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

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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.

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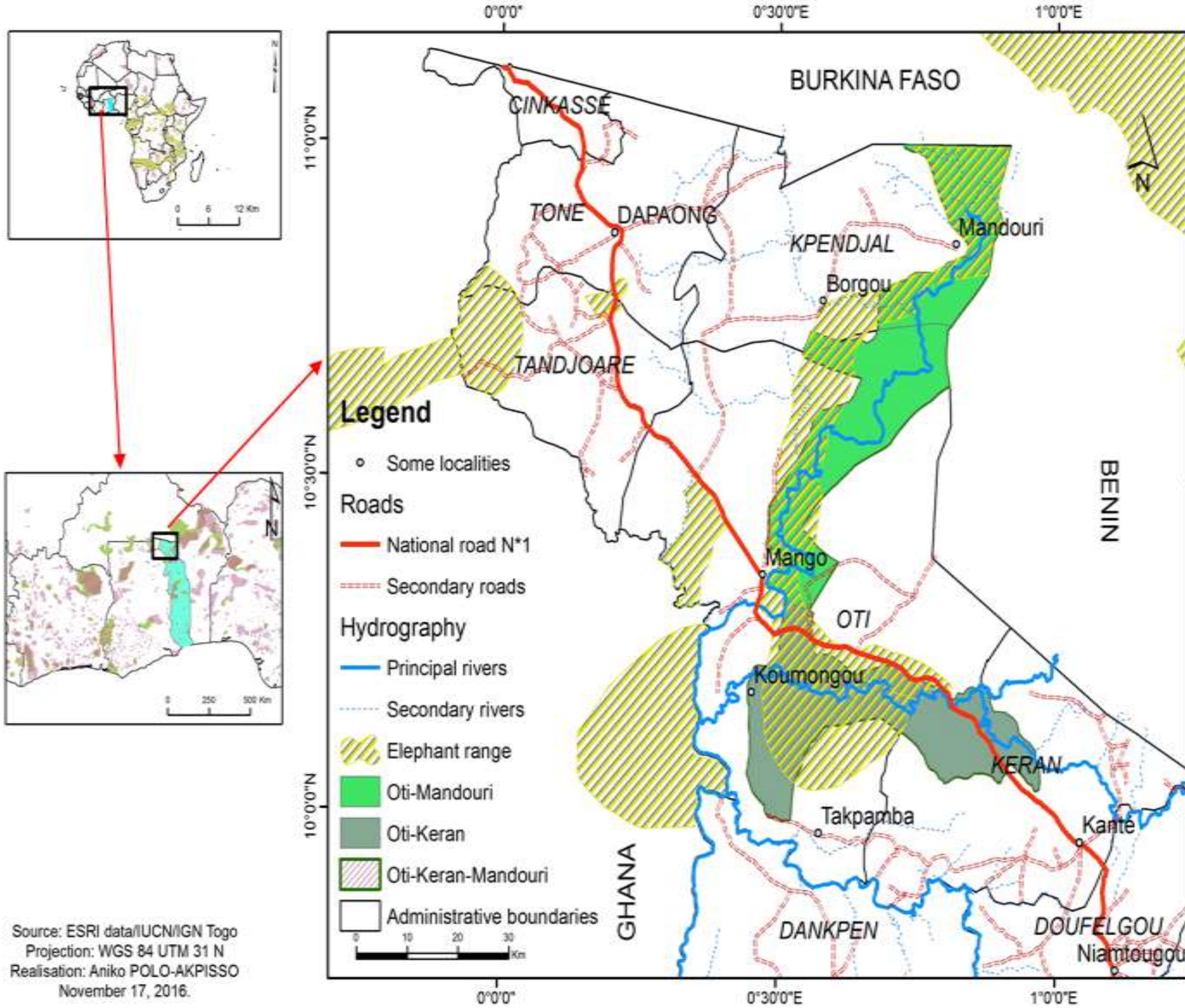

Figure 1. Study area.

