A Test of the Enhanced Vegetation Index as an indicator of human–elephant conflict around Bia Conservation Area, Ghana

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Abstract

Human–elephant conflict (HEC) occurs across Africa and is a major threat to the continued existence of the African elephant. To effectively and efficiently implement mitigation measures, a thorough understanding of the spatial and temporal patterns of HEC is required. This study used a systematic, grid-based geographic information system to analyse the spatial and temporal relations between HEC onset and intensity in 2004 and 2008 and underlying environmental variables in a forest habitat, the Bia Conservation Area, Ghana. Relationships between crop-raiding incident data, Moderate Resolution Imaging Spectroradiometer (MODIS) Enhanced Vegetation Index (EVI) values and remotely sensed derived data were investigated at a 10 km^2 scale using principal component analysis and correlation analysis. The onset of crop-raiding in 2004 and 2008 can be attributed to seasonal variation in vegetation biomass. Decreases in EVI values were matched to an increase in crop-raiding incidents. HEC intensity was not significantly related to the environmental variables analysed at the 10 km^2 scale. These results suggest that HEC intensity may be influenced by vegetation quality, soil mineral content and/or human density. The methods used in this study could be applied to other forest habitats experiencing HEC for comparative analysis. The influence of vegetation quality, soil mineral content and human density on HEC intensity in forest habitats requires further analysis.

Résumé

Le conflit homme-éléphant (CHE) se produit en Afrique et constitue une menace majeure pour l'existence continue de l'éléphant d'Afrique. Pour mettre en œuvre effectivement et efficacement les mesures d'atténuation, une compréhension approfondie des modèles spatio-temporels du CHE est requise. Cette étude a utilisé un système systématique d'information géographique basé sur la grille pour analyser les relations spatiales et temporelles entre l'apparition et l'intensité du CHE en 2004 et 2008 et les variables environnementales sous-jacentes dans un habitat forestier, la zone de conservation de Bia, au Ghana. Les relations entre les données sur les incidents de maraude des cultures, les valeurs de l'Indice de Végétation Améliorée (IVA) et les données dérivées détectées à distance par le Radiomètre Spectral pour Imagerie de Résolution Moyenne (MODIS) ont été étudiées à une échelle de 10 km^2 en utilisant l'analyse des composantes principales et l'analyse de corrélation. On peut attribuer le déclenchement de la maraude des cultures en 2004 et 2008 à la variation saisonnière de la biomasse végétale. Les diminutions des valeurs IVA ont été accompagnées par une augmentation des incidents de maraude des cultures. L'intensité du CHE n'était pas significativement liée aux variables environnementales analysées à l'échelle de 10 km^2. Ces résultats suggèrent que l'intensité du CHE peut être influencée par la qualité de la végétation, la teneur en minéraux du sol et/ou la densité humaine. On pourrait appliquer les méthodes utilisées dans cette étude à d'autres habitats forestiers qui connaissent le CHE pour une analyse comparative. L'influence de la qualité de la végétation, de la teneur en minéraux du sol et de la densité humaine sur l'intensité du CHE dans les habitats forestiers nécessite une analyse plus approfondie.

Introduction

Human–elephant conflict (HEC) is a spatial problem; thus spatially explicit factors affecting HEC should be assessed (Smith and Kasiki 1999; Graham et al. 2010; Wilson et al. 2015). While recommended, research on the use of geographic information systems (GIS) to determine the relationship between HEC and environmental variables is limited (Hillman Smith et al. 1995; Hoare 1999 a and b; Smith and Kasiki 1999; Sitati et al. 2003; Prasad et al. 2011). This study tested the use of a systematic, grid-based geographic information system (GIS) to analyse the spatial and temporal relations between HEC onset and intensity in 2004 and 2008 and underlying environmental variables in a forest habitat, the Bia Conservation Area (BCA), Ghana. Relationships between crop-raiding incident data, Moderate Resolution Imaging Spectroradiometer (MODIS) Enhanced Vegetation Index (EVI) values and remotely sensed derived data were investigated at a 10 km^2 scale using principal component analysis (PCA) and correlation analysis. The spatial factors included seasonal vegetation biomass variation and mean vegetation biomass.

