

**Factors influencing human-elephant conflict intensity: an assessment in the
Bia Conservation Area, Ghana**

Research report in part-fulfilment of the requirements for the degree of Master of
Science (by coursework and research report)
School of Geography, Archaeology and Environmental Studies



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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 implement mitigation measures, a thorough understanding of the spatial and temporal patterns of HEC is required. This study used a systematic, grid-based geographical information system (GIS) to analyse the spatial and temporal relations of HEC intensity in 2004 and 2008 with underlying environmental variables in a forest habitat, the Bia Conservation Area (BCA), Ghana. Relationships between crop-raiding incident data, Moderate Image Resolution Spectroradiometer (MODIS) Enhanced Vegetation Index (EVI) values and remotely sensed derived data were investigated at a 10 km² scale using principal components analysis (PCA) and correlation analysis.

Crop-raiding was found to be clustered into distinct areas. The onset of crop-raiding in 2004 and 2008 can be attributed to seasonal variation in vegetation biomass. Decreases in EVI values were matched with crop-raiding incidents. The high number of crop-raiding incidents in 2004 could be attributed to the large fluctuations in vegetation biomass in comparison to 2008. HEC intensity was not significantly related to the environmental variables analysed at the 10 km² scale. These results suggest that HEC intensity may be influenced by vegetation quality, soil mineral content and/or human density. A grid-based GIS system with a 10 km² resolution used in combination with remotely sensed data and statistical tools is useful for identifying spatial patterns of HEC, even with relatively small incident data sets. 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.

Key words: human-elephant conflict, EVI, crop-raiding

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ACRONYMS

AfESG	African Elephant Specialist Group
BCA	Bia Conservation Area
BNP	Bia National Park
BRR	Bia Resource Reserve
CAR	Central African Republic
CBCM	Community-Based Conflict Mitigation
CBNRM	Community-Based Natural Resource Management
CITES	Convention on the International Trade in Endangered Species
EVI	Enhanced Vegetation Index
FC	Forestry Commission of Ghana
GDP	Gross Domestic Product
GIS	Geographical Information Systems
GPS	Geographical Positioning System
HEC	Human-Elephant Conflict
HECWG	Human-Elephant Conflict Working Group
IUCN	World Conservation Union
MODIS	Moderate Image Resolution Spectroradiometer
NDVI	Normalized Difference Vegetation Index
NIR	Near-Infrared
NS	Not Significant
PCA	Principal Components Analysis
SSC	Species Survival Commission
TM	Thematic Mapper
UTM	Universal Transverse Mercator
VI	Vegetation Index
WD	Wildlife Division of Ghana
WGS	World Geodetic System
WWF	World Wide Fund for Nature

1. INTRODUCTION

Elephants (*Loxodonta africana*, *Loxodonta cyclotis*, *Elephas maximus*) are in the unusual situation of being listed on CITES Appendix 1 and also being a pest to communities who live with them (Sitati *et al.*, 2003). Perceptions of elephants differ widely between international organizations and local communities – the elephant revered as an animal of wonder and beauty by one and as a continual pest and threat to livelihood by the latter (Lindeque, 1995). Elephant populations in Southern and East Africa have increased over the last 10 years and constitute 88% of elephant numbers. West Africa holds only 1.5% of Africa's elephants (Blanc *et al.*, 2005; Blanc *et al.*, 2007). Conservationists are thus trying to manage a species which requires protection over some portions of its range, yet which is so abundant in other portions, culling has been considered (Tchamba, 1995). Only 31% of the African elephants' total range is protected (Blanc *et al.*, 2007) which puts the unprotected elephant range in a vulnerable situation as increasing human populations demand more land. As elephant habitats are fragmented and lost to human settlement, the human-elephant interface increases. This results in increased competition for resources and consequently an increase in human-elephant conflict (HEC) (Nelson *et al.*, 2003).

HEC in Africa largely takes the form of crop-raiding which causes great economic and food losses to farmers. Tolerance to crop-raiding is also shaped by the indirect costs of living with elephants including, loss of life, stress, lack of sleep and restricted movement (Dublin and Hoare, 2004). Whilst elephants may not cause the greatest economic loss nationally, the impact on the individual farmer is perceived far greater than other wildlife pests (Nelson *et al.*, 2003).

With elephant ranges continually being converted to agricultural land to meet food requirements of a growing population, the survival of elephants outside of protected areas can only be ensured if the communities that co-exist with them can benefit more than what they lose to elephants (Lindeque, 1995). If not, communities will take action to defend their livelihoods by injuring and killing elephants (Amwata *et al.*, 2006).

Numerous studies have been initiated to deepen understanding of crop-raiding behaviour of elephants, evaluate the impact and perception of crop-raiding, determine the efficacy of traditional deterrents, experiment with novel ideas and analyze the

environmental and land-use factors influencing crop-raiding in an attempt to find solutions to this persistent and destructive conflict.

Research on the use of geographic information systems (GIS) to determine the relationship between HEC and environmental variables is limited despite being recommended (Hoare, 1999b; Smith and Kasiki, 1999; Sitati *et al.*, 2003). To date, only one GIS-based study has been conducted in a forest habitat to determine the factors affecting HEC (Hillman Smith *et al.*, 1995). No studies have used Enhanced Vegetation Index (EVI) time series data from Moderate Image Resolution Spectroradiometer (MODIS) in the analysis of human-elephant conflict. The MODIS Vegetation Index (VI) products provide consistent spatial and temporal data of global vegetation conditions which can be used in phenologic, change detection and biophysical interpretations. The EVI, adapted from the Normalized Difference Vegetation Index (NDVI), has improved sensitivity in high biomass regions through a de-coupling of the canopy background signal and a reduction in atmosphere influences (Silveira *et al.*, 2008).

As human populations increase and elephant populations become concentrated in isolated protected areas, conflicts are most likely to increase. The continued existence of elephants in West Africa is threatened (Sam *et al.*, 2005) unless HEC can be predicted and successfully mitigated. Linking incident data to the same environmental variables, in conflict areas across the continent will determine factors influencing HEC. If combined with a grid-based GIS, a model to predict HEC intensity can be developed and used for land-use planning and for planning the implementation of mitigation methods (Sitati *et al.*, 2003).

This study sheds light on some of the factors significantly influencing HEC in a forest habitat in Ghana using a simple grid-based GIS and statistical analytical procedure not previously used in forest HEC research. The aim of this study is to highlight the role of GIS and EVI in HEC research and contribute to the development of a predictive model for HEC intensity.

2. AIMS AND OBJECTIVES

HEC is a spatial problem thus spatially explicit factors affecting HEC should be assessed (Smith and Kasiki, 1999). The aim of this study is to use a 10 km² grid-based GIS system to determine what spatial factors are significantly influencing the onset and intensity of HEC, specifically crop-raiding, in the Bia Conservation Area of Ghana. A further aim is to update the investigations conducted by Sam *et al.* (2005) and Oppong *et al.* (2008) which examined the nature and extent of HEC at the incident scale around Bia Conservation Area (BCA).

Using a combination of HEC incident data from 2004 and 2008, remote sensing data and GIS software the research sought to determine:

1. the influence of seasonal vegetation biomass variation on crop-raiding
2. the influence of mean vegetation biomass on crop-raiding intensity
3. the influence of proximity to human settlement on crop-raiding intensity
4. the influence of proximity to BCA on crop-raiding intensity
5. the influence of mean farm size on crop-raiding intensity
6. the influence of farm size and proximity to BCA on HEC intensity at the incident scale for the year 2004 and 2008

It is hoped that the results of this research will present an overview of the current HEC situation around BCA and deepen understanding of the underlying causes of HEC. The foundations are laid for the development and testing, in future studies, of a predictive model for HEC intensity in forest habitats.