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

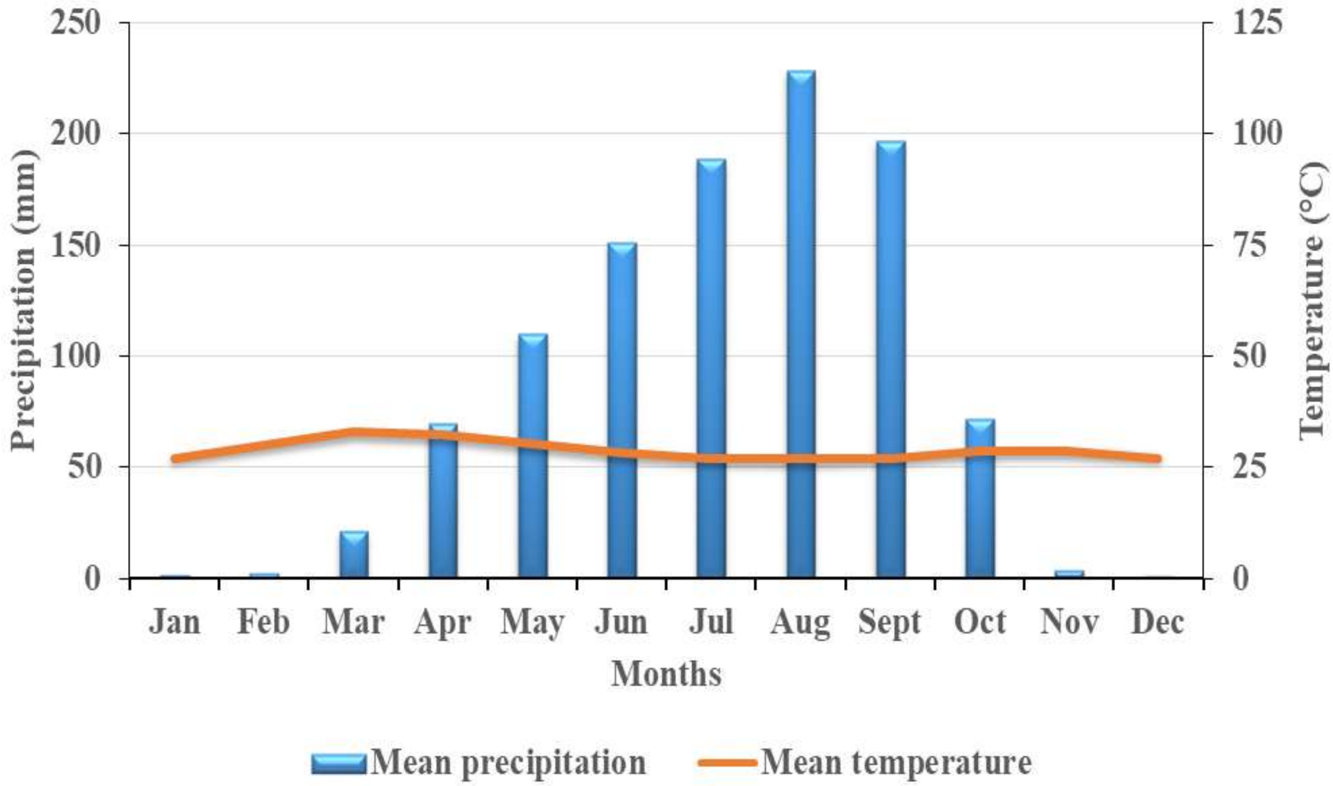

Figure 2. Mean precipitation and temperature at the meteorological station of Mango from 1981 to 2013 (Data source: National Direction of Meteorology).

