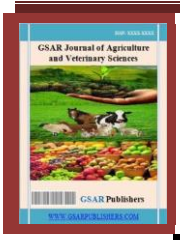

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Species Association Patterns of *Prosopis Africana* with Woody Species in North Eastern Nigeria Savanna Ecosystem

By

Soba T.M[1]., H.I. Ndagi[1], and Masok L.J.[2],

[1]Department of Forestry, Wildlife and Ecotourism, Nasarawa State University, Keffi, Nigeria
[2]Department of Geography Federal College of Education Odugbo, Benue State, Nigeria

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Abstract

Rapid deforestation, bush burning, overgrazing, and increasing agricultural expansion have continued to threaten the survival and ecological relationships of indigenous woody species within the savanna ecosystems of North Eastern Nigeria, thereby creating serious concerns for biodiversity conservation and ecosystem sustainability. This study investigated the species association patterns of Prosopis africana with woody species in the savanna ecosystems of North Eastern Nigeria. The study was conducted in three protected areas namely Wawa-Zange Forest Reserve in Gombe State, Yankari Game Reserve in Bauchi State, and Gashaka-Gumti National Park in Taraba and Adamawa States. A systematic sampling technique involving transects, clusters, and sample plots was adopted for data collection. All woody species with diameter greater than 10 cm within the plots were identified and recorded. Species association was analyzed using Chi-square (χ^2), Phi coefficient, and Cramér's V statistics to determine the significance, strength, and direction of associations between P. africana and other woody species. The findings revealed that P. africana had significant positive associations with forty-two woody species across the study areas. Species such as Combretum glutinosum, Dialium guineense, Vitellaria paradoxa, Strychnos spinosa, and Pterocarpus erinaceus showed very high Chi-square and Cramér's V values, indicating strong ecological relationships with P. africana. Positive Phi values further confirmed strong positive coexistence among the associated species. The study concluded that P. africana plays an important ecological role in maintaining savanna biodiversity and ecosystem stability. The study recommends sustainable conservation practices, afforestation programmes, and effective control of anthropogenic disturbances to preserve the species and associated woody vegetation within the savanna ecosystem.

INTRODUCTION

Savanna ecosystems constitute one of the largest and most ecologically significant vegetation formations in tropical Africa. They are characterized by the continuous interaction between grasses and woody plant species under seasonal climatic conditions, especially alternating wet and dry periods. The African savanna supports a wide range of biodiversity and provides several ecological functions, including nutrient cycling, soil conservation, carbon sequestration, watershed protection, and habitat provision for wildlife species (Scholes and Archer, 1997). In Nigeria, the savanna ecosystem occupies a substantial portion of the northern region and is broadly divided into the Guinea, Sudan, and Sahel savanna zones. These ecosystems are highly influenced by environmental factors such as rainfall variability, soil properties, fire occurrence, grazing intensity, and anthropogenic activities, all of which determine the structure, composition, and distribution of woody vegetation (Sankaran *et al*., 2005). The interaction among woody species within savanna ecosystems contributes significantly to vegetation dynamics and ecosystem stability. Consequently, understanding species association patterns is important for effective biodiversity conservation and sustainable management of savanna resources.

Among the numerous woody species found within the Nigerian savanna ecosystem, *Prosopis africana* is recognized as one of the most valuable indigenous multipurpose tree species. The species belongs to the family Fabaceae and is widely distributed across the savanna regions of West and Central Africa (Orwa *et al.*, 2009). *Prosopis africana* provides

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several socioeconomic and ecological benefits, including the production of timber, charcoal, fuelwood, fodder, traditional medicine, and fermented food condiments from its seeds. Ecologically, the species contributes to soil fertility improvement through nitrogen fixation and organic matter accumulation, thereby enhancing productivity within agroforestry and natural ecosystems (Teklehaimanot, 2004). Due to its resilience to drought and harsh environmental conditions, the species is commonly retained on farmlands and grazing areas by local communities. However, unsustainable exploitation, agricultural expansion, bush burning, overgrazing, and climate variability have contributed to the continuous decline in the population of *Prosopis africana* across many savanna landscapes (Ouédraogo *et al*., 2006). This decline poses serious ecological and socioeconomic concerns, particularly in regions where rural livelihoods depend heavily on savanna tree resources.