3. LITERATURE REVIEW

3.1 The African Elephant

The most serious issue in African elephant *Loxodonta africana* and *Loxodonta cyclotis* conservation in previous decades has been the rapid decline of populations as a result of the legal, and now illegal, ivory trade. From a continental population of 1.3 million in 1979, the elephant population plummeted to just 609,000 ten years later (Douglas-Hamilton, 1989). Despite the ban on ivory trade implemented in 1989, the elephant population currently stands at 472,269 (Blanc *et al.*, 2007). The elephant population of West Africa suffered near collapse as a result of the surge of ivory hunting between 1890 and World War 1, followed by decades of habitat fragmentation which further reduced elephant numbers (Barnes, 1999). By 1984 elephants in West Africa occupied only 6-7% of the area occupied in 1900 with the total population estimated at 17,600 (Roth and Douglas-Hamilton, 1991).

Conservation strategies for African elephants have long been based on the consensus that all belong to the single species *Loxodonta africana*. However the recognition of two African elephant species, *Loxodonta africana* (savannah elephants) (Fig. 1) and *Loxodonta cyclotis* (forest elephants) (Fig. 2) is supported by morphological and habitat distinctions, extremely limited hybridization of gene flow between forest and savannah elephants, large genetic distance and multiple genetically fixed nucleotide site differences (Roca *et al.*, 2001). Roca *et al.* (2001) found the genetic and phylogenetic distinctiveness evident without exception between 36 forest elephants from three populations and 121 savannah elephants from 15 populations throughout sub-Saharan Africa. Each savannah population was genetically closer to every other savannah population than to any of the forest populations, even where the forest population was geographically closer. However the acceptance of two distinct African elephant species is not universal. Whilst the recognition of two distinct species remains debated it has serious implications for conservation. Instead of assuming there are 472,269 elephants in Africa (Blanc *et al.*, 2007) there are fewer than that of each species and consequently, both species are more endangered, particularly the forest elephant.

Whilst there is a wealth of data on savannah elephants, forest elephants remain poorly known (White *et al.*, 1993). The evolution of savannah and forest elephants in distinct habitat conditions is reflected in differences in morphology, ecology and social

organization. Morphologically, forest elephants are smaller, with straighter and thinner tusks, have lobeless, rounded ears and distinct skull morphology (Sikes, 1971; Morgan, 2003).

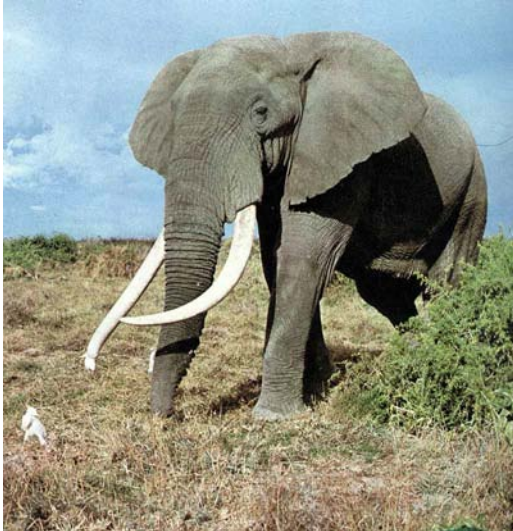


Figure 1: *Loxodonta africana*
(www.terramambiente.org)



Figure 2: *Loxodonta cyclotis*
(dzangaforestelephants.wildlifedirect.org)

The habitat of savannah elephants is more homogenous and has lower species diversity compared to the highly diverse, heterogeneous habitat of forest elephants. As a result, savannah elephants are generalist grazer/browsers, with 60% - 95% of their diet made up of grass depending on season and habitat (Owen-Smith, 1988). The abundance of highly nutritional grass in savannahs decreases during the dry season necessitating the supplementation of the diet with browse. Forest elephants, lacking an abundance of grass, eat a highly diverse selection of species and plant parts including leafy browse, roots, pith and bark. Grass is eaten minimally and unlike savannah elephants, forest elephants are highly frugivorous (White *et al.*, 1993; Morgan, 2007; Morgan and Lee, 2007).

The range of savannah elephants varies from tens of square kilometres to over 10,000 km² in the arid areas of Namibia (Lindeque and Lindeque, 1991) with their movements determined by the productivity gradient of grasslands and availability of water. Whilst the range of forest elephants remains uncertain the seasonal distribution of forest elephants appears to be associated with human activity and fruit availability (White, 1994; Blake, 2004; Buij *et al.*, 2007).

Whilst savannah elephants often form groups of ten to hundreds of individuals, forest elephants tend to form small groups of only two to four individuals (White *et al.*, 1993; Morgan and Lee, 2007). Turkalo and Fay (1996) have observed small groups coming together to form larger 'bond groups' at the Dzanga Bai in Central African Republic (CAR) indicating a higher order social organization. Young males leave their mothers earlier in the forest which Turkalo and Fay (1996) attribute to the lack of large predators in the forest. Like savannah elephants, forest elephants appear to be governed by a dominance hierarchy, form strong attachments and sound is an important method of communication. It has been suggested that forest elephants may form large social groups whose individuals use low frequency infrasound rumblings to communicate, as some small elephant groups appear to have co-ordinated meeting times (Turkalo and Fay, 1996).

Forest elephants play a vital role in forest ecology as the seed dispersal of many woody forest species is dependent on elephants (Chapman *et al.*, 1992; White *et al.*, 1993; Yumoto *et al.*, 1995). This is especially true of *Balanites wilsoniana*, a species whose survival is threatened by declining elephant populations (Hawthorne and Parren, 2000). Forest elephants are believed to account for between a quarter and a third of Africa's elephants, with the majority living in Central Africa and the rest in West Africa. Central Africa is believed to be the main source supplying the world's illegal ivory trade with poaching exacerbated by new roads for logging operations and mineral and oil extraction (which provide access to the forests and transport routes for the transport of meat and ivory) (Blanc *et al.*, 2007). In West Africa, elephants are restricted to about 70 small isolated populations that cover only 5% of the area. Two-thirds of the populations are thought to consist of fewer than 200 animals (Barnes, 1999) with human encroachment and human-elephant conflict continuing to threaten these remaining populations. There is no doubt that the survival of forest elephants is uncertain and can only be ensured through the mitigation of HEC and a decrease in poaching.

3.2 Human-Elephant Conflict

Ghana's elephant population is estimated at 789 elephants (Blanc *et al.*, 2007). Bia Conservation Area (BCA) is estimated to have 115 elephants in a 306 km² forest block (Blanc *et al.*, 2007). No elephant population surveys have been undertaken in BCA since

2004. Whilst elephant populations continue to decline as a result of poaching, a new major topic of concern has evolved: that of human-elephant conflict (HEC) (Naughton-Treves, 1998; Sam *et al.*, 2005; Amwata *et al.*, 2006). As the human landscape expands, elephant habitats are further fragmented and limited (Parker and Graham, 1989; Tchamba, 1996; Hoare and Du Toit, 1999) thereby increasing the human-elephant interface.

HEC occurs when elephants, whose ranges have been fragmented by humans, go into human populated areas and feed on available crops; damage water supplies, food stores, fences and barriers or injure or kill people (Hoare, 1999a). The general definition of HEC adopted by the World Conservation Union (IUCN) Species Survival Commission's (SSC) African Elephant Specialist Group (AfESG) is "Any human-elephant interaction which results in negative effects on human social, economic or cultural life, on elephant conservation or on the environment" (Hoare, 2001a, 1).

HEC is common throughout most of the distributional range of the African elephant (Kamiss and Turkalo, 1999; O'Connell-Rodwell *et al.*, 2000; Anderson and Pariela, 2005; Heffernan, 2005; Malima *et al.*, 2005; Hanks, 2006) and is also increasingly common in the Asiatic elephant *Elephas maximus* range (Choudhury, 2004; Hedges *et al.*, 2005; Chatterjee, 2008). The most frequent form of human-elephant conflict is agricultural crop-raiding. Humans come into conflict with many other species and elephants do not always cause the greatest amount of damage on a national scale. However, the damage inflicted by elephants is highly catastrophic for the individual farmer, often destroying a farmer's entire crop in one foray (Naughton-Treves, 1998; Adjewodah *et al.*, 2005; Parker *et al.*, 2007). In Baringo, Kenyan farmers suffered a mean loss of US\$450 per farmer annually (Amwata *et al.*, 2006), where the annual gross domestic product (GDP) per head is US\$640 (www.economist.com). Communities co-existing with elephants also suffer major indirect costs. These include restriction of movement for fear of running into elephants which affects school attendance, collection of firewood, water and/or other resources; loss of sleep and energy of farmers as a result of guarding fields at night; increased exposure to malaria during field watches and stress (Dublin and Hoare, 2004). It is difficult to quantify these indirect costs into economic value but their impact is nonetheless significant.