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

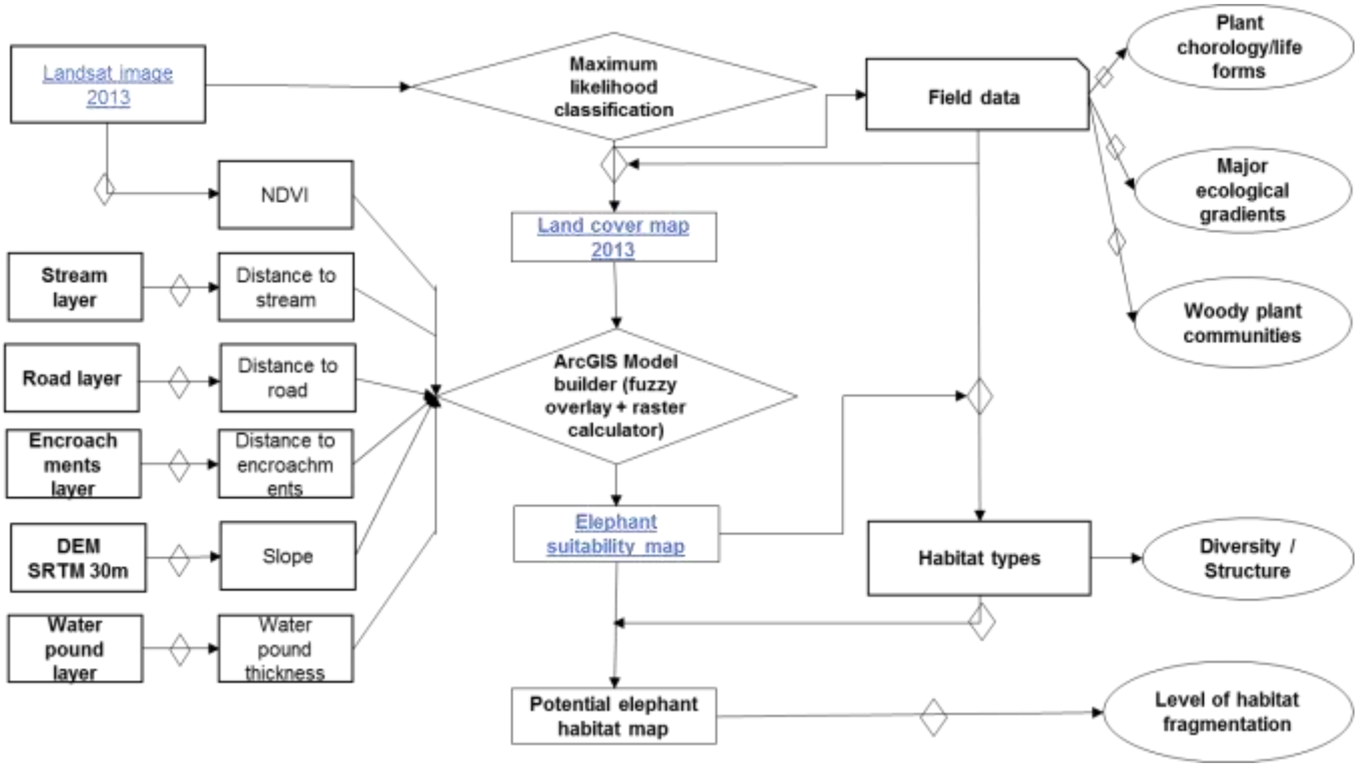

Figure 3. Summary of the workflow to assess elephant habitat within Oti-Keran-Mandouri.

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:

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

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

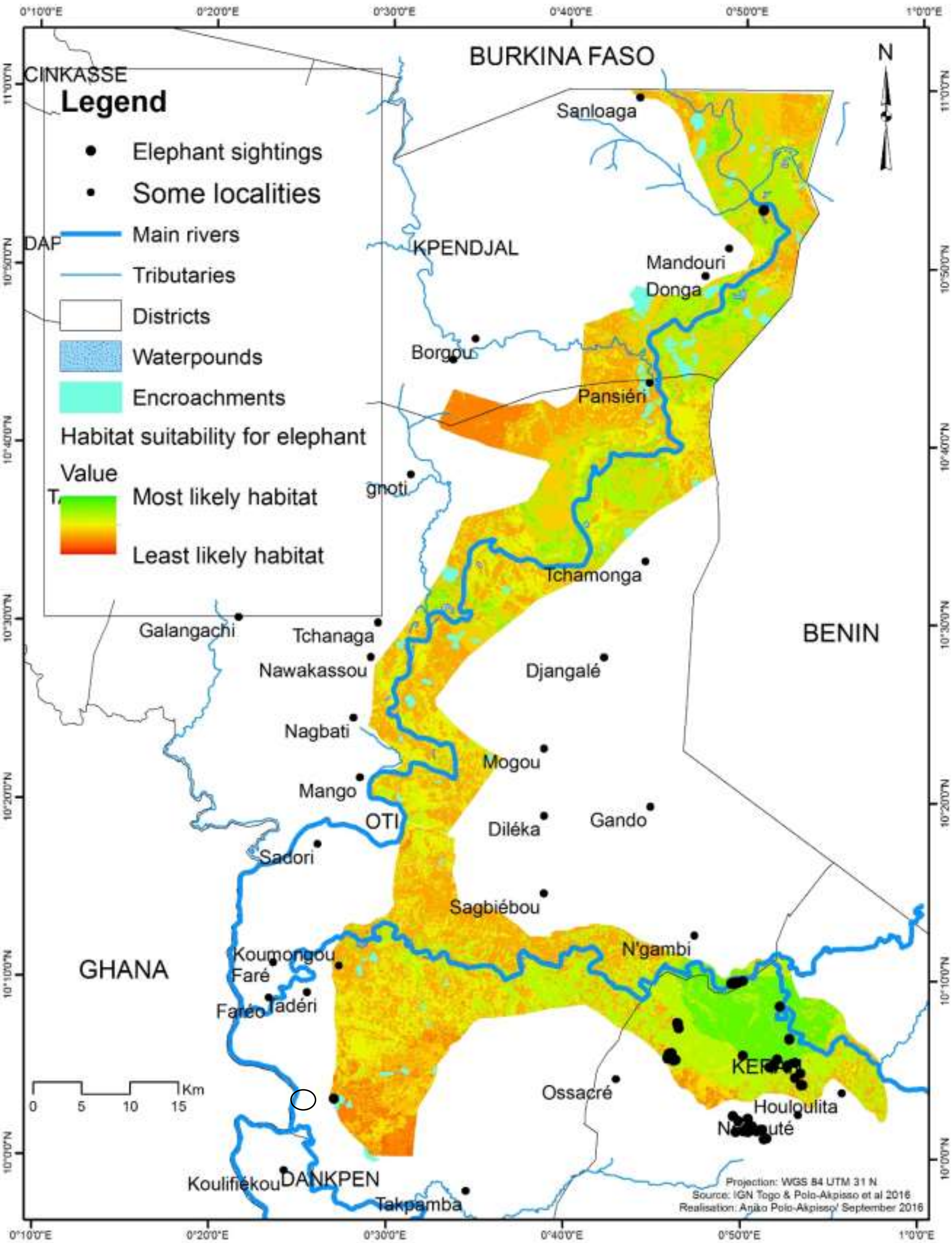

Figure 4. Elephant suitable habitat within Oti-Keran-Mandouri.