Species association studies are essential in vegetation ecology because they provide insight into the relationships and interactions that exist among plant species within a community. Such associations may be positive, negative, or neutral depending on environmental conditions and resource availability. Positive associations often indicate similarities in ecological requirements or mutual facilitation, while negative associations may reflect competition for nutrients, moisture, light, or space (Kent, 2012). In savanna ecosystems, woody species association patterns are influenced by climatic conditions, topography, disturbance regimes, and human activities (Walker and Noy-Meir, 1982). Investigating the association patterns of *Prosopis africana* with other woody species in the North Eastern Nigerian savanna ecosystem provided valuable information on vegetation structure, species coexistence, ecological adaptation, and community dynamics. The findings from this study contributed to biodiversity conservation, ecological restoration, and the development of sustainable management strategies aimed at protecting indigenous woody species and maintaining the ecological integrity of the savanna ecosystem

MATERIALS AND METHODS

Description of the Study Area

The study was conducted in the northeastern region of Nigeria, situated between latitudes 6° 26′–13° 45′N and longitudes 8° 42′–14° 39′E. This region includes the states of Borno, Yobe, Bauchi, Gombe, Adamawa, and Taraba. Covering an area of 262,578 km², the region is projected to have a population of approximately 26 million people, which constitutes around 12% of Nigeria's total population (National Population Commission [NPC], 2006). The climate is characterized by relatively high temperatures year-round, with average annual temperatures ranging from 28.32°C in Yola to 25.92°C in Bauchi. Rainfall varies across the region, from 467 mm in Nguru to 1,091 mm in Ibi (Hassan *et al.*, 2017). The study was carried out in a forest reserve, a game reserve, and a national park, located in the states of Gombe, Bauchi, and Taraba, respectively. The forest reserve was the Wawa-Zange Forest Reserve in Dukku Local Government Area of Gombe State. The game reserve was the Yankari Game Reserve in Alkaleri Local Government Area of Bauchi State. The national park was the Gashaka-Gumti National Park, spanning both Taraba and Adamawa States in northeastern Nigeria.

Wawa- Zange Forest Reserve

The Wawa-Zange Forest Reserve, located in Gombe State, was established in 1962 and lies within the Sudan Savannah vegetation zone of Sub-Saharan Africa. Positioned at latitudes 10° 49' 22"N and 10° 46' 23"E, and at an elevation of 411 meters above sea level, the reserve spans an area of 1,536.57 km² (153,657 hectares), straddling the Dukku and Funakaye Local Government Areas (Abba *et al.*, 2022). The reserve is home to seven major settlements: Zange, Bozonshulwa, Tappe, Shuwe, Dile, Wasado, and Wawa. The region experiences a climate marked by two distinct seasons: the rainy season from May to October, and the dry season from November to April. During the dry season, temperatures often exceed 40°C, especially in the hottest months of March and April, while the wet season sees an average temperature of around 24°C, with an annual rainfall averaging 850 mm (Hayatu and Abba, 2021). The topography of the reserve is predominantly mountainous, with undulating and hilly terrain in the southeast, while the northern, northeastern, western, and northwestern parts are largely flat plains. The reserve is primarily characterized by woodland, particularly in the southeastern and southwestern regions, with a light-closed canopy of stunted shrubs and trees ranging from 4.87 to 6.09 meters in height, and a sparse undergrowth of grasses (Abba *et al.*, 2022). Notable tree species found in the reserve include *Parkia biglobosa*, *Combretum mole*, *Afzelia africana*, *Prosopis africana*, *Urena lobata*, *Palisota hirsuta*, *Cassia rotundifolia*, *Amorphophallus abyssinicus*, *Corchorus olitorius*, and *Palisota hirsuta* (Abba and Timothy, 2021).