The direct and indirect costs of HEC create highly negative attitudes towards elephants from the communities who co-exist with them. Retaliation, either by killing elephants or 'allowing' poaching, is not uncommon as communities consider there to be few benefits from elephants (Tchamba, 1996; Kioko *et al.*, 2006). In most African countries, the government is responsible for elephant management (Parker *et al.*, 2007). Thus communities believe the government should protect their fields from elephants and pay compensation for damage caused (Naughton *et al.*, 1999). Most often, governments do not have the resources to act, amplifying the communities' resentment towards elephants and government efforts (O'Connell-Rodwell *et al.*, 2000). These negative attitudes have serious implications for the conservation of elephants outside of protected areas (Parker *et al.*, 2007).

3.3 Behaviour of Crop-Raiding Elephants

Understanding the behaviour of crop-raiding elephants is vital to successfully mitigating HEC. Crop-raiding behaviour varies in different areas but it appears all crop-raiding elephants are optimizing foraging by maximizing the nutrients ingested for the least amount of effort (Heffernan, 2005). Certain characteristic behaviour patterns are exhibited by most crop-raiding elephants allowing for some prediction of HEC at a local level.

Elephants tend to raid in small groups. Eighty-nine percent of raiding groups consisted of 10 animals or less in Sebungwe, Zimbabwe (Hoare, 1999a). A median group size of three was reported in Cabinda, Angola (Heffernan, 2005). A median group size of six found in Transmara, Kenya (Sitati *et al.*, 2003) and groups of one to eight reported in Kibale National Park, Uganda (Chiyo and Cochrane, 2005). An exception to this behaviour was noted in Cameroon with elephants congregating in herds of 100 individuals or more (Tchamba, 1995).

Elephants eat a wide range of crops including maize, bananas, manioc, millet, sorghum, yams, sweet potatoes, pineapples and cane sugar. Bananas, manioc and maize are the most damaged (Hillman Smith *et al.*, 1995; Kiiru, 1995; Lahm, 1996; Hoare, 1999a; Sitati *et al.*, 2003; Barnes *et al.*, 2005; Sitati *et al.*, 2005; Kioko *et al.*, 2006). Mature crops are preferred by elephants. Sixty-two to sixty-four percent of mature crops were selected

versus 35% in intermediate growth stages and 3% in early growth stages (Hoare, 1999a; Kioko *et al.*, 2006).

Crop-raiding usually occurs during the night (Hillman Smith *et al.*, 1995; Sitati *et al.*, 2003; Kioko *et al.*, 2006; Jackson *et al.*, 2008). Elephants are able to distinguish, and vary their behaviour accordingly, between a 'safe' zone and a 'higher risk' zone. They often move more quietly and are less aggressive in the latter (Hoare, 2001a). The same agricultural areas are often re-visited, with raided farms in Ghana having a 79% probability of being visited again (Lahm, 1996; Sam, 2000; Chiyo and Cochrane, 2005; Sitati *et al.*, 2005).

It has been proposed that crop-raiding is instigated by the same individuals, that is, habitual problem elephants. The existence of habitual problem elephants was evaluated and little evidence was found to support this theory. A portion of any elephant population may be involved in crop-raiding but raids are conducted by variable re-combinations of individual animals (Hoare, 2004).

There is also very little evidence to suggest that crop-raiding intensity is elephant density dependent (Hoare, 1999a; Hoare, 2001b). A 'male behaviour hypothesis' has been proposed by Hoare (1999a) in which males are more tolerant to human disturbance which allows them to live near the natural vegetation/settlement interface. It has also been proposed that males take more risks to maximize reproductive success through better nutrition (Sukumar and Gadgil, 1988). Thus males account for a higher percentage of HEC incidents than females (Hoare, 1999a; Chiyo and Cochrane, 2005; Jackson *et al.*, 2008). Whilst cows would also benefit from the better nutrition offered by crop-raiding, the risks are higher. They live in family groups, thus in addition to matriarchs risking their lives, they risk the lives of their offspring and siblings (Sukumar and Gadgil, 1988). Cow groups, if they raid, normally do so at the peak of the growing season and in agricultural areas close to natural vegetation (Hoare, 2001a).

Whilst there are many similarities in crop-raiding behaviour across Africa there are many differences. These are largely attributed to differences in vegetation, crops grown and seasonal variance. In Ghana, crop-raiding occurs mainly from August to November, during the pre-harvest and harvest period (Adjewodah *et al.*, 2005). In the Democratic

Republic of Congo, peak damage periods occur during the mango season in May and June and during the pre-harvest and harvest period from September to November (Hillman Smith *et al.*, 1995). In Gabon, crop-raiding varies between seasons with the majority of crop-raiding occurring during the wet season in forest areas and in savannah areas, during the dry season (Lahm, 1996). In Kenya, Botswana and Zimbabwe, crop-raiding begins at the onset of the dry season when grasses decline in nutritional quality, crops are mature and elephants expand their home range to increase their area to forage (Osborn, 2003; Osborn, 2004; Kioko *et al.*, 2006; Jackson *et al.*, 2008). Chiyo *et al.* (2005) suggested that crop-raiding behaviour in forest habitats is influenced by crop availability and not forage quality. Whereas in savannah habitats, large seasonal fluctuations in forage quality influence crop raiding (Osborn, 2004).

Other factors that play a role in crop-raiding behaviour which have been investigated are age and human density. Results indicate that crop-raiding elephants are normally 15 years or older (Chiyo and Cochrane, 2005). When a threshold of human density is reached at about 15.6 persons/km², elephants move away from the remaining patches of natural habitat (Hoare and Du Toit, 1999).

3.4 The Impact and Perception of Crop-Raiding

3.4.1 Impact of Crop-Raiding

The lack of accurate data on crop-raiding incidents is extremely frustrating for those working on HEC and makes quantifying the impact of crop-raiding difficult (Hoare, 2001a). The direct costs of crop-raiding are currently estimated from the area of cultivation damaged and the market value of the crops damaged. However, getting a true assessment of the costs can be difficult as monitoring systems are flawed in several ways. Crop damage can be difficult to distinguish from poor crop production during droughts. Crop loss data gathered are often not suitable for comparative statistical analysis and field staff collecting data has low numeracy skills. This results in inaccurate reporting. Communities may also overestimate crop damage in the hopes of receiving compensation either by money, food or meat from problem elephants shot (Tchamba, 1995; Hanks, 2006). Researchers may also exaggerate crop losses by extrapolating results from areas with high HEC levels to larger areas and by not comparing farmers' estimates to scientific data (Naughton *et al.*, 1999). The indirect costs of HEC are much more difficult to quantify but can be investigated through interviews and questionnaires.

Whilst of no monetary value, the indirect costs are nonetheless significant (Dublin and Hoare, 2004). Similarly, the loss of human life has no financial value and no compensation can truly cover the loss (Tchamba, 1995).

In northern Cameroon in 1992 and 1993, elephants damaged between 22% and 42% of agricultural land, with the total economic loss estimated between US\$14,460 and US\$75,180 (Tchamba, 1995) and in central Cameroon between US\$77,950 and US\$127,620 (Tchamba, 1996). These losses are substantial in a country whose annual GDP per head is US\$1,100 (www.economist.com). In Mochongoi Forest, Kenya, 92% of farmers interviewed had lost crops to elephants (Amwata *et al.*, 2006) and in Caprivi, Namibia, elephants destroyed 677 hectares of crops and gardens between 1996 and 2001 (Hanks, 2006). These losses may not be entirely accurate but they highlight that communities relying on subsistence farming for income and food bear huge personal costs. If losses incurred are too great these communities turn to solutions that jeopardize the continued survival of elephants.

