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Full Length Research Paper

How far can climate changes help to conserve and restore *Garcinia kola* Heckel, an extinct species in the wild in Benin (West Africa)

Akotchiffor Kévin G. DJOTAN*, Augustin Kossi N. AOUDJI, Sylvie Akouavi F. CODJIA, Alain J. GBÈTOHO, Kourouma KOURA and Jean Cossi GANGLO

Laboratoire des Sciences Forestières, Faculté des Sciences Agronomiques, Université d'Abomey-Calavi, BP: 1493 Calavi, Bénin.

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A study was conducted to assess how well climate changes can help to conserve and restore *Garcinia kola* Heckel in the Protected Area Network (PAN) and in urban areas in Benin. To achieve this, occurrence data from GBIF was used and the environmental data from AfriClim was used in order to model the species' potential habitat under current and future climates. The maximum entropy modeling approach of MaxEnt was used with scenarios RCP4.5 and RCP8.5 for future predictions. Geographic information systems were used to establish the high confidence prediction areas (HCPA) for *G. kola*. Gap analysis was performed throughout PAN and municipalities with regard to the HCPA. Considering the climate envelop, results revealed that climate change prooved to have only positive consequences on the distribution of the species. Moreover, considering the HCPA, the percentage of municipalities that were suitable for the species is far above the percentage of PAN that was predicted as suitable (7.44% versus 0.93%). RCP4.5 and RCP8.5 indicated respectively 3.00 and 6.27% of PAN as positive climate change impact zones. As for the municipalities, it was respectively 13.60 and 17.60% of the total municipalities areas. Therefore, it is not worth relying only on PAN to conserve and restore the species, rather urban forestry and reforestation in PAN may be key actions to save this genetic resource. Further studies with regard to introduction of *G. kola* in urban areas and its use for reforestation are compulsory.

Key words: *Garcinia kola*, Urbanization, climate change, medicinal woody plants, biodiversity conservation.

INTRODUCTION

Human activities threaten highly tropical forests (Htun et al., 2011; Bargali et al., 2015; Baboo et al., 2017). Clearing the half of the world's residual forests would remove 85% of all the species that inhabit them (Pimm

*Corresponding author. E-mail: geoffroydjotan@yahoo.fr.

and Raven, 2000). In tropical forests, natural and biotic disturbances as well as habitat alterations cause continuous loss of more than one higher plant species per day (Myers, 1990), a disappearance of 20 ha forests and destruction of more than 1800 populations per hour (Hughes et al., 1997), and loss of species populations at a percentage rate of 3 to 8 times than the rate of species extinction (Costanza et al., 1997).

Garcinia kola (Heckel) also known as "bitter kola" is one of multiple non-timber forest products that is of socio-economic importance in Benin (Akoegninou et al., 2006; Assogbadjo et al., 2017) and in the sub region (Yakubu et al., 2014). The species belongs to the top ten priority non-timber forest products in Benin (Assogbadjo et al., 2017). *G. kola* is also a medicinal tree species that provides active compounds for the treatment of many diseases (Esimone et al., 2002; Farombi et al., 2005). It occupies the third rank of medicinal plants in Benin in terms of number of recipes in which the species is incorporated (Souza de, 2001). Some of its medicinal uses include the treatment of cough, of imminent abortion, diabetes, palpitations, colic, of dysmenorrheas, jaundice, anaemias, etc. (Akoegninou et al., 2006).

G. kola belongs to the Benin red list of IUCN and has been listed since 2011 as extinct in the wild (Neuenschwander et al., 2011). The use of the species for vegetable toothbrush and the trade of its nuts constitute the main threats (Neuenschwander et al., 2011). In fact, the species' high interest because of its multipurpose character (Rai, 2003) results in its overexploitation leading to extinction in several African countries (Tchatat, 1999). Moreover, climate changes and relatives consequences (McClean et al., 2005), population growth and urban planning (Clergeau, 2010; Beninde et al., 2015; Scapino, 2016), and deforestation (Babalola and Agbeja, 2010) constitute some other impactful threats for forest species like *G. kola*.

Plants are known to be part of the mankind's healthcare system worldwide (Parihaar et al., 2014; Padalia et al., 2015); and all parts of a plant, even the whole plant, could be used in the treatment of illness in Africa (Falodoun, 2010). The use of herbal medicines in Africa has greatly elevated and enhanced the primary healthcare system in Africa (Falodoun, 2010). It was therefore found important to align our investigations with those of previous researches, including their implications and their recommendations to contribute to the sustainable management and conservation of forest resources. More precisely, this study is intended to inform natural resource managers and decision makers so that they can incorporate the impacts of global changes to reforestation policies and strategies of valorization of *G. kola* in urban planning in Benin and the management of protected areas in the country.

In line with this aim, the following research questions were addressed: (1) Will the climate change impact positively the potentially suitable areas for the growth of *G. kola* either in municipalities or in protected areas network? (2) Would it stand only in protected areas network for actions toward the conservation of *G. kola*? (3) Which municipalities would likely host the urban forestry actions, and which protected areas to reforest with the species?

MATERIALS AND METHODS

Study species and presence data

G. kola Heckel (Clusiaceae) is a medium-sized and shade-tolerant tree with a cylindrical trunk that is slightly buttressed to the ground. It is endemic to the humid lowland rainforest vegetation of the West and Central African sub regions, and is found in coastal areas and lowland plains up to 300 m above sea level with an average of 2000 to 2500 mm of annual rainfall, with temperatures ranging from 21.4 to 32.15°C (Ntamag, 1997). Its geographical distribution area extends from Congo to Sierra Leone (Vivien and Faure, 1985). Figure 1 shows the spatial distribution of the species downloaded occurrences in the landscape of interest. The area of interest for the present work is Benin. However, modeling on the countries within the sub-region was made for best results applicable in Benin (Fitzpatrick et al., 2009). A total of 67 occurrence points of the species (Figure 1) have been collected on the site of GBIF (http://doi.org/10.15468/dl.obgpne).

Environmental data

Present and future data were collected for modeling potential suitable areas of *G. kola*. These environmental data were obtained on the website of AfriClim (https://webfiles.york.ac.uk/KITE/AfriClim/GeoTIFF_150s/baseline_worldclim/; Platts et al., 2015) at the resolution of 2.5 min (150 s); format GeoTIFF at the extent of Africa. Those layers belong to the climate timescale 1950 to 2000 (Hijmans, 2005), representing data for modeling currently suitable areas for a given species or a set of living forms. As for projection in the future, bioclimatic variables built under realistic representative concentration pathways were also downloaded from AfriClim (https://webfiles.york.ac.uk/KITE/AfriClim/GeoTIFF_150s/africlim_ensemble_v3_worldclim/; Platts et al., 2015). The file set used was the ensemble v3 worldclim. The scenarios used were the Representative Concentration Pathways 4.5 that is realistic and optimistic (Meinshausen et al., 2011), and the Representative Concentration Pathways 8.5 that is realistic and pessimistic (Meinshausen et al., 2011), at the horizon 2055. AfriClim website was used because climate experts had set up data with regard to the climate specificity and ecological realities in Africa (Platts et al., 2015), so that the use of those data lead to meaningful results on the continent.

Model fitting and evaluation

The MaxEnt model has been used to model the potentially favorable areas for the species under present and future climates (Philips et al., 2006; Pearson et al., 2007). Future predictions were done using the optimistic scenario (RCP 4.5) and pessimistic scenario (RCP 8.5) (Meinshausen et al., 2011) at horizon 2055. For each scenario, the ensemble mean v3 model (Platts et al., 2015)

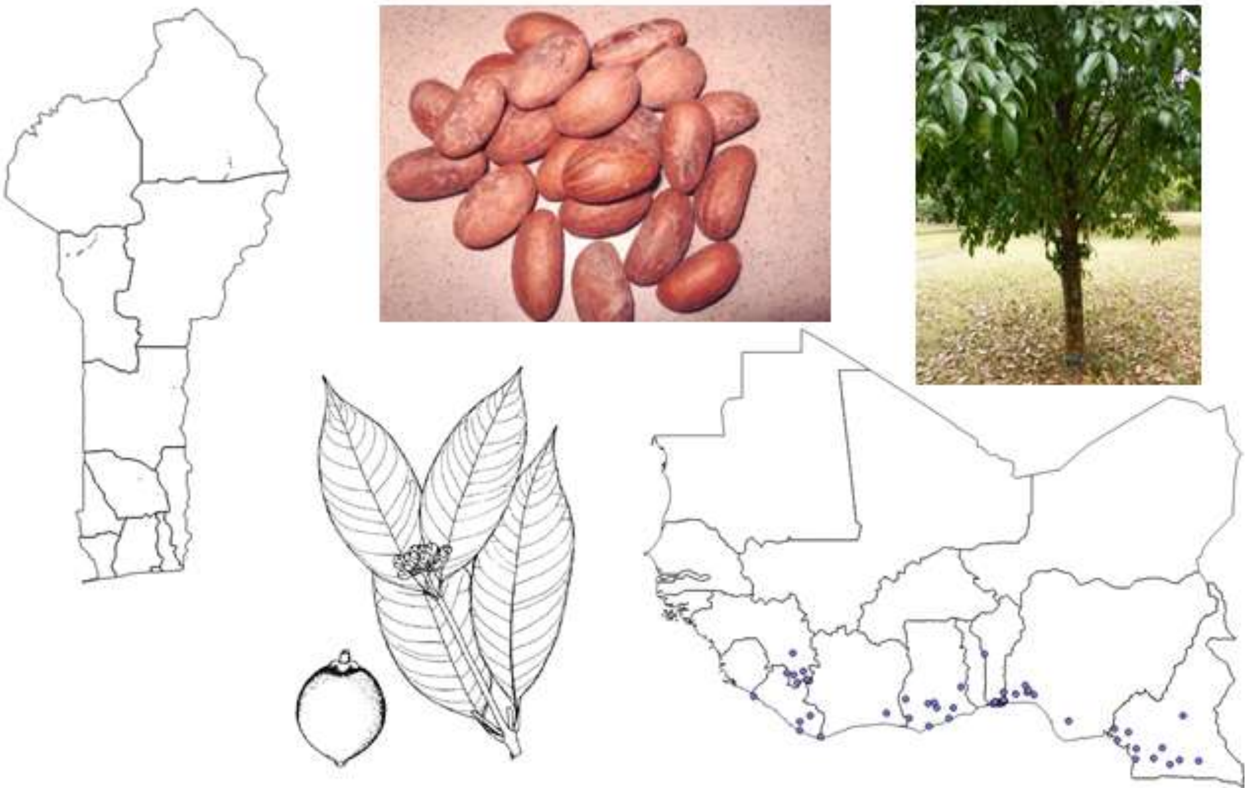

Figure 1. Study areas, species parts, and distribution of occurrences.

was used. As for the MaxEnt parameters, default values were used as recommended by Dossou et al. (2016). But in addition to default parameters of MaxEnt, we set randomly 25% of the present points as test points. The model was run step by step and selected the variables to exclude at each run based on cross-validation sampling. In these ways, the five most explanatory variables in the distribution of the species were selected while giving each variable a reasonable chance to show its importance in the species' distribution model building. For the variable selection, the correlations between variables (Warren et al., 2010), the statistics computed by MaxEnt itself such as Jackknife chart, the Area Under the Curve (AUC) value, the response curves, and the contribution table were taken into account (Elith et al., 2006). The species ecology was also considered in the process of selection. The models were evaluated on three bases. Those bases were AUC (Elith et al., 2006), TSS (Allouche et al., 2006), and the Partial ROC (Peterson et al., 2008). With the five most representative variables, the model was run again using bootstrap as sampling method with 10 replications.

Spatial analysis and decision

The logistic probability corresponding to the threshold "10 percentile training presence" was chosen from the last step MaxEnt model outputs that had been run on a cross validation sampling method to classify using Geographical Information Systems (GIS), the areas as suitable or unsuitable. In addition, the suitable areas are subdivided into two classes: highly suitable when the probability of the presence is higher than or equal to 0.5 and suitable when the probability is between the threshold and 0.5. The "10 percentile training presence" corresponds to the logistic probability above which, when sampled to grid values, the 10% least suitable presence points cannot fall. This threshold classified fairly the continuous maps for our studied species, and it also was used by Fandohan et al. (2015). The model used for the classification was the average of the ones that came from the bootstrapping sampling with 10 replications. The high confidence prediction areas (HCPA) was defined, and corresponded to areas where a model for current climate, and both models (RCP 4.5 and RCP 8.5) for future climate, revealed favorable conditions for our species. The HCPA was used to recommend restoration and conservation actions in favor of *G. kola*. Quantum GIS was used to perform gap analysis across Benin's protected areas network and municipalities. The proportion of protected areas and the proportion of municipalities that were shown to be in the HCPA were calculated and compared. The same computations were done to assess the climate change impact on the species' potentially suitable areas.

RESULTS

Model validation

The Area Under the Curve (AUC) associated to the model was 0.941 while the one associated to its test was 0.936 (Figure 3). The "10th percentile training presence" threshold gave a value of 0.275, 0.000 for test omission

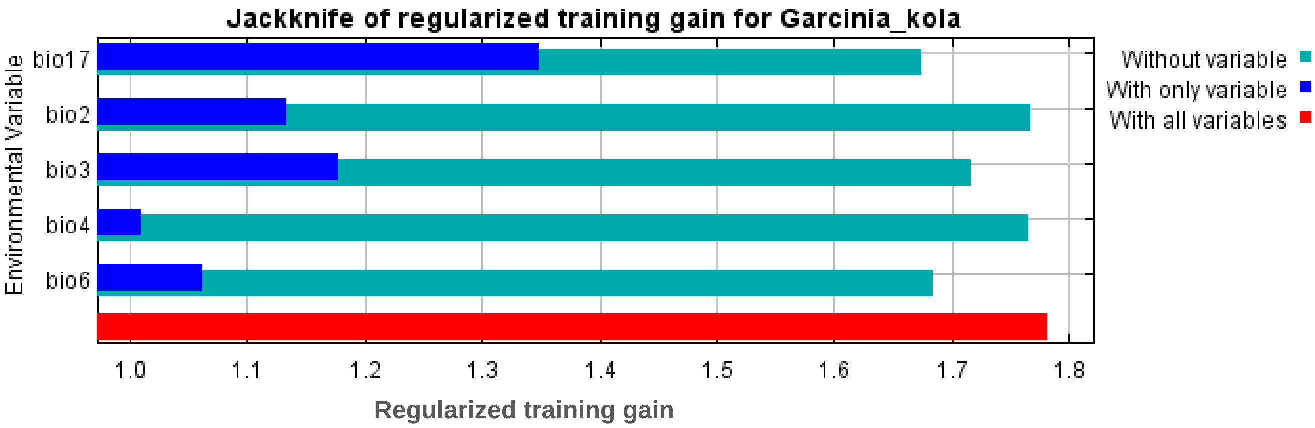

Figure 2. Jackknife of regularized training gain (*Garcinia kola*).

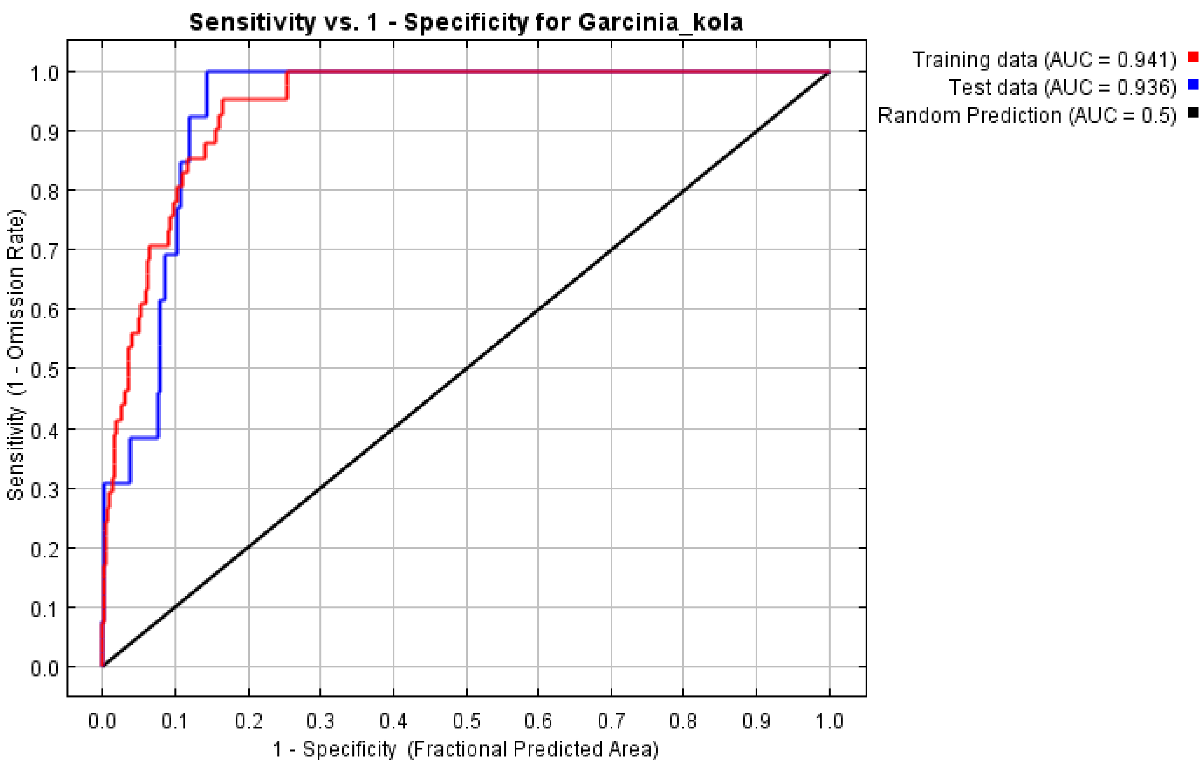

Figure 3. Receiver operating characteristic.

rate and 0.098 for the training omission rate. The True Skill Statistic (TSS) calculated with that threshold gave a value of 0.790. As for the Partial ROC, the minimal ratio was 1.01 and the maximal one was 1.15. All ratios on 1000 iterations were well above 1. These statistics indicated that our models were very good, predictive and performed better than random. The value of the standard deviation among runs was 0.032 for the AUC test, showing that the model is stable and did not fluctuate randomly. Variables bio 17, 6, 2, 3, and bio 4 were the most significant among bioclimatic variables were inputted in the algorithm MaxEnt (Figure 2). Bio 17 is the rainfall of the driest quarter (mm); Bio 6 is the minimal temperature of the coolest month (°C ×10); Bio 2 is the

Table 1. Variables contribution.

Variable	Percent contribution	Permutation importance
Rainfall of the driest quarter (mm)	74.3	63
Minimal temperature of the coolest month (°C ×10)	18.5	1.6
Mean diurnal range in temperature (°C ×10)	3.6	2.8
Isothermality (°C ×10)	2.9	29.5
Temperature seasonality (°C ×10)	0.8	3.1

Values are in percentages.

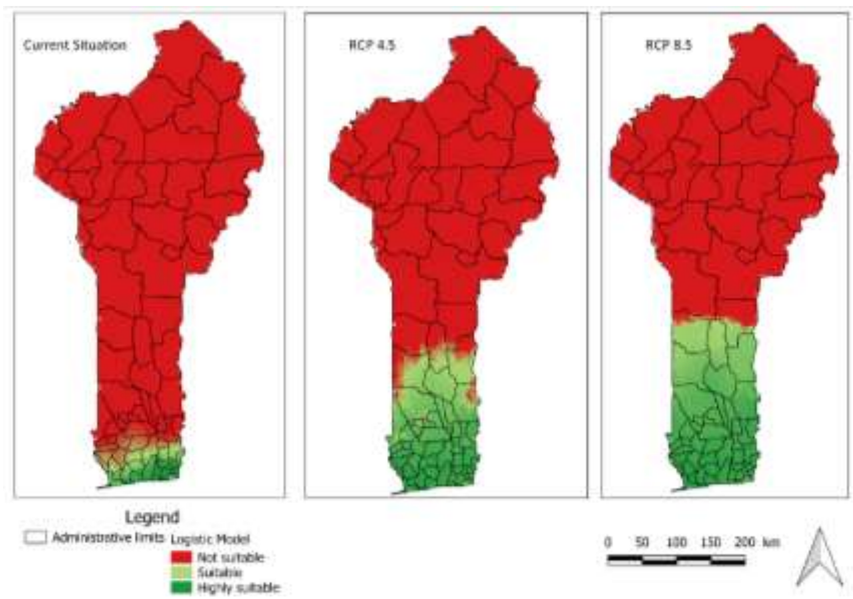

Figure 4. Distribution of predicted suitable areas for *Garcinia kola* from current scenario to scenarios of 2055s.

mean diurnal range in temperature (°C ×10); Bio 3 is the isothermality (°C ×10); and Bio 4 is the temperature seasonality (°C ×10). Table 1 shows the contribution of the retained variables.

Suitable areas for the species

Considering the results that were obtained from the models, the evolution of the climate is in favor of the extension of the climate envelop-based potential ecological niche of *G. kola*. In fact, it was found from the present scenario that the favorable areas range from the coastal areas of Benin (South) to the latitude of Zogbodomè (6.95°N). Meanwhile, a projection in future at 2055 using the RCP4.5, the optimistic one, revealed that the species can enlarge its potentially suitable areas from the coastal areas to the latitude of center Glazoué (8.19°N). It was found that it was much better according to the projection done with the RCP8.5, a pessimistic scenario. This latter showed us that the species can have its favorable areas extended beyond the latitude at the center of Glazoué, it is projected to reach the latitude at the end of Glazoué and the beginning of the municipality of Bassila (8.56°N). So, estimate can be retained in that the climate change is in favor of the species *G. kola* in Benin, whether we consider either the optimistic or the pessimistic scenario. Moreover, whether a scenario is pessimistic or optimistic depends on the species that we consider. Figure 4 shows more details on the maps.

Climate change impacts and conservation of *G. kola*

Protected areas network

Areas that were projected to belong to the HCPA encompass four protected areas (Table 2). But the

Table 2. Distribution of suitable areas and climate change impacts across protected areas (areas in Km²)

Protected areas	Suitable areas/Climate change impacts		
	All scenarios	**RCP4.5**	**RCP8.5**
FC Agoua	0	44.46	691.19
FC Atcherigbe	0	31.13	31.13
FC Dassa-Zoume	0	32.57	32.57
FC Dogo	0	319.88	319.88
FC Ketou	0	129.95	129.95
FC Logozohe	0	26.1	26.1
FC Monts Kouffe	0	0	221.45
FC Oueme Boukou	0	0	231.88
FC Oueme-Boukou	0	231.88	0
FC Savalou	0	14.35	14.35
FC Setto	0	13.03	13.03
FC Toui-Kilibo	0	0	51.94
FC Pahou	8.59	-	-
FC Agrime	27.59	-	-
FC Djigbe	47.22	-	-
FC Lama	178.39	-	-
Total	261.79	843.35	1763.47
Percentage of total PAN	0.931486514	3,000760731	6,274680176

projection using the RCP 4.5 at 2055s gave suitable areas that cover eleven more protected areas as results of positive climate change impacts (Table 2). As for the one using the RCP 8.5 at 2055, twelve more protected areas were found in addition to the stable one, as results of positive climate change impacts (Table 2). It was also remarked that there were no areas with negative climate change impacts. Figures 5 and 6 show more details of the climate change impacts on the distribution of suitable areas for *G. kola* across municipalities and across protected areas network (PAN).

Municipalities

Numerous municipalities fell into the potentially suitable areas for *G. kola*, equally well under current climate as under the future's one with both RCPs. The trend was the same as the one observed in the distribution of the suitable areas across PAN over time and space. Overall, forty municipalities belonged to the HCPA (Table 3). The changes in the climate borne by the RCP 4.5 showed twenty-four more suitable municipalities for the species as positive impacts of climate change (Table 3). As for the information obtained by the RCP 8.5 at 2055, 26 more municipalities were added to those that were suitable with all scenarios together (Table 3). No negative climate change impacts were indicated. The percentage of municipalities that were suitable for the species far above the percentage of protected areas network that were predicted as suitable (7.44% versus 0.93%) when considering the domain of maximal prediction confidence (HCPA) (Figures 5, 6 and 7). The trend remains similar with the RCPs individually (Tables 2 and 3).

DISCUSSION

Some previous studies including those of Assogbadjo et al. (2017) recommended appropriate incentives for the valuation of priority species such as *G. kola*. The present results led to some recommendations that may be a useful guide to be used by resource managers and decision makers in implementing the incentives. In fact, Cuni-Sanchez et al. (2010) stated that fundamental niche and potential distributions are convenient when the purpose of the modeling is the introduction of a species in a geographic region. Moreover, it is worth knowing the environmental requirement of a species, its potentially suitable areas, and its potential response to climate change for conservation and management purposes (Bowe and Haq, 2010). Therefore, Blach-Overgaad et al. (2010) and Bowe and Haq (2010) recognized that Ecological Niche Modeling of threatened species, agroforestry species, pests, and invasive species is useful to recommend policy and decision makers on their management. Other studies from Gbètoho et al. (2017) indicated that Ecological Niche Modeling could also be

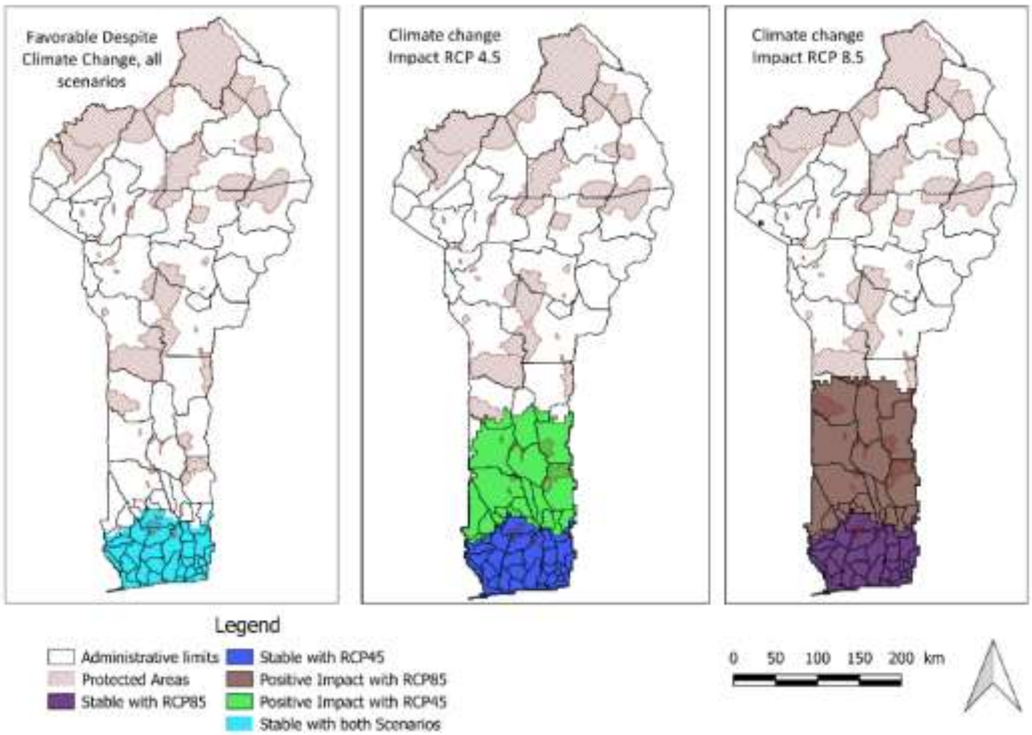

Figure 5. Climate change impacts on the distribution of suitable areas for *Garcinia kola* across municipalities and across protected areas network.