Yankari Game Reserve

Yankari was designated as Nigeria's first Game Reserve in 1956 and was later upgraded to a National Park in 1991. Yankari National Park was reverted to Yankari game reserve in 2006 (Habu and Muhammad, 2017). This long period of conservation has allowed the park to become the country's leading wildlife area and a major tourist destination. Located between latitudes 9° 40' 00" N and 10° 00' 00" N, and longitudes 10° 20' 00" E and 10° 40' 00" E, it spans the Duguri, Pali, and Gwana districts within the Alkaleri Local Government Area of Bauchi State, covering an area of 224,400 hectares (Ezealor, 2001). The park experiences annual rainfall ranging from 350 mm to 1,300 mm, with an average annual temperature of 32°C (Ayoade, 2000). The soils in the region are primarily clay loams, with alluvial soils found along the Fadama areas. The soils are typically dark and rich in humus in the "A horizon," while lateritic soils dominate the "B horizon" (Udo, 2000). Yankari is divided by the Gaji River, and two main habitat types can be identified: dry savanna woodlands and riparian vegetation, which includes fadama areas. The dry savanna woodlands are home to a variety of tree species such as *Afzelia africana*, *Burkea africana*, *Pterocarpus erinaceus*, *Isoberlinia doka*, *Monotes kerstingii*, *Combretum glutinosum*, *Detarium microcarpum*, and *Anogeissus leiocarpus*. Common shrubs include *Gardenia*

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aquallam and *Dichrostachys glomerata*, while the dominant grasses are *Hyparrhenia involucrata* and *Hyparrhenia bagirmica*. In the riparian forests, species such as *Khaya senegalensis*, *Vitex doniana*, *Acacia sieberiana*, *Tamarindus indica*, *Borassus aethiopum*, and *Daniella oliveri* are common. One of the defining features of Yankari is the presence of large, monodominant stands of *Pteleopsis habeensis*, which grow in the drier regions along riverbanks. In the seasonally flooded fadamas, *Ficus spp*. and *Mitragyna sp. d*ominate the tree layer, while *Mimosa pigra* dominates the shrub layer (Ezealor, 2001).

Gashaka Gumti National Park (GGNP)

Gashaka-Gumti National Park is situated in the remote mountainous region of Northeastern Nigeria, straddling the borders of Adamawa and Taraba states (Sahabo, 2019), and encompasses an area of approximately 6,411 km² (Madaki *et al.*, 2020). The park's name derives from two of the region's oldest and most historically significant settlements Gashaka village in Taraba state and Gumti village in Adamawa state (Usman *et al.*, 2022). It is located between latitudes 6° 55'N and 8° 05'N, and longitudes 11° 13' E to 12° 11' E (Madaki *et al.*, 2020). Ecologically, the park lies within the Guinea Savannah Zone of sub-Saharan Africa, in the subtropical highlands of southeastern Nigeria, south of the River Benue (Sahabo, 2019). The region experiences an average temperature range between 21°C and 32.5°C and has a distinct dry and wet season (Usman *et al.*, 2022). The rainy season typically spans from March or early April through mid-November (Umar *et al.*, 2019), with rainfall ranging from 1,200 mm in the northern part of the park to 3,000 mm in the south (Dunn, 1999). The high rainfall is facilitated by the area's mountainous terrain, where humidity from the Atlantic is lifted into higher elevations, cools, and condenses to form rain-bearing clouds, supporting the growth of moist forests (Umar *et al.*, 2019).

The park is divided into two sectors: the northern Gumti sector in Adamawa State and the southern Gashaka sector in Taraba State. It serves as the primary watershed for the Taraba River, a major tributary of the River Benue, and shares an international boundary with Cameroon, adjacent to Faro National Park. To the south of the park lies the impressive Mambila Plateau (Sahabo, 2019). Within Gashaka-Gumti National Park, seven distinct habitat types are found: lowland gallery

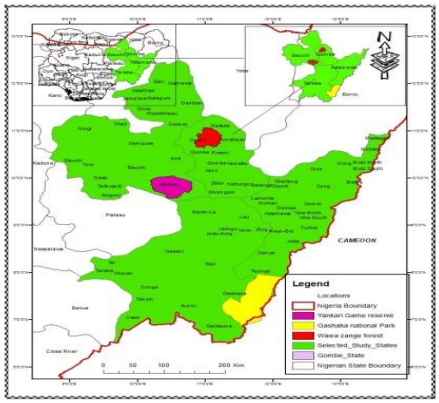

FIGURE 1: Map of Nigeria Showing North East States, Bauchi, Taraba, Adamawa and Gombe State, Wawa Zange, Yankari, and Gashaka Gumti National Park