3.4.2 Perception of Crop-Raiding

In order for any HEC mitigation to be successful, communities must want to participate and feel empowered to manage problem elephants. Currently, negative perceptions of both wildlife authorities and elephants prevail. In Cameroon, communities view wildlife authorities as a law-enforcement agency not willing to help the communities and they do not benefit from any problem elephant control in terms of meat (which is distributed among authorities and not communities) (Tchamba, 1995; Tchamba, 1996). In Kenya, communities were told, 'You are illegally settled in this forest. You must adjust and live with the elephants.' This left communities feeling helpless and excluded (Amwata *et al.*, 2006, 33).

Elephants are largely considered to be of no benefit at all (Tchamba, 1995). They cause communities to fear for their lives, restrict movement and cause farmers to abandon their farms (Amwata *et al.*, 2006). Opinions of how problem elephants should be dealt with include wanting wildlife authorities to translocate elephants and fence them elsewhere; shooting all elephants; shooting elephants responsible for crop-raiding and/or scaring elephants (Tchamba, 1995; Tchamba, 1996; Amwata *et al.*, 2006).

These negative perceptions have serious implications for the wildlife authorities, conservation organizations and governments wanting to conserve elephants. For example, communities blocked a major highway for eight hours in northern Cameroon to protest against the lack of action by government to deal with problem elephants (Tchamba, 1995). Fortunately, some communities are tolerant of the elephant problem, hoping that solutions will soon come (Amwata *et al.*, 2006).

3.5 Symptomatic Measures to Reduce HEC

Since the ban on ivory trade in 1989 and a decrease in illegal commercial poaching, the population of the African elephant in Southern and East Africa has increased by approximately 66,302 elephants (an estimated annual rate of increase of 4%). However, this is no indication of the situation in Central or West Africa and on a continental scale, elephant populations have yet to reach pre-ivory trading numbers (Blanc *et al.*, 2007). In mid-2008, the human population in Africa was 967 million with an estimated annual rate of increase of 2.4% and a projected population of 1.4 billion in mid-2025 (www.prb.org). As human populations increase, human settlement expands and elephant ranges are reduced. Conflict between elephants and humans has thus amplified into a major issue for wildlife management and rural developments throughout Africa. Finding solutions to alleviate this conflict is a conservation priority (Walpole *et al.*, 2006). At present, there are a number of symptomatic and strategic measures for reducing conflict. Symptomatic measures are short-term solutions to alleviate HEC whilst strategic measures aim to address the underlying causes of HEC and thus prevent it (Boafo *et al.*, 2004).

Traditional deterrents are developed by local farmers to protect their crops using materials that are widely available in the area (Parker *et al.*, 2007). Whilst these methods are cheap and easy to apply they have limited success. Elephants quickly learn they are harmless and once realized, the methods are ineffective (Boafo *et al.*, 2004). Problem elephants can be also be disturbed by the firing of shotguns or rifles near the elephants (Sam *et al.*, 2005); lighting of thunder flashes and flares (Sitati and Walpole, 2006) and using trip wire alarms (O'Connell-Rodwell *et al.*, 2000). However, these methods rely on funds being available to buy the necessary resources and should be implemented by trained personnel, who are not normally on-site to act immediately (Sitati and Walpole, 2006).

Physical barriers include fencing, walls, moats and buffer crops (Hanks, 2006). Electric fencing is highly effective if well-constructed and maintained (Hoare, 1992) and can be designed for the control of specific species (Bothma, 2002). However, the cost of materials, installation and maintenance of electric fencing often render this method unfeasible for rural communities in developing countries. Thouless and Sakwa (1995) found that elephants eventually break through most physical barriers and can overcome modifications to fences.

The killing of problem elephants has been and continues to be a popular method with wildlife managers and communities. Shooting is usually implemented by wildlife personnel but these personnel usually have limited access to rifles and ammunition (Parker and Anstey, 2002). Often they are not able to respond immediately due to policies involving a series of protocols (O'Connell-Rodwell *et al.*, 2000) thus the elephant responsible is long gone before action is taken. The result is misidentification and a token animal being killed instead (Hoare, 2001b). A more constructive approach to the killing of problem elephants is used in Namibia and Zimbabwe, where problem animals are offered to trophy hunters on regulated safari hunts. The meat and a substantial portion of the trophy fee are then given to the community (Hoare, 1995; WWF, 2005). This increases the value of elephants to the communities but the correct identification and shooting of the problem animal is not guaranteed. Overall the killing of problem elephants is a 'quick-fix' solution (Hoare, 1995). As one problem component is removed, it is replaced by another (Hoare, 2001b) and the destruction of economically valuable mammals is not justified by the relatively small value of the damaged crops (Tchamba, 1996).

The translocation of problem elephants provides an alternative to killing which appeals more to conservation organizations opposed to shooting yet still appeases angry communities. Fischer and Lindenmayer (2000) found them to be ineffective overall as a solution to HEC in Asia. Whilst translocation remains an option in Africa it is expensive and requires much logistical support.

Acoustic deterrents have been found to scare or influence elephants (Whyte, 1993; Langbauer *et al.*, 1991). Tests by Vollrath and Douglas-Hamilton (2002) and Karidozo

and Osborn (2005) suggest elephants are deterred by the smell and sound of bees but these methods are experimental and require further testing.

Osborn and Rasmussen (1996), Osborn (2002) and Osborn and Parker (2002) tested the use of a capsicum to deter crop-raiding elephants in Zimbabwe. Deterrents using chilli include erecting a chilli string fence, applying chilli grease to the fence, burning chilli briquettes and planting a chilli buffer (Parker and Osborn, 2006). These methods are currently being implemented and their effectiveness investigated in a number of areas including Angola, Namibia, Zambia, Botswana, Zimbabwe and Mozambique but results remain largely unpublished. Of those published, chillies appear to have great potential in reducing HEC by Community-Based Conflict Management (CBCM) with the possibility of producing extra income for communities (Parker and Osborn, 2006; Sitati and Walpole, 2006; Warner, 2008).

Communities that suffer financial losses from damage caused by crop-raiding elephants often seek some form of compensation from wildlife authorities, especially where no benefits are derived from the elephants (Hoare, 2001a). In a review of monetary compensation schemes the AfESG Human-Elephant Conflict Working Group (HECWG) found little evidence of success at HEC mitigation (www.african-elephant.org). All compensation schemes are flawed in that they alleviate the symptoms of HEC but do not help to reduce it (Hoare, 1995).

3.6 Strategic Measures to Reduce HEC

Community-based natural resource management (CBNRM) aims to develop rural communities through the sustainable use of natural resources and by empowering communities to take some responsibility for wildlife management (www.cbnrm.net). As elephants are in the dual position of being economically valuable assets and also being highly problematic to communities they often play a central role in both consumptive and non-consumptive CBNRM projects (Taylor, 1994; Hoare, 1995; Taylor, 1999). The aim of legitimate elephant utilization is to change the perception of elephants from a liability to an asset, especially as elephants have potential to generate more income than subsistence farming.

Land-use planning is fundamental to the long-term management of HEC and most likely offers the highest chance of success (Nelson *et al.*, 2003). This is due to conflict being largely spatial and temporal as opposed to density dependent (Hoare, 1999a; Smith and Kasiki, 1999). Whilst the effects of land-use planning on reducing HEC remain largely unevaluated, land-use planning provides a means of accommodating elephants in current and future land use plans. As 80% of elephant range in Africa is unprotected, co-existence between people and elephants with limited conflict is vital to the survival of elephant populations (Hoare, 2001a).

3.7 Environmental and Land-Use Factors Influencing Crop-Raiding

Elephants are constantly losing range to human settlement expansion. Lack of land-use and sustainable development planning will only lead to an undefeatable increase in HEC, with a predictable outcome for the elephant (Lindeque, 1995). In order to effectively reduce HEC through land-use planning the environmental and land-use factors influencing crop-raiding must be researched. The incidence of crop-raiding varies greatly across Africa and appears to be a seasonal and localized problem (Lahm, 1996). Various studies have been undertaken in an attempt to determine factors influencing crop raiding intensity including: rainfall, distance from protected areas, distance from permanent water, distance from human settlement and farm size.