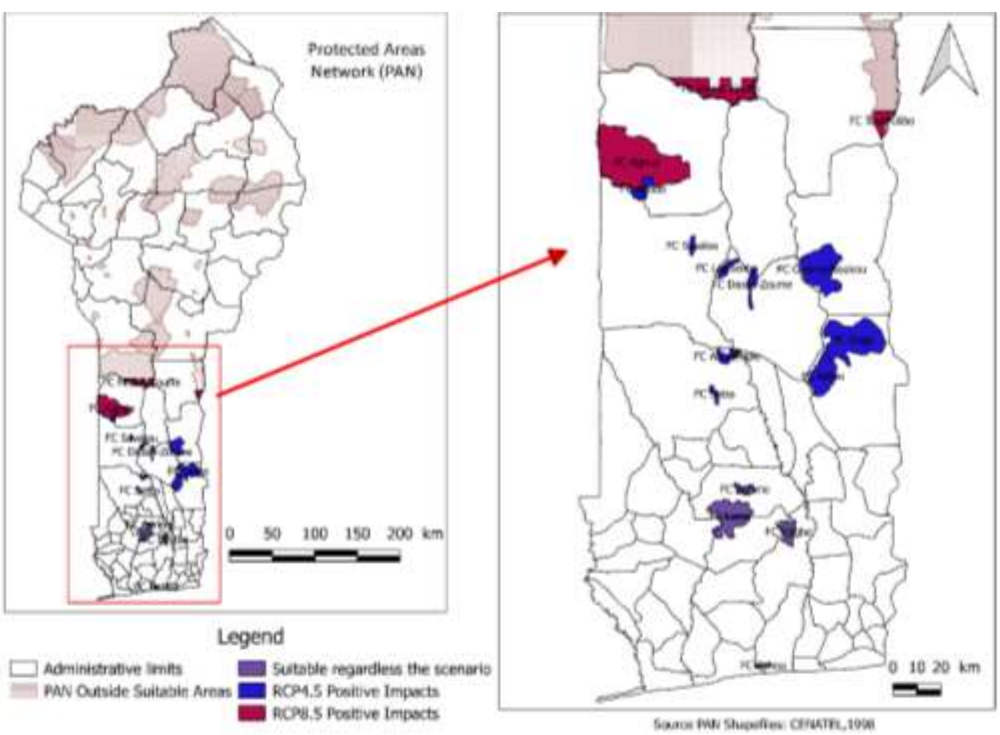

Figure 6. Protected Areas Network along with the climate change impact with regard to suitability areas for *Garcinia kola*.

Table 3. Distribution of suitable areas and climate change impacts across municipalities (areas in Km²).

Municipality	Suitable areas/Climate change impacts		
	All scenarios	RCP4.5	RCP8.5
Bante	0	473.45	2432.01
Bassila	0	0	199.22
Boukounbe	0	0	21.04
Cove	0	443.54	443.54
Dassa	0	1715.84	1715.84
Djidja	0	2181.85	2203.02
Glazoue	0	1111.81	1781.67
Ketou	0	1764.53	1764.53
Savalou	0	2311.23	2688.29
Save	0	1845.39	2236.07
Tchaourou	0	213.96	1260.49
Zangnanado	0	536.04	536.04
Abomey	4.02	146.73	146.73
Za-kpota	4.37	400.29	400.29
Aplahoue	4.43	970.82	970.82
Ouinhi	9.1	287.27	287.27
Bohicon	24.29	132.59	132.59
Klouekanme	25.5	398.89	398.89
Agbangnizoun	46.12	144.84	144.84
Porto-Novo	50.85	-	-
Adjara	61.88	-	-
Cotonou	70.57	-	-
Pobe	73.93	303.09	303.09
Avrankou	85.54	-	-
Toviklin	95.65	38.41	38.41
Akpro-Misserete	95.7	-	-
Djakotome	113.5	96.65	96.65
Seme-Kpodji	137.44	-	-
Aguegue	150.55	-	-
Dangbo	159.27	-	-
Come	162.28	-	-
Athieme	163.79	-	-
Ifangni	170.06	-	-
So-Ava	176.93	-	-
Adja-Ouere	181.36	273.07	273.07
Grand-Popo	220.65	-	-
Dogbo-Tota	262.71	-	-
Ouidah	264.55	-	-
Bonou	267.6	3.91	3.91
Houeyogbe	296.31	-	-
Adjohoun	306.26	-	-
Kpomasse	309.04	-	-
Lokossa	321.27	-	-
Tori-Bossito	334.64	-	-
Bokpa	387.01	-	-
Allada	397.63	-	-
Lalo	422.1	0.92	0.92
Sakete	431.76	-	-

Table 3. Contd.

Abomey-Calavi	488.03	-	-
Toffo	547.35	-	-
Ze	687.04	-	-
Zogbodome	695.52	120.19	120.19
Total	8706.6	15915.31	20599.43
Percentage of total municipalities	7,440585812	13,60108766	17,6040965

used for exploring species that could be used for restoration of secondary forests. The selection of variables to include in the model differs from one scientist to another. It was found that the distribution of a species at large scale depends mainly on climate (Vayreda et al., 2013). However, contrary to Gbètoho et al. (2017) who selected “a priori” four variables that they found to be the most biologically relevant in plant ecology in tropical West Africa and easy to interpret and Adjahossou et al. (2016) who selected variables only on the correlations between them before running the model, gave chance to all variables, even those that are shown to be correlated to reveal how well it contributes to the model building before making a decision to remove it. The present study is in line with all previous sources of information about recommended strategies for the conservation and the restoration of *G. kola* in its potentially suitable areas.

Neuenschwander et al. (2011) reported that the species’ nut trading and its use for vegetable toothbrush constitute the main threats and that the species occurs in inhabited areas, but may also occur in dense humid forests and riparian forests. Our findings confirm their statement because models showed first that the species may find its climatic preferences in dense forests in Southern Benin, and can be grown in some cities always in Southern Benin. The same authors recommended that conservation efforts should include the restoration of the species in natural occurrence sites, and that further research may profitably focus on the distribution, ecology, regeneration, and silviculture of the species. There are now some advances based on research for vegetative propagation of *G. kola* (Kouakou et al., 2016) and this may ease multiplication and introduction of the species in urban forestry, agroforestry and home garden systems. However, many other parameters may drive the introduction of *G. kola* in urban areas.

The present study focused on the distribution and biogeography of the species, and then gave background on areas where the species can be restored. The suitable areas shown by our models for *G. kola* also conform to the ecological and geographical descriptions made on the species by Vivien and Faure (1985) and Ntamag (1997). The favorable zones according to the present results corresponded to parts of the Guinean zone in Benin and the coastal areas; and this highlights the evidence of the concentration of suitable areas in Southern Benin. The protected forests that may be retained for the conservation of the species are all in the Southern Benin, the part of the country belonged to the high prediction confidence areas. So, just a part of protected areas can conserve a given species. This information is an addition to the conclusions of Houehanou et al. (2013) and Adjahossou et al. (2016), who noted that some protected areas are threatened by unsustainable use of the existing resources. The use of the High Confidence Prediction Areas (HCPA) is a means to keep at the lowest level as possible the prediction error, giving more confidence to the users of the study results. The HCPA represented areas that were shown suitable for *G. kola,* whether under the conditions of the current climate, or regardless of the likely future scenario as used among the RCP4.5, and RCP8.5 at 2055s. The HCPA represented areas that were shown suitable for *G. kola* as well under current climate as under future climates regardless of used scenario among RCP4.5 and RCP8.5 at 2055s.

Positive climate change impacts include some municipalities and some protected areas in the center Benin to be suitable for hosting the species upon 2055s. In contrast to the findings of some authors who modeled other species, for example Ganglo et al. (2017) who modeled *Dialium guineense*, climate change has only positive impacts on the distribution of *G. kola*. But it is worth mentioning that different thresholds had been used for the classification, and this may create a slight difference on the classification results that they observed. It is unfortunate that many protected areas are in the northern parts of the country and those protected areas may not guarantee sustainable conservation sites for *G. kola*. Areas where *G. kola* may find its climatic envelope are medium to high population density areas. So, as remarked on one hand by Sogbohossou and Akpona (2006, 2007), Santini (2013), Idohou et al. (2014), Salako et al. (2014), and Gbedomon et al. (2015, 2016) that home gardens, botanical gardens in cities, urbanization through the green spaces and any other area in urban centers maintain the urban biodiversity and their remark aligns with the present findings. On the other hand, urban biodiversity is essentially influenced by human pressure (Sogbohossou and Akpona, 2006, 2007; Santini, 2013), giving more importance to the results that were obtained emphasizing the importance of the promotion of urban forestry and agroforestry.

CONCLUSION AND PERSPECTIVES

Climate changes were shown to have negative as well as positive consequences on the distribution of species. Modeling the ecological niche of *G. kola* gave background on its environmental envelop. More insights have been found on whether the evolution of climate is in favor of sustaining the species or not. Each research question found an appropriate response at the conclusion of the study. *G. kola* is a valuable tree species, which can benefit from predicted climate changes in Benin, regardless of the scenario. Evidence in response to the second research question revealed that decision makers and resources managers may not rely only on the protected areas network to conserve and restore the species in Benin. Our municipalities can provide a greater chance for *G. kola* (an extinct species in the wild) to extend its favorable areas due to likely climate changes. The percentage of municipalities that were suitable for the species is far above the percentage of PAN that was predicted as suitable habitats. Municipalities and protected areas that would be able to host conservation measures and actions toward enhancing the survival and habitat expansion of the species were identified. Thus, decision makers and resource managers may focus on those identified sites.

Overall, there are suitable natural and human habitable spaces to introduce *G. kola* and expect a success. With regard to the synthesis of suitability areas shown in Tables 2 and 3, it is worth introducing the species in farmland, homeland, cities, streets, public spaces, and home gardens. However, some additional research is needed to focus on some key physiological and horticultural aspects. First, a better understanding of the root system requirement of the species. On the other hand, more documented evidence of the interactions between humans and this species are needed when introduced in cultivation as another important research focus.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Habitat biophysical and spatial patterns assessment within Oti-Keran-Mandouri protected area network in Togo

Aniko Polo-Akpisso[1,2*], Fousseni Folega[2], Ouattara Soulemane[3], Wouyo Atakpama[2], Mamadou Coulibaly[4], Kpérkouma Wala[2], Achim Röder[5], Koffi Akpagana[2] and Tano Yao[3]

[1]West African Science Service Centre on Climate Change and Adapted Land Use, Graduate Research Program on Climate Change and Biodiversity, University Félix Houphouët-Boigny, P. O. Box 461, Abidjan, 22 BP 461 Abidjan 22, Côte d'Ivoire.
[2]Laboratory of Botany and Plant Ecology, Faculty of Science, University of Lomé, P. O. Box 1515, Lomé, Togo.
[3]Laboratory of Zoology and Animal Biology, UFR Biosciences, University Félix Houphouët-Boigny, Abidjan, 02 BP 1170 Abidjan 02, Côte d'Ivoire.
[4]Department of Geography and Urban Planning, University of Wisconsin Oshkosh, 800 Algoma Boulevard, Oshkosh WI 54901-8642, USA.
[5]Department of Environmental Remote Sensing and Geinformatics, Trier University, 54286 Trier, Germany.

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Oti-Keran-Mandouri (OKM) is part of the elephant historical range and one of the priority corridors proposed for elephant conservation in West Africa. However, its potentialities to be a functional corridor are yet to be evaluated in a context of increasing anthropogenic pressure. This study aims at assessing habitat biophysical patterns and fragmentation level. A multicriteria evaluation using fuzzy logic was performed to model elephant habitat suitability and vegetation sampling conducted in 123 plots to describe the habitat. In each plot, the physical parameters of woody plants species were recorded. Biodiversity indices, dendrometric parameters, and diameter structure were computed for each habitat type and compared using Jaccard Index and Kruskal-Wallis test. Habitat fragmentation was assessed using the hypsometric method. Apart from a core area located in the south-east, the remnant good habitat is in small patches. Four habitats were distinguished based on their level of degradation. There is a steady increase in habitat diversity from degraded habitat (Habitat 1) to primary habitat (Habitat 4) with the Shannon index increasing from 0.83 to 1.43 bit. In all the habitats, trees are evenly distributed with an evenness higher than 0.7. Dendrometric parameters are significantly different from one habitat to another (P-value < 0.05) apart from the mean diameter and the average regeneration rate. The suitable habitat for elephant constitutes only 31.5% of the area of OKM. The overall habitat fragmentation is 84.74%. Regeneration rates make an eventual restoration possible but further assessment of the socio-ecological system is needed.

Key words: Elephant, habitat suitability, habitat, fragmentation, conservation.

INTRODUCTION

Biodiversity conservation amid global change becomes an important issue for ecologists. For ecosystems resilience effectiveness, it is proposed that protected areas be managed at the landscape level including planning for dynamics in concert with the surrounding matrix and other protected areas (Lovejoy and Hannah, 2005). This is particularly important for large-bodied mammals. Those large mammals depend on extended areas of suitable habitat to meet their dietary requirements. This is the case, for instance, of the African savanna elephant *(Loxodonta africana* Blumenbach, 1797*)*. However, with the increasing anthropogenic impacts on natural resources, conservation planning at the landscape scale implies maintaining corridors or transboundary areas for species (Vasilijević et al., 2015). These corridors could reverse the consequences of habitat fragmentation. They are of critical importance for maintaining the viability of isolated populations and conserving ecosystem functionality (Beier and Noss, 1998).

The strategy to conserve the African elephant in West Africa designed several transboundary protected areas and conservation corridors to enable the conservation and the seasonal migration of the remaining groups of elephant population (Sebogo and Barnes, 2003). There are eighteen transboundary ranges or conservation corridors of elephant in West Africa. The most important one comprises several adjacent protected areas, including the tripartite W Park, the Pendjari Park, and Arly Park (WAP ecosystem), the wildlife reserve of Oti-Mandouri and Keran National Park (Sebogo and Barnes, 2003). The two latter constitute the complex Oti-Keran-Mandouri (OKM) in Togo. At a wider range, OKM can be considered as a link between the two main blocks of the remaining elephant population in West Africa including many protected areas (Po, Nazinga, Sissili and W, Arly, Pendjari) that constitutes the most vast and important eco-geographical region for the African elephant migration in West Africa (Bouché et al., 2011). OKM is also considered as one of the first priority migration corridor for elephant population conservation in West Africa (Bouché et al., 2011). Unfortunately, these protected areas are under continuous anthropogenic pressure that transformed their biotopes into degraded habitats (Polo-Akpisso et al., 2016). While reducing human impacts (e.g. illegal killing) is critical to the persistence of elephants across this range, conserving links and establishing corridors between the largest populations and largest blocks of protected areas should be of a primary management objective particularly in West Africa where poaching is better controlled (Bouché et al., 2011).

Most of the studies in elephant research and conservation efforts in West Africa have mainly focused on estimating elephant densities, distribution and human elephant conflicts. Some studies assessed the ecology of the species and the interactions between elephant and some plant species in its habitat. Although, these studies have been proven to be useful to monitor elephant population trends, they mentioned the problem of the increasing degradation of elephant habitat. Since the habitat of the elephant in West Africa is currently converted into fragmented patches, some populations are now completely isolated genetically (Barnes, 1999). There is a need for the design of corridor as suggested by the Action Plan for Elephant conservation in West Africa (Sebogo and Barnes, 2003). But the first action to take is to gain better understanding of the habitat condition in the potential or already designated corridors. However, there are few studies focusing on the integrity of the habitat in such corridors.

The study of habitat conditions and how animals use patchy environments has a long tradition in ecology and a rich literature exists on such topics especially in North America as reviewed by Morrison et al. (2006). Without knowledge of environmental conditions, recommendations for conservation planning have limited effects. Though basic, the first step in gaining such knowledge is to assess habitat structure and composition. Therefore, with the general objective to improve biodiversity conservation in Togo, this study aims at describing the biophysical characteristics of habitats and to assess their level of fragmentation. The outputs of this study could serve as baseline for a sustainable management in the context of the changing climate.

MATERIALS AND METHODS

Study area

OKM is a complex of protected areas covering about 179 000 ha (IUCN, 2008) and located in the northern flat plains of Oti River basin in Northern Togo (Figure 1). It belongs to the eco-floristic zone I of Togo (Ern, 1979). It is characterized by a tropical climate with a rainy season during June to October and a dry season between November and May. The annual rainfall is between 800 and 1100 mm and the temperature vary between 17 and 39°C during the dry season and between 22 and 34°C during the rainy season (Addra et al., 1990) (Figure 2).

The predominant vegetation is Sudanian savanna, with some dry forest patches and riparian's forests along rivers. The large wetlands of Oti River and its tributaries (Koumongou, Keran, Kara, Naweni, Wapoti) present important biotopes for migrating birds and is internationally recognized as Important Bird Area (Cheke, 2001). Oti-Keran National Park and Oti-Mandouri Game Reserve, which together form OKM complex, are representative of several key terrestrial ecosystems found in Togo. They are part of the most important protected areas in Togo and considered as a key component of the range of the savanna elephant in West Africa.

*Corresponding author. E-mail: anikopolo@gmail.com. Tel: +228 90 30 21 45.

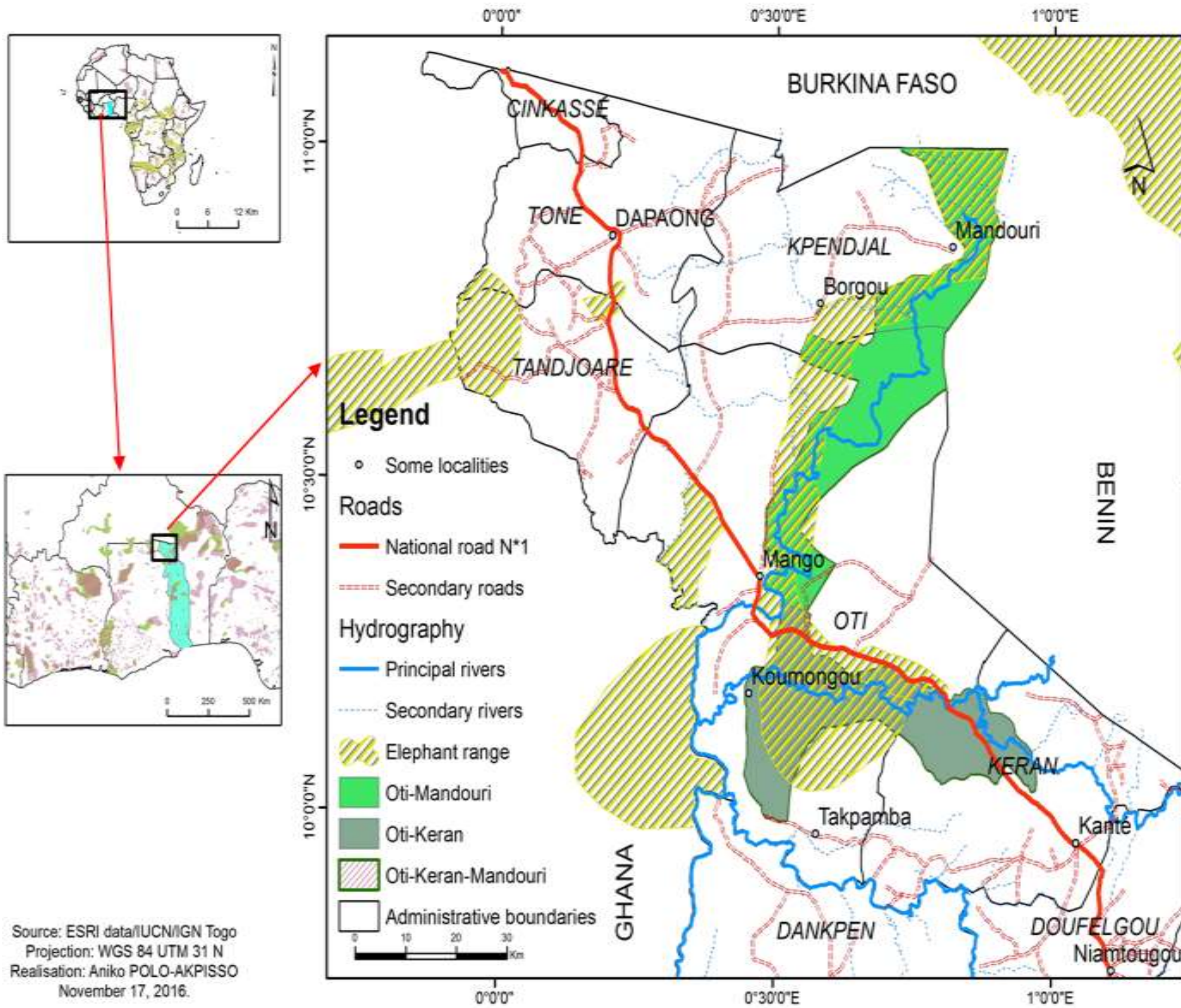

Figure 1. Study area.

Oti-Keran-Mandouri lies within two administrative regions: “Savanes” and “Kara”. The communities it straddles are among the poorest in the regions. The highest per annum population growth in Togo is found in “Savannes” region with 3.18% growth rate whereas it is 2.04% in “Kara” region. The ethnic groups who share this area are mainly Gourmantche, Tchokossi, Lamba, Temberma, Ngamgam, Moba, Gnande, Mossi, Berma
and, Bissa.

Agriculture especially smallholder farming is the principal activity in this area and occupies around 70 to 80% of the active population in these districts (UICN, 2009). The most cultivated crops are sorghum (*Sorghum bicolor* (L.) Moench.), corn (*Zea mays* L.), millet (*Pennisetum glaucum* (L.) R. Br. Ssp. *glaucum*), rice (*Oryza sativa* L.), yams (*Dioscorea* species.), and cassava (*Manihot esculenta* Crantz.). There is currently increasing interest in cash crop production such as cotton (*Gossypium hirsutum* L.). Consequently, there is a great pressure from peasants to access fertile lands. Except farming, service timber lodging, firewood harvest (Adjonou et al., 2009; Folega et al., 2011) and non-timber products (fruits, medicinal plants, straw), charcoal production (Kokou et al., 2009; Atato et al., 2011; Folega et al., 2012), hunting and fishing (Dimobe et al., 2012) are other activities exerted by local communities. Transnational livestock transhumance constitutes also another important activity and threat to biodiversity that is remaining to be documented in this area. The evicted people, when the parks were gazetted, have resettled by creating large cleared areas in the natural landscape.

There still conflict over the land between local communities and administrative authorities.

Data collection

The assessment of the elephant habitat was conducted using a

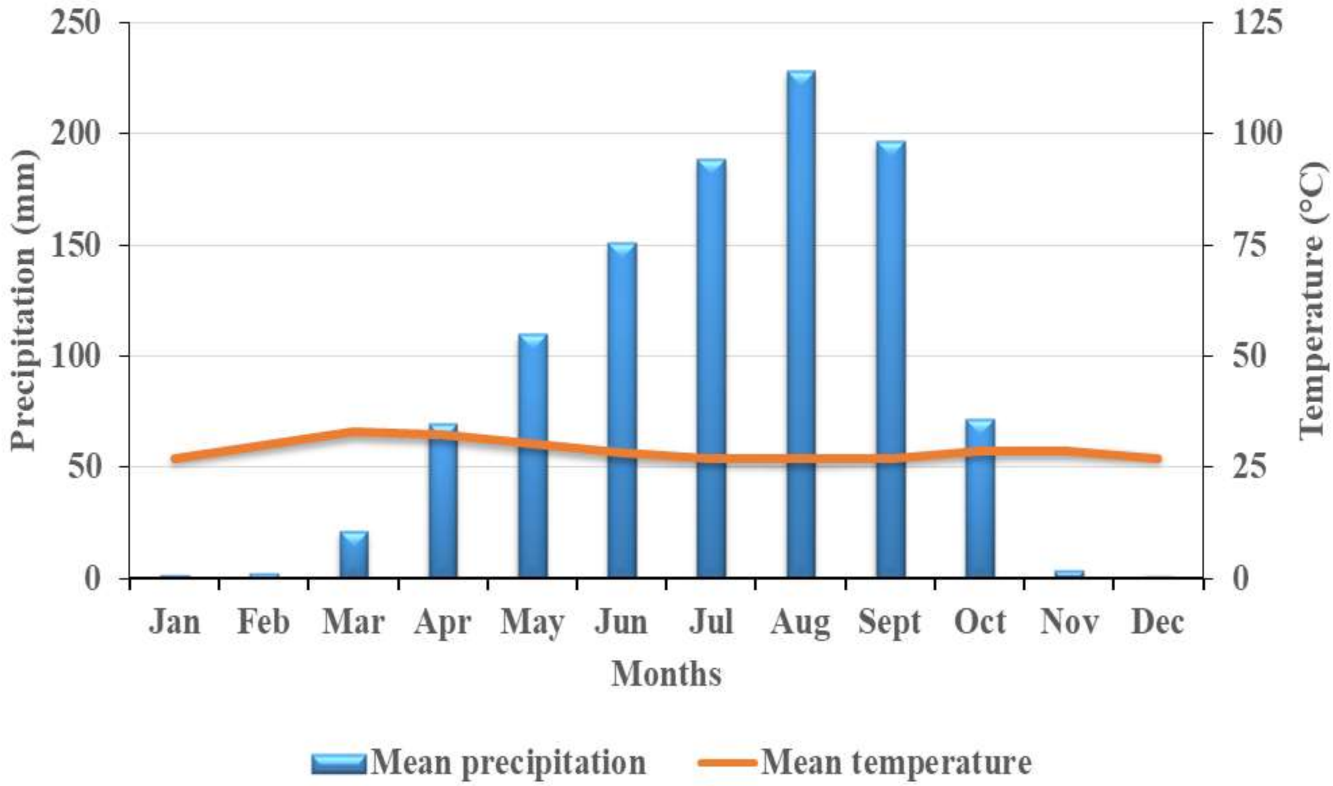

Figure 2. Mean precipitation and temperature at the meteorological station of Mango from 1981 to 2013 (Data source: National Direction of Meteorology).

multidisciplinary approach combining remote sensing, geographic information system (GIS) and botany (Figure 3). A multicriteria evaluation was performed based on defined criteria considered as necessary for elephant habitat. These criteria and corresponding source layers used to rate suitable habitat are listed in Table 1. The source layers represent site characteristics that are factors know to determine locations that are suitable for the elephant (Boettiger et al., 2011).