Study area

Situated in south-western Ghana, BCA covers an area of 306 km^2 and has an elephant density of 0.44 per km^2, with a population of approximately 136 elephants (Sam 2000; Sam et al. 2005; Sam et al. 2006; Danquah et al. 2009) (Figure 1; see colour plates: page i). The rainfall is bimodal, peaking in June and October. Average monthly temperatures range between 24 (±7) and 28 (±12)°C (Sam et al. 2005). Vegetation is characterised by moist evergreen and moist semi-deciduous forest (Hall and Swaine 1976) that exhibits seasonality in flowering, fruiting and leaf-flushing. Agriculture is small-scale, rain fed and practised throughout the year. Crops grown include cassava (*Manihot esculenta*), plantain (*Musa* × *paradisiaca*), cocoa (*Theobroma cacao*), maize (*Zea mays*), yam (*Dioscorea* spp.), cocoyam (*Colocasia esculenta*), banana (*Musa* spp.) and vegetables (Sam et al. 2005; Oppong et al. 2008). Cocoa agroforestry and intercropping are common practice, and BCA is surrounded by subsistence and small-scale farms on all sides, with no dividing barriers (pers. obs. 14 October 2009). The population density is approximately 99.3 persons per km^2 with an average household size of 4.2 persons (Ghana Statistical Service 2013). Settlement is evenly distributed along the BCA border with an average farm size of 1.7 ha (pers. obs. 14 October 2009). Crop-raiding increases steadily from June and peaks in September and October, coinciding with the minor rainy season (Sam 2000; Sam et al. 2005; Oppong et al. 2008).

Methods

This study, undertaken in 2010, used data collected by the Wildlife Division of the Forestry Commission of Ghana from the years 2004 and 2008. This time period was chosen as these were the years with the most complete data sets, that is, with elephant damage report forms completed in full. A land-cover classification was undertaken using 30 m LANDSAT 7 TM images, and monthly EVI profiles for 2004 and 2008 derived from MODIS 16-day EVI composites with 250 m spatial resolution. The EVI, adapted from the Normalized Difference Vegetation Index (NDVI), has improved sensitivity in high biomass regions through a decoupling of the canopy background signal and a reduction in atmospheric influences. Given the uniform topography and high biomass of the study area, the EVI was applied without using the NDVI for comparative analysis. The loss of accuracy due to lower spatial resolution MODIS images was deemed acceptable in order to obtain higher temporal resolution.

To analyse the relationship between EVI values and the onset of crop-raiding, a 10 km^2 grid and the locations of the crop-raiding incidents (n = 83) were overlaid on the monthly EVI composites for 2004 and 2008. A 10 km^2 resolution for the grid-based analysis was chosen given the higher density of vegetation cover and resources, and a denser concentration of humans and farms compared to a savannah habitat, where lower resolutions are often used (Sitati et al. 2003). Each block around BCA in which crop-raiding had occurred in either 2004 or 2008 was extracted and the mean monthly EVI value calculated for 2004 and 2008. The mean monthly EVI value of the entire conservation area for 2004 and 2008 was also calculated.

To analyse the relationship between EVI values and intensity of crop-raiding, the 10 km^2 grid and locations of crop-raiding instruments were overlaid on the land cover classification. For each block around BCA in which crop-raiding had occurred in either 2004 or 2008 the following were calculated: (i) the mean HEC intensity (defined as the percentage of the farm damaged), calculated for each farm and then averaged for each grid block; and (ii) mean EVI value, calculated from the EVI composite of the month(s) in which the crop-raiding occurred and then averaged for each grid block.

Spearman's rank correlation was performed to determine if there was any significant relationship between EVI values and HEC intensity.

Results

In 2004, 53 crop-raiding incidents were recorded with all raids occurring along the south and south-eastern boundary of BCA. Crop-raiding occurred only in July (n = 24) and August (n = 9). The mean cultivated area damaged was 0.39 ha. In 2008, 17 crop-raiding incidents were recorded, with all raids occurring along the north and north-western boundary of BCA. Crop-raiding occurred in May (n = 6), June (n = 3), September (n = 4) and October (n = 4). The mean cultivated area damaged was 0.22 ha. (Figure 2; see colour plates: page i).

In 2004, the mean EVI of the conservation area was highest in May and lowest in August (Figure 3; see colour plates: page i). Two peaks in the mean EVI of the conservation area were observed, one in May and the other in October. The greatest increase in the mean EVI of BCA in 2004 occurred between March and April. The greatest decrease occurred between July and August (Table 1). In 2008, the mean EVI was highest in August and lowest in March (Fig. 4). The greatest increase in the mean EVI of the conservation area in 2008 occurred between March and April. The greatest decrease occurred between February and March (Table 1). No distinct peaks in the mean EVI of BCA were observed in 2008.

In 2004, similar trends in EVI fluctuations were observed in all the 10 km^2 crop-raiding blocks around the conservation area, although Block 4 in August presented an anomaly (Fig. 3). In general, the mean EVI increased rapidly between March and April, peaked in May and steadily decreased from May to August. EVI values were lowest in August. The most rapid decrease in mean EVI occurred in the same months as crop-raiding occurred, namely July and August. The mean EVI increased from August to October, a second peak, and decreased again from October to December (Fig. 3). The mean EVI of the conservation area in 2004 was less than in all crop-raiding blocks (with the exception of Block 8) from the beginning of July to mid-August.