The effect of seasonal rainfall variance on patterns of crop-raiding in Zimbabwe was studied by Parker and Osborn (2001). They found crop-raiding to be a dual-season phenomenon with high levels of crop-raiding occurring from January to September, the dry season. Chiyo *et al.* (2005) found no seasonal variation in crop-raiding despite strong seasonal variances in rainfall in Uganda. The effect of annual rainfall variance on crop-raiding was found to be insignificant in Kenya (Hoare, 1999a). It has been suggested that in savannah habitats where rainfall greatly influences forage quality, crop raiding levels are highest during the dry season when forage quality is lowest. In forest habitats, crop raiding levels are not likely associated with nutritional stress but crop availability (Lahm 1996; Chiyo *et al.*, 2005).

The relationship between crop-raiding incidents and distance from protected areas in the wet season in Zimbabwe was found to be strong, negative and non-linear by Parker and

Osborn (2001) and strong and negative in Ghana (Dudley *et al.*, 1992; Barnes *et al.*, 2005).

A strong, negative non-linear relationship was found between crop-raiding incidents and distance from major perennial rivers in the dry season in Zimbabwe (Parker and Osborn, 2001) and in the wet and dry season in Kenya (Smith and Kasiki, 1999). This suggests elephant movements are restricted by access to water in the dry season thus crop-raiding intensity is highest near water.

Barnes *et al.* (2005) found a significant association between crop-raiding and farm size. Similarly, Sitati *et al.* (2003) found a positive correlation between crop-raiding and area under cultivation for both male and family groups in Kenya. However, Hoare (1999a) found no association between crop-raiding and the total area transformed by human settlement, including fields and villages in Zimbabwe. Crop-raiding is negatively correlated with distance from human settlement indicating that elephants avoid areas of human settlement (Hillman Smith *et al.*, 1995; Sitati *et al.*, 2003). The risk of crop-raiding was found to be positively correlated to the number of crops grown in Ghana (Sam *et al.*, 2005; Oppong *et al.*, 2008). Collectively, these results show inconclusive associations between crop-raiding and characteristics of the crops.

Barnes *et al.* (1995) proposed that increased crop-raiding levels in Ghana are a direct result of logging. Logging causes an increase in secondary growth which is a preferred habitat of elephants and until logging was stopped in 1989, occurred mainly on the periphery of the forest for easy access. The greater abundance of food from secondary growth on the forest perimeter has thus attracted elephants. Furthermore, logging on the periphery causes a decrease in the forest radius which consequently causes an increase in elephant density. Thus more elephants occur on the forest boundary and near fields. This is compounded by an increase in elephant numbers as survival and pregnancy rates increase due to improved food supplies.

Areas of high density use outside of protected areas were positively correlated to core areas of elephant density within protected areas (Hillman Smith *et al.*, 1995) indicating that crop-raiding is limited by distance from daytime elephant refuges. Smith and Kasiki (1999) found elevation and crop-raiding incidents to be negatively related. This led them

to suggest that elephant migration routes could be influencing crop raiding as migration routes avoid steep slopes and higher ground and elephants follow migration routes year round. The role of daytime elephant refuges and corridors in determining crop-raiding incidents thus warrants further study (Smith and Kasiki, 1999; Sitati *et al.*, 2003).

Of all studies done to date, no study has attempted to analyze the association between the onset of crop-raiding and EVI data and collectively analyze the association between crop-raiding intensity and proximity to protected areas, proximity to human settlement, farm size and vegetation biomass. In addition, very few studies have utilized GIS software to generate unique spatial data and units and analyze factors influencing HEC (Hillman Smith *et al.*, 1995; Hoare, 1999a; Smith and Kasiki, 1999; Sitati *et al.*, 2003). Only two studies have used a GIS grid-based system (Smith and Kasiki, 1999; Sitati *et al.*, 2003). Furthermore, of these few studies, none have been carried out in a forest habitat with forest elephants.

3.8 GIS as a Tool for the Study of HEC

Smith and Kasiki (1999) used GIS-based analysis to determine factors influencing HEC in the Tsavo ecosystem. The study area of 5,000 km² was divided into 31 study blocks that ranged in size from 8.5 km² to 426 km². A GIS, using general linear models, analyzed the relationship between HEC incident data and the spatial characteristics of each block. It was found that the arbitrary delineation of study blocks can have a dramatic effect on HEC density calculations. It has been recommended that a GIS be used to divide each study area into uniform grid squares and define a HEC zone as those squares where HEC has occurred in the previous five years. The analysis of HEC data at two different spatial scales has also been recommended. At the regional scale, each HEC zone is one data point and at the HEC zone scale, each HEC zone is further divided into a series of blocks with the HEC incident data grouped for each block. To maintain consistency, Smith and Kasiki (1999) recommend the use of LANDSAT 7 Thematic Mapper (TM) satellite imagery. If comparisons are to be made between study areas, the data should be analyzed at the same scale, using the same set of factors and the same statistical tests, with general linear models preferred.

GIS was used to analyze several factors influencing HEC in Sebungwe, Zimbabwe (Hoare, 1999a). Whilst no significant relationships were found, the measurement of

problem elephant incidents in standard area units, for both human and elephant densities, allows for better comparison across varying areas.

Sitati *et al.* (2003) tested a simple grid-based GIS combined with statistical tools to predict spatial aspects of HEC in the Transmara District, Kenya. Crop-raiding incidents and data for seven independent variables that might determine the spatial pattern of HEC were imported into ArcView GIS software and super-imposed onto 1 km² and 25 km² grids covering the entire 1000 km² study area. At the 1 km² scale significant spatial autocorrelation affected analysis. At the 25 km² scale, spatial autocorrelation was not significant and spatial correlates could be identified. The results of this study indicate that a compromise in resolution on statistical grounds does not affect the identification of underlying relationships and may improve clarity by reducing noise. Whilst coarser than the 1 km² scale, the 25 km² scale is still considerably finer than units used in previous studies (Hoare, 1999a; Smith and Kasiki, 1999). Sitati *et al.* (2003) concluded that predictive models could easily be developed using the same variables at the same resolution in other areas. This would enable a comparative assessment of factors affecting HEC across the continent. If combined with a grid-based GIS, these models could be a vital tool for future land-use planning and implementation of mitigation methods.

The NDVI and EVI are widely used remotely sensed measures of vegetation quality and biomass (Serneels *et al.*, 2001) in which higher values indicate greater vegetation vigour. As elephant movement is usually in response to seasonal rainfall and food availability, NDVI/EVI should be useful in predicting elephant movements. Hien (2005) hypothesized that elephant distribution would be associated with high NDVI values in Nazinga Game Ranch, Burkina Faso. Elephants were found to be associated with higher NDVI values in the wet season and lower NDVI values close to permanent water in the dry season. Ngene (2010) found elephants in Marsabit Protected Area, Kenya occupied lower elevations when the mean NDVI in the elephants' home range was high and higher elevations when vegetation biomass was low.

The use of time series data of EVI from MODIS together with HEC incident data to analyse patterns of HEC has not yet been undertaken and forms a novel aspect to this research.

4. MATERIALS AND METHODS

4.1 Study Area

The Bia Conservation Area (BCA) is made up of Bia National Park (BNP) in the north and Bia Resource Reserve (BRR) in the south. The BCA is bordered by Cote d'Ivoire in the west and by the Bia River in the east (Fig. 3). The total area is 306 km² and lies between latitude 6°20' to 6°40' N and longitude 3°00' to 3°10' W (Sam *et al.*, 2005). The annual precipitation of the area is between 1,500 and 1,750 mm. The rainfall is bimodal with a major season from March to July, peaking in June and a minor season between September and November, peaking in October. The main dry season is from December to February or March when many water sources dry up (Danquah and Oppong, 2006) with rainfall peaking in June and October. The average monthly temperature is between 28 and 24°C (Sam *et al.*, 2005).