The normalized difference vegetation index (NDVI) (Rouse et al., 1974) was used as a proxy of the Net Primary Production of the habitat. Potential for the use of NDVI as a proxy for land productivity (one of the indicators of the state of land degradation) is based on numerous and rigorous studies that have identified a strong relationship between NDVI and NPP (Field et al., 1995; Prince and Goward, 1995; Vlek et al., 2010; Folega et al., 2015). The distance to stream, road and encroachments layers were derived from Euclidean distance analysis. The slope was derived from a Digital Elevation Model (SRTM) 30 m distributed by the United State Geological Survey (USGS), whereas the thickness of water pounds was calculated for the water pounds located within OKM by using ArcGIS (ESRI, 2014). The land cover/land use map was derived from the supervised classification of Landsat 8 image for October 2013 (Polo-Akpisso et al., 2016).

Vegetation sampling

Floristic data and dendrometric measurements of all woody plant species were recorded in 123 plots of 50 m × 20 m in natural vegetation types and 50 m × 50 m in human modified landscapes (croplands). Dendrometric measurements concerned total height and diameter of woody species with diameter at breast height equal or greater than 10 cm (Tehou et al., 2012; Dimobe et al., 2014; Folega et al., 2014b). In both plots, three 5 m × 5 m subplots were installed diagonally to assess tree plant natural regeneration by counting juvenile individuals (*dbh* <10 cm) such us seedlings and suckers. The geographic coordinates of each sampling plot as well as any elephant occurrence point were recorded using a handheld Global Positioning System receiver (Figure 3).

Data analysis

Assessment of the elephant habitat suitability within OKM

An elephant habitat suitability model was developed using overlay technics within the framework of ArcGIS Model Builder (ESRI, 2014). The source layers were assigned fuzzy membership values and then the resultant layers were combined using raster calculator and fuzzy overlay to generate an overall suitability layer. For each source layer, the likelihood that each
observed value is a member of the defined set of suitable locations was based on the relationship between observed values and fuzzy membership values that captures the best that criterion.

Assessment of habitat biophysical and spatial patterns

Recorded plant species were named and categorized into their respective genera and families according to Akoègninou et al. (2006) and Brunel et al. (1984). Different habitat types were

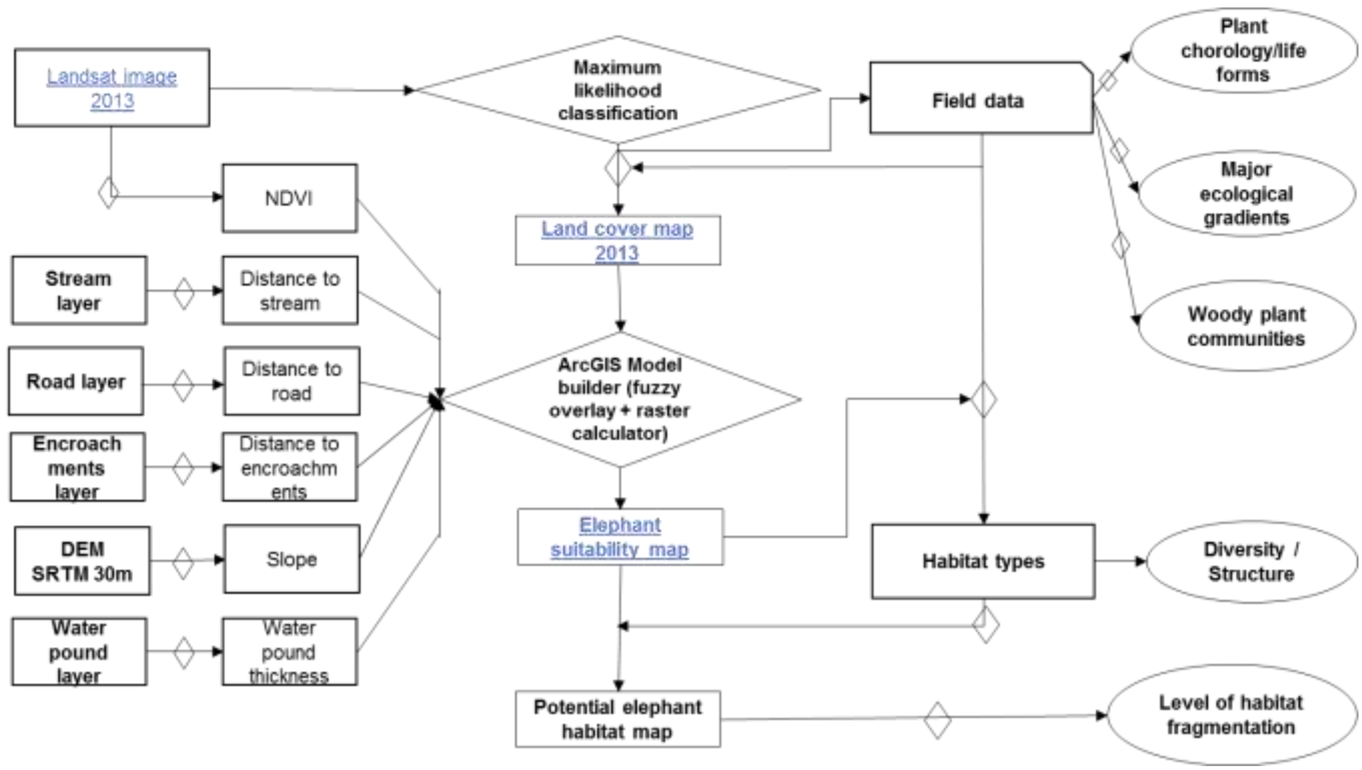

Figure 3. Summary of the workflow to assess elephant habitat within Oti-Keran-Mandouri.

Table 1. Criteria and source layers for elephant suitable habitat within Oti-Keran-Mandouri.

Criteria	Source layer
Areas that provide food (vegetation)	NDVI
Areas near streams	Distance to streams (rivers)
Areas with low elevation	Slope
Areas with large water pounds are more suitable	Thickness of water pounds
Areas far from roads	Distance to road
Areas far from encroachments	Distance to encroachments
Areas well conserved	Land use / land cover map

distinguished according to their level of degradation. Alpha diversity and dendrometric parameters were computed for the distinguished habitats. Alpha diversity was assessed through species richness (S), Shannon-Wiener diversity index (H'), and Pielou evenness index (E) were computed for each habitat type. The Pielou's evenness measures the similarity in the abundance of sampled woody species. Its value varies between 0 and 1. The value tends to 0 when one or few species have higher abundance than others and 1 in the situation where all species have equal abundance. Whereas, high values of Shannon-Wiener index would be representative of more diverse communities (Magurran, 2004).

The formulas of these indexes are:

$$H' = -\sum_{i=1}^{s} p_i \log_2 p_i$$

with $p_i = \frac{r_i}{r}$

Where r_i is the number of individuals belonging to the species *i*, *r* is the total number of all individuals in the considered plot and *s* is the species richness in the plot. *H'* represents the Shannon-Wiener's diversity index, *H'* max is the maximum value of the diversity index and *S* is the number of species recorded in the considered plant community.

$$E = \frac{H'}{H'_{max}}$$

with $H'_{max} = \log_2 s$

Tree density for one habitat (*N*) which is the number of trees per plot for a given habitat expressed in trees/ha:

$$N = \frac{n}{s}$$

where *n* is the overall number of trees in the plot and *s* the area.

The mean diameter (*D*) in cm of the trees in a given habitat:

$$D = \left(\frac{1}{n}\sum_{i=1}^{n} d_i^2\right)^{1/2}$$

Where n is the number of trees found on plots.

The combinations of indicator species for each habitat were described using R package ''Indicspecies'' (De Cáceres and Legendre, 2009). This package provides a set of functions to assess the strength and statistical significance of the relationship between the species occurrence or abundance and site groups, which may represent habitat types, community types, disturbance states, etc. The indicator value index is the product of two components, referred to as 'A' and 'B' (Dufrene and Legendre, 1997). Component 'A' is the probability that the surveyed site belongs to the target site group given the fact that the species has been found. This conditional probability is called the specificity or the positive predictive value of the species as indicator of the site group. Component 'B' is the probability of finding the species in sites belonging to the site group. This second conditional probability is called the fidelity or sensitivity of the species as indicator of the target site group (De Cáceres, 2013).

Beta diversity was described by computing Jaccard index of similarity (Chao et al., 2005) by using the R package "Fossil" (Vavrek, 2011). Jaccard index depends on three simple incidence counts: the number of species shared by two assemblages and the number of species unique to each of them. These counts are referred to as A, B and C, respectively:

$$J = \frac{A}{A+B+C}$$

The basal area of trees in each habitat (G) was also computed. This is the sum of the cross-sectional area at 1.3 m above the ground level of all trees on a plot of a given habitat, expressed in m^2/ha:

$$G = \frac{\pi}{4s}\sum_{i=1}^{n} 0.0001 d_i^2$$

Where d*i* is the diameter (in cm) of the *i*-th tree of the plot and *s* is the plot area.

The Lorey's mean height (H_L in meters) was also computed. This is the average height of all the trees found in a plot weighted by their basal area:

$$H_L = \frac{\sum_{i=1}^{n} g_i h_i}{\sum_{i=1}^{n} g_i}$$

with gi= $\frac{\pi}{4} d_i^2$

Where g*i* and h*i* are the basal area (in m^2/ha) and the total height of tree *i*.

The different habitats were compared with each other for the computed parameters using a Kruskal-Wallis test. Furthermore, the diameter structure of tree stem of each habitat was assessed by the frequency of tree stems grouped in different diameter classes. The observed diameter structure was fitted to the 3-parameter Weibull distribution (Johnson and Kotz, 1970). This is a density function very useful because of its flexibility and has been used to describe vegetation structure in many studies (Bonou et al., 2009; Aleza et al., 2015). The density function *f* of the 3-parameter Weibull distribution is expressed for a tree-diameter x by the following formula:

$$f(x) = \frac{c}{b}\left(\frac{x-a}{b}\right)^{c-1} e^{-\left[x-\frac{a}{b}\right]^c}$$

Where x=tree diameter, a=10 cm, b=scale parameter linked to the central value of diameters, and c=shape parameter of the structure.

Finally, the similarity in species composition guided the identification and the mapping of the potential habitat of the elephant and the degraded habitat. The level of fragmentation of these habitats was then assessed using morphological image processing with eight connectivity (Vogt et al., 2006). The fragmentation analysis was conducted following the hypsometric method by using GUIDOS Toolbox 2.5 (Vogt, 2016). This method accounts for the dual nature of fragmentation (foreground is fragmented by background and vice versa). The degree of fragmentation for a given image is defined by the weighted sum of fragmentation (Frag) in the foreground and the background:

$$Frag\ (hypso) = \left(\frac{background_{area}}{100} \times backgroun\,g_{frag}\right) + \left(\frac{forground_{area}}{100} \times forground_{frag}\right)$$

The so-defined fragmentation provides values in the range of [0, 100] percentage, accounting for and summarizing key fragmentation aspects such as duality, perforations, amount, division, and dispersion of image objects.

All elephant occurrence points recorded during field campaigns were projected on top of the interpolation by natural neighbor of human population census (RGPH, 2011). The resulting map enabled a visual spatial analysis of the pattern of elephant occurrence within OKM and its surrounding area.

RESULTS

Elephant habitat suitability within OKM

The Figure 4 shows the elephant habitat suitability within OKM. Apart from a core area located in the south-east, the remnant good habitat is in small patches sparsely distributed in the protected area. It is mostly located along the rivers and around water pounds. The most important portion of suitable habitat and largest suitable patch is located south-east of the park.

Structure of habitat types

Four habitats were distinguished based on their level of degradation. These are degraded land (Habitat 1), least suitable habitat (Habitat 2), secondary habitat (Habitat 3) and primary habitat (Habitat 4). The primary habitat is considered as a good and well conserved habitat. The secondary habitat is a moderately conserved habitat, while the least suitable habitat undergone a certain level of degradation. Figure 5 shows the spatial distribution of

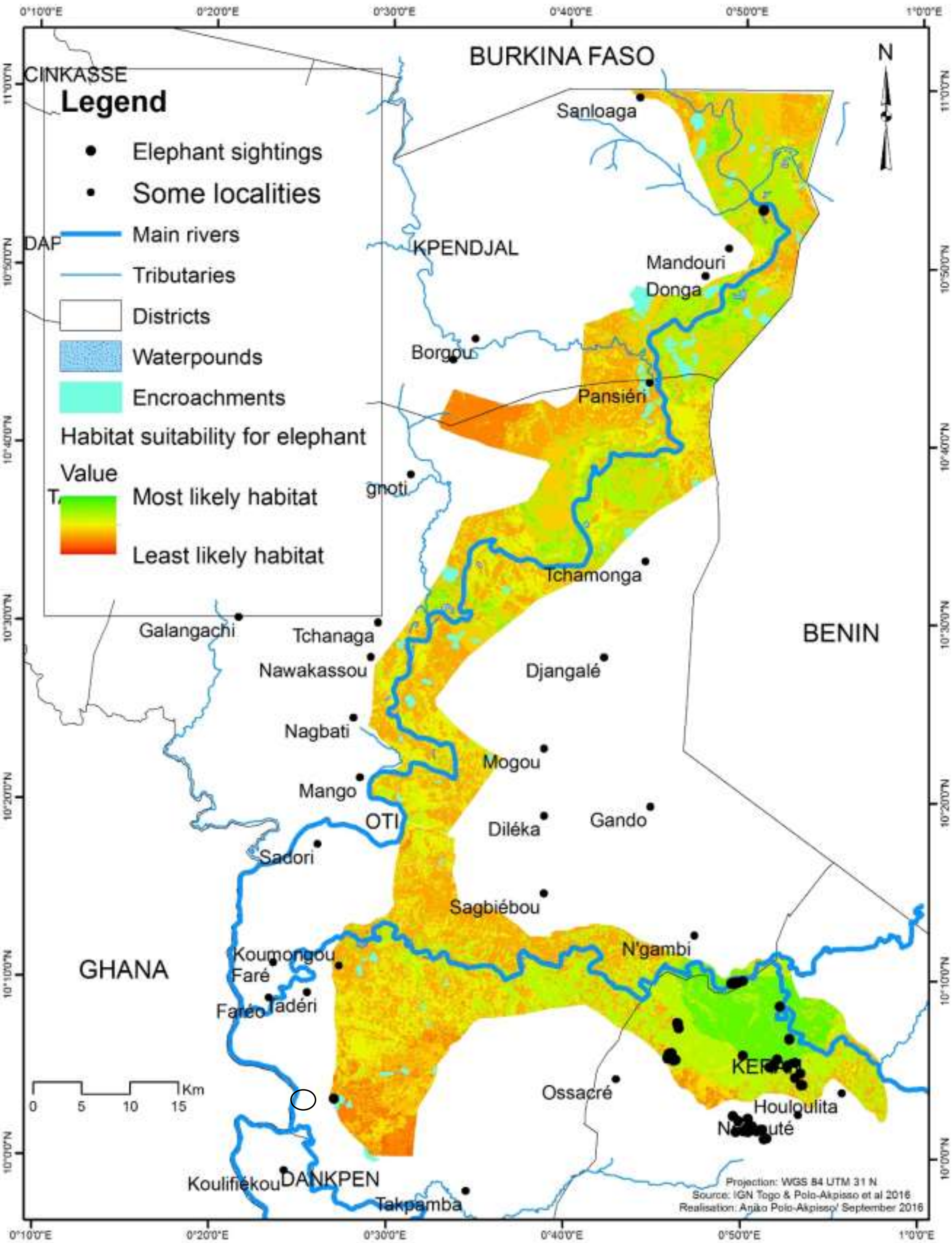

Figure 4. Elephant suitable habitat within Oti-Keran-Mandouri.

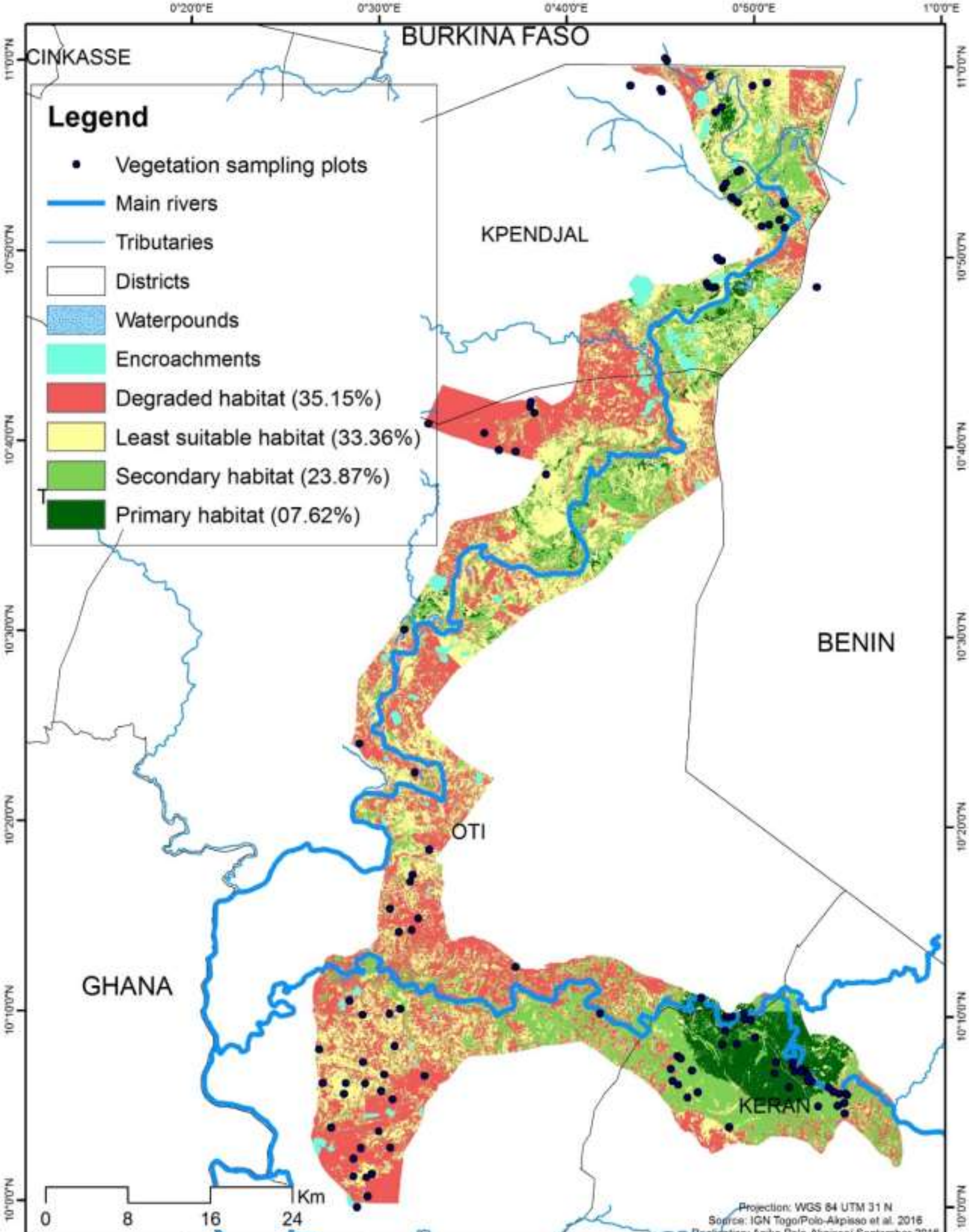

Figure 5. Distribution of habitat types according to their level of suitability within Oti-Keran-Mandouri.

these habitats within OKM.

Characteristic woody plant species for each habitat

The values of biodiversity indices for each habitat type are reported in Table 2. The species richness is higher in Habitat 3 than in others type of habitats, meanwhile Shannon index is higher for Habitat 4. The species richness varies from eight (34) species in degraded habitat (Habitat 1) to sixteen (56) species in secondary habitat (Habitat 3). Shannon index shows a steady increase in habitat diversity from degraded habitat (Habitat 1) to primary habitat (Habitat 4) with the Shannon index increasing from 0.83 to 1.43 bit. In all the habitats, trees are more or less evenly distributed with an evenness higher than 0.7.

Many woody plant species and combination of species were identified as characteristics for each habitat. Nine species were associated with Habitat 1, seven species with Habitat 2, ten species with Habitat 3 and 81 with Habitat 4. Table 3 reports the most important indicator species for each habitat according to their level of significance in the given habitat. With regard to their species composition, Habitats 1 and 2 are quite similar (J>50%). The same pattern was noticed for Habitats 3 and 4 (Table 4).

Biophysical parameters of each habitat

The dendrometric parameters of the different habitats such as the density (N), the mean diameter (D), the basal area (G), the mean height (HM), the lorey's mean height (HL) and the average regeneration are reported in **Error! Reference source not found.** Apart from the mean diameter and the average regeneration rate, all the other dendrometric parameters are significantly different from one habitat to another (p-value < 0.05). Plant density (N), the mean height (HM) and the Lorey's mean height (HL) increase steadily from the degraded habitat (Habitat 1) to the well conserved habitat (Habitat 4). However, the basal area (G) is higher for the moderately conserved habitat (Habitat 3). The mean diameter (D) is almost the same in all the habitats. Meanwhile, the regrowth rate is higher in the least suitable habitat (Habitat 2) and more important in the degraded habitat (Habitat 1) compared to Habitats 3 and 4.

Figure 6 shows the observed diameter structure for the distinguished habitats. Apart from Habitat 1 which shows a bell shape with the shape parameter c=2.07, the others habitat types which showed an inverse ''J'' shape with the c values of 1.11, 1.5 and 1.27 for Habitats 2, 3 and 4, respectively. The shape parameter c has its values ranged between 1 and 3.6 ($1<c<3.6$) characterizing the high frequency of plants with small diameter. The difference in shape of Habitat 1 (bell shape) with the others (inverse "J" shape) is a sign of the gradual increase in density of trees with small diameter. Plants with a center diameter of 15 cm are almost absent in Habitat 1, while present in all the other habitats with the highest density in Habitat 4. Individuals of 25 cm of center diameter are well represented in every habitat and their density increases steadily from Habitats 1 to 4. Meanwhile, plants with diameter from 55 cm and higher are rare however individuals of such diameter could be found in Habitat 1 and mostly in Habitat 4.

Fragmentation of the potential elephant habitat within OKM

With regard to their species composition Habitats 1 and 2 were aggregated into degraded habitat (background) meanwhile Habitats 3 and 4 were aggregated into potential suitable habitat of elephant (foreground). The potential suitable habitat of elephant constitutes 31.5% of the area of OKM while 68.5% is degraded habitat. The overall habitat fragmentation (for the whole of OKM) is 84.74%. Meanwhile the potential suitable habitat is 81.81% fragmented and the degraded habitat is fragmented at 86.08% (Figure 7).

DISCUSSION

Biophysical patterns of habitats

Although trees are evenly distributed in all the four distinguished habitats (Eveness between 0.74±0.17 and 0.79±0.17 bit), the lowest woody species diversities were recorded in Habitats 1 and 2 (Shannon index is 0.83±0.58 and 1.04±0.61 bit, respectively). The highest species richness found in Habitat 3 (n=56) could be simply explained by the number of sampling plots within this habitat because of species-area relationship. The number of sampling plots (n=28) for Habitat 3 is the largest.

The characteristic species for Habitat 1 were mostly *Parkia biglobosa* and *Vitellaria paradoxa*. These are multipurpose species left on farmland by local population. These species are combined with species such as *Pteleopsis suberosa* Engl. & Diels or species of *Combretum*. Such combination is remarkable mostly on young farmlands or fallows. Habitat with such species combination is a result of degradation by agricultural expansion. The presence of *Terminalia* species in Habitat 2 suggests that it encompasses swampy or periodically flooded areas since *Terminalia* spp. are characteristic of such environment. The characteristic species in Habitat 3 are species of dry area and usually found at top of glacis with concretionary soil. Habitat 4 is a typical forested area with a mix of dry forest and gallery forest. The largest habitat patch characteristic of this habitat is located

Table 2. Alpha diversity for the distinguished habitats.

Parameter	Sp Richness	Shannon	Evenness
Habitat 1 (n=27 plots)	34	0.83±0.58	0.75±0.16
Habitat 2 (n=19 plots)	35	1.04±0.61	0.79±0.17
Habitat 3 (n=28 plots)	56	1.07±0.75	0.74±0.18
Habitat 4 (n=24 plots)	55	1.43±0.48	0.74±0.17

Table 3. Most important indicator species for each habitat according to their significance level.

Indicator species	Habitat 1	Habitat 2	Habitat 3	Habitat 4
Individual species	*Vitellaria paradoxa**	*Combretum glutinosum**	*Burkia africana***	*Anogeissus leiocarpus****
	*Parkia biglobosa**	*Terminalia mollis**	-	*Diospyros mespiliformis****
	-	*Terminalia avicennioides**	-	*Oncoba spinosa***
	-	-	-	*Celtis integrifolia***
Combination of species	*Combretum glutinosum* and *Parkia biglobosa**	*Combretum glutinosum* + *Piliostigma thonningii***	*Crossopteryx febrifuga* + *Lannea acida***	*Anogeissus leiocarpus* and *Lannea barteri****
	Combretum molle and *Pteleopsis suberosa**	*Combretum glutinosum* and *Terminalia mollis***	-	*Anogeissus leiocarpus* and *Vitex doniana****
	Lannea barteri and *Parkia biglobosa**	*Combretum glutinosum* and *Terminalia macroptera***	-	*Anogeissus leiocarpus* and *Pterocarpus erinaceus***
	Lannea barteri and *Pseudocedrela kotschyi**	-	-	*Anogeissus leiocarpus* and *Oncoba spinosa***
	Acacia gourmaensis and *Combretum collinum**	-	-	*Anogeissus leiocarpus* and *Mitragyna inermis***
	Parkia biglobosa and *Vitex doniana**	-	-	*Anogeissus leiocarpus* and *Diospyros mespiliformis***
	Combretum collinum and *Combretum glutinosum**	-	-	*Anogeissus leiocarpus* and *Piliostigma thonningii***
	-	-	-	*Mitragyna inermis* and *Tamarindus indica***
	-	-	-	*Diospyros mespiliformis* and *Mitragina inermis***
	-	-	-	*Acacia Polyacantha* and *Mitragyna inermis***
	-	-	-	*Anogeissus leiocarpus* and *Terminalia laxiflora***
	-	-	-	*Oncoba spinosa* and *Pterocarpus erinaceus***
	-	-	-	*Diospyros mespiliformis* and *Oncoba spinosa***
	-	-	-	*Diospyros mespiliformis* and *Lannea barteri***
	-	-	-	*Acacia polyacantha* and *Grewia carpinifolia***
	-	-	-	*Celtis integrifolia* and *Diospyros mespiliformis***
	-	-	-	*Diospyros mespiliformis* and *Pouteria alnifolia***

***, **, * Significance at 0.001, 0.01, 0.05.

around the basement of park rangers.

Habitats 3 and 4 appeared to be better preserved compared to Habitats 1 and 2 regarding dendrometric parameters. This reinforces the results from the Jaccard indices computation on species composition. The stem density and height values are higher in Habitats 3 and 4 in contrary to Habitats 1 and 2. This confirms their state of degradation by anthropogenic activities mostly agricultural expansion. Though, there is high variation within a given habitat (27.78% ≤CvD≤57.23%), the mean diameter is almost the

Table 4. Similarity between distinguished habitats according to Jaccard similarity index.