Sources: Zin Geo partial (2024)

forest, riparian forest, montane forest, derived savanna, southern and northern guinea savanna, and montane grassland (Dishan *et al.*, 2010). The northern Gumti sector is predominantly woodland, characterized by tall grasses and trees with short boles and broad leaves. Some of the commonly occurring tree species in this sector include Acacia spp., *Afzelia africana, Khaya senegalensis, Daniella oliverii*, *Isoberlina doka*, and *Vitellaria paradoxa* (Akinsoji, 1994). In contrast, the southern Gashaka sector is mainly southern guinea savanna, with dominant tree species such as *Albizia gummifera, Afzelia africana, Symphonia globulifera, Mallettia spp., Triplochyton schleroxylon*, and *Aubrvillea kerstingii* (Dishan *et al.*, 2010).

Sampling Method

Site Selection

There are six States in North eastern Nigeria; they include Borno, Bauchi, Adamawa, Taraba, Yobe, and Gombe. Gombe, Bauchi, Taraba and Adamawa State were purposively selected for this study based on the presence of functional protected areas, accessibility, vegetation type and the presence of target tree species. The following protected areas were randomly selected from the list of the reserves in this study; Wawa-Zange Forest Reserve in Dukku and Funakaye Local Government Areas of Gombe State, Yankari Game reserve in Alkaleri Local Government Area of Bauchi State and Gashaka Gumti National Park of Taraba and Adamawa State.

Choice of Trees Species

The choice of trees species for this study was based on the literature reviews that reported their multiple economic benefits drives from food, medicine, timber, fuel, and agroforestry (Saleh *et al.*, 2021). The *Daniellia oliveri*, is one of the most widespread and ecologically important plants species, with broad distribution across tropical and subtropical regions. The tree species belong to the Fabaceae family and is commonly found in savanna ecosystems, where it plays a significant ecological and socio-economics roles. The trees species have been reported to occur in almost all the natural protected reserves areas within the savannah region where the

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study was carried out as noted by Christenhusz and Byng, (2016).

Sample Plots

Three protected areas (natural forest) were used. In each of the protected area 2 transects lines of 2,000m were established. On each transect 2 clusters of 500 x 500m square were systematically located at 1,000m interval, this gave a total of 4 clusters per study protected area and 12 clusters for the entire three study protected areas. In each cluster, 5 plots of 20m x20m square were established, such that 4 plots were at the vertex and 1 plot at the center as adopted by Soba *et al.* (2023). This gave a total of 20 plots per study location, 60 plots for the entire study.

Data Collection

All the tree species (> 10cm in diameter) found within the sample plots were generally identified, counted and documented for the study locations as adopted by Nurochman *et al.*, (2018).

Statistical Analysis

Association between the study tree species and other tree species found in the study plots were analyzed using Chi-Square (χ^2) as modified by Denny *et al.*, (2021).

$$\chi^2 = \frac{(ad-bc)^2 xN}{(a+b)(c+d)(a+c)(b+d)} \quad \text{.....eqn1}$$

Where:

χ^2 = Chi-square

a = Number of plots containing both species A and B

b = Number of plots containing species A only

c = Number of plots containing species B only

d = Number of plots that does not contain both species A and B

N = Number of plots

The calculated Chi-Square was compared to the Chi-Square table (χ^2 table) at free degrees (df) of 1 at the level of 1 % and 5%, to determine the association between the species. If the calculated χ^2 is greater than or equal to the χ^2 table at a 1% level means that the association is very significant. If the calculated χ^2 is greater or equal to the χ^2 table at the 5% level means the association significant. Finally, if the calculated table is less than the χ^2 table at a 5% level means no association or the association is not significant.

Furthermore, the Phi and Cramér's V values was used to determine the strength and direction of the association:

Cramér's V values between 0 and 1:

- 0.00 to 0.10: Very weak or no association.
- 0.10 to 0.30: Weak association.
- 0.30 to 0.50: Moderate association.
- 0.50 and above: Strong association.

If the Phi value is Positive or negative from the calculation, the results indicate positive or negative associations between the two species.