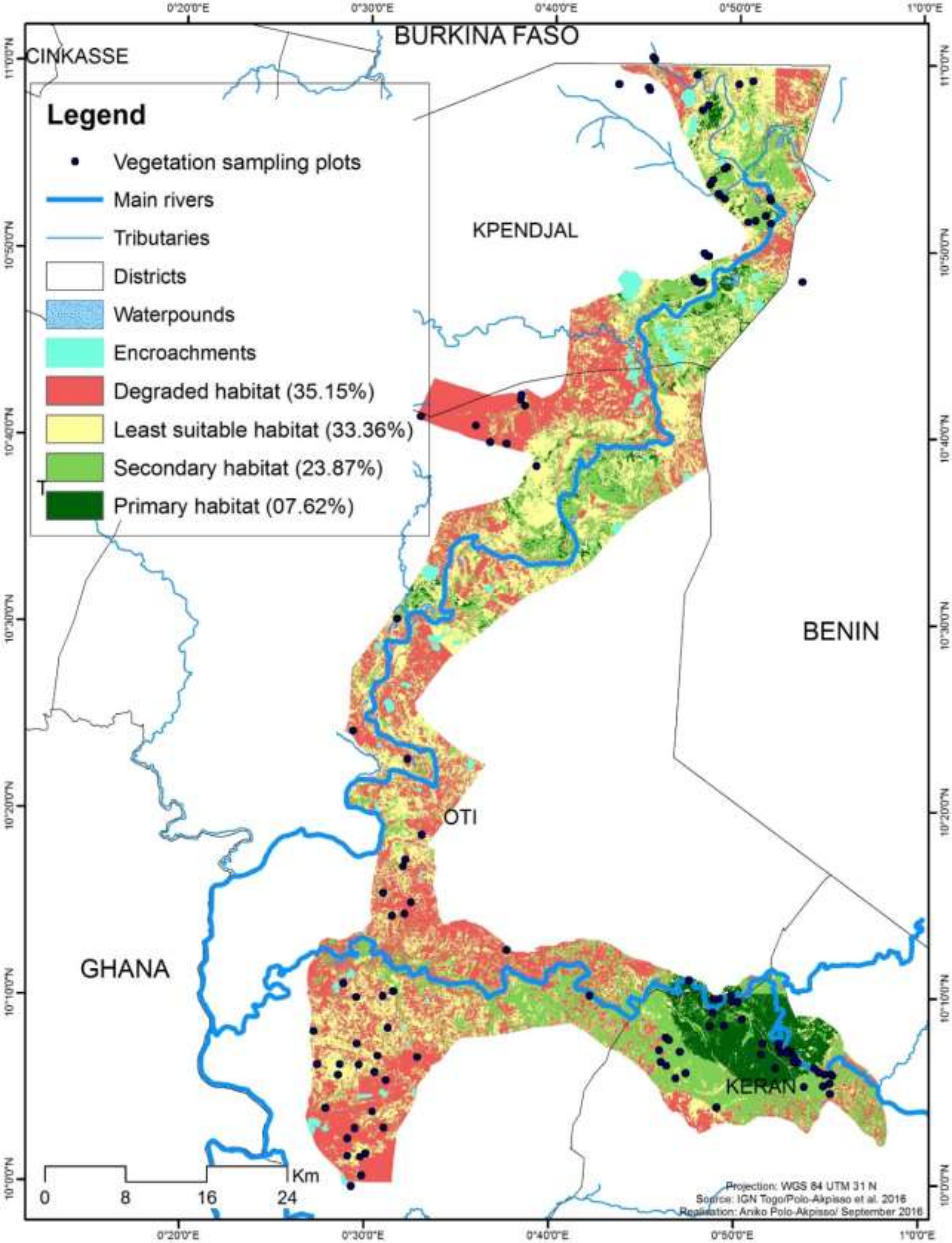

Figure 5. Distribution of habitat types according to their level of suitability within Oti-Keran-Mandouri.