Jaccard similarity index	Habitat 1	Habitat 2	Habitat 3	Habitat 4
Habitat 1	1			
Habitat 2	0.60	1		
Habitat 3	0.43	0.44	1	
Habitat 4	0.39	0.38	0.54	1

Table 5. Dendrometric parameters of the different habitat.

Parameter	N	CvN	D	CvD	G	CvG	HM	CvHM	HL	CvHL	R	CvR
Habitat 1 (n=27 plots)	143	63.58	33.31	35.23	10.83	49.24	10.30	21.00	11.39	17.98	10922	97.65
Habitat 2 (n=19 plots)	156	58.30	32.42	34.75	12.81	84.31	10.41	22.57	11.47	23.04	12680	83.65
Habitat 3 (n=28 plots)	293	48.31	33.29	57.23	32.91	157.97	12.74	39.79	14.59	38.91	6444	68.37
Habitat 4 (n=24 plots)	305	33.08	27.63	27.78	18.32	49.97	14.12	35.17	17.21	30.99	4855	95.21
p-value*	<0.001	-	0.4538	-	0.003245	-	0.01778	-	<0.001	-	0.05584	-

*Kruskal-Wallis Test. N: Density (Nb of individual plants/ha); Cv: coefficient of variation; D: mean diameter (cm); G: basal area (m^2/ha); HM: mean height (m); HL: Lorey's mean height (m); R: regrowth rate (Nb of Juveniles/ha).

same in all the habitats. This suggests that anthropogenic pressure is present in every habitat. Individual trees of almost the same diameter size are logged regardless of the type of habitat. While agricultural expansion is threatening the peripheral area of the protected area, illegal tree logging is ongoing in the dry and gallery forests located in the core area. On the other hand, the traditional agroforestry system implemented in this area by local population described by Padakale et al. (2015) tends to equalize the diameter of stem in old fallows and old parklands to the diameter of stem in well preserved forests.

The importance of the regrowth rate especially in degraded habitats in addition to the high frequency of plant with small diameter suggests that the restoration of these habitats is still possible. However, the high regrowth rate in Habitat 1 is to be considered carefully. The coefficient of variation for regrowth rate is very high in the degraded land ($CvR_{Habitat\ 1}$ = 97.65%). Anthropogenic activities such as cropping reduce drastically the regrowth rate in some areas as reported.

The diameter structures of Habitats 2, 3 and 4 are almost the same. The difference in shape from Habitat 1 (bell shape) to the other habitats (inverse “J” shape) traduces the difference in the frequency of plant with small diameter. The diameter structure in Habitats 2, 3 and 4 is similar to riparian forest community of Northern Togo (Folega et al., 2014b), and to those described for elephant habitat within Pendjari reserve of biosphere (Tehou et al., 2012). The inverse “J” shape diameter structure is the characteristic of natural vegetation where the density of trees with small diameter is found generally high. However, the diameter structure of Habitat 1 has a bell shape such as the ones described for farmlands and some young fallows in Northern Benin (Aleza et al., 2015) and in old fields in the ecological zone 1 of Togo (Padakale et al., 2015). This is a bell shape structure with a positive asymmetry (c=2.067; 1<c<3.6). Although, there is absence of individual with diameter less than 10 cm, this diameter structure is also characteristic of stable and healthy regenerating population (Djossa et al., 2007).

Almost all the indicator species have been reported as species browsed by elephant (*L. africana*), (Blumenbach, 1797) in the hunting zone of Djona (North Benin) (Tehou and Sinsin, 2000) and in Nazinga Game Ranch (South Burkina Faso) (Hien, 2001). Therefore, habitats in Oti-Keran-Mandouri are suitable to provide for food to elephant. This is one of the factors that may

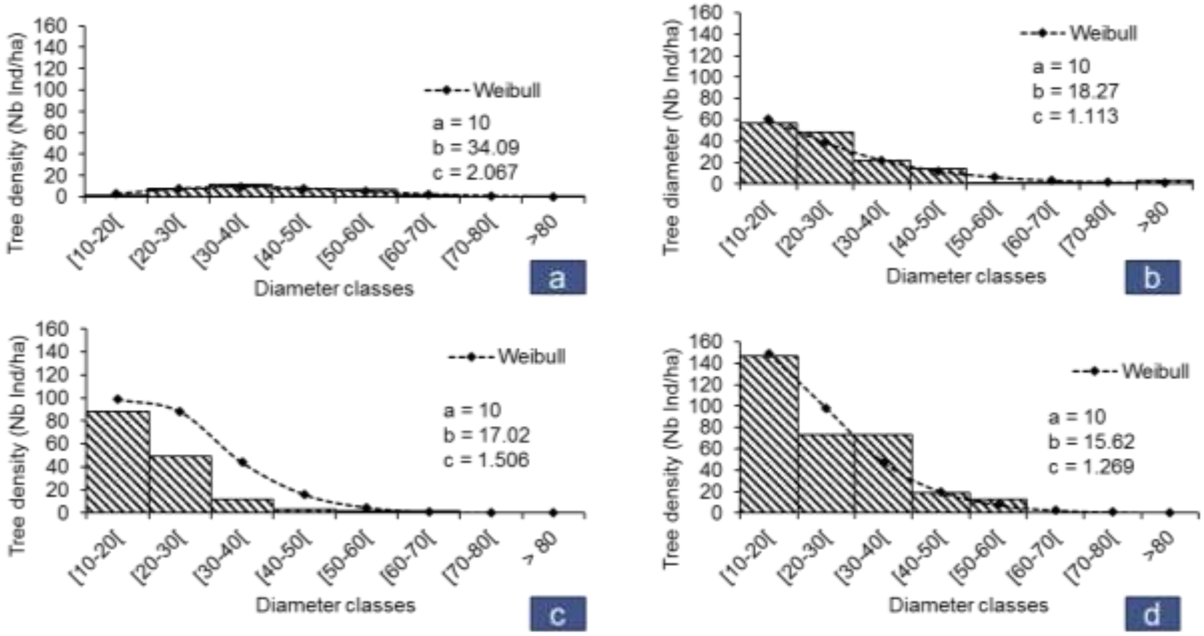

Figure 6. Tree stems diameter structure for distinguished potential habitats of elephant (a=habitat 1; b=habitat 2; c=habitat 3 and d=habitat 4).

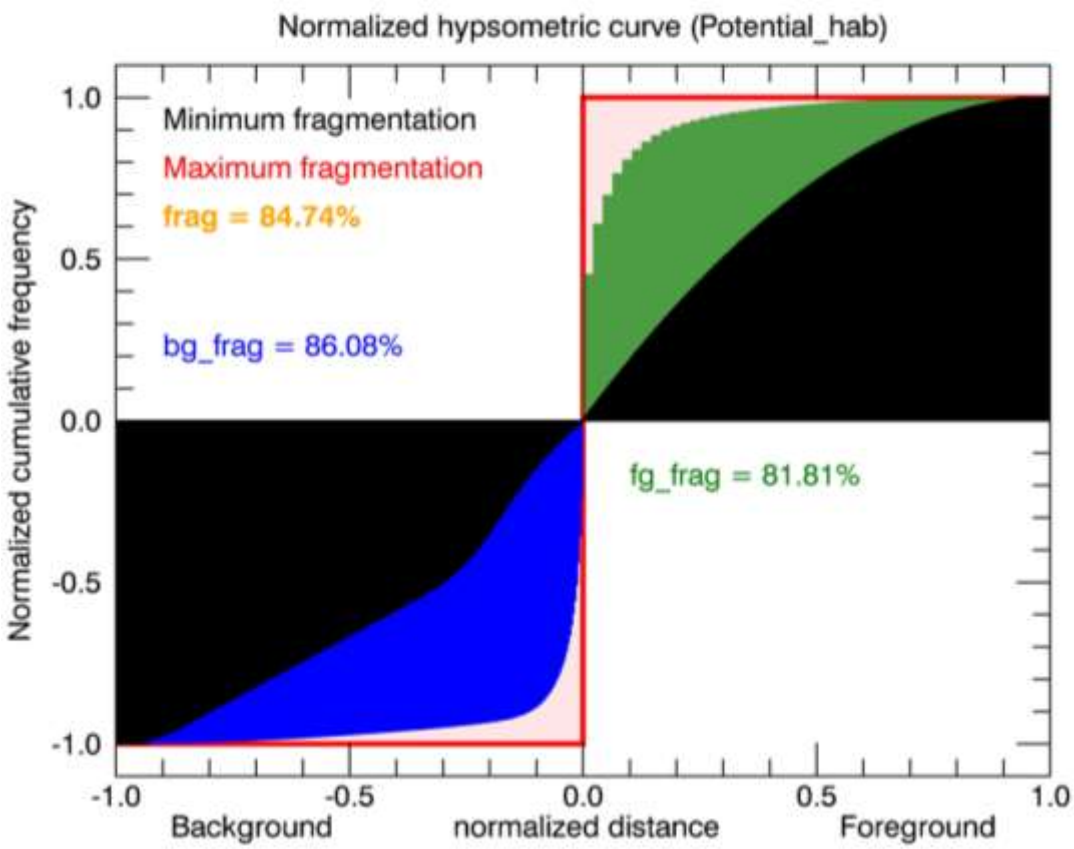

Figure 7. Normalized hypsometric curve of the fragmentation analysis of the elephant potential habitat within Oti-Keran-Mandouri.

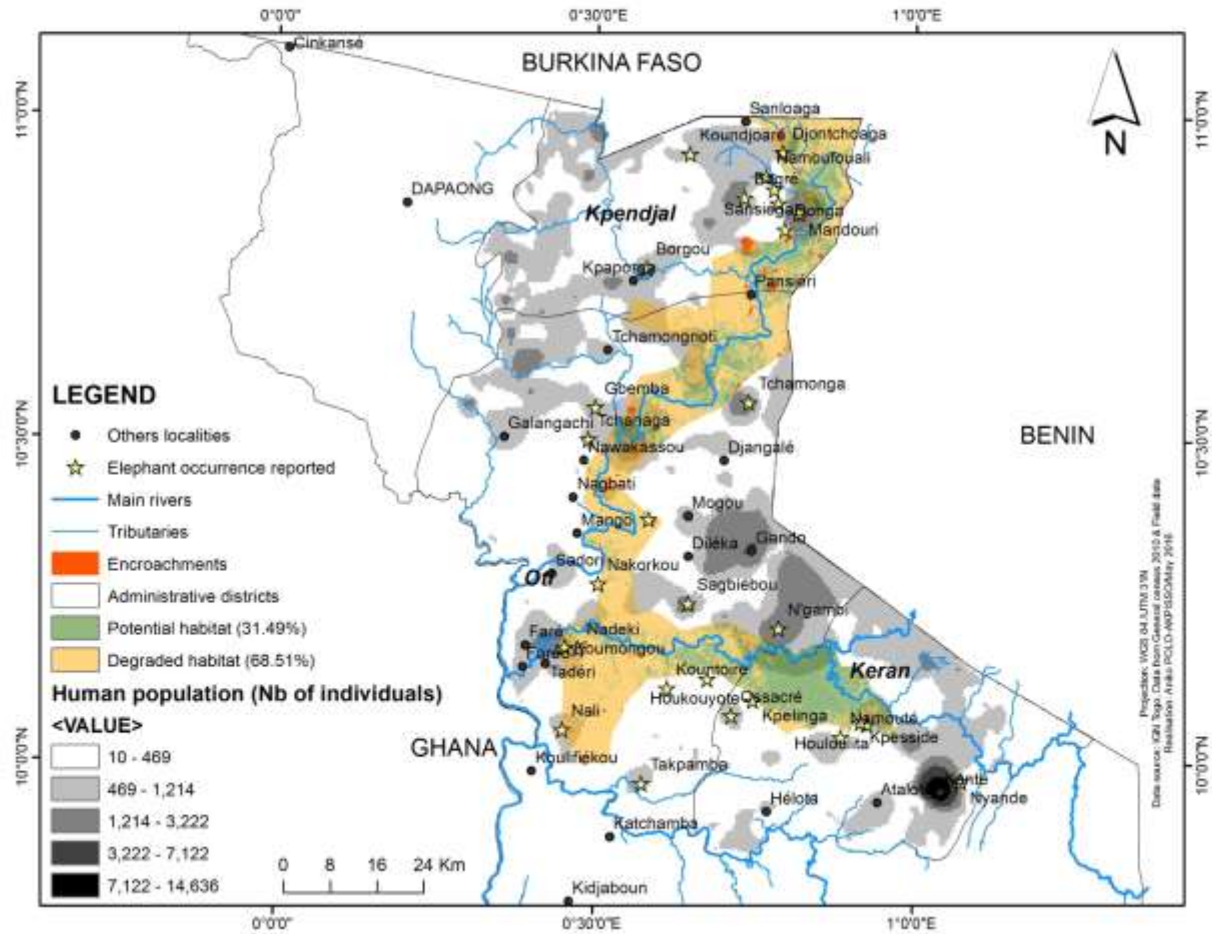

Figure 8. Elephant occurrence with regard to potential habitat and anthropogenic pressure.

explain the occurrence of elephant within OKM.

Habitat fragmentation

Habitats within OKM are severely degraded. The level of fragmentation is high and that could limit or even prevent species' dispersal capacity. Ecological responses to such changes in habitat may be gradual, as species expand, contract, or shift distribution but when systems are pushed beyond thresholds of disturbance, changes may be sudden (Van Horne and Wiens, 2015). Though poaching was the primary reason why elephant extirpated from OKM, their current periodic occurrence may be due to the level of habitat fragmentation that is not enabling permanent establishment. The current habitat fragmentation level may be irreversible resulting in new habitats and ecosystems. These new habitats will require novel approaches to conservation and management.

At its current state, OKM could hardly play its roles as biodiversity refuge and as corridor for wildlife species. The issue of habitat degradation in this landscape remains. This issue is globally important and seems to be the main threats to biodiversity and ecosystem services (Dimobe et al., 2014; Folega et al., 2014a; Boakye et al., 2015). Habitat degradation is considered as causing a biome crisis by Hoekstra et al. (2005).

There are still some patches of suitable habitat for elephant that could be considered as remnant good habitats. However, only the area located in the south-eastern part of the protected area seems to be the best conserved and could be considered as a core habitat. This area was reported by previous studies (IUCN, 2008; Adjonou et al., 2009; Folega et al., 2014c) and its state of conservation could be linked to the presence of park rangers' basement. This basement is deterring the spread of anthropogenic activities in this area as noticed elsewhere in the park. Since the relatively good patches of habitat are near the stream network, a corridor of gallery forest connecting isolated habitats could be restored along the main rivers. This kind of corridor was proposed in a study of elephant corridor between Côte d'Ivoire and Ghana (Parren and Sam, 2003). Furthermore, riparian and streams forests are considered to act like a natural corridor for many species and to deliver many ecosystem services (Natta et al., 2004; Folega et al., 2014a). Therefore, the area next to rivers should be considered as a priority restoration area and be kept from any anthropogenic activity. Since plant species in cultivated areas have low regrowth capacity and the river banks are subjected to recessional agriculture activities, only an active restoration process involving resident communities could be successful. The restoration process implies the implementation of a sustainable land management system based on participatory activities as described by Bierbaum et al. (2014).

This restoration is naturally feasible due to the fact that elephants are recognized to have long memories (McComb et al., 2001; Foley et al., 2008) and the could participate in the restoration process through their seed dispersal habit. The restored corridor could as well be beneficial to medium sized ungulates that can resume migration (Bartlam-Brooks et al., 2011). Simberloff and Cox (1987) have defined conservation corridors as constructed corridors intended to connect habitat reserves to facilitate immigration and genetic exchange. But OKM looks currently like a vanishing corridor and an effective restoration would require further research mostly to investigate socio-ecological system and how to integrate such system in the process.

Implications for elephant conservation

Elephants are reported to occur in almost all the surrounding villages regardless to the importance of human settlements (Figure 8) while their footprints were mainly recorded in the largest patch of suitable habitat located in the south-eastern part of OKM. Feeding resources and water availability may explain elephant occurrence within and around OKM. For instance, swampy areas constitute 39 267 ha and about 22% of OKM area. In addition to that, individuals that exhibit fidelity to previous breeding locations may continue to occupy those areas even after the original habitat has been drastically altered (Wiens and Rotenberry, 1985). Considering this aspect, killing of problem elephant is not an option if the habitat and the persistence of elephant population within OKM are to be restored.

Human population data interpolation gives an idea of anthropogenic pressure on OKM ecosystem by delineating high human populated zones. Human population may have an important impact on elephant movement as well. The presence of human settlements around Mandouri, Donga and even Pansieri counties in Kpendjal prefecture could be the factor preventing larger number of elephants coming from Pendjari reserve of biosphere to reach the largest patch of well-preserved habitat located in the south-eastern part of OKM.

Planning for and protecting elephant corridors have been shown to have large benefits for biodiversity conservation by many authors in East Africa especially in Tanzania (Epps et al., 2011; Jones et al., 2012). Furthermore, the African elephant remains a good candidate as a surrogate species for conservation planning. It encompasses all the attributes of a focal species and associated conservation needs as proposed by Brock and Atkinson (2013). An effective conservation of the elephant would require management or mitigation of almost all elements affecting the needs of the total species community and provides ecosystem-level protection. On the other hand, confined population of elephant exert a damaging influence on their habitat. For instance, this effect has already been described in the biosphere reserve of Pendjari where elephants are responsible of inducing bark damage to baobab trees (*Adansonia digitata*) (Kassa et al., 2013) and to drive spatial isolation in *Borassus aethiopum* (Salako et al., 2015). A landscape level management of elephant population would alleviate their damaging effect in confined habitat. A corridor between OKM and the nearby block of elephant population in the biosphere reserve of Pendjari could provide a solution to this damaging impact.

Conclusion

Apart from a core area in the south-eastern part, habitats within OKM are degraded. Despite its potential of being part of the strategy and an important corridor for the conservation of elephant in West Africa, OKM looks more like a vanishing corridor. Plant species regeneration rate and occurrence of elephant give hope for an eventual restoration but further research and data are still needed especially on the socio-ecological system. Nevertheless, the occurrence of elephant recorded in the largest habitat patch suggests that a corridor between this habitat patch and the nearby block of elephant population in the biosphere reserve of Pendjari could be restored.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Effects of bush encroachment on plant composition, diversity and carbon stock in Borana rangelands, Southern Ethiopia

Siraj Kelil Gobelle[1*] and Abdella Gure[2]

[1]Department of Agroforestry, Oromia Agricultural Research Institute, Yaballo Pastoral and Dryland Agriculture Research Center, P. O. Box 85, Yaballo, Ethiopia.
[2]Department of Forestry, Hawassa University, Wondo Genet College of Forestry and Natural resource, P. O. Box 128, Shashemene, Ethiopia.

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Bush encroachment is reducing rangeland productivity in Borana rangelands. This study was conducted in Teltele Woreda of Borana zone, to evaluate the effects of bush encroachment on plant species composition, diversity and its contribution to carbon stock. Bush encroached, non-encroached and bush thinned rangeland types were selected for the study. Nested plots for collecting tree, shrub, herbaceous and soil data were placed systematically along the geographic gradient within each of the rangeland types. Herbaceous plants were clipped to the ground, collected, oven dried, and their carbon stock was estimated. The tree/shrub biomass was estimated using allometric models, and converted to per hectare. A total of 53 vascular plant species belonging to 19 families were identified. Poaceae and Fabaceae families dominated the site. Bush encroachment had reduced diversity and species richness of herbaceous plants, but did not affect other tree/shrub plant diversity and richness. Although bush thinning improved herbaceous diversity and richness, it reduced tree/shrub richness. The tree/shrub aboveground carbon stock in bush encroached areas is greater than non-encroached rangeland types. Soil carbon stock is highest in bush thinned locales. Total organic carbon stock is ranked from largest to least as follows: Bush encroached, >Bush thinned, and >non-encroached. Generally, bush encroachment increased the rangeland carbon stock, but reduced herbaceous plant biomass and density.

Key words: Biomass, bush thinned, encroachment, herbaceous, rangeland type, soil carbon stock, climate change.

INTRODUCTION

Rangelands include natural grasslands, savannas, shrublands, many deserts, steppes, tundra’s, alpine communities and marshes in which indigenous vegetation (climax or sub-climax) are grazed or have the potential

*Corresponding author. E-mail: kelilsiraj2012@gmail.com.

to be grazed to produce grazing livestock and wildlife (Allen et al., 2011). Grasslands are terrestrial ecosystems dominated by herbaceous and shrub vegetation, which include savannas, woodlands, shrublands, and tundra, as well as other forms of grasslands that are conventional and maintained by fire, grazing, drought and/or freezing temperatures and cover about 40.5% of terrestrial ecosystems (Robin et al., 2000). In Ethiopia, grassland ecosystems cover about 72.9% of the land area (Robin et al., 2000). Savanna ecosystems are characterized by the coexistence of trees and grass (Scholes and Archer, 1997), and provide comprehensive economic and ecological benefits for society, particularly to pastoralist communities (Robin et al., 2000). Increasingly, dense thickets of woody vegetation, termed as bush encroachment, are undermining the productivity and long-term economic viability as well as the ecological integrity of savanna and grasslands. Bush encroachment is characterized by an increase in density, cover, and biomass of indigenous woody or shrubby plants (Auken, 2009). Encroachment of woody plants into grasslands, and the conversion of savannas and open woodlands into shrublands, has been widely reported during the past decade (Auken 2000, 2009; Maestre et al., 2009; Eldridge et al*.,* 2011), and this phenomenon has been observed across much of the world's arid and semi-arid biomes (Andela et al., 2013). It is particularly visible in African savannas and grasslands (Mitchard and Flintrop, 2013).

Scientists have long been attempting to explain cause of bush encroachments. The most frequently-mentioned driving factors explaining bush encroachment include overgrazing, availabilities of soil nutrient and moisture, frequency and intensity of fire, raised CO_2 levels, spread of seeds of woody species by livestock and wild animals (Anteneh and Zewdu, 2016). Encroachment of woody plants into Savanna ecosystems has generated considerable interest among ecologists, because of the global trans-national nature of encroachment and its putative association with widespread landscape degradation (Eldridge et al., 2011). On the other hand, the widespread occurrence of woody plant encroachment in global arid and semiarid regions could have important implications for the global terrestrial carbon balance. The adverse impact of greenhouse gas emission and consequent climate change is emerging all over the world. Reducing atmospheric concentrations of carbon dioxide (CO_2) through carbon fixation by photosynthesis is an important biotic technique to mitigate climate change. Plants capture CO_2 from the atmosphere and subsequently stored in above and belowground biomass. The storage of carbon in terrestrial carbon sinks such as plants, plant products, and soils for longer periods is a win-win strategy, and a growing research topic addressing ways to effectively overcome the challenges of climate change (Lal, 2008; Wilfred et al*.,* 2012; Sheikh et al*.,* 2014). The grassland carbon cycle models generally focus on three carbon 'pools': Carbon stored in living vegetation, litter, and soil carbon. The increase in tree density in grass-dominated areas can increase carbon storage capacity of grassland systems and rates of carbon sequestration (Hughes et al*.,* 2006; Tennigkeit and Wilkes, 2008*).*

Like other African rangelands, most rangelands in Ethiopia are currently affected by woody plant encroachment. The Borana rangelands, located in the southern part of the country, are among those heavily affected by bush encroachment (Ayana, 2002; Gemedo et al., 2006; Ayana and Gufu, 2010). In the Borana low lands, the spread of bush encroachment was noticed after the Gada Liiban Jaldesa (1960 to 1968); and 83% of the rangelands were threatened by a combination of bush encroachment and increase of unpalatable forbs (Ayana and Gufu, 2008). In the mid-1980s, about 40% of the Borana rangelands were affected by bush encroachment (Coppock, 1994) and its cover increased to 52% in early 1990s (Gemedo et al., 2006). A study conducted by Daniel (2010), showed bush cover within Borana rangelands increased from 51% in 1986 to 53.8% in 2002, and to 57% in 2010. Moreover, the major shifts were from grassland and bare land to bushlands. Hasen (2013) reported that the area covered by bushland thickets and bushes within savannah rangelands had increased from 22 to 61% between 1976 and 2012. The density and total area covered by bush encroachment is increasing as time progresses. The density of encroaching woody species in the Borana Zone is beyond the critical limit (Adisu, 2009), and enclosure areas were more threatened by invasive species than free grazing areas (Ayana and Gufu, 2010). The suppression of fire declared by government policy contributed to the expansion of bush encroachment in Borana (Ayana and Gufu, 2008). The other problem in Borana rangelands is crop cultivation encroachment. Borana communities were highly involved in crop cultivation as an alternative means of livelihood (Tilahun et al., 2017), however it is not self-sufficient in grain production, and produces yields at only 31% of the Ethiopian national average (Tache and Oba, 2010).

In Borana rangelands, bush encroachment is considered as one of the major problems affecting rangeland ecosystem structures and functions. Several studies (Coppock, 1994; Gemedo et al., 2006; Ayana, 2007; Ayana and Gufu, 2007; Adisu, 2009; Hasen, 2013; Bikila et al., 2014) reported the adverse effects of woody plant encroachment on grass productivity and the diversity of the native vegetation, particularly grasses and forbs and reduced ground cover, exposing large parts of the rangelands for soil erosion and other degradation processes. On the other hand, the on-going woody encroachment in savanna and grassland ecosystems has significant implications for the global carbon cycle. Widespreading woody encroachment in Borana rangelands has substantially increased the carbon stock in aboveground biomass, which will foster future carbon trade discussions with respect to climate change mitigation strategies (Hasen, 2013). Bush encroachment is a wide spread problem in the Borana Zone. In particular, this phenomenon has altered the ecological condition and value of rangeland for livestock grazing, leading to reduction in economic benefits of the rangelands. To overcome or mitigate the effects of chronic overgrazing, Borana pastoralists started several adaptation approaches, like diversification of livestock type through including browser animals such as camel, goat and bush thinning/clearing. Controlling the spread of bush encroachment through thinning/clearing, the woody plant species could improve rangeland productivity. Some studies have been conducted on methods of controlling bush and these are recommended in Borana rangeland. Bush removal methods such as tree cutting and fire, tree cutting followed by fire and grazing, fire and grazing, and tree cutting alone improved herbaceous biomass, basal cover and species diversity (Ayana et al., 2012). Re-sprouting nature of the encroaching species after cutting during controlling the species is one of the other challenges. Prior published research indicated that cutting at 0.5 m aboveground and debarking the stumps down into the soil surface, or cutting at 0.5 m aboveground alone, were good in controlling *Acacia drepanolobium.* For controlling *Acacia mellifera* cutting at 0.5 m aboveground and dissecting the stumps and cutting at 0.5 m aboveground and debarking the stumps down into the soil surface had a significant effect (Bikila et al., 2014).

Previous studies by (Coppock, 1994; Ayana, 2005; Gemedo et al., 2006; Daniel, 2010) conducted in the Borana rangelands on bush encroachment were more emphasized on bush encroachment covers and its effects on grass production and plant diversity than on the contribution of bush encroachment for carbon sequestration, because the primary objective of rangeland management in Borana is for livestock production. It is also essential to assess the impacts of bush encroachment on plant diversity over time, and the value of woody vegetation for storing carbon. As such, this study was conducted to evaluate the effects of bush encroachment on plant community composition, diversity, and carbon stocks by comparing these metrics across three rangeland types (bush encroached, non-encroached, and land exposed to bush thinning).