Vegetation is characterized by moist evergreen and moist semi-deciduous forest (Hall and Swaine, 1976). The *Celtis zenkeri* and *Triplochiton scleroxylon* moist semi-deciduous forest is transitional towards the *Lophira alata* and *Triplochiton scleroxylon* rainforest association found in the southern part of Bia RR (Sam *et al.*, 2006). Tropical tree communities exhibit seasonality in flowering, fruiting and leaf-flushing. Most phenological cycles follow a 12 month or semi-annual cycle but may be influenced by temporal abundance of dispersers or predictable temporal variations in rainfall, temperature, radiation and photoperiod (Anderson *et al.*, 2005). *Panda oleosa*, *Balanites wilsoniana*, *Strychnos aculeata* and *Parinari excelsia* were identified as the most frequently consumed fruit species by elephants (Lieberman and Lieberman, 1987). Abundance of these species in the study area varies from relatively common (*P. oleosa*) to not recorded at all in a five hectare area (*B. wilsoniana*) (Lieberman and Lieberman, 1987).

Agriculture is small-scale, rain-fed and continues throughout the year. Crops grown include cassava, plantain, cocoa, maize, yam, cocoyam, banana and vegetables (Sam *et al.*, 2005; Oppong *et al.*, 2008). Similar crops are cultivated throughout the study area and cocoa agroforestry and intercropping are common practice (pers. obs., 14th October 2009). When land is cleared, indigenous fruit, medicinal and timber trees are retained. Cultivation of these tree crops amongst the cocoa ensures a productive, diverse system resembling the evergreen forests, beneficial to cocoa production. Food crops, planted as

nurse crops within and around cocoa plots, serve to shade and protect young cocoa seedlings and ensure food security (www.new-ag.info). However cocoa agroforestry and intercropping make the detection and identification of crop-raiding elephants on farms extremely difficult, especially at night.

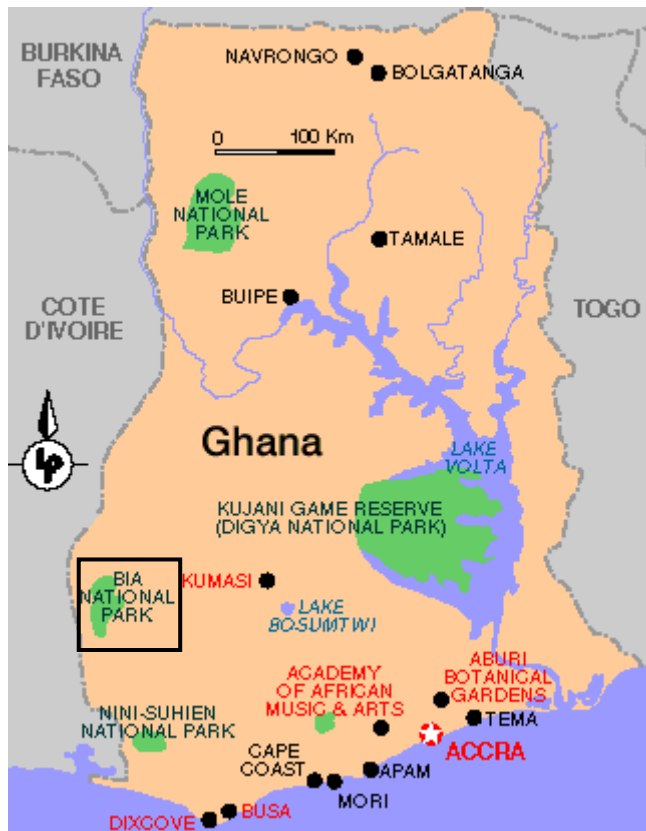


Figure 3: Bia Conservation Area (BCA), Ghana (<http://academics.smcvt.edu>)

Sam (2000) and Sam *et al.* (2006) estimated the elephant density of BCA at 0.42 per km², approximately 115 elephants, with the distribution of elephants found to be influenced by poaching and water availability. Levels of crop-raiding at BCA are increasing and are a major cause of concern for farmers and wildlife officers. Crop-raiding increases steadily from June and peaks in September and October, coinciding with the minor rainy season. Farms that border the south and south-eastern boundary of BRR are raided most frequently (Sam, 2000; Sam *et al.*, 2005; Oppong *et al.*, 2008). It has been suggested that the elephants left BNP and moved downwards into BRR, attracted by palatable secondary growth as a result of logging in the early 1980s. Crop-raiding intensity has been found to increase with proximity of farms to the BCA

boundary, the diversity of crops cultivated and size of farms (Sam *et al.*, 2005; Oppong *et al.*, 2008).

This study area was chosen for several reasons. Data on elephant damage has been gathered using the elephant damage report form developed by the IUCN AfESG (Hoare, 1999b) thus data are consistent. In previous studies the geographical position of raided farms was recorded using a geographical positioning system (GPS) allowing for easy mapping of raided farms. The study area includes protected areas and is relatively small which aids access. No study to date has incorporated the use of GIS to analyze factors influencing HEC intensity in a forest habitat.

4.2 Data Collection

Data on elephant damage for the years 2004 and 2008 was obtained from the Wildlife Division (WD) of the Forestry Commission (FC) of Ghana. Wildlife guards from the WD continuously collect data on elephant damage as it occurs using the standard elephant damage report form developed by the IUCN AfESG (Hoare, 1999b). The specific use of only these data was to prevent any variance between data sets which could affect the accuracy of analysis. All data were recorded by trained enumerators to circumvent over-exaggerated reports of conflict. Information recorded on the elephant damage report form included: date of raid; type, quality and age of raided crops; total area of farm; total area of damaged crops; other damage; geographical coordinates of the farm and details of elephants involved. Data on all crops being cultivated on each farm were not recorded. Details of elephants involved were not always recorded due to the farmers' absence at the time of raiding or identification being hindered by darkness (Appendix 1). A total of 53 and 17 forms were obtained for the years 2004 and 2008, respectively. 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.

Geo-referenced, orthorectified LANDSAT 7 TM images of the study area were obtained from the Global Land Cover Facility (<http://glcf.umd.edu/data/landsat>). The images, each consisting of seven bands, were acquired on the 2nd February 2000. Whilst

there was concern about the accuracy of the images for land cover classification there are currently no other recently acquired, usable images of the study area at the desired resolution of ≤ 30 m.

MODIS 16-day EVI composites of 250 m spatial resolution from NASA's Terra satellite were used to derive monthly EVI profiles of the study area for 2004 and 2008. Whilst the use of higher spatial resolution LANDSAT 7 TM images would have been preferable, the loss of accuracy due to lower spatial resolution MODIS images was waived in lieu of higher temporal resolution accuracy. All EVI composites were obtained from the Global Land Cover Facility (<http://glcf.umd.edu/data/modis>). Geo-referenced vector layers of roads and towns in the study area were also obtained.

4.3 Input and Processing Methods

An Excel spreadsheet was compiled of the relevant elephant damage data with columns including (Appendix 2): date of raid; geographical co-ordinates of the farm (decimal degrees); total area of the farm (acres); total area of damaged crops (acres); intensity of the raid (% of farm damaged); type of crop(s) damaged and number of elephants involved.

The crop-raiding incidents with geographical positions were imported into IDRISI Andes GIS software (Clark Labs, Clark University, Worcester, MA) to create separate layers for the 2004 and 2008 raiding incidents together with layers for the roads and towns. The LANDSAT TM satellite images were imported into IDRISI Andes GIS software and concatenated, specifying automatic placement using reference co-ordinates and transparency, to obtain a complete image of the study area. A window image of the study area was extracted which then required pre-processing techniques to remove noise due to sensor detection errors and natural noise from atmospheric effects. Sensor errors are common since the satellites are transferring vast amounts of data over huge distances. Reflectance can be affected by the interaction between the incoming and outgoing electromagnetic radiation, which alters the true ground reflectance (Eastman, 2006). A Principal Components Analysis (PCA) transforms a collection of bands into statistically separate components which allows the removal of those components holding information relevant to noise and the re-assemblage of the remaining components (Eastman, 2006). Analysis of the PCA transformation performed on the LANDSAT TM

image revealed that reverse transformations with only the first three components were necessary to significantly reduce the noise (Appendix 3).

