical name
01	Acacia	*Acacia gourmaensis* A. Chev
02	Acacia	*Acacia polyacantha* Hochst ex A. Rich
03	Gum Arabic tree	*Acacia senegal* (L) Willd.
04	White thorn	*Acacia sieberiana* DC
05	Baobab	*Adansonia digitata* L.
06	African oak	*Afzelia africana* Smith ex Pers
07	Women's tongue	*Albizia lebbeck* (L) Benth.
08	Cashew	*Anacardium occidentale* L.
09	African birch	*Anogeissus leiocarpus* (DC) Guill & Perr.
10	Wild custard apple	*Annona senegalensis* Pers.
11	Neem	*Azadirachta indica* A. Juss.
12	Thorn tree	*Balanites aegyptiaca* L. (Del.)
13		*Bauhinia rufescens* Lam.
14	Red kapok	*Bombax costatum* Pellegr & Vuillet
15	Elephant palm	*Borassus aethiopum* Mart.
16	Sodom apple	*Calotropis procera* Ait. F.
17	Pawpaw	*Carica papaya* L.
18	Drum stick tree	*Cassia sieberiana* DC
74		*Catharanthus roseus* L.
19	Kapok	*Ceiba pentandra* (L.) Gaertn.
20	African nettle	*Celtis integrifolia* Lam.
21	Orange	*Citrus sinensis* (L.) Osbeck
22		*Combretum collinum* Fresen
23		*Combretum glutinosum* Perr. ex Dc
24		*Combretum nioroense* Aubrév. ex Keay
25		*Combretum paniculatum* Vent.
28	Flamboyant	*Delonix regia* (Boj.) Raf
26		*Detarium microcarpum* G. Don.
27	Ebony tree	*Diospyros mespiliformis* Hochst. ex A. Rich
29		*Ekebergia senegalensis* A. Juss.
30	Oil palm	*Elaeis guineensis* Jacq
31		*Entada africana* Guill. & Perr.
32	Coral tree	*Erythrina senegalensis* DC
33		*Erythrina sigmoidea* Hua
34	Eucalyptus	*Eucalyptus citriodora* Hook
35	Cactus	*Euphorbia kamerunica* Pax
36	Winter thorn	*Faidherbia albida* (Del.) Chev.
37	Ficus	*Ficus sycomorus* C.C. Berg
38	Ficus	*Ficus trichopoda* Baker
39		*Gardenia erubescens* Stapf & Hutch
40		*Gardenia aqualla* Stapf & Hutch

(continued)

Table 8.1 (continued)

Plant code	Common name (English)	Botanical name
41		*Gliricidia sepium* (Jacq.) Walp
42	White teak	*Gmelina arborea* Roxb.
43		*Grewia cissoides* Hutch. & Dalz.
44	Doum palm	*Hyphaene thebaica* (L.) Mart.
45		*Ipomoea carnea* D. Austin
46	Barbados nut	*Jatropha curcas* L.
47	Wild cassada	*Jatropha gossypiifolia* L.
48	Mahogany	*Khaya senegalensis* A. Juss.
49	Sausage tree	*Kigelia africana* Lam.
50		*Lannea acida* A. Rich.
51		*Lannea velutina* A. Rich.
52		*Lucernia spp.* L.
53	Mango	*Mangifera indica* L.
54	Moringa	*Moringa oleifera* Lam.
55		*Ozoroa insignis* Del.
56	Dawadawa	*Parkia biglobosa* R.Br. ex G. Don
57	Camel's foot	*Piliostigma thonningii* Milne-Redh
58	Guava	*Psidium guajava* L.
59	Senegal Redwood	*Pterocarpus erinaceus* Poir
60	Castor plant	*Ricinus communis* L.
61	African peach	*Sarcocephalus latifolius* (Smith) Bruce
62		*Sclerocarya birrea* Hochst
63		*Securinega virosa* Voigt
64	Cassia	*Senna siamea* Lam.
65	Karaya gum tree	*Sterculia setigera* Del.
66		*Strophanthus sarmentosus* DC
67	Monkey ball tree	*Strychnos spinosa* Lam.
68	Tamarind	*Tamarindus indica* L.
69	Teak	*Tectona grandis* L.
70		*Terminalia avicennioides* Guill. & Perr.
71		*Terminalia glaucescens* Planch.
72		*Terminalia montalis* Laws
73	Milk bush	*Thevetia neriifolia* Juss.
75	Shea	*Vitellaria paradoxa* Gaertn. F.
76	Blackberry	*Vitex doniana* Sweet
77	Catch thorn	*Ziziphus abyssinica* Hochst. ex A. Rich
78	Buffalo thorn	*Ziziphus mucronata* Willd.

The identified tree species, both native and introduced, fall within the general inventory of woody plant species of the Northern Savanna Biodiversity Conservation Project (NSBCP 2000). The open parklands were marked by a richness of woody perennials similar to those found in several other tropical savanna grasslands (Brown 1997).