MATERIALS AND METHODS

Description of the study area

The study was undertaken in Teltele Woreda of Borana zone, Southern Oromia National Regional State, Ethiopia. Borana zone lies approximately between 4°3´N to 5° N and 37° 4´E to 38° 2´E, and the landscape is characterized by slightly undulating peaks up to 2000 meters above sea level (m.a.s.l) in some areas (Coppock, 1994). Teltele Woreda is found at 100 km West of Yaballo, while the Sarite specific study site is found at 80 km Southwest of Yaballo (Figure 1). Borana weather is characterized by erratic and variable rainfall with most areas receiving between 238 and 896 mm annually (Ayana and Gufu, 2007). The rainfall pattern is distinctly bimodal, 59% of annual precipitation occurs from March to May, while 27% occurs from September to November (Coppock, 1994). The geological formations of the central Borana plateau are a Precambrian basement complex (38%), sedimentary deposits (2%), volcanic (20%) and 40% is quaternary deposits (Coppock, 1994), which influence soil fertility, and in turn, influences the vegetation characteristic. The three (3) main soils include 53% red sandy loam soil, 30% black clay, and volcanic light-colored silt clay and 17% silt (Coppock, 1994). The majority of Borana vegetation is characterized as Acacia-Commiphora woodland and bush land (Friis et al., 2011). The major land covers of the Borana zone are shrubland, grassland, woodland, cultivated land, and exposed surface (OWWDSE, 2010).

However, high rates of land cover changing from grassland and bare land to shrubland have recently been observed (Daniel, 2010). The Borana communities use their grazing land as enclosures (Kalo), and also utilize open-grazed communal rangelands in which livestock graze throughout the year (Coppock, 1994). The specific study site was located around 04° 56’ 23” N and 37° 41’51” E at 970 to 100 m above sea level. As local elders reported, the rangeland was pure grassland with clay soil texture.

Commonly encroaching woody species, and those that frequently thinned, include *Senegalia mellifera, Vachellia reficiens* and *Vachellia oerfota.*

Selection of the study site and sampling design

Teltele Woreda was selected because of the existence of bush encroachment and bush management practices. Sarite Kebele was selected because of the three rangeland types (bush encroached, non-encroached and bush thinned) found in proximity to one another. The term bush-encroached was used to designate the areas that were invaded by previously uncommon and subdominant woody plant species.

The term bush thinned was used to designate bush-encroached areas in which encroaching woody plants were previously thinned for range management, while non-encroached rangelands include savannas and grasslands that had not been invaded by woody encroachers prior to the study.

Within each rangeland type, one linear transect was systematically placed along a geographic gradient (elevation). Systematically placed plots along transect lines were selected since they are of considerable importance in the description of vegetation changes along environmental gradients or in relation to some marked features of topography (Mueller-Dumbois and Ellenberg, 1974). Six nested sampling plots were placed at 100 m intervals along each transect.

Nested sampling plots consisted of a single 10 × 10 m^2 subplot for sampling shrubs within a larger 20 × 20 m^2 main plot used for sampling trees. Stratified within the main sampling plot and across the subplot, three additional 1 × 1 m^2 quadrats were used for sampling seedlings, herbs, and grasses (Figure 2). Totally 18 nested sample plots, six from each rangeland type (encroached, non-encroached and bush thinned) were sampled. Soil samples were collected from the four corners and the center of all 20 × 20 m^2 plots (main plot) at two depths (0-15 cm, 16-30 cm) and additional soil samples at the same depths were taken from the center of each of the main plots to determine bulk density.

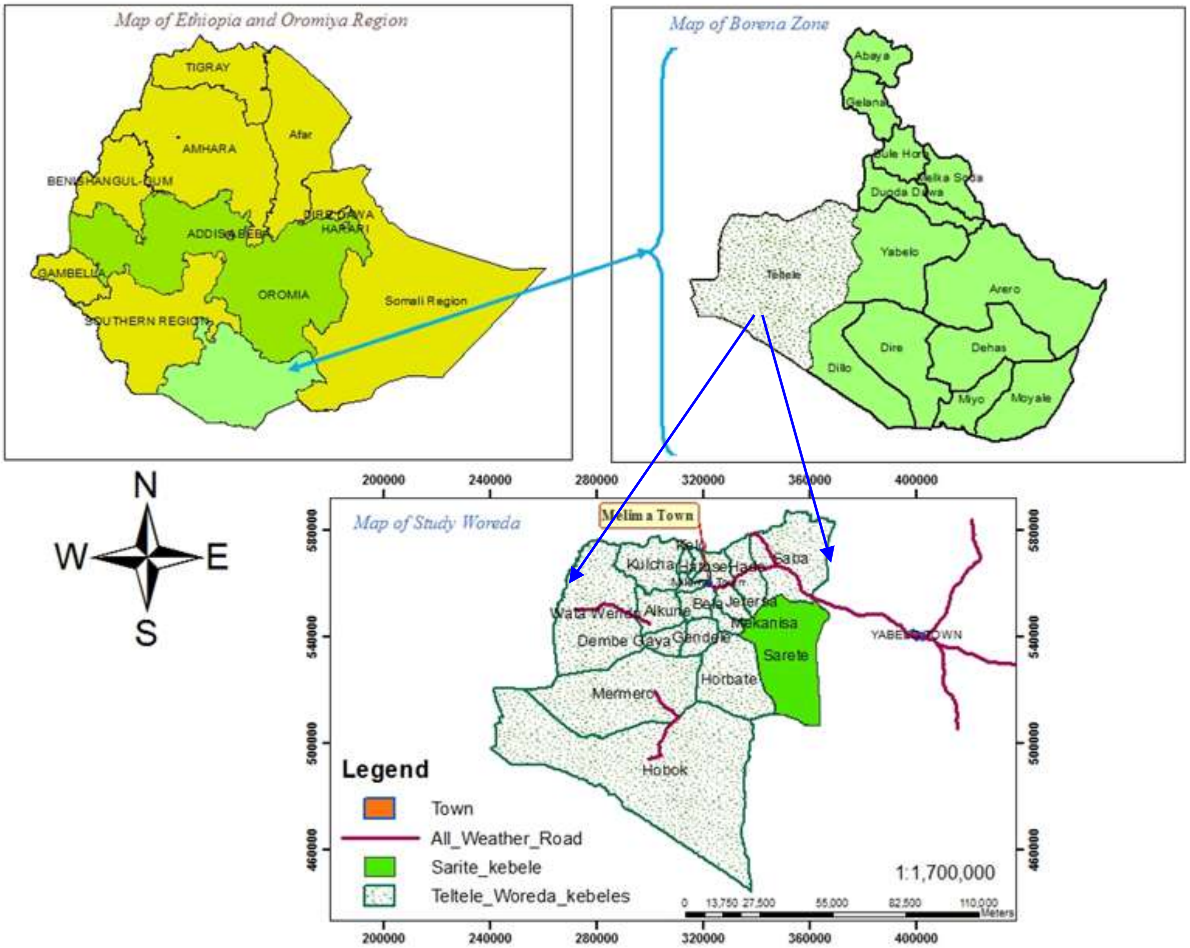

Figure 1. Map of the study area.

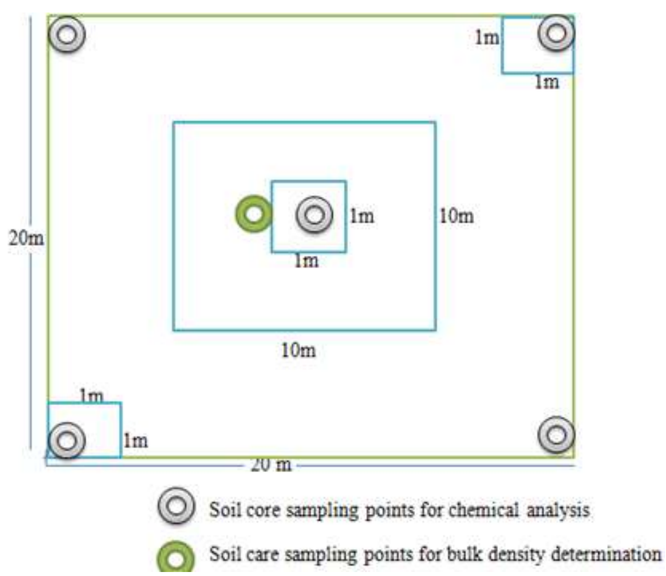

Figure 2. The layout of nested plots used for data collections, modified from FAO (2004).

Vegetation data collection and identification

Tree sampling

Tree (all individuals of woody species with DBH >5 cm) sampling was carried out by laying down 20 × 20 m^2 plots using a measuring tape along the transect line at 100 m intervals. Within each 400 m^2 plot, height and diameter of all individual trees were measured. The height was measured using a Silva-Hypsometer for trees taller than 4 m and using a measuring stick for trees less than 4 m high. Tree diameter was measured at the ankle (5 to 10 cm aboveground) and at breast height DBH (1.3 m above the ground) using a caliper. The longest crown diameter and diameter perpendiculars to the longest diameter and the crown height were measured using a 5 m long metal stick. In the case of multi-stemmed trees branched below DBH, the diameter was measured as the average of the DBH of each stem. If trees were branched or had separate trunks below the diameter at the ankle, each trunk was considered as a separate individual and thus their diameter was measured at DBH.

Shrub sampling

Shrubs are woody plants with multiple stems arising at or near the base and their canopy are intermediate between larger tree canopy and the understory plant (Allen et al., 2011). They were woody plants that were less than 5 cm DBH and greater than 2.5 cm circumferences at ankle and heights of less than 3 m. Shrub, bush and saplings measurements were collected from the 10 × 10 m^2 subplots using similar methods used for measuring trees. As most of the encroaching species branched below DBH, measurements of the shrub diameter were made at the ankle; and crown diameter, crown height and total height were used to estimate aboveground biomass and carbon stocks, following previous study methods (Hasen et al., 2013).

Understory (grass and other herbaceous plants) sampling

In 1 × 1 m^2 subplots, all herbaceous plants were identified, counted and recorded. All herbs, grasses, seedling, and climbers were clipped to the ground and separated into two groups; grass and non-grass after the species were identified. Their fresh weight was taken immediately in the field using a field balance, and sub-samples were taken where the sample was too large to manage for drying in an oven. For a small and manageable sample, the whole samples were stored in polyethylene bags and taken to Yaballo Pastoral and Dryland Agriculture Research Center soil laboratory and oven dried for 24 h at 105°C to determine the biomass and carbon stock.

Identification of the species was made in the field with the help of field identification keys and plates and Flora of Ethiopia books (Edwards et al., 1995; Edwards et al., 1997; Edwards et al., 2000), or based on herbarium specimens collected from the sample plots. The name of the plant species was cross-checked with previous studies conducted in the study areas (Gemedo et al., 2005).

Plant diversity indices, similarity, and species composition

Measurement of diversity indices

The formula for calculating the Shannon diversity index was from Magurran (2004):

$$\mathbf{H'} = -\sum_{i=1}^{S} \mathbf{P_i} * \mathbf{lnP_i} \quad (1)$$

where H' = Shannon index of diversity; Σ = Summation symbol; total number of species in the sample; Pi = the proportion of the i^{th} species (Pi = n_i/N), n_i= abundance of i^{th} species and N = total number of individuals and ln = natural logarithm.

Dominance and Simpson index

Dominance was calculated as:

$$\mathbf{D} = \sum_{i}^{S} (\mathbf{P_i})^2 \quad (2)$$

and Simpson index = 1-D

where D = Simpson index of dominance, (Pi =n_i/N), n_i= abundance of i^{th} species and N = total number of individuals

Evenness or equitability index was calculated as:

$$E = (H')/\ln S = (H')/(H' max) \quad (3)$$

where E = Evenness; H' = Shannon-Wiener Diversity Index; H max =ln(S).

Measures of similarity

Bray-Curtis similarity index and Sorensen coefficient of Similarity (S_s) were calculated following Hammer et al. (2001), using Equations 4 and 5:

$$S_S = 2a/(2a+b+c) \quad (4)$$

where S_s= Sorensen similarity coefficient, a = number of species common to both samples, b = number of species in sample 1, and c = number of species in sample 2.

The Bray-Curtis similarity index is given by the formula:

$$\mathbf{d_{jk}} = \mathbf{1} - \frac{\sum_i |\mathbf{X}_{ij} - \mathbf{X}_{kj}|}{\sum_i (\mathbf{X}_{ij} + \mathbf{X}_{kj})} \quad (5)$$

The counts of the species collected from each plot were pooled for each of the rangeland types. To determine the proportional representation of each species relative to the entire plant community, relative density and relative frequency values for each species were computed and expressed as a percentage following method used by Baxter, (2014).

$$\text{Relative density} = \frac{\text{Number of individuals of a species}}{\text{Total numbers of individuals of all species}} \times 100 \quad (6)$$

$$\text{Relative frequency} = \frac{\text{Frequency of a species}}{\text{Frequency of all species}} \times 100 \quad (7)$$

$$\text{Plant density} = \frac{\text{Total Numbers of individuals}}{\text{Area in hectares (ha)}} \quad (8)$$

Aboveground biomass and carbon stock determination

Tree and shrub biomass and carbon stock were estimated by non-destructive methods using an allometric equation. For major

Table 1. Allometric models used for biomass estimation of the trees and shrubs.

Tree/Shrub	Models (Allometric equations)	Variables unit of measurements	Ecology	References
General	AGB(kg) = $0.0673\times(\rho D^2H)^{0.976}$	D (DBH) (cm), H(m) and ρ (g/cm^3)	Tropical trees	Chave et al. (2014)
General	AGB = $0.0763*dbh^{2.2046}* H^{0.4918}$	(DBH) (cm), H(m)	Savanna	Mugasha et al. (2013)
Commiphora species	ln (Wt) = -2.7882 + 1.1324 ln (SB) + 0.3163 ln (CV)	CV(m^3), SB(cm)	Savanna	Hasen et al. (2013)
Vachellia etabaica	ln (Wt) = -7.0822+ 2.877 ln(SB)	SB(cm)	Savanna	Hasen et al. (2013)
Vachellia oerfota	ln (Wt) = -1.32+1.1084 ln(CV)	CV(m^3)	Savanna	Hasen et al. (2013)
Vachellia reficiens	ln (Wt) = -0.1774 + 0.872 ln (CV)	CV(m^3)	Savanna	Hasen et al. (2013)
Senegalia mellifera	ln (Wt) = -2.7777 + 0.963 ln (SB) + 0.7503 ln (CV)	CV(m^3), SB(cm)	Savanna	Hasen et al. (2013)

Wt: Total aboveground dry biomass, CV=crown volume, SB=circumference at of the stem ankle height, ρ=wood density, D=trees and shrubs diameter, H=trees and shrubs height, dbh=diameter at breast height.

encroacher, woody species the locally developed allometric equations by Hasen et al*.*, (2013) were used (Table 1). The canopy areas (CA) and volume (CV) of woody plants used as parameters in the model were calculated as an elliptic crown nature of shrubs following Hasen et al., (2013) using Equations 6 and 7, respectively.

$$CA= \pi \times a\times b \quad (9)$$

$$CV = 4/3\times\pi\times a\times b\times h \quad (10)$$

where a = Crown radius, *B* = Crown width and h = Crown height

For trees and shrubs which have no locally developed allometric equation but have a wood density in the global wood density database, a general allometric model of Chave et al. (2014) was used to estimate the biomass (Table 1). The tree and shrub wood densities were estimated from the global wood density database (Zanne et al., 2009) by averaging the wood density of the tropical Africa region genera and families of that species. For the trees and shrubs which have no data in the global wood density database, an allometric model of Mugasha et al. (2013) was used to estimate biomass (Table 1). Aboveground tree/shrub carbon stock was calculated for each tree and shrub species as Equation 8 and belowground tree/shrub biomass was determined using a tropical tree regression model of Pearson et al. (2005). The total amount of tree and shrub biomass, and carbon stock per plot, were converted to per hectare basis (Pearson et al., 2005).

$$\text{Carbon Stock} = \text{Aboveground biomass}\times 0.5 \quad (11)$$

$$BBD = EXP (-1.0587+0.8836\times \ln ABD) \quad (12)$$

where BBD = belowground biomass density, and ABD = aboveground biomass density (t/ha).

Understory plants (herbaceous) biomass and carbon stock were determined by destructive methods. The herbaceous plants were clipped within 1 m x 1 m subplots along the diagonal of the main plot (Figure 2) and oven dried. The oven-dry weight was taken with a sensitive balance. The oven-dry weight of the three sub-sample plots from the main plots were averaged and converted to a hectare basis. The herbaceous carbon stock potential was estimated from the biomass of herbaceous plants using Equation 8. Belowground biomass of herbaceous plants was estimated from aboveground herbaceous biomass using a recommended root-to-shoot ratio value that is 50% of the ABG. Belowground carbon stock was calculated by multiplying the belowground herbaceous biomass by 0.5 (Persson et al., 2005).

$$BGB = AGB \times 0.5 \quad (13)$$

Methods of data analysis

Plant diversity was analyzed using PAST version 3.10, Paleontological Statistical software (Hammer et al., 2001). Prior to analysis, the data were tested for normal distribution using SPSS version 20 following Shapiro-Wilk methods. Diversity results with other vegetation attributes were analyzed using General Linear Model (GLM) procedures of the statistical analysis system with IBM SPSS version 20. One way analysis of variance (ANOVA) was used for all vegetation attributes and Tukey HSD (at *P*<0.05) was used to test for possible statistically significant mean pair differences.

RESULTS AND DISCUSSION

Floristic compositions and diversity

Floristic composition

A total of 53 vascular plant species belonging to 19 families were encountered (Table 2) across the bush encroached, bush thinned and non-encroached rangeland types. Of the total species encountered in the study area, 12 species *(Brachiaria eruciformis, Chlorosis roxburhiana, Cyprus obtusiflorus, Dactyloctenium aegyptium, Doberaglabra, Echinochloa colony, Indigofera arrecta, Endostemon Keller, Justicia calyculata, S. mellifera, Sporobolus pyramidalis and Volkensinia prostrata)* were found on all three rangeland types. From the total species recorded in the

Table 2. Trees, shrubs and herbaceous species recorded at the Sarite study site.

Species name	Vernacular name	Family	Growth form
Aristidaadoensis Hochst.	Biilaagaaraa	Poaceae	Grass
Aristidaadscensionis, Linn.	-	Poaceae	Grass
Aspilia mossambicensis Klotzsch	Hadaa	Asteraceae	Herb
Balanites aegyptiaca (L.) Del.	Baddana lu`oo	Balantiaceae	Tree
Bidens biternata (Lour.) Merr. &Sherff	Cogoitii	Asteraceae	Herb
Blepharisedulis (Forssk.) Pers.	Galgadaana	Acanthaceae	Herb
Boscia mossambicensis Klotzsch	Qalqalcha	Capparidaceae	Tree
Brachiaria eruciformis (J f. Smith) Griseb.	Marga laafaaa	Poaceae	Grass
Brachiaria lachnantha (Hochst.) Stapf.	-	Poaceae	Grass
Chlorosis roxburhiana Schult	-	Poaceae	Grass
Chrysopogon auheri (Boiss.) Stapf.	Alaloo	Poaceae	Grass
Commelina africana L.	Qaayyoo	Commelinaceae	Herb
Commiphora africana (A. Rich.) Engl.	Hammeessa dhiiroo	Burseracea	Tree
Commiphora schimperi (Berg) Engl	-	Burseracea	Tree
Cordia gharaf (Forssk.) Ehrenb.	Madhera raphacho	Boraginaceae	Shrub
Cyprus obtusiflorus Vahl.	Saattuu	Cyperaceae	SG
Dactyloctenium aegyptium (L.) Willd.	-	Poaceae	Grass
Digeramuricata (L.) Mart.	Darguu	Amaranthaceae	Herb
Dinebra retroflexa (Vahl) Panzer	Marga babal`aa	Poaceae	Grass
Doberaglabra (Forssk.) Poir.	Garsee	Salvadoraceae	Tree
Echinochloa colona (L.) Link	Meellaa	Poaceae	Grass
Endostemon kelleri (Briq.) M.	Urgoo	Lamiaceae	Herb
Eragrostis cilianensis (All.) Vign. ex Janchen	-	Poaceae	Grass
Eragrostis papposa (Roem. &Schult.) Steud.	-	Poaceae	Grass
Euphorbia cuneata Vahl	Bursa	Euphorbiaceae	Shrub
Euphorbia indica Lam.		Euphorbiaceae	Herb
Grewia tembensis Fresen.		Tiliaceae	Shrub
Indigofera arrecta Hochst. ex A. Rich.	Harcumman	Fabaceae	Herb
Indigofera spicata Forssk.	-	Fabaceae	Herb
Justicia calyculata Defiers	Darguu	Acanthaceae	Herb
Justicia odora (Forssk.) Vahl	Agagaroo Harree	Acanthaceae	Herb
Kleinia squarrosa Cufod	Xixixxu	Asteraceae	Shrub
Kohautia coccinea Royle	-	Rubiaceae	Herb
Maeruatriphylla A. Rich. Var. calophylla (Gilg.) De Wolf	Dhumasoo	Capparidaceae	Tree
Pavonia arabica	-	Malvaceae	Herb
Pollichia campestris Ait.	Gungumaa korbeessa	Caryophyllaceae	Herb
Pupalia lappacea (L.) A. Juss.	Hanqarree	Amaranthaceae	Herb
Rhynchosia ferruginea A. Rich.	Kalaalaa	Fabaceae	Climber
Ruellia patula Jacq.	Doqa	Acanthaceae	Shrub
Senegalia mellifera (Vahl.) Benth	Saphansa gurraacha	Fabaceae	Tree
Sesbania spp.	-	Fabaceae	Herb
Setaria pumila (Poir.) Roem. & Schult.	-	Poaceae	Grass
Setaria verticillata (L.) P. Beauv.	-	Poaceae	Grass
Solanum giganteum Jacq.	Hiddii loonii	Solanaceae	Herb
Solanum incanum L.	Hiddii waatoo	Solanaceae	Herb
Sporobolus pellucidus Hochst.	Salaqoo	Poaceae	Grass
Sporobolus pyramidalis P. Beauv.	-	Poaceae	Grass
Tragus berteronianus Schult.	-	Poaceae	Grass
Vachellia oerfota (Forssk.) Schweinf	Kophaafa	Fabaceae	Shrub

Table 2. Contd.

Vachellia reficiens Wawra	Sigirso	Fabaceae	Tree
Vachellia seyal Del.	Waaccuu	Fabaceae	Tree
Vernonia phillipsiae S. Moore	Qaxxee kormaa	Asteraceae	Shrub
Volkensinia prostrata (Volkens ex Gilg) Schinz	Gurbii	Amaranthaceae	Herb

Table 3. Mean (± standard error) of tree/shrub species richness, Shannon index (H`), Simpson (1-D) index and evenness (e^H/S) of two rangeland types of the Sarite study site (n = 18).

Vegetation variable[1]	Rangeland types	
	Bush encroached	Non-encroached
Trees/Shrub species richness	5.50 ± 0.53[a]	3.17 ± 0.53[b]
Trees/Shrubs H`	1.20 ± 0.13[a]	1.02 ± 0.13[a]
Tree/Shrub simpson	0.61 ± 0.07[a]	0.60 ± 0.07[a]
Tree/Shrub evenness	0.65 ± 0.04[b]	0.90 ± 0.04[a]

[1]Means with similar superscripts shows no significant differences (P < 0.05).

study site, 15 species were either trees or shrubs and the remaining 38 were grass and non-grass herbaceous plant species. Among the total trees and shrubs identified, four species (*Senegalia mellifera*, *Vachellia reficiens*, *Vachellia oerfota* and *Commiphora africana*) were found to be encroacher plant species. From the 19 total plant families recoded in the study area, *Poaceae* had the highest percentage (30.19%), while *Fabaceae* (15.09%), had the second highest followed by three families (*Acanthaceae*, *Asteraceae* and *Amaranthaceae)*, which each accounted for 7.55% of the families encountered during the study.

To determine the proportional representation of each species relative to the entire plant community, the relative density and frequency of all species were calculated for the bush encroached, bush thinned and non-encroached rangeland types of the study site and expressed as a percentage using the methods of Baxter (2014). Only the species with high relative density and frequency are presented here. *Senegalia mellifera, Vachellia reficiens, Dobera glabra* and *Vachellia oerfota* were the tree/shrub, which had a relative density of 20.97, 7.98, 5.76 and 1.92%, respectively, in bush-encroached rangeland types. The relative frequencies of these trees and shrubs species were also high compared to other trees and shrubs in the bush-encroached rangeland types. *Chlorosis roxburhiana, Setaria verticillata, Brachiaria eruciformis* and *Aristida adoensis* were grass species encountered in the bush encroached rangeland types with high relative density and frequency compared to other grass species; on the other hand, *Pupalia lappacea* was the herb found only in bush-encroached rangeland type with the high relative density of 27.77% and frequency 4.76% in the study area. In bush thinned rangeland type, the trees/shrubs with high relative density were *Senegalia mellifera* and *Dobera glabra,* and the herbaceous plant species with high relative density and frequency were *Brachiaria eruciformis, Aristida adoensis*, *Digera muricata, Sesbania* sp. and *Setaria verticillata*; all of them were grasses except *Sesbania* species and *Digera muricata.* In non-encroached rangeland type, *Brachiaria eruciformis, Sporobolus pyramidalis, Sporobolus pellucidus, Kohautia coccinea, Indigofera arrecta* and *Chlorosis roxburhiana* were found with high relative density and frequency compared to other species.

The Sarite study rangeland was moderately encroached and the explanation of bush encroachment is a recent phenomenon as noticed from field observations and according to local key informants. The evidence from this study suggests that the total number of species (tree/shrub and herbaceous) recorded in bush-encroached rangeland types was the highest compared to non-encroached and bush thinned rangeland types. Most of the plant recorded in bush thinned and non-encroached rangeland types were grasses and herbs.

Plant diversity

The diversity of flowering plant species varied widely among the studied rangeland types and vegetation types (tree/shrub and herbaceous). There was a significant difference between bush encroached and non-encroached rangeland types in terms of tree/shrub richness. However, the tree/shrub Shannon and Simpson diversity indexes were not significantly different between the two rangeland types (F=3.31, P=0.064; F=1.59, P=0.236, respectively). Bush encroached rangeland had the highest tree/shrub richness (Table 3). These two

Table 4. Mean (± standard error) herbaceous plant species richness, Shannon index (H`), Simpson (1-D) index, evenness and herbaceous density per hectare of the three rangeland types of the Sarite study site (n = 18).