All geographic files are assumed to be stored according to a grid reference system whereby the plane co-ordinates of the map sheet can be related back to the geodetic co-ordinates of measured earth positions (Eastman, 2006). The LANDSAT TM images obtained were assigned to the (World Geodetic System) WGS-84 Universal Transverse Mercator (UTM)-30n co-ordinate system. To facilitate easier understanding and use of the resulting maps by those not familiar with the UTM grid reference system and for the easier import of geographical positions in decimal degrees, the images were re-projected into a standard latitude/longitude co-ordinate system. Similarly the MODIS 16-day EVI composites were re-projected from the Albers equal area conic projection to the latitude/longitude co-ordinate system. The roads and towns vector layers were re-projected from the Ghana Metre Grid co-ordinate system to the latitude/longitude co-ordinate system.

4.4 Unsupervised Classification

To broadly classify the study area into land cover classes an unsupervised classification was performed. Unsupervised classification aims to uncover the major land cover classes that exist in an image without prior knowledge of what they may be. The procedure is based on cluster analysis whereby clusters of pixels with similar reflectance characteristics are extracted (Eastman, 2006). Unsupervised classification uncovers the major land cover classes and tends to ignore those that have low frequencies of occurrence.

Using the module CLUSTER in IDRISI Andes GIS software, dropping the 5% least significant clusters and using the broad generalization, seven clusters were produced. The seven clusters were then re-assigned into four major land cover classes: agriculture, primary forest, secondary forest and human settlement and roads. The re-assigning of the seven clusters was based on a four day field investigation undertaken in October 2009.

4.5 Enhanced Vegetation Index (EVI)

Slope-based vegetation indices are simple arithmetic combinations that concentrate on the contrast between the spectral response patterns of vegetation in the red and near-infrared (NIR) areas of the electromagnetic spectrum (Eastman, 2006). The NDVI, a widely-used slope-based vegetation index, produces a spectral vegetation index that separates background soil brightness from green vegetation. In spite of the widespread use of the NDVI and its variety of applications, several limitations of the index are apparent. These include the sensitivity for soil background, saturation of the index values with dense and/or multilayered canopies and sensitivity for atmospheric influence (Silveira *et al.*, 2008).

A feedback based approach was developed to correct for the interactive canopy background and atmospheric influences. This enhanced vegetation index was simplified to (Huete *et al.*, 1994):

$$\text{EVI} = 2.5(\text{NIR} - \text{RED})/(\text{L} + \text{NIR} + \text{C}_1\text{RED} + \text{C}_2\text{BLUE})$$

Where L is a canopy background adjustment term and C₁ and C₂ weigh the use of the blue reflectance in aerosol correction of the red reflectance (Huete *et al.*, 1994). The blue band is sensitive to atmospheric conditions and is often used for atmospheric correction.

EVI values are delivered as 16-bit numbers scaled to a valid range from -2,000 to 10,000. Non-land surfaces typically assume negative values and land surfaces typically assume positive values with the calculated EVI approaching 10,000 as vegetation becomes denser (Wallace and Thomas, 2008).

4.6 Data Generation

Sitati *et al.* (2003) conducted a grid-based GIS study using HEC data from a 1,000 km² savannah area in Kenya. The study showed the limitations of using a 1 km² scale and the advantages of using a 25 km² scale. This study, being conducted in a forest habitat investigated an area with a higher density of vegetation cover and resources and a denser concentration of humans and farms than a savannah habitat. Therefore, a

resolution between 1 km² and 25 km² was chosen to investigate this forest habitat namely, 10 km².

To generate the data required for the analysis of the relationship between EVI values and the onset of crop-raiding a 10 km² grid, together with the crop-raiding incidents, was overlaid the monthly EVI composites for 2004 and 2008. Each block around BCA in which crop-raiding had occurred in either 2004 or 2008 (n = 13) was extracted and the mean monthly EVI value calculated for 2004 and 2008 (Appendix 4). The mean monthly EVI value of BCA for 2004 and 2008 was also calculated (Appendix 4).

To generate the data required for the grid-based GIS analysis a 10 km² grid was overlaid the land cover classification together with the crop-raiding incidents, roads and towns layers (Fig. 4). Using the final land cover classification map and EVI composites, each block around BCA in which crop-raiding had occurred in either 2004 or 2008 (n = 13) was extracted and the following calculated using IDRISI Andes GIS software and Excel (Appendix 5):

- mean HEC intensity, calculated for each farm and then averaged for each grid block (intensity defined as the percentage of the farm damaged) (%)
- total number of crop-raiding incidents recorded in each grid block
- mean distance from the crop-raiding incidents to the nearest human settlement (houses and villages), calculated for each crop-raiding incident and then averaged for each grid block (metres)
- mean distance from the crop-raiding incidents to the BCA border, calculated for each crop-raiding incident and then averaged for each grid block (metres)
- mean farm size in each grid block (acres)
- 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

The position of the grid overlays was according to the latitude/longitude co-ordinate intervals of 0.029 specified.

4.7 Data Analysis

Given the small amount of data available, the high number of variables, the high possibility of non-linear relationships and to check for autocorrelation, a Principal

Components Analysis (PCA) was first performed. Whilst spatial autocorrelation may have affected the analysis, given the already small data sample, it was not possible to test the independence of the data points.

The relationships between the variables were determined using Community Analysis Package 2.04 (Pisces Conservation Ltd., Hants, UK). Those variables with the highest eigenvector weightings in the components with the greatest eigenvalues were then selected for further analysis. Variables included were mean farm size, mean distance to BCA, mean EVI and EVI difference between block and BCA.

The natural logarithms of the selected independent variables against HEC intensity and number of raids were calculated and Spearman's rank correlation analysis carried out using OpenStat (OpenStat, Bill Miller). The relationship between individual crop-raiding incidents and mean farm size and distance to BCA was also analysed using Spearman's rank correlation analysis for 2004 and 2008.

Land Cover Classification of Bia Conservation Area with 2004/08 Crop-Raiding Incidents