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

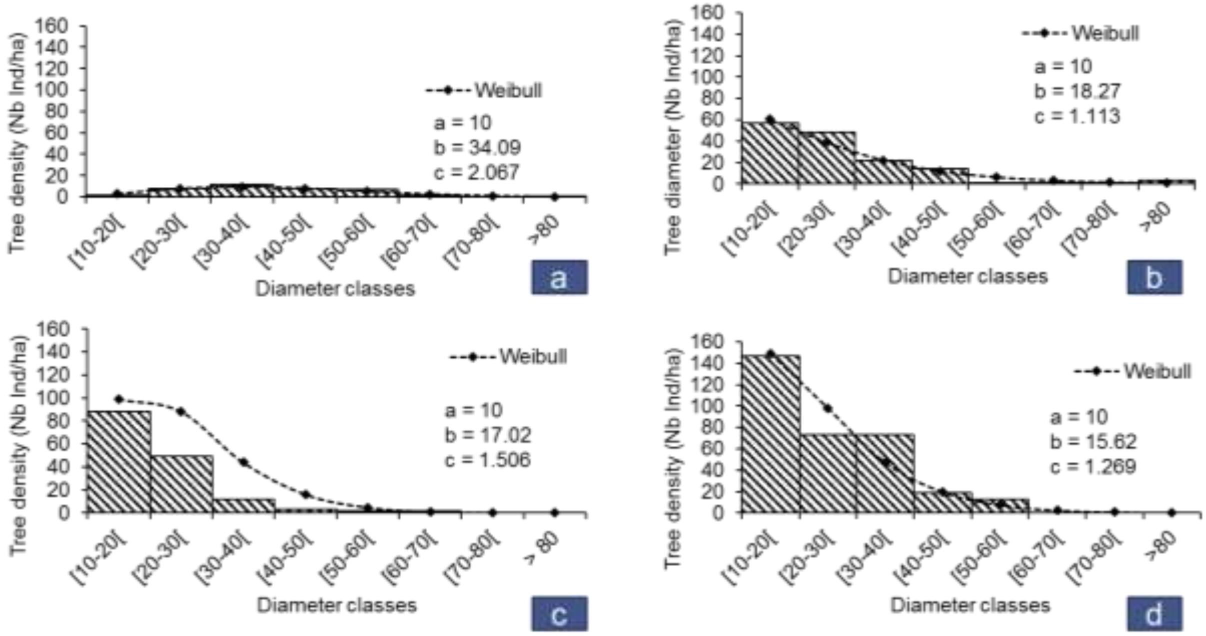

Figure 6. Tree stems diameter structure for distinguished potential habitats of elephant (a=habitat 1; b=habitat 2; c=habitat 3 and d=habitat 4).

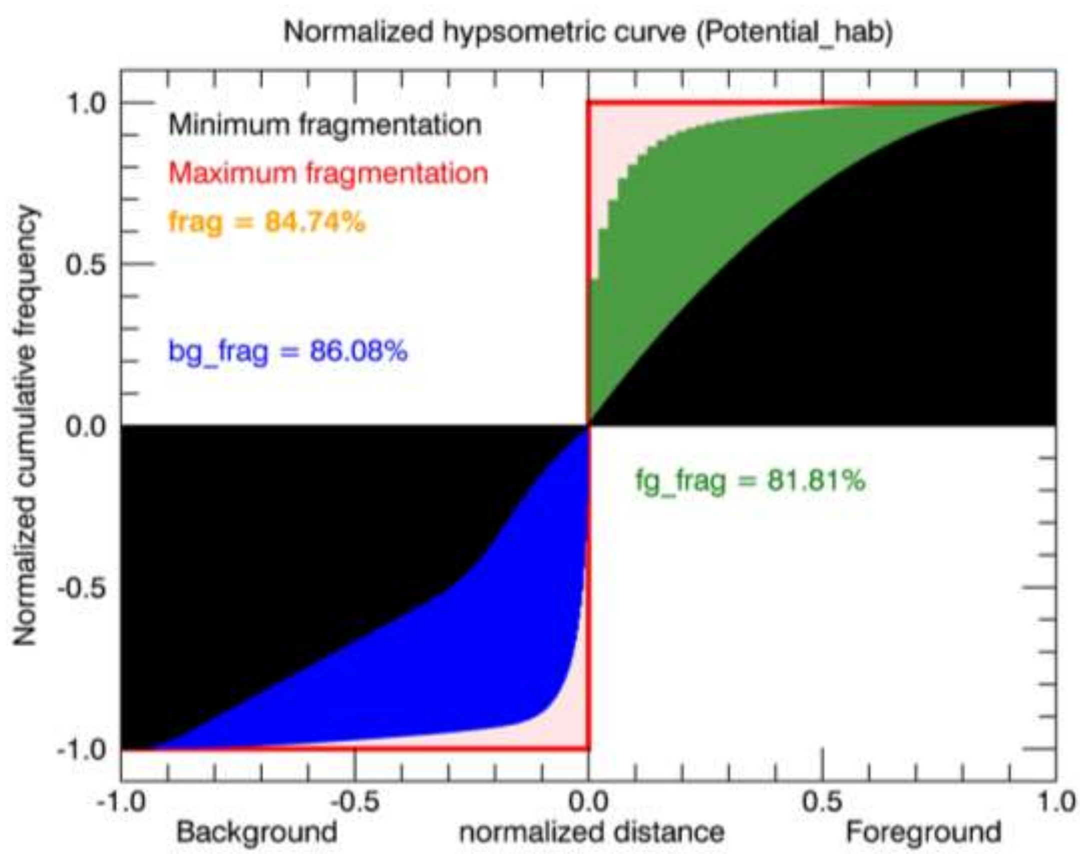

Figure 7. Normalized hypsometric curve of the fragmentation analysis of the elephant potential habitat within Oti-Keran-Mandouri.