Vegetation variable[1]	Rangeland types		
	Bush thinned	Bush encroached	Non-encroached
Herbaceous richness	10.67 ± 1.11[a]	8.5 ± 1.11[a]	10.50 ± 1.11[a]
Herbaceous density/ha	833333 ± 161462[a]	227222 ± 161462[b]	882778 ± 161462[a]
Herbaceous H`	1.79 ± 0.10[a]	1.60 ± 0.10[ab]	1.33 ± 0.10[b]
Herbaceous simpson	0.77 ± 0.04[a]	0.72 ± 0.04[ab]	0.57 ± 0.04[b]
Herbaceous evenness	0.59 ± 0.07[ab]	0.64 ± 0.07[a]	0.38 ± 0.07[b]

rangeland types were significantly different in the trees and shrubs evenness. Non-encroached rangeland types had more evenly distributed trees and shrubs as compared to bush encroached rangeland types; whereas, the tree/shrub species in the bush encroached rangeland type were less evenly distributed. The tree/shrub species richness was significantly higher in bush-encroached rangeland types as compared to non-encroached and bush thinned, which agrees with Tamrat et al. (2013) findings. This result indicated that bush encroachment increased woody plant species richness. The tree/shrub Shannon and Simpson diversity indices of bush encroached, and non-encroached rangeland types were not significantly different, this might be due to the encroaching species' dominance in bush encroached rangeland types, while the non-encroached rangeland types tree/shrub were evenly distributed. Shannon diversity index (H) rises with an increasing number of species, as well as increasing equal distribution of species and vice versa. The herbaceous Shannon and Simpson diversity indexes and herbaceous species evenness were significantly different among bush encroached, bush thinned and non-encroached rangeland types, while the herbaceous richness did not show significant differences among the three rangeland types (Table 4). The herbaceous plant Shannon (1.79 ± 0.1) and Simpson (0.77 ± 0.04) diversity indices of bush thinned rangeland type was higher than that of the non-encroached rangeland Shannon (1.33 ± 0.1) and Simpson (0.57 ± 0.04) diversity indices; while the encroached rangeland type was not significantly different in terms of Shannon and Simpson diversity indices relative to the other two rangeland types (Table 4). Bush encroached rangeland type had the lowest herbaceous density; however, bush thinned and non-encroached rangeland types had higher and similar herbaceous plant density.

The herbaceous plant species Shannon and Simpson diversity indices were the highest in bush thinned and the lowest in non-encroached rangeland types; however, bush encroached rangeland types were similar with the two rangeland types in terms of herbaceous plant species Shannon and Simpson diversity indices. These findings are in line with the results of Tamrat et al. (2013), who found an increase of plant species diversity, evenness and richness with woody plant encroachment. Contrary to this, previous studies by Bikila et al. (2014) and Niguse et al. (2014) in Borana ganglands showed that bush encroachment reduces the rangeland plant diversity compared to non-encroached. The findings of the current study showed that the Shannon and Simpson diversity indices of herbaceous species in non-encroached rangeland type were not significantly different from the bush encroached rangeland types. Shannon and Simpson diversity indices of herbaceous species are higher in bush-encroached range type, even though it was not statistically significant. The reasons might be due to the establishment of shade-loving (tolerant) species (e.g. *Pupalia lappacea* was the herbaceous plant found only in bush-encroached rangeland type with a high relative density and frequency in the current study), or due to the heavy grazing in non-encroached rangeland type, or possibly due to the fact that the bush encroachment was a recent phenomenon in the area (the site moderately encroached). Its impact is highly variable depending on the level of encroachment and the local species composition.

The herbaceous plant species density (number of individuals per hectare) and herbaceous biomass were lowest in bush-encroached rangeland types as compared to the non-encroached and bush thinned rangeland types. The result is in line with previous studies in the same agroecology, showing that woody density in both communal and enclosure grazing negatively correlated with the botanical composition of grass, basal cover, total range condition and grass yield (Gemedo et al., 2006; Teshome et al., 2012; Niguse et al., 2014). The increase in herbaceous plant species diversity, density and biomass following bush thinning were related with previous study findings that showed bush thinning increased herbaceous species composition and richness (Ayana, 2002; Ayana et al., 2012). Another study by Lesoli et al. (2013) indicated that bush controlling shifts the rangeland vegetation from dominance by woody vegetation to dominance by herbaceous vegetation through increased production of herbaceous vegetation.

Table 5. Bray-Curtis and Sørensen's similarity ratio of the plant species for bush thinned, bush encroached and non-encroached rangeland types at study site.

Rangeland type	Bush thinned	Bush encroached	Non-encroached
Bush thinned	1	0.19	0.41
Bush encroached	0.57	1	0.13
Non-encroached	0.47	0.52	1

Numbers above diagonal are Bray-Curtis similarity ratios and below the diagonal are Sørensen's similarity ratios.

The reduction in species richness and density of herbaceous plant species do not only result in the loss of biodiversity, but may also affect savanna ecosystem functions. In savanna ecosystems, the herbaceous component is considered to be a controlling element of the ecosystem and regulates functional processes such as water balance, productivity, nutrient cycling, fire and herbivores (Otto et al., 1996).

The reduction in species richness, density and biomass of herbaceous plant species in bush-encroached rangeland types might be due to the aboveground (light) and belowground competitions. *Senegalia mellifera,* one of the encroaching species that occurs dominantly in the study area, was found to reduce understory radiation by approximately 53 to 65% (Belsky et al*.,* 1993). Woody plant functional traits such as crown diameter, crown-base-height, evergreen and deciduous woody plants was found to be the major encroacher characteristics affecting the herbaceous cover in arid and semi-arid of southern Ethiopia (Tamrat and Moe, 2015). Woody encroachers with larger crown diameter and smaller crown base height usually have intact canopies that prevent solar radiation and rainwater infiltration to the understory vegetation (Tamrat and Moe, 2015). Encroaching species competition for light through shading, and for soil moisture and nutrients, because of their deeper root systems, reduce the growth of herbaceous species (Lesoli et al*.,* 2013). In the non-encroached rangeland types, herbaceous plant composition and diversity declined; this might be due to increasing grazing pressures because of increasing livestock populations and the shrinkage in rangeland size due to the expansion of bush encroachments. According to Ayana and Gufu (2010), grazing pressure results in a reduction of herbaceous species composition and diversity.

Plant species composition similarity

Vegetation composition similarity among the three rangeland types was compared using the Bray-Curtis similarity and Sørensen's similarity indices. The Sørensen's similarity index indicated that the bush thinned, and bush encroached rangeland types were more similar (0.57) than non-encroached and bush thinned rangeland types (0.47), and also for non-encroached and bush encroached (0.52). In contrast, Bray-Curtis similarity index, that considers the relative abundance of species, revealed that non-encroached and bush thinned rangeland types had the highest similarity ratio (0.41) than bush encroached and bush thinned rangeland types (0.19), and the least Bray-Curtis similarity ratio was showed by non-encroached and bush encroached rangeland types (0.13) (Table 5).

Plant biomass and carbon stock

Aboveground tree/shrub biomass and carbon stock

The density (that is the number of tree/shrub per hectare) in bush-encroached, bush thinned and non-encroached rangeland types were 2000 ± 111.98, 345.83 ± 111.98, and 104.17 ± 111.98, respectively; bush encroached rangeland type was significantly (df = 2, F = 84.92, P< 0.01) denser than bush thinned and non-encroached rangeland types (Table 6).

Like the number of trees and shrubs per hectare, the trees, and/or shrubs aboveground biomass (df = 2, F = 120.7, P < 0.01) and carbon stock (df = 2, F = 120.7, < 0.01) were significantly different among the three rangeland types. The bush-encroached rangeland type stored significantly higher tree/shrub aboveground biomass and carbon stock (28.73 ± 1.33 t ha^{-1} and 14.37 ± 0.66 t ha^{-1}, respectively) compared to non-encroached and bush thinned rangeland types; whereas, bush thinned, and non-encroached rangeland types were similar in terms of tree/shrub aboveground biomass and carbon stocks.

Belowground tree/shrub biomass and carbon stock

Belowground tree/shrub biomass and carbon stock showed similar trends to aboveground biomass and carbon stock. There were significant differences between bush encroached and the other two rangeland types (bush thinned and non-encroached) (P< 0.01 for both).

Table 6. Mean (± standard error) of aboveground and belowground biomass and carbon stock of tree/shrub in the three rangeland types at the study site.

Vegetation variable[1]	Rangeland types[2]		
	Bush encroached	Bush thinned	Non-encroached
Tree/Shrub (ha^{-1})	2000 ± 111.98[a]	345.83 ± 111.98[b]	104.17 ± 111.98[b]
Tree/Shrub$_{AGB}$ (t ha^{-1})	28.73 ± 1.33[a]	3.81 ± 1.33[b]	3.24 ± 1.33[b]
Tree/Shrub$_{AGC}$ (t ha^{-1})	14.37 ± 0.66[a]	1.91 ± 0.66[b]	1.62 ± 0.66[b]
Tree/Shrub$_{RBM}$ (t ha^{-1})	6.73 ± 0.28[a]	1.13 ± 0.28[b]	0.98 ± 0.28[b]
Tree/Shrub$_{RCS}$ (t ha^{-1})	3.37 ± 0.14[a]	0.56 ± 0.14[b]	0.49 ± 0.14[b]

[1]AGB: Aboveground biomass, AGC: aboveground carbon stock, RBM: root biomass, RCS: root carbon stock.
[2]Means with similar superscripts shows no significant differences (*P*<0.05).

The tree/shrubs root biomass and carbon stock in bush-encroached rangeland types were by far greater than non-encroached and bush thinned rangeland types, but not significantly different between non-encroached and bush thinned rangeland types (Table 6). The results revealed that tree/shrub aboveground and roots biomass and carbon stock was highly affected by the rangeland types. Bush encroached land stored carbon about 71% higher than the non-encroached, and 69% higher than the bush thinned rangeland types. The current result of aboveground tree/shrub carbon stock in bush-encroached (14.37 t ha^{-1}) was related to the previous study by Hasen's (2013) findings of the aboveground trees and shrubs carbon stock in highly encroached (13.8 $Mgha^{-1}$) and severely encroached (13.6 $Mgha^{-1}$) rangeland types.

The increase in aboveground biomass and carbon stock following bush encroachment might indicate a positive contribution of bush encroachments for rangeland carbon sequestration and aboveground carbon stock. This finding agrees with Hasen (2013) who found significantly higher mean total AGC, shrub AGC, and tree AGC stocks were significantly increased with an increasing gradient of woody encroachment levels from low encroached to severely encroached rangeland. Another study in woody encroached savannas of central Argentina showed that the ecosystem carbon stock increased with increasing woody cover with mean values of 4.5 and 8.4 kg C m^{-2} in grassland and shrubland, respectively (Mariano et al., 2014). Like these findings, reviews of different studies by Archer and Predick (2014) indicated that the aboveground carbon pool could increase within the range from 0.3 t ha^{1} to 44 t ha^{-1} in less than 60 years of woody encroachment. The current study indicated that bush thinning significantly reduced the tree/shrub density and aboveground biomass and carbon stock as compared to bush encroached rangeland types. This result is consistent with a study by Archer and Predick (2014) who showed that bush management substantially and rapidly reduces the aboveground biomass and carbon stock of woody plants.

Herbaceous plant biomass and carbon stock

The results indicated significant differences in herbaceous biomass and carbon stock among the studied rangeland types. The aboveground herbaceous plant biomass was significantly (*df* = 2, *F* = 8.84, *P*< 0.01) higher in bush thinned and non-encroached rangeland types than bush encroached rangeland types; however, there was no significant difference between the bush thinned and non-encroached in terms of herbaceous biomass (Table 7). Like the aboveground herbaceous biomass, the aboveground and belowground herbaceous carbon stock was significantly affected by the studied rangeland types (*df* = 2, *F* = 8.76, *P*< 0.01) for both the aboveground and root herbaceous carbon stock. Bush encroached land had the lowest herbaceous aboveground and belowground carbon stock (Table 7). In general, most herbaceous parameters studied were affected by the rangeland types. Bush encroachment decreased herbaceous biomass and carbon stock. There was no significant difference between bush thinned and non-encroached rangeland types in terms of herbaceous aboveground and belowground biomass and carbon stock.

In contrast to tree/shrub aboveground biomass and carbon stock improvements that follow bush encroachment, herbaceous aboveground carbon stock and biomass were significantly reduced by bush encroachment. Bush encroachment reduced the herbaceous aboveground carbon stock by 42% as compared to non-encroached rangeland types. The herbaceous aboveground carbon stock in bush-encroached rangeland types (0.03 t ha^{-1}) in the current study was similar with that reported by Hasen (2013) for severely encroached open grazing land (0.03 t ha^{-1}) in Borana rangelands; however, less than highly encroached (0.5 t ha^{-1}), moderately encroached (0.5 t ha^{-1}) and low encroached (1 t ha^{-1}) of open grazing land. The herbaceous aboveground carbon stock in bush thinned and non-encroached rangeland types were similar (0.28 t ha^{-1}), but the result was less than that

Table 7. Means (± standard error) of aboveground and belowground biomass and carbon stock of herbaceous plant in three rangeland types at the Sarite study site.

Vegetation variables[1]	Rangeland types[2]		
	Bush-encroached	Bush thinned	Non-encroached
$Herbaceous_{AGB}$ ($t\ ha^{-1}$)	0.06 ± 0.1^b	0.56 ± 0.1^a	0.56 ± 0.1^a
$Herbaceous_{RBM}$ ($t\ ha^{-1}$)	0.03 ± 0.05^b	0.28 ± 0.05^a	0.28 ± 0.05^a
$Herbaceous_{AGC}$ ($t\ ha^{-1}$)	0.03 ± 0.05^b	0.28 ± 0.05^a	0.28 ± 0.05^a
$Herbaceous_{RCS}$ ($t\ ha^{-1}$)	0.01 ± 0.03^b	0.14 ± 0.03^a	0.14 ± 0.03^a

[1]AGB: Aboveground biomass, AGC: aboveground carbon stock, RBM: root biomass, RCS: root carbon stock. [2]Means with similar superscripts shows no significant differences (at $P < 0.05$).

Table 8. Means (± standard error) of soil bulk density (BD) and soil carbon stock (SOC) of the two soil depths in bush-encroached (B.E), non-encroached (N.E) and bush thinned (B.T) rangeland types of the Sarite study site.

Rangeland type	Soil depths (cm)	Dependent variables[1]		
		BD ($g\ cm^{-3}$)	SOC (%)	SOC ($t\ ha^{-1}$)
Bush thinned	0-15	0.97 ± 0.07^b	1.03 ± 0.06^a	14.36 ± 0.93^{ab}
	16-30	1.12 ± 0.07^{ab}	0.96 ± 0.06^a	16.83 ± 0.93^a
Total				31.19 ± 1.69^a
Bush encroached	0-15	1.17 ± 0.07^{ab}	0.81 ± 0.06^{ab}	14.67 ± 0.93^{ab}
	16-30	1.17 ± 0.07^{ab}	0.66 ± 0.06^b	12.29 ± 0.93^{bc}
Total				26.95 ± 1.69^{ab}
Non-encroached	0-15	1.13 ± 0.07^{ab}	0.79 ± 0.06^b	12.86 ± 0.93^{bc}
	16-30	1.32 ± 0.07^a	0.51 ± 0.06^c	9.53 ± 0.93^c
Total				22.39 ± 1.69^b

[1]Means with similar superscripts shows no significant differences ($P < 0.05$).

reported by Bikila et al. (2016) in the communal grazing land (0.4 t ha^{-1}) of Borana rangeland. This difference in herbaceous Biomass and carbon stocks might be due to the precipitation, edaphic and topography variations of the two study areas. Similarly, Ayana, (2007) and Bikila et al., (2014) found that bush controlling improved herbaceous biomass accumulation and species diversity in the Borana rangelands. Review of studies in other areas shows that even with increased herbaceous biomass enhanced by bush management, the results were relatively short-lived (less than 6 years), because the encroaching plants regenerate again after some time (Archer and Predick, 2014).

Soil bulk density and carbon stock

The soil bulk density was significantly different among the rangeland types ($P = 0.034$); however, it did not significantly vary across soil depths ($P = 0.051$). There were no significant rangeland types and soil depth interactions effects on soil bulk density ($P = 0.31$). The bush thinned rangelands had lower soil bulk density as compared to non-encroached rangelands, while the soil bulk density of the bush encroached rangeland types was not significantly different from the other two rangeland types (Table 8). The soil carbon store of the studied land rangeland types was significantly different (df =2, F = 11.22, $P < 0.01$) and there were significant rangeland types and soil depth interaction effects on soil carbon stock (F=5.57, $P < 0.01$); however, soil carbon stock was not significantly different among the different soil depths ($P = 0.17$).

The total soil carbon stock in 0 to 30 cm soil depth was greater (31.19 ± 1.69 t ha^{-1}) in the bush thinned rangeland types as compared to the non-encroached rangeland types (22.39 ± 1.69 t ha^{-1}), but not significantly different (26.95 ± 1.69 t ha^{-1}) from bush encroached rangeland types (Table 8). The results of total soil carbon stock in bush thinned, bush encroached and non-encroached rangeland types fell within the range of earlier studies reported by Vågen and Winowiecki (2013) for tropical woodland and savanna ecosystems (20 to 80 t ha^{-1}). The soil organic carbon stock in bush encroached rangeland types was greater than that of non-encroached rangeland type even though it was not statistically significant. The results indicated that bush encroachments improve soil carbon stock by about 5% compared to non-encroached; and bush thinning also improves soil carbon stock by 6% compared to bush encroachments in the study area. The increase in soil carbon stock with bush encroachment might arise from high amounts of litter deposits and dead root addition to the soil from encroaching species, or the improvement of microclimate under bush encroached rangeland types. Alternatively, it might be due to the heavy grazing in non-encroached rangeland types. Soil carbon sequestration may initially increase with bush encroachment, but then declines if bush densities become so high as to inhibit understory herbaceous growth (Hudak et al., 2003). A study by Hasen et al. (2015) showed that soil organic carbon stock (SCS) is affected by grazing, woody encroachment and soil texture. Changes in soil organic carbon (SOC) such as those associated with the conversion of grasslands to shrublands or woodlands ranged from positive to neutral to negative (Eldridge et al., 2011).

Bush thinned rangeland types had lower soil bulk density (not statistically significant) and have higher soil organic carbon stock as compared to non-encroached rangeland types. A review by Archer and Predick (2014) showed that we have insufficient information about potential outcomes of bush management effects on the soil carbon stock. The increases of SOC in the current study that were observed following bush thinning might be due to several reasons. These include the high biomass return from cutting woody species or root death after cutting woody plants to the soil, or the increase in herbaceous plant species density (positively correlated (48%) with soil carbon stock), and biomass which in turn reduces soil erosion, or could be due to heavy grazing in the non-encroached rangeland type. However, the herbaceous plant density and biomass was similar for bush thinned and non-encroached rangeland types. So, the scenario that the potential cause for increases in SOC following bush thinning might be more evident due to the high biomass return from cutting woody species or root death after cutting woody plants. The extent to which shrub roots are impacted by bush management is unknown; but if bush stumps are killed, large amounts of carbon could enter the soil pool and accumulate to significant amounts (Archer and Predick, 2014). The net soil carbon sequestration in dryland primarily depends on the rate of input of organic matter, the rate of decomposition of organic matter and the rate of carbon loss through soil respiration (Tennigkeit and Wilkes, 2008).

Total carbon stock

As Figure 3 shows, the overall carbon stock (that is aboveground and belowground living tree/shrub, herbaceous, and soil carbon stock up to 30 cm depths) was highly significantly different among the three rangeland types (df =2, F = 19.31, P<0.01). Bush encroached rangeland types had the highest amount of total carbon stock (44.73 ± 1.76 t ha^{-1}), followed by the bush thinned rangeland type (34.08 ± 1.76 t ha^{-1}). The lowest total carbon stock was found in non-encroached rangeland types (24.92 ± 1.76 t ha^{-1}). The soil carbon stock had the highest total carbon stock of the three rangeland types. The total carbon stock (aboveground and belowground living tree/shrub, herbaceous, and soil carbon stock up to 30 cm depths) of the studied rangeland type, bush encroached, bush thinned and non-encroached of the current study were 44.73, 34.08 and 24.92 t ha^{-1}, respectively. The result was less than that reported in semi-arid areas of a communally grazed (141.5 t ha^{-1}) Borana pastoral ecosystem (Bikila et al., 2016), and that reported in communal grazing management (93.01 t ha^{-1}) in the semi-arid pastoral ecosystem of northern Kenya (Dabasso et al., 2014). The variation might be due to the climate, vegetation, topography and edaphic variations of the study areas; moreover there could be differences in the methods of estimating the aboveground carbon stock and the carbon pool components incorporated in the total aboveground carbon stock. Dryland organic carbon stock, in aboveground vegetation and soils, declines with aridity; and inorganic soil carbon increases as aridity increases (David et al., 2005).

According to the present study, bush encroached rangelands store more carbon (19%) than non-encroached, and 10% more store carbon than bush thinned rangeland types. In all studied rangeland types, soil carbon stock has the highest proportions, that is 92% in bush thinned, 60% in bush-encroached and 90% in non-encroached rangeland types for total carbon stocks of the rangeland ecosystem as compared to the vegetation components. These results concurred with studies indicating that most of the carbon in grassland ecosystems is stored in soils (Tennigkeit and Wilkes, 2008; Dabasso et al., 2014; Bikila et al., 2016). This study found, a significant increase in ecosystem carbon stock with woody plant encroachments. These results are consistent with other studies in the same agroecology that have shown the estimated AGC stocks in highly encroached sites were up to three times greater than that of the less encroached sites (Hasan, 2013). Moreover, the current results were similar to those of a study in woody encroached savannas of central Argentina (Mariano et al*.,* 2014) that indicated total carbon stocks in grasslands, shrublands, open and closed forests are 4.5, 8.4, 12.4, and 16.5 kg cm^{-2}, respectively. A study in South

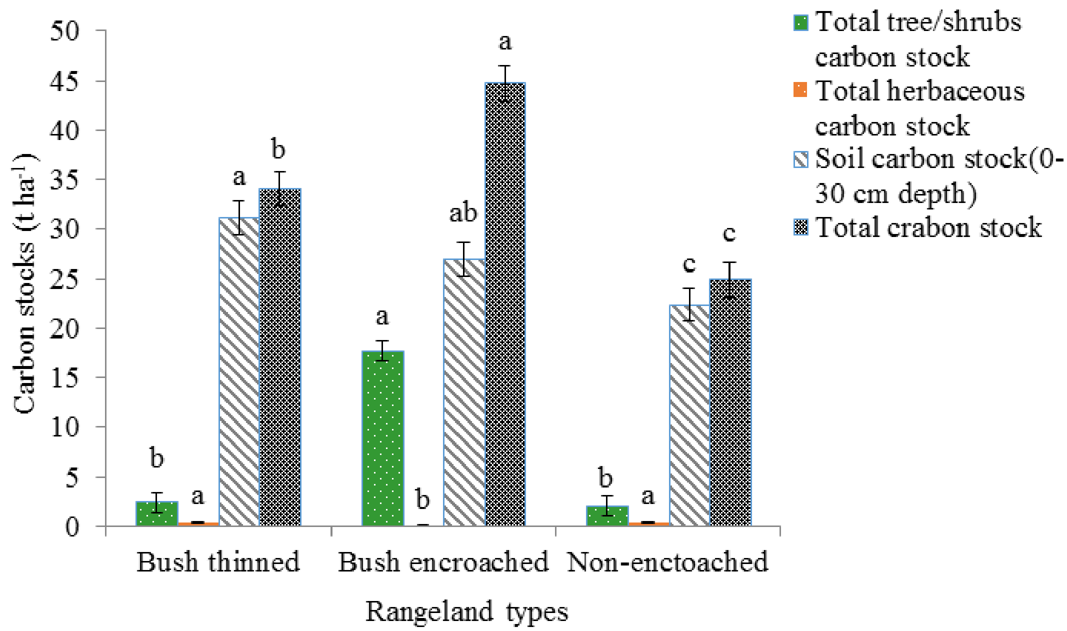

Figure 3. Total carbon stock (t/ha) for different rangeland types. Error bars show the standard error.

American semi-arid savanna showed that closed woodlands have three times more total ecosystem carbon than grasslands, and the net gain in the ecosystem carbon stocks along the woody cover gradient was due to the increases in soil organic carbon stock (González-Roglich et al., 2014). The tree and shrub plant species richness and Shannon diversity index were significantly positively correlated with aboveground tree/shrub carbon stock and total carbon stock of the studied rangeland ecosystem. This indicates that woody plant species diversity and richness have a significant contribution for the rangeland ecosystem carbon sequestration.

The dramatic shift in the AGC stock with woody plant encroachment is likely to increase overall AGC stock within the ecosystem; however, encroachment supersedes the herbaceous biomass, density and carbon stock component of the ecosystem. The reduction in herbaceous biomass and density is adversely affecting the pastoral economy, which is often the main reason for starting bush controlling or management practices in the study area. However, bush thinning, or clearing reduced the total carbon stock, and did not significantly increase the soil carbon stock as compared to bush encroachment in the study area.

Conclusions

The change in vegetation communities following bush encroachment has direct consequences on ecosystems functioning and services delivery. Our study found that bush encroachment increased tree and/or shrub species richness, and aboveground tree/shrub and soil carbon stock. Consequently, herbaceous plant biomass and density were reduced, and resulted in declining productivity of the rangeland ecosystem. On the other hand, controlling bush encroachment in the form of thinning improved herbaceous species density and biomass, and soil carbon stock. In general, this study confirmed bush encroachment increased total carbon stock of the studied rangeland ecosystem. These results might lead to the assumption that bush encroachment could contribute to climate change mitigations and payments for ecosystem service from the rangelands in the study area. However, it reduces the productivity of rangelands, which is the mainstay of a pastoralist's livelihood. Moreover, further study is also important to detect the effects of bush encroachment on others rangeland ecosystem processes such as underground water and contributions by soil microorganisms.

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Study of floral diversity from rural pockets of Odisha, India: Plants for fun and games

Mahendra K. Satapathy, Sidhanta S. Bisoi* and Sanjeeb K. Das

Department of Botany, Regional Institute of Education (NCERT), Bhubaneswar, India.

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In earlier days, children used to play in outdoors with plant parts and their products for fun making and games. However with modernity and advancement in science and technology, this indigenous knowledge is vanishing day by day. There is no scientific documentation of plants being used for fun and games by children. The present study carried out in different tribal and non-tribal village schools of Koraput and Khordha districts of Odisha, India in a systematic manner documented 90 plant species distributed in 85 genera spread over 44 families. The plant species recorded include 35 trees, 21 shrubs, 24 herbs and 10 climbers/creepers. The plants widely used as play material include *Artocarpus heterophyllus*, *Dendrocalamus strictus*, *Cocos nucifera*, *Calotropis gigantea*, *Ficus benghalensis*, *Mangifera indica*, *Musa paradisiaca*, *Phoenix sylvestris*, *Tamarindus indica*, etc. The different plant parts such as leaves, fruits, flowers, seeds etc. and their mode of use by the participating respondents have been recorded and discussed. It was noted that the most and frequently used plant parts as the source of play were fruits followed by leaves, flowers, and seeds. The economic importance of plants, besides their implications in teaching and learning along with their sustainable utilization and conservation is discussed.

Keywords: Plant biodiversity, conservation, fun, modernity, advancement, technology, utilization.