Table 1. Number of crop-raiding incidents reported, average rainfull and change, from the previous month, in mean Enhanced Vegetation Index (EVI) values for the Bia Conservation Area (BCA) in 2004 and 2008.

	2004			2008		
Month	No. of incidents	Average rainfall (mm)	Change in mean EVI	No. of incidents	Average rainfall (mm)	Change in mean EVI
February	0	11.02	828.62	0	8.24	1074.52
March	0	21.18	–445.16	0	17.96	–1267.68
April	0	52.19	2887.65	0	79.53	1869.67
May	0	89.85	166.09	6	101.07	14.46
June	0	115.95	–1230.11	3	154.20	–811.66
July	24	98.56	–579.93	0	200.08	315.76
August	9	176.84	–1708.30	0	185.01	514.06
September	0	138.50	1648.47	4	216.42	–147.75
October	0	183.84	929.21	4	157.78	–161.34
November	0	144.12	–1236.87	0	106.29	–1121.47
December	0	28.33	–917.40	0	26.88	675.92

The mean EVI of BCA was consistently lower than the mean EVI of most crop-raiding blocks around the conservation area throughout 2004 (Fig. 3).

In 2008, similar trends in mean EVI fluctuations were observed from January to April (Fig. 4). While there was an overall decrease in mean EVI from April to July, the trends were less clearly observed. Dissimilar to 2004, the mean EVI increased from July to August, followed by a decrease from August to September. An increase in mean EVI was observed from September to October again followed by a decrease. Crop-raiding in 2008 occurred in May, June, September and October, coinciding with decreases in the mean EVI. The mean EVI of Bia Conservation Area was consistently lower than the mean EVI of most crop-raiding blocks around the conservation area from January to June and October to December (Figure 4; see colour plates: page i).

No significant relationship was found between EVI values and HEC intensity.

Discussion

The onset of crop-raiding in this study can be attributed to seasonal variation in vegetation biomass. In both 2004 and 2008, decreases in EVI values matched the months in which crop-raiding occurred. In 2004, crop-raiding was highest (July and August) when the mean EVI values were lowest. However the absence of crop-raiding in December and January when EVI values were also low indicates the influence of other variables, most likely vegetation quality and fruiting. Crop-raiding elephants select mature crops high in nutritional content. Crops mature from May to October; thus the vegetation quality outside the conservation area is most likely higher during those months. In December and January, while the vegetation biomass is low, the vegetation quality inside the conservation area may equal or exceed that outside it. Thus crop-raiding during those months does not provide nutritional benefits. The seasonal peak of HEC corresponding to the wet season during which food crops mature is supported by Hoare (1999a) and Lahm (1996). Danquah and Oppong (2006) studied the diet of elephants in Kakum National Park, a nearby reserve with similar vegetation and farming practices. They found the highest fruit availability levels during the late minor wet season to the early dry season (October to January). This was also the period when elephants' intake of forest fruits was highest, while their intake of cultivated crops was limited. In contrast, in the major wet season (May and June), consumption of cultivated crops was highest and the availability and intake of fruit lowest.

One of the main objectives of this study was to utilise GIS and EVI to generate new data on underlying environmental factors that may be influencing crop-raiding intensity. At the 10 km^2 scale, no significant relationships between HEC intensity and mean EVI or between HEC intensity and EVI difference between the blocks and conservation area were found. While the onset of crop-raiding is linked to vegetation biomass the intensity of crop-raiding is not. The common practice of agroforestry and intercropping throughout the study area results in similar EVI values in all blocks. Agroforestry aims to resemble natural evergreen forests therefore differences in EVI values between BCA and the surrounding area are minor. The vegetation biomass of the conservation area and the blocks in which crop-raiding occurred was found to be similar in both 2004 and 2008. Therefore it is not vegetation biomass that influences HEC intensity but more likely vegetation quality. Data on the nutritional content of the available forage in the conservation area and the crops cultivated should be collected. In combination with data on the proportion of the different crops cultivated, the relationship between HEC intensity, crop types and their associated nutritional content could be analysed.