RESULTS AND DISCUSION

The findings of the association between *Prosopis africana* and forty-two (42) other tree species within the study plots is presented in Table 1. The results indicate that significant positive association exist between the tree species. The findings also show that tree species such as *Dialium guineense, Terminalia microptera, Sterculia setigera,* and *Combretum glutinosum*, exhibit a high and positive correlation with *Prosopis africana*. The Chi-Square values of these species were also extremely high, such as 61.504 for *Dialium guineense* and 65.320 for *Combretum glutinosum*. These high Chi-Square values indicate a high association with *Prosopis africana*. The p-value for both species is given as 0.000, demonstrating that *P. africana*'s correlations with these particular species are extremely significant. For example, both *Strychnos spinos* and *Pterocarpus erinaceous* had a p-value of 0.000, highlighting the fact that these kinds of relations are not arbitrary. A p-value of this sort corroborates the assertion that the likelihood of such associations arising at random is minimal, therefore implying the ecological relation between *P. africana* and the species under study to be significant. A similar study by Usman (2015), on biodiversity and species interactions along altitudinal gradients in the Atlantika Mountain range in Koma, Adamawa State, Nigeria, revealed that positive correlations were found among species with similar environmental needs in savanna habitats.

Trees species such as *Sterculia setigera*, *Strychnos spinos* and *Guiera senegalensis* had high Cramér's V values of 0.707, 0.714 and 0.709 respectively which indicated a strong relationship. These values attested to the fact that *P. africana* had close and positive association with these species. This is beyond coincidence and suggests that the species are cooperating in a common environment, perhaps enjoying the same soil, climatic, or ecological niche functions within the environment. The Phi values, which quantify the strength of the association, are all positive and ranged from 1.0 to 1.035. A positive Phi coefficient means that as the abundance of *P. africana* increases, there is a greater chance of the presence of the other species. For instance, *Burkea africana* had Phi value of 1.000 and *Guiera senegalensis* had Phi value of 1.002 were highly positively correlated with *Prosopis africana*. The results are consistent with the results of Liu *et al*. (2012), who reported that species with high Phi values are likely to have complementary

Table 1: *Prosopis africana* is Association with other Tree Species in the Study Area

Tree Species	Chi-Square (χ^2)	Df	p-value	Cramér's V	Phi	Strength of Association	Direction of Association
Dialium guineense	61.504[a]	4	.000**	.710	+1.004	Strong association	Positive
Terminalia microptera	61.006[a]	4	.000**	.707	+1.000	Strong association	Positive

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Sterculia setigera	61.025[a]	4	.000**	.707	+1.000	Strong association	Positive
Combretum glutinosum	65.320[a]	4	.000**	.732	+1.035	Strong association	Positive
Strychnos spinos	62.245[a]	4	.000**	.714	+1.010	Strong association	Positive
Pterocarpus erinaceous	62.109[a]	4	.000**	.714	+1.009	Strong association	Positive
Anageisus leiocarpus	61.302[a]	4	.000**	.709	+1.002	Strong association	Positive
Guiera senegalensis	61.264[a]	4	.000**	.709	+1.002	Strong association	Positive
Isobalinia doka	61.222[a]	4	.000**	.708	+1.002	Strong association	Positive
Securidaca longepedunculata	61.979[a]	4	.000**	.713	+1.008	Strong association	Positive
Burkea Africana	61.006[a]	4	.000**	.707	+1.000	Strong association	Positive
Parinary excelcia	61.504[a]	4	.000**	.710	+1.004	Strong association	Positive
Grewal molle	61.099[a]	4	.000**	.708	+1.001	Strong association	Positive

Table 2. Cont'd: *Prosopis africana is* Association with other Tree Species in the Study Area