INTRODUCTION

The environment is the sum total of all components and factors that influence the life of an organism including human being from birth to death. One of the major concerns of the environment today is the loss of biodiversity that includes varieties of plants, animals, and microorganisms that exist on the surface of planet Earth (Baliga, 1996; Satapathy, 2007).

This rich biodiversity of life has ever been instrumental in providing humanity with food security (Swaminathan and Bhavani, 2013), shelter, health care, and to certain extent, industrial goods and livelihood leading to improvement in people's standard of living in the modern world. Further, biodiversity has played a unique role in the evolution and differentiation of various species. It sustains the system we live in and forms a part of our daily lives and livelihood and constitutes resources upon

*Corresponding author. E-mail: sidhantasekhar91@gmail.com.

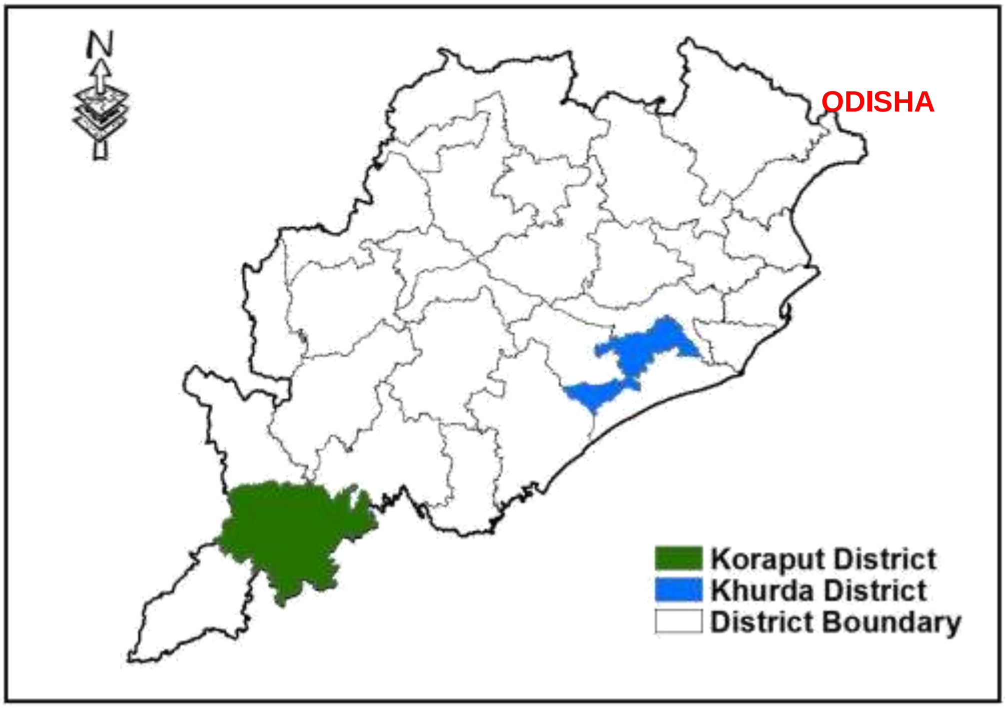

Figure 1. Map of Study site (Koraput and Khordha district Odisha, India).

which families, communities, nations and future generations do depend (Chavan et al., 2016). Worldwide, ten thousand species of higher plants and several hundred lower plants are currently used by human beings for a wide variety of purposes such as, household items, rituals, food, fuel, fiber, medicines, oil, spices, and as forage and fodder of domesticated animals (Haywood, 1992).

Trees are the symbol of environmental as well as socio-economic sustainability of the globe (Chavan, 2016). Traditionally, trees are being used for the interdependent benefit of 6Fs: food, fruit, fodder, fuel, fertilizer and fibre. The multivarious benefits and services generated from tree-based systems have helped to improve the livelihood of people globally, directly or indirectly. As such it sustains the lives we lead and the societies we form (Dutta, 2007; Silver, 1991).

Many investigations have been carried out pertaining to the economic and socio-cultural values (Khoshoo, 1994) of plant diversity such as food resources (Mohanty et al., 2013; Rout et al., 2007), source of medicines (Subudhi, 1992; Pattanaik, 2008; Panda, 2010; Kumar and Satapathy, 2011; Mohanty et al., 2015), sustaining livelihood (Chavan, 2016), rituals (Mohanty et al., 2011), and cultural functions.

However, no study has been made to understand their educational importance in terms of plants being used for fun and games. Under this background, the present study has been carried out with the following objectives: i) to identify and document plant species used for fun and games from local biodiversity; ii) to know the plant part being used and the nature of its use; iii) to find out the economic value, if any of the plants identified.

MATERIALS AND METHODS

The present study was carried out in two districts, Koraput and Khordha of the State of Odisha. Koraput is located (18°13' to 19°10' N, 82°5' to 83°23' E) in the Southern part of Odisha, which is mostly tribal dominated with alow literacy rate. Khordha district stands (19°40' to 20°25' N, 84°40' to 86°5' E) in the eastern part of the state and mostly influenced by modernity (Figure1).Twenty elementary and secondary schools were selected from each district for the present study. Ethnobotanical information of plants used for games, fun, and play was gathered through survey, structured oral interviews and informal conversation with school children, teachers, and local people (Huntington, 2000; Mohanty, 2011). The information included the local name of the plant, plant part, nature of its use, habitat of the plant etc. All the gathered information was cross checked with students and parents of the nearby schools. Besides fun and games, other economic and medicinal values of the plants, if any, were also recorded from the students, parents, and teachers. Ethnographic qualitative methods were used to summarize the major themes and categories of information collected from the respondents.

The plants along with their part(s) were collected and brought to the Department of Botany, Regional Institute of Education (NCERT), Bhubaneswar for identification. The plants were identified (Table 1) following the Flora of Odisha (Saxena and Brahman,

Table 1. List of Plants with their families and common names used for Fun and Games.

S/N	Name of the plant	Family	Common Name	Hindi Name	Part(s) used as play material	Mode of use
1	*Abelmoschus esculentus* L. Moench	Malvaceae	Lady's finger	Bhindi	Fruit Stalk	Used to make horns
2	*Abrus pricatorius* L.	Fabaceae	Indian liquorice	Ratti/Gunchi	Seed	Used for making necklace
3	*Abutilon indicum* (L.)	Malvaceae	Country Mallow	Kanghi	Fruit	Used for games and joy by joining two fruits
4	*Acalypha hispida* Burm.f.	Euphorbiaceae	Red hot cat's tail		Flower	Used to make tails while playing different games.
5	*Achyranthes aspera* L.	Amaranthaceae	Prickly chaff flower	Chirchita	Leaf	Leaf is used as crackers
6	*Adenanthera pavonina* L.	Mimosaceae	Red Lucky Seed	Badigumchi	Seed	Used to make necklace/bracelets as it is deep red in colour
7	*Aegle marmelos* L. Correa	Rutaceae	Wood apple	Bel	Fruit	Used as short foot for throwing
8	*Aeschynomene aspera* L.	Fabaceae	Sola, pith plant	Sola	Stem	Used to make boats and other craft items for playing as the it is the lightest wood among all the plants
9	*Albizia saman* (Jacq.) Merr.	Fabaceae	Rain Tree	GulabiSiris	Sirisa	Used as money (coins) while playing
10	*Allium cepa* L.	Amaryllidaceae	Onion	Pyaz	Leaf	Used as straw to suck juice/water
11	*Areca catechu* L.	Arecaceae	Areca palm	Supari	Fruits, leaves	Fruit is used as ball and leaf branch used as lorry carrier
12	*Aristida* spp.	Poaceae			flower	Flowers stalk is used for making toy like snake.
13	*Artocarpus heterophyllus* Lam.	Moraceae	Jack fruit	Katahal	Leaves & fruits	Leaves are use for making utencils, whistles, tiaras and fruits are used for making toys like cow, horse etc.
14	*Azadirachta indica* A. Juss.	Meliaceae	Neem	Neem	Fruit, stem	Fruit used as marbles and stem used to make bows and arrows.
16	*Barleria prionitis* L.	Acanthaceae	Percupine Flower (Daskarenta/	Jhinti (H)	Fruits	Used as crackers by putting it into water
17	*Basella alba* L.	Chenopodiaceae	Vine spinach	Poi	Fruit	Used for coloration of hand
18	*Bauhinia purpurea* L.	Caesalpiniaceae	Butterfly tree	Khairwal	Leaf	Used to make container in different games
19	*Bixa orellana* L.	Bixaceae	Annatto	Latkan/Kumkum	Seeds	Seeds are used as colouration of palm and foots
20	*Bombax ceiba* L.	Bombacaceae	Red silk cotton	Shalmali	Stem	Used for making wheels and toys
21	*Borassus flabellier* L.	Araceae	Palm	Taad	Fruit, leaf, stem	fruit used for making wheel, leaves for making watch, stem for making bat
22	*Bryophyllum pinnatum* (Lam.) Oken	Crassulaceae	Miracle leaf	Zakhm-haiyal	Leaf	Used for cleaning slates

Table 1. Contd.

23	*Butea monosperma* (Lam.) Taub	Fabaceae	Bastard teak	Palash	Leaves, flower	Leaves used for making utensils (plates, bow) and flowers used for making coloured water (especially in holy)
24	*Caesalpinia bonduc* L.	Caesalpiniaceae	Grey nicker	Kat-karanj	Seed	Used for making necklace and bracelets by girls and boys use it as marbles.
25	*Caesalpinia pulcherrima* L.	Caesalpiniaceae	Peacock flower	Guletura	Flower (petals)	Used for Making artificial nail
26	*Calotropis gigantea* R. Br.	Asclepiadaceae	Gaint milk weed	Akoa	Fruit, Flower bud	Fruit is used for making parrot and flower is broken to produce sound play
27	*Calotropis procera*(Aiton) Dry and	Apocynaceae	Rubber bush	Akada	Fruit, stem	Fruit used as ball and stem used as hockey stick.
28	*Carica papaya* L.	Caricaceae	Papaya	Papaya/Pateet a	Petiole/leaf stalk	Used for making pipe to pass water and to make whistle
29	*Cassia fistula* L.	Fabaceae	Golden shower	Sundaraj	Fruit	Used as sward to play
30	*Citrus reticulate* Blanco.	Rutaceae	Orange	Santra	Spine,pulp	Spines used as injection while playing doctor game and pulp used as small bombs by exposing to fire
31	*Clerodendrum infortunatum* L.	Verbenaceae	Hill glory bower	Bhant	Flower(Stamen)	Stamens are used for playing by doing fight between two stamen to break their anther
32	*Cocos nucifera* L.	Arecaceae	Coconut	Nariyal	Shells, leaves and fruit	Shells used as utensils in kitchen set, telephone and making play material like tortoise, leaves are used to make watch, necklace, trumpet, hat, mat, baskets. Young coconut used for making cart
33	*Codiaeum variegatum*(L.) Rumph. Ex A. juss	Euphorbiaceae	Croton		Leaf	Used for making flower bookies
34	*Coix lacryma-jobi* L.	Poaceae	Adlay	Gurlu	Seed	Used as egg while playing kitchen game
35	*Colocasia esculenta* (L.) Schott	Araceae	Elephant ear taro	Kachu/Kachlu	Leaf	Used to capture dragonfly and play water bubble game
36	*Corchorus capsularis* L.	Malvaceae	White jute	Titapat	Stem	Use for making cigarette, straw/pipe as play material
37	*Cordia dichotoma* G. Forst.	Boraginaceae	Indian cherry	Lasora	fruit	Used as gum to prepare kites
38	*Crotalaria pallida* Aiton.	Fabaceae	Rattle pods	San	Fruit	Used as crackers
39	*Cucumis hardwickii* L.	Cucurbitaceae	Wild cucumber		Fruit	Used for making toys like Chickens, horse etc.

Table 1. Contd.

40	*Cuscuta reflexa* Roxb.	Convolvulaceae	Giant dodder (Nirmuli)	Amar bel	Vines	Used as noodles while playing kitchen game
41	*Cynodon dactylon* L.	Poaceae	Bermuda grass	Dub	Shoot	Used for sweeping while playing
42	*Datura stramonium* L.	Solanaceae	Datura	Dhatura	Fruits	Used for punching one another by children to make fun as it contain spines.
43	*Delbergia sisoo* Roxb.	Fabaceae	Rosewood	Shisham	Wood	Used for making bats
44	*Delonix regia*(Hook.) Raf.	Fabaceae	Gold mohar	Gulmohar	Seed pods, Stamen	Seed pods are used to prepare fan by children and Stamens are used for playing by doing fight between two stamen to break their anther
15	*Dendrocalamus strictus* (Roxb.) Nees	Poaceae	Bamboo	Bans	Stem	Used for making glass, pen stand, gun, flute, whistles, pushing car and young stem used as hockey stick
45	*Dillenia indica*L.	Dilleniaceae	Elephant apple/ouu	Chalta	Fruit	Used as short foot for throw
46	*Drypetes roxburghii* (Wall.) Hurus.	Euphorbiaceae	Lucky Bean Tree	Putija	Fruit	Used to make 'Natu' for playing
47	*Erythrinavariegata* L.	Fabaceae	Indian coral tree	Pangara	Flower	Used for colouration of palm and decoration as it is deep red in colour
48	*Eucalyptus globulus* L abill.	Myrtaceae	Blue gum	Nilgiri	Bud	Operculum of stamen is used as tooth(canines) and dried ovary used as top
49	*Ficus benghalensis*L.	Moraceae	Banyan	Barh	Leaves, prop roots	Leaves are used to make utensils and umbrellas, prop roots are used as the swings.
50	*Ficus recemosa*L.	Moraceae	Clister fig tree	Goolar	Fruit	Used for making cars
51	*Ficus religiosa*L.	Moraceae	Peepal tree	Peepal	Leaves	Used to make whistles, decoration, greeting cards and swings on branches
52	*Impatiens balsamina*L.	Balsaminaceae	Garden Balsam	Gul-mendi	Flower	Used for colouration of palms and decoration purposes.
53	*Ipomoea hederifolia* L.	Convolvulaceae	scarletcreeper	Lalpungli	Flower	Used for decoration of foreheads, also used as ornaments.
54	*Ipomoea parasitica* (Kunth) G. Don	Convolvulaceae	Yellow-throated Morning Glory		Leaves	Used for making different ornaments for playing
55	*Jasminum arborescene* Roxb.	Oleaceae	Royal jasmin	Chameli	Flower	Used for decoration of hair
56	*Jatropha gossypiifolia* L.	Euphorbiaceae	Bellyache bush	Ratanjoti	Petiole, seeds	By breaking the petiole foam bubbles are prepared for playing, seeds are used to play king-queen game

Table 1. Contd.

57	*Jatropha integerrima* Jacq.	Euphorbiaceae	Spicy jatropa		Stem, flower	Stem used as making baskets and flower for ornamental purpose.
58	*Lagenaria siceraria* (Molina) Standl.	Cucurbitaceae	Calabash(Lau tumba)	Lauki	Fruit	Epicarp of fruit is used to make utencils and musical instrument
59	*Lantana camara* L.	Verbenaceae	Wild sage	Raimuniya	Fruits, flower	Bullets
60	*Luffa acutangula* L. Roxb.	Cucurbitaceae	Angled luffa	Karvitori	Fruits	Used for making Chakri
61	*Mangifera indica* L.	Anacardiaceae	Mango	Aam	Leaves, seed	Leaves used as currency (notes) and seed used to make whistle
62	*Martynia annua* L.	Martyniaceae	Tiger's claw	Ulatkanta	Fruits	Used as play material as it Contain spines & looks like1tiger's claw
63	*Mimosa pudica* L.	Mimosaceae	Shame plant	Lajwanti	Leaves	Children play with the leaf as it is sensitive and become close when they touch it
64	*Mimusops elengi* L.	Sapotaceae	Bullet-wood tree/Baula	Maulsari	flower	Used for making Ornaments (brasslate, ear rings)
65	*Musa paradisiaca* L.	Musaceae	Banana	Kela	Stem sheath, Leaf stalk, spathe of inflorescence	Stem sheath used to make boat, Leaf stalk used to make drum stick and Spathe used as slipper in games
66	*Neolamarckia cadamba* (Roxb.) Bosser.	Rubiaceae	Bur flower	Kadamb	Flower	Used as ball to play cricket/volley
67	*Nicandra physalodes* (L.) Gaertner	Solanaceae	Shoo-fly plant	Popti	Fruit	Used as crackers
68	*Nymphaea pubescens* Wild.	Nymphaeaceae	Water lily	Kanval	Flower	Used for decoration as necklace
79	*Olax scandens* Roxb.	Oleaceae	Olax (Bhadavadalia)	Dheniani	Leaf	Used as money (notes) for playing
70	*Oryza sativa* L.	Poaceae	Rice	Chaval	Dry stalks	Dry stalk used to make fuel, livestock bedding, fodder and for seating, children mainly used it as straw to drink and to make bubbles from foam.
71	*Pandanus fascicularis Lam.*	Pandanaceae	Screw pine	Kewra	Flower	Used to keep in bags by children and for decoration of hair as it is very much scented.
72	*Peltophorum pterocarpum* (DC.) K. Heyne	Fabaceae	Yellow flamebouyant	Peelagulmohar	Petals, stamens	Petals used to make artificial nails and anthers are crossed with each other and pulled opposite direction by children while playing
73	*Phoenix sylvestris* (L.) Roxb.	Arecaceae	Date palm	Khajur	Leaves	Used to make different craft items, ornaments and toys.
74	*Plumbago zeylanica* L.	Plumbaginaceae	wild leadwort	Chitrak	Flower	Used to decorate eyelashes
75	*Polyalthia longifolia* (Sonn)	Annonaceae	False Asoka (Deb daru)	Ashok	Leaf, branches	Leaves used for decoration and branches used to build small houses for playing

Table 1. Contd.

76	*Pseudobombax ellipticum* (Kunth) Dugand	Malvaceae	Shaving brush tree		Flower	Used as shaving brush by children
89	*Quisqualis indica* L.	Combretaceae	Rangoon creeper	Madhumalti	Flower	Used for making Ornaments (necklace, ring)
77	*Ricinus communis* L.	Euphorbiaceae	Castorbean	Arandi	Fruit	Used as weapon by children
78	*Rosa indica* L.	Rosaceae	Rose	Gulab	Flower (petals)	Used for nail art or decoration by children
79	*Ruellia tuberosa* L.	Acanthaceae	Fever root	Ruwel	Pod	Seeds are used as cracker by putting in water
80	*Saccharum officinarum* L.	Poaceae	Sugarcane	Ganna	Inflorescence stalk	Used for general counting/multiplication/addition etc.
81	*Solanum viarum* L.	Solanaceae	Tropical soda apple		Fruit	Used as 'gottiyan' to play games like 'guli-bati'.
82	*Tagetes erecta* L.	Asteraceae	Marigold	Genda	Flower, seed	Flower Used as ball and seed used as microphone.
83	*Tamarindus indica* L.	Fabaceae	Tamarind	Imli	Seeds, leaves	Seeds are used to make 'gottiyan' for playing ludo, and for learning counting number, addition, subtraction etc. and leaves are used as food while playing kitchen-set.
84	*Tectona grandis* L.f.	Verbenaceae	Teak	Sagun	Leaf	Used for colouration of palms by rubbing
85	*Tinospora cordifolia* (Willd.) Miers.	Menispermaceae	Indian tinospora	Gulbel	Stem	Used as telephone cord
86	*Trewia nudiflora* L.	Euphorbiaceae	False white teak	Pindar	Fruit	Used for making Wheels as play material
87	*Tridax procumbens* (L.)	Asteraceae	Coat buttons	Khal-muriya	Flower	Used to make tiara
88	*Triumfetta rhomboidea* Jacq.	Tiliaceae	Burr Bush	Chikti	Fruit	Used for making fun by throwing it to the hair of each other.
90	*Xanthium strumarium* L.	Asteraceae	Common Cocklebur	Chhotadhatura	Fruit	Used for throwing at each other and sticking it to their hairs and dresses

1996). The herbarium of collected plants is available in the Botany Section (Department of Education in Science and Mathematics) of Regional Institute of Education, Bhubaneswar.

The structured interview included the following open-ended questions, such as: 1) Do you play outside and make fun with plants? 2) What game do you play? 3) Which plant do you use to make fun? 4) what is the local name of the plant? 5) Where is the plant seen? 6) What kind of plant it is (tree/herb/shrub/climber/creeper)? 7) Which plant part do you use for play or fun? 8) When does the plant flower and bear fruits? 9) Any economic use of the plant you know besides as play material? 10) Can you demonstrate the fun you make with the plant?

RESULTS AND DISCUSSION

Learning occurs in a joyful environment. Teaching should explore the joyful environment in order to promote learning among children through creative activities (NCERT, 2005). As such learning takes

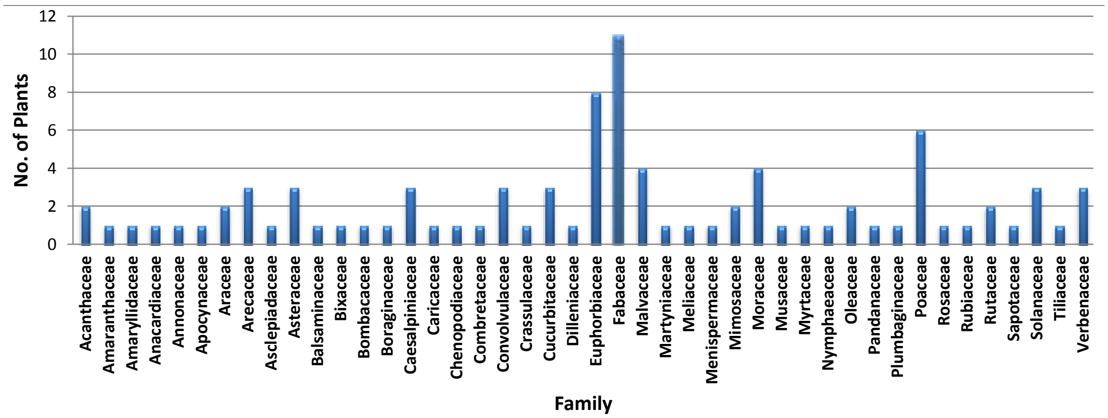

Figure 2. Diversity of Plants used for fun and games according to Family.

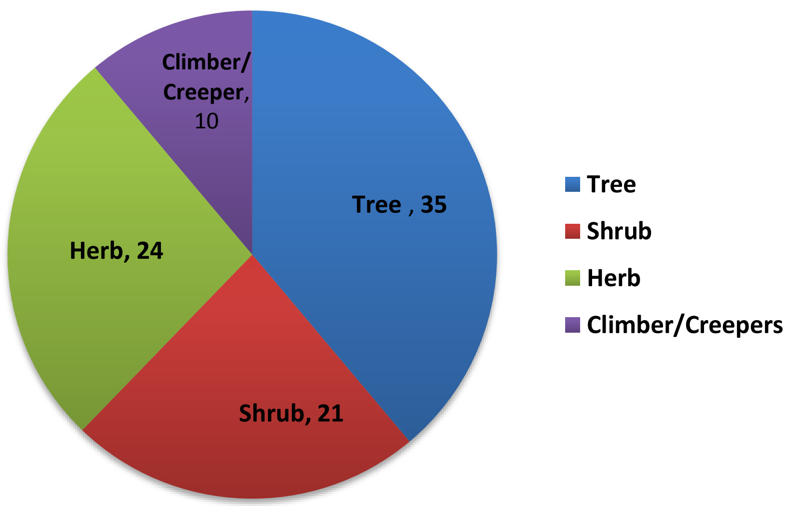

Figure 3. Diversity of plants used for fun and games.

place through child's interactions with the environment, nature, things, and people around them. Discoveries and inventions are based on keen observations and happenings in nature. As such, environment in terms of plants, animals, soil, water etc. not only provides materials for fun and games but also provide opportunities to learn and discover. Children learn language and skills by observing and describing the leaves, flowers, and fruits; and exploring the patterns that they observe in nature around them.

Objective 1

To identify and document plant species used for fun and games from local biodiversity

The reconnaissance survey included some selected schools and villages of tribal and nontribal regions and some 90 plant species used for fun and play. These are distributed in 85 genera belonging to 44 different families (Table 1).

The largest number of plant species are distributed under family Fabaceae (11), followed by Euphorbiaceae (8) and Poaceae (6) (Figure 2). The plants used for fun and games are distributed in 35 trees, 21 shrubs, 24 herbs and 10 climbers/creepers (Figure 3). Some common plants that are frequently used by the children for making play materials include: *Artocarpus heterophyllus, Dendrocalamus strictus, Cocos nucifera, Calotropis gigantea, Cucumis hardwickii, Ficus benghalensis, Ficus recemosa, Ipomoea parasitica, Mangifera indica, Musa paradisiaca, Phoenix sylvestris, Polyalthia longifolia, Tamarindus indica*, etc (Figure 4).

Figure 4. Some common plants and its part used as play material by the children. **(a)** *Artocarpus heterophyllus* Lam. leaves used for making toys, tiaras and fruit used to make toys of horse/cow. **(b)** *Cocos nucifera* L.: Children use the coconut shells as utensils in their kitchen set. **(c)** *Dendrocalamus strictus* (Roxb.): Nees stem is used for making toys like gun, whistle, penstand and carts. **(d)** *Calotropis gigantean* R. Br: Children use the fruits for making artificial parrots for fun making **(e)** *Areca catechu* L. leaf branch used as lorry carrier. **(f)** *Cucumis hardwickii* L.: Children use the fruits to make toys of different shapes like horse, chicks, etc. **(g)** *Phoenix sylvestris* (L.) Roxb: Children use the leaves to make different craft items like handfans, mats, rings, etc. **(h)** *Ficus benghalensis* L.: Children use these prop roots in order swing one point to other and leaf is used as container. **(i)** *Mangifera indica* L.: Children use leaves to make craft items like small vanity bags, and decoration purpose **(j)** *Ficus recemosa* L.: Children use the fruits as wheels for making Chariots. **(k)** *Musa paradisiaca* L.: Children use stem sheath to make boats and spathe as slipper for walking. **(l)** *Ipomoea parasitica* (Kunth): Children use the leaves for different decoration and ornamental purposes. **(m)** *Tamarindus indica* L. Children use these seeds to make 'gottiyan' for playing different games like 'ludo' or drawing squares on the floor. **(n)** *Polyalthia longifolia* (Sonn) children use the branches with dense leaves for thatching& usually use the leaves for decoration purposes.