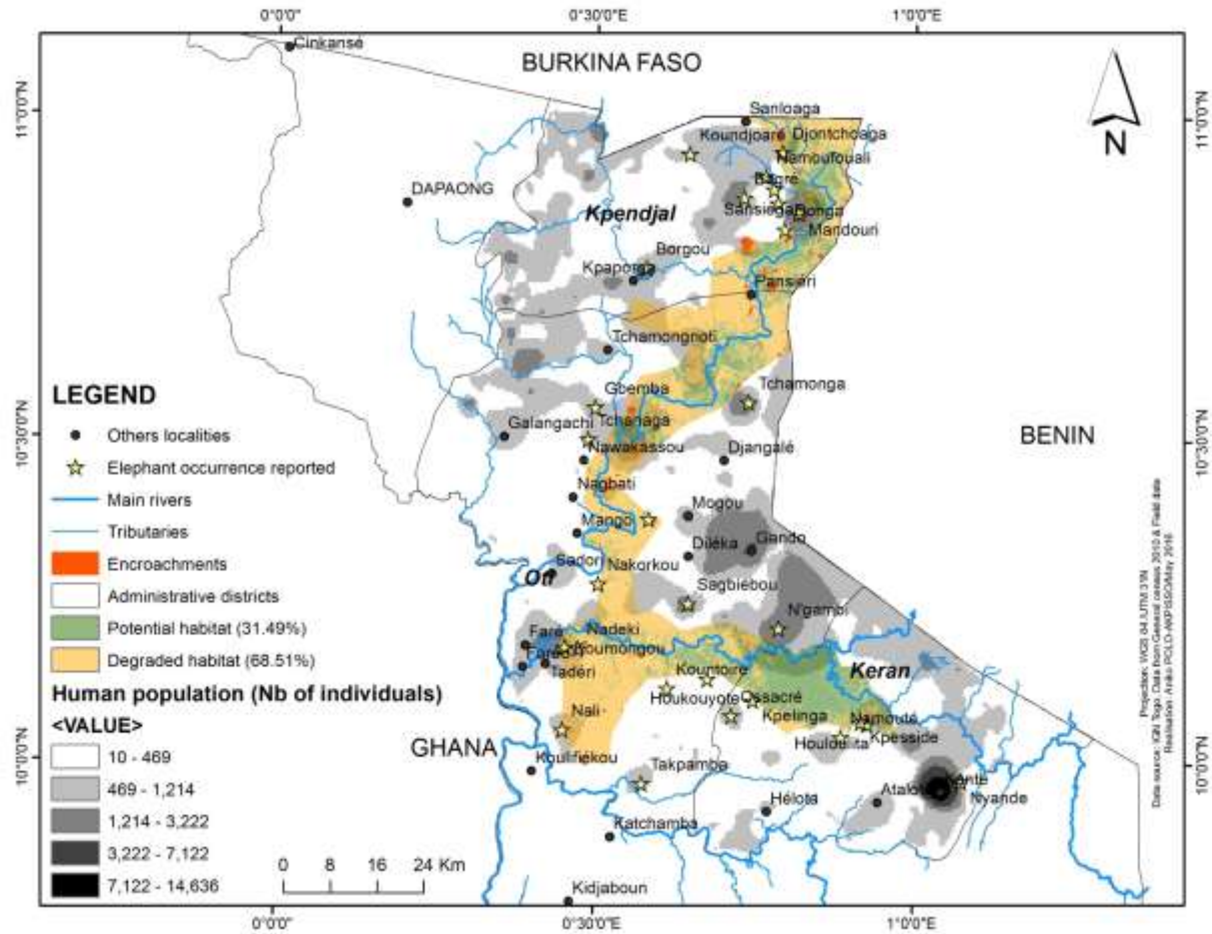

Figure 8. Elephant occurrence with regard to potential habitat and anthropogenic pressure.

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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