Table 8.2 Species diversity for household farmlands and open parklands in the four study strata

Study stratum	Household farmlands				Open parklands			
	Richness	Abundance	Diversity (*H*)	Evenness (*E*)	Richness	Abundance	Diversity (*H*)	Evenness (*E*)
Strata 1 (*TFE*)	37	164	0.30	0.07	17	26	0.36	0.09
Strata 2 (*TME*)	40	132	0.27	0.06	26	45	0.34	0.08
Strata 3 (*TC*)	40	227	0.27	0.06	30	81	0.30	0.07
Strata 4 (*TW*)	35	134	0.31	0.07	25	37	0.34	0.08

Strata key: *TFE* Talensi Far East, *TME* Talensi Middle East, *TC* Talensi Central, and *TW* Talensi West

Table 8.3 Species diversity in household farmlands and open parklands

Land type	Richness (number of species)	Abundance (number of individuals)	Diversity (*H*)	Evenness (E_H)
Household farmlands	60	657	1.15	0.26
Open parklands	49	189	1.34	0.34

Species richness is the simplest of subspecies diversity. The number of species per sample in a location is a measure of richness. The more species present in a sample, the richer the sample. Richness does not account for the proportion and distribution of each subspecies within a stratum. *Species abundance* gives an indication of the total number of individual species present in a given location. In all the study strata, household farmlands were richer in species than open fields, as shown in Table 8.2 above. *Species evenness* is a measure of the relative abundance of the different species making up the richness in an area. As species richness and evenness increase, diversity also increases (Table 8.3).

The species abundance in household farmlands was much greater (657) than in open parklands (189). Diversity based on the Shannon-Weiner index *H* was slightly different for household farmlands (1.15) and open parklands (1.34). To the ecologist, this indicates that household farmlands are more abundant in species than open parklands but relatively low in diversity. According to Rosenzweig (1995), diversity indices provide more information than the number of species present (i.e., they account for some species being rare and others being common). These findings imply that household farmlands contain more of the commonly seen and known species compared to open parklands; this indicates that ecological planners should consider farmlands with households since most of the tree species are well cared for and protected.

Evenness (E_H), which indicates the relative abundance of species, was relatively low for both household farmlands and open parklands (0.26 and 0.34, respectively).

Table 8.4 Dispersion patterns of species based on variance-to-mean ratios

Land type	Mean	Variance (s^2)	s^2/mean	Pattern indicated	t	Significant? (yes/no)
Household farmlands	164.25	1473.18	8.97	Clumped	3.26	Yes
Open parklands	47.25	425.18	8.99	Clumped	3.27	Yes

According to Begon et al. (1996), E_H assumes a value between 0 and 1, with 1 indicating complete evenness. According to Roth et al. (1994), evenness also indicates the level of disturbance in a field and shows how equitably the species are distributed.

8.3.2 *Dispersion Patterns of Tree Species in the Talensi Area*

As shown in Table 8.4, the variance-to-mean ratios for household farmlands and open parklands were greater than 1, indicating clumped dispersion pattern of tree species in both land types. In a clumped dispersion, the occurrence of one individual increases the likelihood of finding another individual nearby. In this study, some quadrats contained a large number of individuals, whereas others were empty. The clumped distributions in this study may be attributed to several factors. However, Sokal and Rolf (1981) reported that clumped distributions in plants may also occur because of slight variations in soil chemistry or moisture content.

According to Lambshead and Hodda (1994), the test statistic t can be used to determine the significance level of a known dispersion pattern based on the calculated variance-to-mean ratio. The absolute values of t determined for household farmlands and open parklands in this study were 3.26 and 3.27, respectively. Values greater than 1.96 indicate statistical significance (at a 95% confidence level); thus, the clumped distribution patterns in this study were significantly different from the other patterns (random and uniform).

8.4 Conclusion

Understanding biodiversity in an ecosystem in the current changing climate is critical. In this paper, we examined diversity in two land types, household farmlands and open parklands. We also examined these land types in terms of species richness, abundance, and dispersion patterns.

A total of 78 woody plant species were identified and studied. We found that household farmlands have greater species richness and abundance than open parklands, whereas the two land types were not significantly different in terms of species diversity. The values of species richness and abundance for both land types were high in two of the four study strata: Stratum 2 (TME) and Stratum 3 (TC). Household farmlands were much higher in species abundance (657) than open parklands (189).

Evenness (E_H) was low for both household farmlands and open parklands (0.26 and 0.34, respectively). The tree species in both land types in the Talensi area were found to exhibit clumped dispersion patters, indicating a large variation in species numbers between the different quadrats of the study area.

This study on species abundance and dispersion pattern provides important information about tree species in the Talensi area. The ability to quantify diversity in this manner is critical to determine the effects of climate change on tree species diversity and enhance the production of food crops, fibers, fuelwood, and cash crops.

8.5 Recommendations

It is recommended that local citizens should be encouraged to adopt the system of farm forestry as they continue maintaining and planting already existing indigenous tree species and at the same time incorporating them with other exotic plants rather than cutting indigenous tree species with the aim of planting exotic plants.

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