Fryxell and Sinclair (1988) found wet season dispersal areas tend to have higher concentrations of nitrogen and calcium than dry season dispersal areas near to permanent water sources. Significant relationships exist between elephant trail density, trail network complexity, trail width and trail distance from forest clearings with important mineral deposits in Nouabalé-Ndoki National Park in the northern Republic of Congo (Blake and Nkamba-Nkulu 2004). Thus the intensity of HEC could also be due to agricultural areas having higher soil mineral contents than the conservation area. Elephant damage report forms are completed by the Wildlife Division when a crop-raiding incident is reported. The discrepancy in the number of forms filled out in 2004 and 2008 could be attributed to a decrease in crop-raiding events or to a decrease in the number of crop-raiding incidents reported. Farmers may be less inclined to report crop-raiding events if there is no action or compensation following the report and/or wildlife guards may have limited transportation to incident sites. Despite a decrease in the number of reported raids and the intensity of crop-raiding incidents from 2004 to 2008, elephant crop-raiding around the conservation area remains a problem and the Wildlife Division should continue to respond to reported incidents and seek measures to mitigate HEC. Since this study a further population survey was undertaken putting the most recent population estimate at 146 elephants with a density of 0.48 per km^2 for the BCA (Danquah and Oppong 2014). Barnes et al. (1995) suggested that increasing elephant densities result in greater HEC intensity. Given that BCA is bounded on all sides by human settlement and farms, the growing elephant population could be constrained by diminishing vegetation quality leading to increased crop-raiding as elephants seek nutritionally rich diets. However, Hoare (1999a) found that HEC intensity was not dependent on elephant density but represented opportunistic feeding forays with the intensity dependent on the behavioural ecology of individual elephants.

Thus HEC data are necessary for the effective monitoring and management of this population, which is under pressure from poaching and habitat loss, and the Wildlife Division has identified the need for further studies of the Bia elephants to support their conservation. Bia may be the largest population of forest elephants in Ghana and therefore is a priority population in Ghana, where many elephant populations are not viable due to genetic isolation and small numbers.

According to the data collected by the wildlife guards, elephant behaviour changed between 2004 and 2008. Whereas in 2004, all raiding occurred along the south and south-eastern boundary of BCA, in 2008 there was a dramatic shift of all crop-raiding incidents to the north and north-western boundary of the conservation area. While reports from wildlife guards and local communities indicate that crop-raiding does periodically shift to the northern sections during the late rainy season, when water resources increase throughout and food crops like maize are mature (Sam et al. 2005), all crop-raiding in 2008 occurred in the northern sectors. Some of the wildlife guards maintain that the spread of raiding activities is a result of elephants crossing over from Cote d'Ivoire during the wet season (Sam et al. 2005). While no data on poaching were available, the influence of poaching activity on elephant movements should not be disregarded. The observations and indigenous knowledge of the wildlife guards should be considered together with the structured data collected on the elephant damage report forms. Cocoa farming in the northern sectors has also increased over the last decade (R. Ofori-Amanfo pers. comm.) and Griebenow (2006) found a strong correlation between the spatial distribution of elephants and cocoa farms. The inclusion of human density data is also recommended in future studies in BCA. Hoare and Du Toit (1999) found elephants in savannah habitats tend to move away from areas where a threshold of human density is reached at approximately 15.6 persons per km^2.

While the mean EVI values of the crop-raiding blocks around the conservation area did not noticeably differ, this can be attributed to the agroforestry and intercropping which is commonly practiced throughout the area. However, the proportion of crop types cultivated in these blocks may differ, and this could have influenced the shift in crop-raiding from the southern to the northern boundary. While data on the crop types damaged was available, data on all the crop types grown on each farm should be collected to enable further investigation of the relationship between crop-raiding and the proportional distribution of crop types in areas around BCA. Knowledge of all the crops grown on raided farms, not just those crops damaged would have allowed an analysis of the best combination of crop types to grow to limit crop-raiding risk.

The results of this study have raised interesting questions about elephant behaviour. Firstly, is the elephant density of BCA limiting forage availability and forcing elephants to raid crops during the wet months? Secondly, is the intensity of crop damage influenced by the proportion of the different crop types cultivated and their associated nutritional content? Thirdly, does soil mineral content influence HEC intensity? While this study has not been able to answer these questions it has highlighted the importance of incorporating vegetation indexes when analysing the spatial and temporal patterns of HEC. The use of a 10 km^2 grid is recommended to generate spatial units for GIS-based HEC analysis in forest habitats. When used in combination with data on nutritional content, soil mineral content, human density and proportional distribution of crop types, this would enable a greater understanding of the factors influencing HEC intensity to be achieved.

The elephant population of Ghana is small, scattered and under threat from poaching and habitat fragmentation. To maintain BCA's vital population intervention is required. While the wildlife guards have encouraged the use of chilli as a mitigation method based on its success in savannah environments, the farmers have limited resources to acquire the necessary equipment and are reluctant to implement methods without visible proof of their effectiveness. Similarly, the Wildlife Division is financially constrained and wildlife guards are not able to respond to all incidents. In addition to a more in-depth study of factors influencing HEC intensity, it is also recommended that a study is undertaken to test the efficacy of multiple mitigation methods in this forest habitat. Furhermore, action should be taken to implement the recommendation of Parren et al. (2002) for the development of a transnational forest network between Cote d'Ivoire and Ghana. Together, these measures could enable a significant alleviation of in HEC in areas surrounding the BCA.

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