Objective 2

To know the plant part being used and the nature of its use

The plant part(s) and mode of their use as play material were also recorded. It was noted that fruits from most plants species were used for games followed by leaves and flower (Figure 5). The stem is the least used plant part. There are also some plants species in which both flower and fruits, fruits and leaves, leaves and fruits were used for making toys and other play materials. The

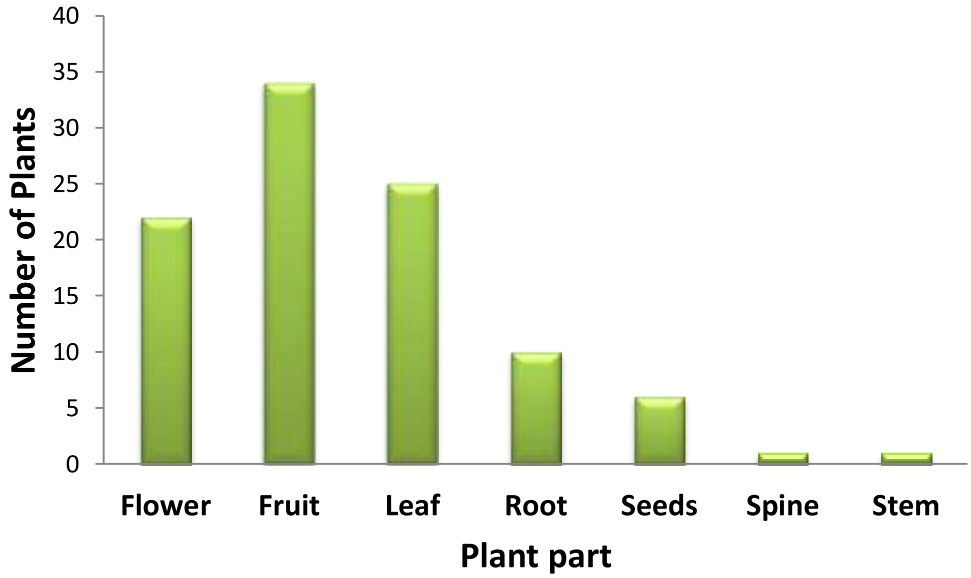

Figure 5. Plant part used as play material.

nature of their use has been explained briefly in Table 1.

Objective 3

To find out the economic value, if any of the plants identified

Among the plants documented for fun and games, some plants were found economically and socially relevant for the local inhabitants. Some plants are used as herbal medicines and others are consumed as food, few are used for building houses, firewood and marketing purposes. The plants like, *Achyranthus aspera*, *Aegle marmelos, Azadirachta indica, Bryophyllum pinnatum*, *Calotropis gigantea*, *Cynodon dactylon*, *Lantana camara*, *Mimosa pudica, Solanum viarum, Tridax procumbens,* etc are commonly used as herbal medicine by the local people for their primary treatments such as vomiting, dysentery, toothache piles, itching, wounds, stomach and skin disorders (Bisoi and Panda, 2015). Besides being used as play materials, the plants having food value include *Abelmoschus esculentus, Allium cepa, Artocarpus heterophyllus, Basella alba, Carica papaya, Citrus reticulata, Cocos nucifera, Dillenia indica, Mangifera indica, Lagenaria siceraria,* etc. that are consumed as fruits and vegetables by the local people. *Aegle marmelos, Azadirachta indica, Ficus benghalensis, Ficus racemosa* and *Ficus religiosa* are the major trees species which are having religious importance and worshiped by the local villagers and remain conserved (Choudhury and Pattnaik, 1982). Multiple uses of the plants observed in the present study have been depicted in Figure 6.

General perspectives

From the present study, it was observed that nature especially plants do provide ample opportunities for children to make fun and games. Creative skills are reflected through activities such as designing of chariots by joining fruits of *Ficus* tree, and from boat preparation by using banana (*Musa*) stem sheaths. These exemplary activities are culturally built up in families. Using plant parts, children design creative games during as well as beyond school hours with the knowledge gained from peers, family and community members.

Teachers use the plant parts (seeds, fruits, leave etc.) in teaching of science and mathematics concepts in the classrooms that is hard to transact. Such activities make learning joyful, effective and durable (Satapathy and Dash, 1994).

In India, the use of trees and their parts such as flowers and fruits have been used in folk songs, folk proverbs, and folk talks has been reported (Agarwala, 1981). However with urbanization, there is degradation of the environment and accelerated loss of biodiversity; consequently, this culturally-established, indigenous knowledge of using plants for various purposes is getting lost over time (Balick, 1996). The cultural knowledge that is available in one locality may not be the same as at other places, because of divergence in the flora and fauna, and people's association with those.

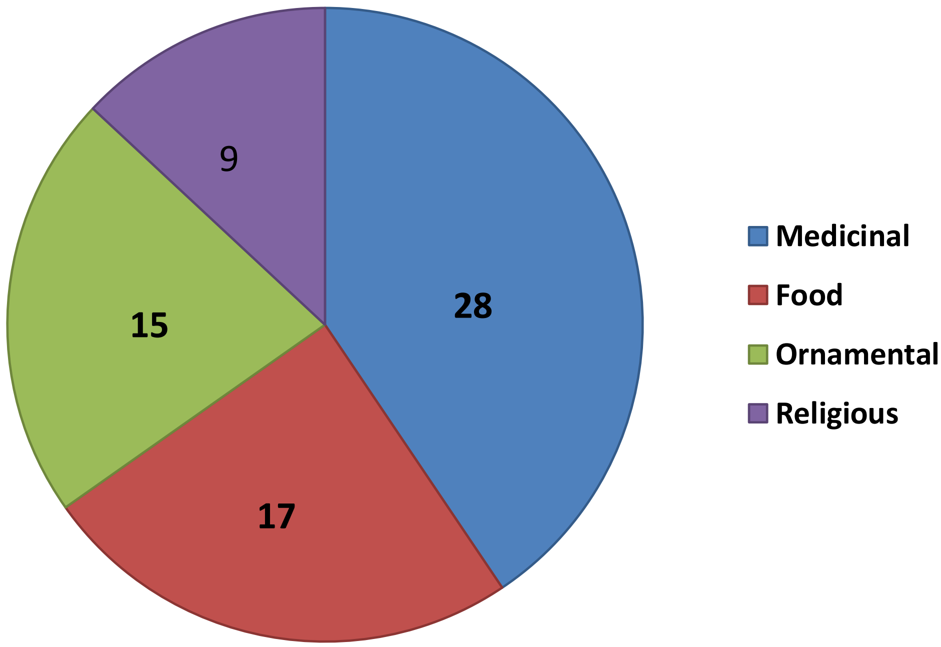

Figure 6. Multiple Economic uses of plants besides being used as play material.

Further, with developments in science and technology, present generation children are more engaged in computers, mobile phones, internets, videogames, rather than with plants in gardens and parks. As such, they are away from nature and have little or no concern for it. The indigenous knowledge gathered over the years is increasingly being eroded. In modern schools and urban pockets, students are completely away from nature and see the plants virtually through computers with support from ICT. As such, it is often noticed that children who are isolated from nature, and spend more time in front of computer screens, face problems such as obesity, irritability, laziness, lack of concentration, aggressive behavior and high frustration levels. Hence there is an urgent need to conserve the plants that are not only economically important but also used as fun and games by children, as well as encouraging them to become more engaged with their natural environment. Further, there is a need for additional studies of more plants that are used as fun and games. Internationally, UNO has declared 2011-2020 as the decade of Bio-diversity conservation in order to create awareness about biodiversity, its importance, and conservation (Kulkarni, 2012). As all genetic resources of living things are useful in one form or the other (Swaminathan, 1989), plants and their parts of interest to children that have educational value in terms of teaching-learning material(s) should be preserved and kept in educational institutions for use as demonstrations and to encourage inquiry learning during teaching of scientific concepts.

CONFLICT OF INTERESTS

The authors declare there is no conflict of interests.

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Full Length Research Paper

Qualitative traits variation in barley (*Hordeum vulgare* L.) landraces from the Southern highlands of Ethiopia

Addisu Fekadu[1,2*] Fantahun Woldesenbet[2] and Shumet Tenaw[2]

[1]Biodiversity Research Center, Arba Minch University, P. O. Box 21, Arba Minch, Ethiopia.
[2]Department of Biology, Arba Minch University, P. O. Box 21, Arba Minch, Ethiopia.

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Thirty six barley landraces were collected from three districts of the southern highlands of Ethiopia and evaluated for 11 morphological traits to assess the extent of qualitative trait variations based on morphological traits. The results showed that 42% of the 36 barley landraces were found to have six kernel row numbers for the three collection districts. The distribution of four kernel raw number was found to be very low among the different landraces. Phenotypic diversity index (H') was analyzed and the result indicated that all characters revealed intermediate to high diversity ranging from 0.78 for kernel row number to 0.34 for glume color in all districts. Individual characters showed different levels of diversity index in different districts. The results clearly showed that there is high diversity of barley landraces in the southern highlands; this can be used for the conservation of these germplasm resources and future improvement work on barley crops.

Key words: Diversity index, conservation, barley landraces, agro morphology.

INTRODUCTION

Barley (*Hordeum vulgare* L.) is one of the earliest cultivated cereal crops in Ethiopia and it is the fifth most important cereal crop both in area coverage and production, with around 1,013,623.72 ha and 18,155,830.29 qt, respectively (CSA, 2012). Ethiopia is considered to be a center of diversity for food barley crop production (Firdissa et al., 2010). The diversity in altitude, soils, climate and topography together with geographical isolation for long periods, are considered as the main factors influencing the large diversity in the country (Mekonnon et al., 2015). The wide cultural diversity in the country also plays an important part in the diversification of the landraces. Lack of improved varieties, disease, insect and pest problems, weed competition, and poor soil fertility have been indicated as major constraints in barley improvement (Lakew and Alemayehu, 2011).

Ethiopian barley landraces are a precious source of genes that control important agronomic traits, such as resistance to disease (for example powdery mildew, barley yellow dwarf virus, net blotch, scald and loose smut), to insect attack (Yitbarek et al., 1998), high lysine and protein quality and content (Munck et al., 1970), and

*Corresponding author. E-mail: addisufkd2@gmail.com.

Table 1. List of barley landraces used in the experiment and their collection site.

Number	Local name	Collection site	Altitude (m.a.s.l.)[1]	Number	Local name	Collection site	Altitude (m.a.s.l.)[1]
1	Duhe I	Chencha	2983	19	Solga II	Dita	2764
2	Locha I	Chencha	2992	20	Morka	Dita	2771
3	Maleno I	Chencha	2986	21	Chega IV	Dita	2867
4	Locha II	Chencha	2984	22	Osaha	Dita	2870
5	Chega I	Chencha	2968	23	NK 1	Dita	2871
6	Chentic	Chencha	2971	24	Maleno III	Dita	2888
7	Wolate	Chencha	2932	25	Locha II	Dita	2948
8	Kawbanga I	Chencha	2931	26	Losha	Dita	2950
9	Bote I	Chencha	2939	27	Bote II	Dita	2950
10	Maleno II	Chencha	2872	28	Kaobanga II	Dita	2904
11	Bote 2	Chencha	2886	29	Chega V	Dita	2762
12	Ye gibirina	Chencha	2885	30	Murka	Bonke	2384
13	Karsa Ocho	Chencha	2895	31	Shilash	Bonke	2365
14	Giso	Chencha	2810	32	Geze Banga	Bonke	2559
15	Bote 3	Chencha	2809	33	Wolkiie	Bonke	2557
16	Chega II	Dita	2536	34	Lealo	Bonke	2372
17	Solga I	Dita	2542	35	Mirichicho	Bonke	2379
18	Chega III	Dita	2636	36	NK II	Bonke	2354

[1]Expressed as metres above sea level (m.a.s.l.).

malting and brewing quality (Lance and Nilan, 1980). For these important aspects, characterization of genetic variability of a population is required; because genetic variation within a population, and between populations, determines the rate of adaptive evolution and response to traditional crop improvement (Hunter, 1996).

Furthermore, the high variability of the environmental conditions in Ethiopia that promote adaptive selection, and the cultivation of barley in two growing seasons per year (Tanto et al., 2009), have probably driven the structure of these landrace variations. Furthermore, utilization of barley for home consumption can contribute to some variation in the type of landraces maintained in a particular geographic location. Continuous efforts to understand the genetic diversity of Ethiopian landraces, as well as the nature and extent of their variations, would be useful for the efficient conservation and use of the existing plant materials.

Previous studies on morphological variability of Ethiopian barley landraces concentrated on random samples and failed to assess variability of landraces within specific localities in terms of economically important traits that pave the way for further evaluation and utilization (Lakew and Alemayehu, 2011). Hence, this study was conducted with the objective to assess the extent of qualitative trait variations based on morphological traits of barley landraces from the southern highlands of Ethiopia, and select potential genotypes for variety improvement program.

MATERIALS AND METHODS

Experimental materials

A total of 36 barley landraces were collected from southern highlands of Ethiopia. Twenty accessions per landraces were collected from each site. The landraces were collected based on their diverse agroecology, origin, and altitude (Table 1). The accessions were collected from farmers' fields, by using a random sampling technique (Hawkes, 1976).

Experimental site

The experiment was conducted at Arba Minch University field Enset Park at Chencha, during the main cropping season of 2014 under rain fed conditions. Altitude of the experimental site is 2537 m.a.s.l and the annual rainfall ranges between 1201 to 1600 mm and mean maximum and minimum temperatures are 22 and 12.7°C, respectively (Table 2). The site is selected based on its barley crop production potential, during the rainy season, which occurs from June to October.

Experimental procedure

The experiment was laid out in a randomized complete block design with three replications. The experimental plots consisted of six rows of 2.5 m length with 30 cm spaces, and seeds were sown by hand. The plant density of 300 plants per m^2 and recommended

Table 2. Metrological data of the study area during the study period (July to December, 2014).

Parameter	July	August	September	October	November	December	Total/average
Total monthly rainfall (mm)	41.2	113	193.6	234.8	121	14.8	718.4
Minimum temperature (°C)	11.5	11.4	11.6	12.6	12.5	12.0	11.9
Maximum temperature (°C)	18.8	18.3	20.4	21.4	21.7	23.5	20.7

[1]Source: Arba Minch University, Dorze Metrological Station.

Table 3. Phenotypic classes of the qualitative characters used for diversity study.

Trait	Type
Kernel row number (KRN)	Two rowed ; Two rowed, deficient; Irregular, variable lateral florets; six rowed, awnless or awnlete; Six rowed, long awns; Others
Spike density (SD)[b]	Lax; Intermediate ;Dense
Lemma awn barb (LAB)	Smooth; Intermediate (small barbs) ;Rough
Glume color (GC)	White; Yellow; Brown; Black
Lemma type (LT)	No lemma teeth; Lemma teeth; Lemma hair
Length of rachila hair (LRH)	Short; Long
Kernel covering (KC)	Naked grain; Semi-covered grain; Covered grain
Lemma/Kernel color (LC)	Yellow; Tan/red; Purple; Black/grey
Growth habit (GH)	Prostrate; Intermediate; Erect
Stem Pigmentation (SP)	Green; Purple (basal only); Purple (half or more)
Awn color (AC)	White; Yellow; Brown; Reddish; Black

dose of fertilizer (100:70:50, NPK) kg per ha were applied. Plots were kept free from weeds.

Data collection

Based on the IPGRI descriptor list (IPGRI, 1994), 11 qualitative characters were recorded (Table 3). For each landrace, 20 randomly selected individual plants were used for recording qualitative traits. Color traits were recorded using the Eagle Sprit Ministry Color Chart, which was developed by Kohe't (1996).

Statistical analysis

Phenotypic frequencies distributions of the characters were calculated for all the barley landraces. Shannon-Weaver diversity index (H') (Poole, 1974) was computed using the phenotypic frequencies to assess the phenotypic diversity of each character for all landraces:

$$H' = \sum_{i=1}^{s} p_i \log_e p_i$$

Where, s represents the number of phenotypic classes of a given character, and P_i the proportion of the total number of accessions consisting of the i^{th} class. Each value of H' was divided by ln s, in order to keep the values of H' between zero and one (Goodwin et al., 1992). To study the patterns of diversity among the sampled populations, a dendrogram was made based on Nei's (1978) unweighted, pairwise distance matrix between populations. This showed the relationships among all of the 36 landrace populations. For this analysis, the Pop Gene version 1.32 (Yah et al., 2000) computer software was also used.

RESULTS AND DISCUSSION

The frequency distribution for the 11 qualitative traits tabulated by source of the landraces is shown in Table 4. Forty two percent of the barley landraces were found to have six kernel row numbers and the distribution of four kernel row number was very low. The variation in spike density revealed the predominance of the intermediate spike density type in all of the districts with overall frequency of 83% followed by dense type; whereas lax type was found to concentrate in Bonke with overall

Table 4. Frequency distribution (%) of different phenotypic classes for 11 qualitative characters in Barley landraces by location of collection.

Location	KRN						SD			LAB			GC				LT		
	1	2	3	4	5	6	3	5	7	3	5	7	1	2	3	4	1	2	3
Chencha	33	0	27	0	0	40	13	53	33	27	20	53	33	53	0	13	60	33	7
Dita	29	7	21	7	0	36	21	36	43	36	21	43	79	14	0	7	21	57	21
Bonke	14	14	14	0	0	57	14	43	43	0	43	57	86	14	0	0	14	14	71
All	28	6	22	3	0	42	17	44	39	25	25	50	61	31	0	8	36	39	25

	LRH		KC			LC/KC				GH			SP			AC				
	1	2	1	2	3	1	2	3	4	3	5	7	1	2	3	1	2	3	4	5
Chencha	87	13	0	87	13	7	7	53	13	20	0	20	80	7	7	87	13	53	13	7
Dita	71	29	0	71	29	29	0	57	7	7	7	7	86	7	50	43	50	36	14	0
Bonke	86	14	0	86	14	57	14	29	0	0	0	57	43	0	43	57	71	14	0	14
All	81	19	0	81	19	33	8	50	8	49	15	36	58	10	32	39	28	22	6	5

frequency of 17%. This suggests preference of farmers for barley landraces with intermediate or dense spike density types, which may be due to the fact that such landraces types are less susceptible to bird damage (Derbew et al., 2013).

Various lemma types were observed in all of the districts. The lemma teeth type was concentrated in Dita and Chencha with 57 and 33%, respectively. This result is generally in agreement with the findings of Tenaw and Tanto (2014) who reported high frequency for lemma teeth type in Dita and Chencha. With respect to growth habit the prostate type was more predominantly followed by erect type with a frequency of 49 and 36%, respectively.

Kernel color is one of the most important characters that determine the quality and acceptance of landraces. It has an economic value because it constitutes the basis for farmers' variety identification and commercial classification of different varieties of crops (Tsehaye and Kebebew, 2002). Purple kernel color was found to be the dominant color followed by yellow kernel color with a frequency of 50 and 33%, respectively, in the present study. Farmers prefer barley with purple kernel color with high yield and hardiness, even though it fetches fewer market prices compared to a black or red color.

Diversity index analysis

Table 5 shows the estimates of diversity index for each of the character. Overall, all characters revealed intermediate to high diversity ranging from 0.34 for glume color to 0.78 for kernel row number in all districts. Individual characters showed different levels of diversity index in different districts. Kernel row number exhibited higher diversity index in most districts than other characters with more than two phenotypic classes. A higher phenotypic diversity index for characters with less number of phenotypic classes was also reported by Mekonnon et al. (2015) in barley landraces. Kemelew and Alemayehu (2011) also reported a high diversity index among 181 barley landraces, using collections from Shewa and Wollo for the eight qualitative characters considered. The result revealed a diversity ranging from 0.32 for kernel covering to 0.90 for spike density.

Phenotypic diversity index across districts

The H' pooled across characters by districts of collection showed high phenotypic diversity among the 11 qualitative characters (Table 6). The mean H' varied from 0.49 for Bonke to 0.53 to Dita. The low H' from Bonke district were not necessarily associated with lack of adequate sample size. This diversity reflects the wide range of ecological and human influences under which the crop has evolved.

Altitudinal diversity index

Most of the qualitative characters showed significant

Table 5. Phenotypic diversity index (H') for the 11 qualitative traits.

Locus	H'	I*
KRN	0.78	1.60
SD	0.52	0.88
LAB	0.51	0.87
GC	0.35	0.70
LT	0.55	0.92
LRH	0.49	0.69
KC	0.53	0.82
LC	0.71	1.36
GH	0.49	0.83
SP	0.46	0.65
AC	0.67	1.27
Mean	0.55	0.96
St. Dev	0.12	0.31

Table 6. Estimation of the diversity index (H') of the 36 barley landraces for the three districts of origin.

District	KRN	SD	LAB	GC	LT	LRH	KC	LC/KC	GH	SP	AC
Chencha	0.77**	0.45**	0.48**	0.49**	0.26*	0.48**	0.52**	0.74**	0.39**	0.39**	0.64**
Dita	0.75**	0.57**	0.56**	0.29*	0.56**	0.49*	0.49**	0.64*	0.44**	0.48*	0.56*
Bonke	0.71**	0.48**	0.41**	0.00*	0.64**	0.39	0.56**	0.66**	0.48**	0.49*	0.61**
Mean H'	0.74	0.50	0.48	0.26	0.49	0.45	0.52	0.68	0.44	0.45	0.60
Overall	0.78	0.52	0.51	0.35	0.55	0.49	0.53	0.71	0.49	0.46	0.67

Table 7. Estimates of the diversity index (H') for the three altitude classes.

Altitude (m.a.s.l)	KRN	SD	LAB	GC	LT	LRH	KC	LC/KC	GH	SP	AC	Mean
2,000-2,400	0.71*	0.41**	0.51*	0.04	0.64	0.49	0.53**	0.65	0.61**	0.47	0.48*	0.50
2,401-2,800	0.75*	0.53*	0.46*	0.30*	0.39*	0.49*	0.42*	0.69*	0.46*	0.50*	0.73*	0.52
2,801-3,000	0.73	0.57**	0.52*	0.55*	0.37*	0.42	0.51**	0.74*	0.26**	0.35*	0.58	0.51
Average H'	0.73	0.50	0.50	0.30	0.47	0.47	0.49	0.69	0.44	0.44	0.60	0.51

variation among altitude groups. The estimates of H' for each of the characters and altitude class are presented in Table 7. In altitude group I (2,000 to 2,400) and group III (2,801 to 3,000) spike density, kernel covering and growth habit showed highly significant variation. The altitude group II (2,401 to 2,800) showed significant variation for all characters measured. Mekonnon et al. (2015) also reported a significant variation among different altitude groups for 102 barley landraces among six qualitative characters.

Cluster analysis

All of the 36 barley landraces were grouped into five clusters (Table 8) and among these four clusters had different compositions in terms of collection districts. The number of landrace populations per cluster varied from 11 landraces in cluster II and IV to four landraces in cluster I (Figure 1) in which 71.4 % of landraces from Dita are grouped in cluster III and IV, and most of them have predominant white glume color, lemma teeth and green stem pigmentation.

Furthermore, cluster I was the only cluster without landraces from Dita and Bonke districts; and Clusters II, II and IV contain landraces from all districts with the following percentages: Chencha (41.67%), Bonke (38.89%) and Dita (19.4%). Landraces, which were grouped in cluster IV, were mainly characterized by the

Table 8. The total number of landraces by cluster.

District	Number of landraces by clusters				Total
	I	II	III	IV	
Chencha	4	4	4	3	15
Dita	0	5	4	5	14
Bonke	0	2	2	3	7
Total	4	11	10	11	36

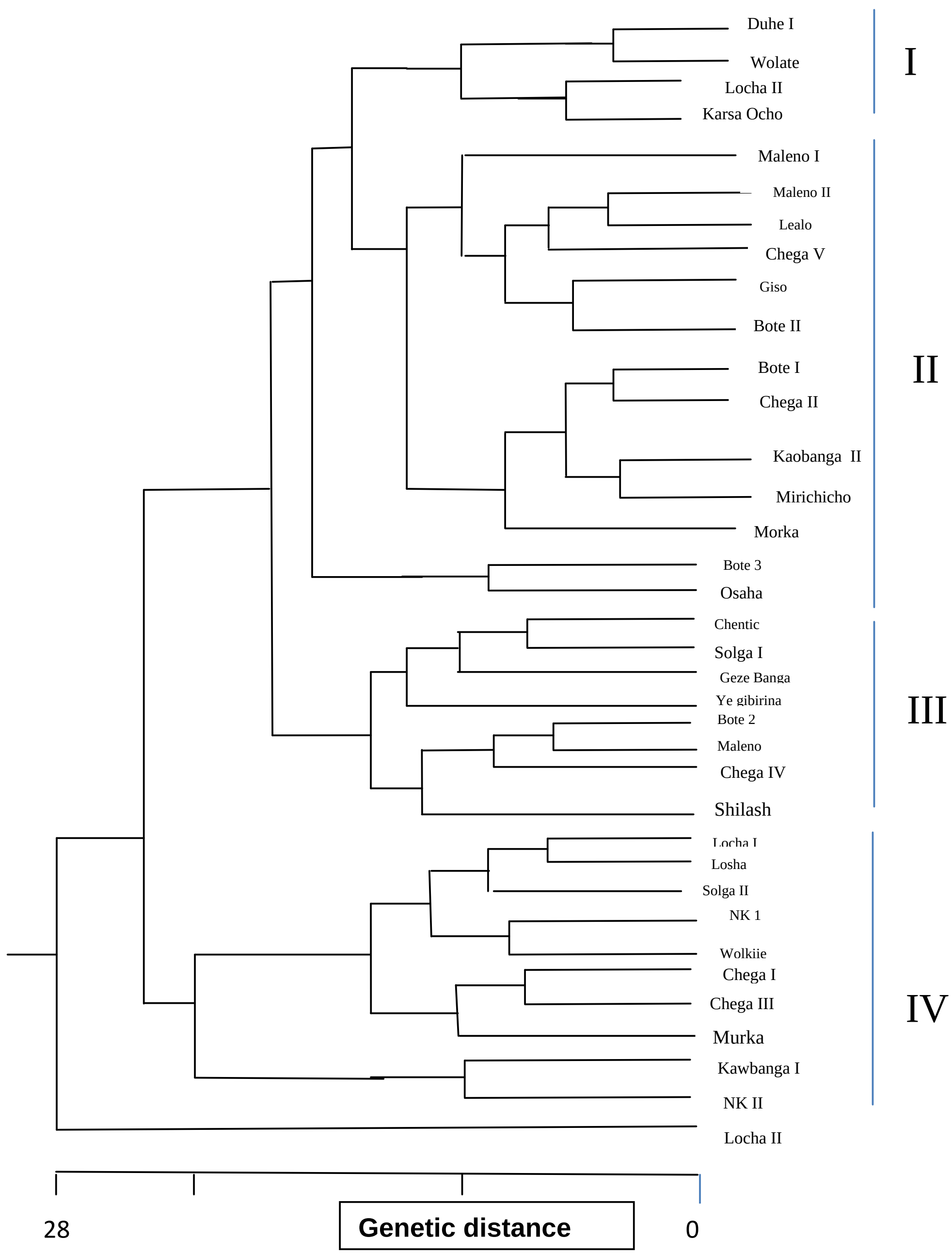

Figure 1. Unweighted pair group method of arithmetic mean (UPGMA) dendrogram based on Nei (1978) genetic distance, showing the relationships among all barley landrace populations.

possession of two row kernel number, short rachila hair, semi covered grain, and white awn color. This result was also in agreement with those of Derbew et al. (2013), who showed that 225 barley genotypes were clustered into five groups based on eight qualitative traits. Their data showed that the number of genotypes belonging to each cluster varied from one in cluster V to 130 in cluster I. Kemelew and Alemayehu (2011) also showed hierarchical clustering analysis using Euclidean distance of 181 barley landraces results in ten clusters, each cluster contained landraces with contrasting expression of agronomic traits. Based on the agronomic merit of each cluster, the ten clusters in turn were re-classified into high and low yielding cluster groups.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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