Tree Species	Chi-Square (χ^2)	Df	p-value	Cramér's V	Phi	Strength of Association	Direction of Association
Combretum nigricans	63.377[a]	4	.000**	.721	+1.019	Strong association	Positive
Afzelia Africana	61.222[a]	4	.000**	.708	+1.002	Strong association	Positive
Combretum lamprocarpum	62.534[a]	4	.000**	.716	+1.012	Strong association	Positive
Hymenocardia acida	61.154[a]	4	.000**	.708	+1.001	Strong association	Positive
Bombax buonopozense	61.007[a]	4	.000**	.707	+1.000	Strong association	Positive
Ziziphus mucronate	62.109[a]	4	.000**	.714	+1.009	Strong association	Positive
Strerospernum kunthinum	61.732[a]	4	.000**	.711	+1.006	Strong association	Positive
Commiphora Africana	61.504[a]	4	.000**	.710	+1.004	Strong association	Positive
Deutarium marcrocarcum	61.302[a]	4	.000**	.709	+1.002	Strong association	Positive
Spondias pinnata	61.861[a]	4	.000**	.712	+1.007	Strong association	Positive
Myrianthus serratus	61.616[a]	4	.000**	.711	+1.005	Strong association	Positive
Tricalysia cherelieri	61.504[a]	4	.000**	.710	+1.004	Strong association	Positive
Parkia biglobosa	63.377[a]	4	.000**	.721	+1.019	Strong association	Positive

Table 3. Cont'd: *Prosopis africana is* Association with other Tree Species in the Study Area

Tree Species	Chi-Square (χ^2)	Df	p-value	Cramér's V	Phi	Strength of Association	Direction of Association
Dichrostochiya cinera	61.044[a]	4	.000**	.707	+1.000	Strong association	Positive
Searsia lancea	61.111[a]	4	.000**	.708	+1.001	Strong association	Positive

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Daniella oliveri	61.027[a]	4	.000**	.707	+1.000	Strong association	Positive
Cassia singuena	61.111[a]	4	.000**	.708	+1.001	Strong association	Positive
Ekebergia capensis	61.074[a]	4	.000**	.708	+1.001	Strong association	Positive
Haemotostolopis barteri	61.190[a]	4	.000**	.708	+1.002	Strong association	Positive
Grewia bicolor	62.688[a]	4	.000**	.717	+1.014	Strong association	Positive
Vitellaria paradoxa	65.168[a]	4	.000**	.731	+1.034	Strong association	Positive
A.senegalensis	61.504[a]	4	.000**	.710	+1.004	Strong association	Positive
Grewol molle	61.504[a]	4	.000**	.710	+1.004	Strong association	Positive
Lofera alata	61.372[a]	4	.000**	.709	+1.003	Strong association	Positive
Crosepteric fenifoga	62.154[a]	4	.000**	.714	+1.009	Strong association	Positive

Table 4. Cont'd: *Prosopis africana is* Association with other Tree Species in the Study Area

Tree Species	Chi-Square (χ^2)	Df	p-value	Cramér's V	Phi	Strength of Association	Direction of Association
Ficus zycomus	64.623[a]	4	.000**	.728	+1.029	Strong association	Positive
Ioparka thugansis	62.098[a]	4	.000**	.713	+1.009	Strong association	Positive
Neocarya macroptera	64.623[a]	4	.000**	.728	+1.029	Strong association	Positive
Nuclear latifolia	61.919[a]	4	.000**	.712	+1.008	Strong association	Positive

Sources: Field Survey, 2024

Ecological functions, including resource partitioning and facilitation. This implies that such species are likely to co-occur within the same habitats and are also likely to interact positively, possibly through shared pollinator activities or comparable growth habits.

Conclusion

The study showed that *P. africana* had strong and significant positive associations with many woody species in the savanna ecosystems of North Eastern Nigeria. High Chi-square, Cramér's V, and positive Phi values indicated that the species coexists closely with several indigenous trees due to similar ecological requirements and habitat conditions. The findings highlight the ecological importance of *P. africana* in maintaining savanna biodiversity and ecosystem stability within the protected areas studied. However, increasing human activities such as deforestation, bush burning, and overgrazing may threaten these important species associations and the sustainability of the ecosystem.

Recommendations

Conservation measures should be strengthened to protect *P. africana* and its associated woody species in the savanna ecosystem. Afforestation and reforestation programmes involving indigenous tree species should be encouraged, while unsustainable activities such as indiscriminate tree felling and bush burning should be controlled. Environmental awareness should also be promoted among local communities to encourage sustainable utilization and conservation of savanna vegetation.

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*Corresponding Author: **Soba T.M.**
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