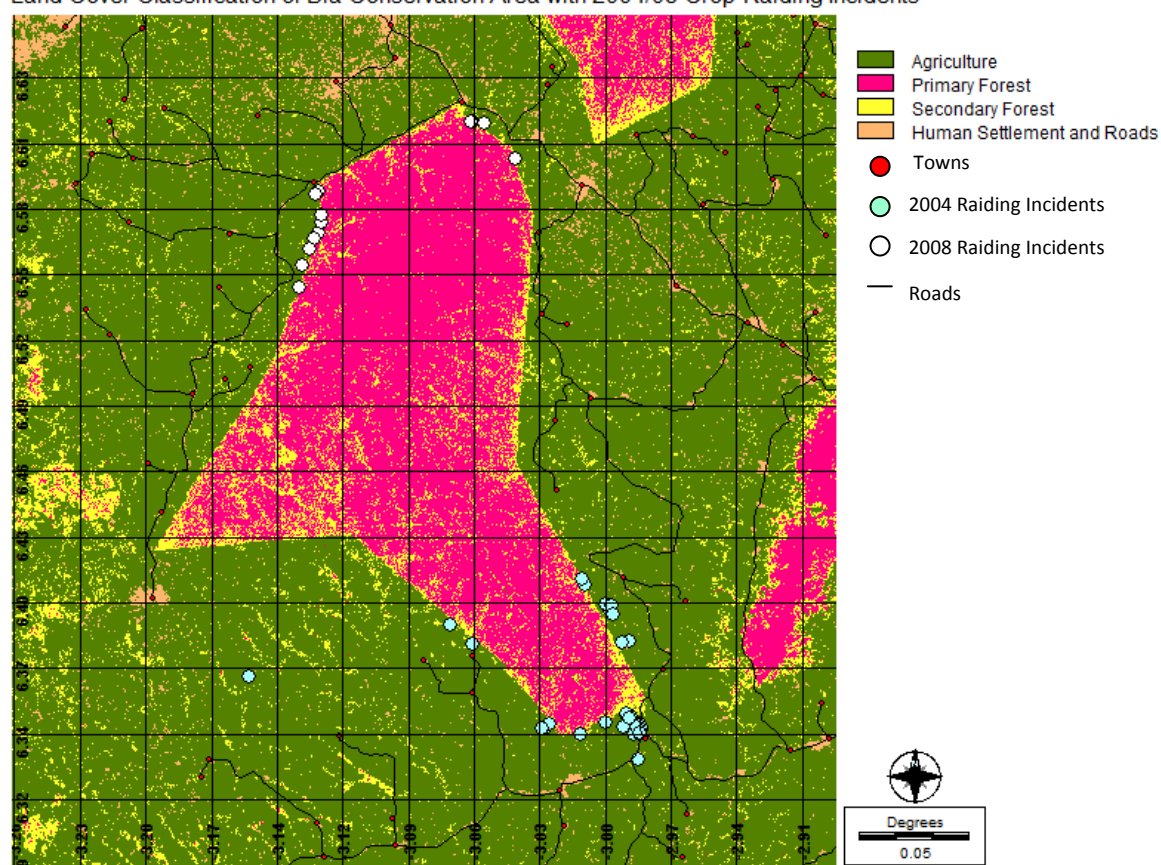


Figure 4: Land cover classification of Bia Conservation Area with crop-raiding incidents for 2004/08, roads, towns and a 10 km² grid overlay

5. RESULTS

5.1 Crop-Raiding Behaviour

In 2004, 53 crop-raiding incidents were recorded with all raids occurring in the south and south-eastern boundary of BCA. The mean farm size of raided farms was 2.53 acres and the mean cultivated area damaged was 0.96 acres (Table 1). Raided crops included cocoa, cassava, maize, cocoyam, plantain, banana, paw-paw, vegetables and yam. Cassava was the most raided crop (eaten/damaged in 58.49% of all crop-raiding incidents), followed by plantain (52.83%) and cocoa (39.62%). Vegetables, paw-paw and banana were the least raided crops (1.89%). The mean number of elephants involved in crop-raiding was five, with ten being the highest number of elephants recorded in any one incident (Table 1). Crop-raiding occurred only in July (n = 24) and August (n = 9) (Fig. 5). Males, males and females, sub-adults and family groups were all sighted during

crop-raiding incidents with family groups accounting for 45.45% of raids in which the elephants involved were recorded (n = 22) (Fig. 6).

Table 1: Details of 2004/08 crop-raiding incidents around Bia Conservation Area

	2004	2008
Number of crop-raiding incidents	53	17
Mean farm size (acres)	2.53	4.34
Mean area damaged (acres)	0.96	0.54
Largest elephant group	10	17
Mean no. of elephants	5	6
Cocoa (% frequency in crop-raiding incidents)	39.62	76.47
Cassava (% frequency in crop-raiding incidents)	58.49	76.47
Cocoyam (% frequency in crop-raiding incidents)	9.43	47.06
Plantain (% frequency in crop-raiding incidents)	52.83	47.06
Yam (% frequency in crop-raiding incidents)	11.32	82.35
Maize (% frequency in crop-raiding incidents)	26.42	35.29

In 2008, 17 crop-raiding incidents were recorded with all raids occurring in the north and north-western boundary of BCA. The mean farm size of raided farms was 4.34 acres and the mean cultivated area damaged was 0.54 acres (Table 1). Yam was the most raided crop, eaten/damaged in 82.35% of all raids followed by cocoa and cassava (76.47%), plantain and cocoyam (47.06%), maize (35.29%) and banana (5.88%). The highest number of elephants recorded in any one incident was 17 and the mean number of elephants involved in crop-raiding was six (Table 1). In 2008 crop-raiding occurred in May (n = 6), June (n = 3), September (n = 4) and October (n = 4) (Fig. 5).

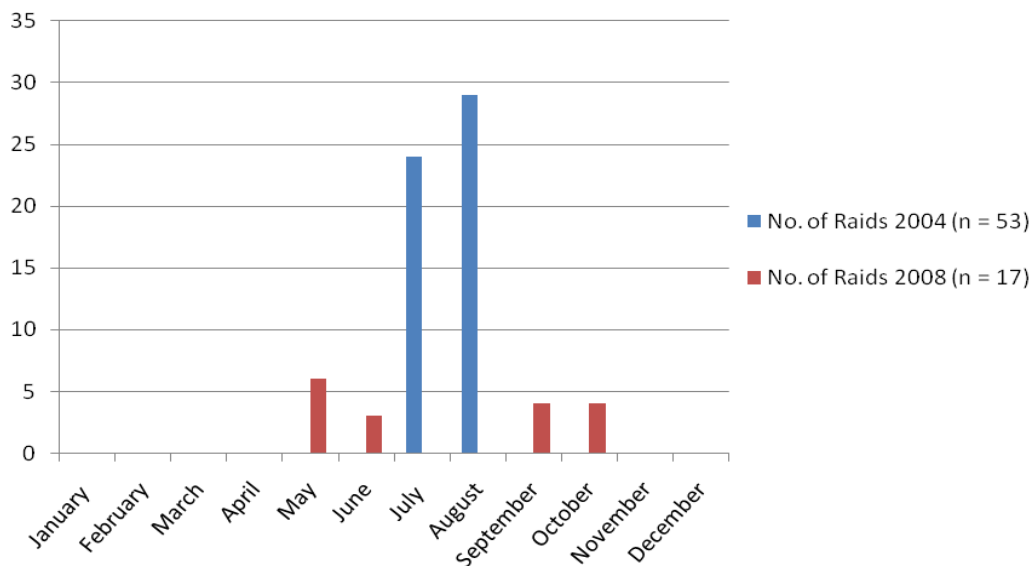


Figure 5: Temporal distribution of crop-raiding incidents around Bia Conservation Area

Only sub-adults and family groups were involved in those crop-raiding incidents in which the elephants involved were recorded ($n = 4$) (Fig. 6).

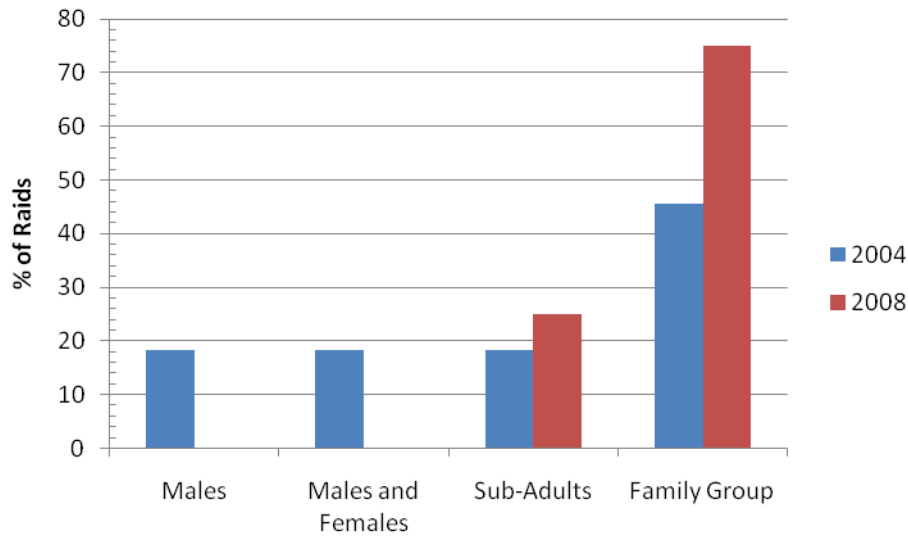


Figure 6: Frequency distribution of elephants sighted during crop-raiding incidents around Bia Conservation Area

5.2 Enhanced Vegetation Index (EVI) Analysis

In 2004, the mean EVI of BCA was highest in May and lowest in August. Two peaks in the mean EVI of BCA were observed, one in May and the other in October (Fig. 7). 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 2 and Fig. 7).

In 2008, the mean EVI of BCA was highest in August and lowest in March. The greatest increase in the mean EVI of BCA in 2008 occurred between March and April. The greatest decrease occurred between February and March (Table 2 and Fig. 7). No distinct peaks in the mean EVI of BCA were observed (Fig. 7).

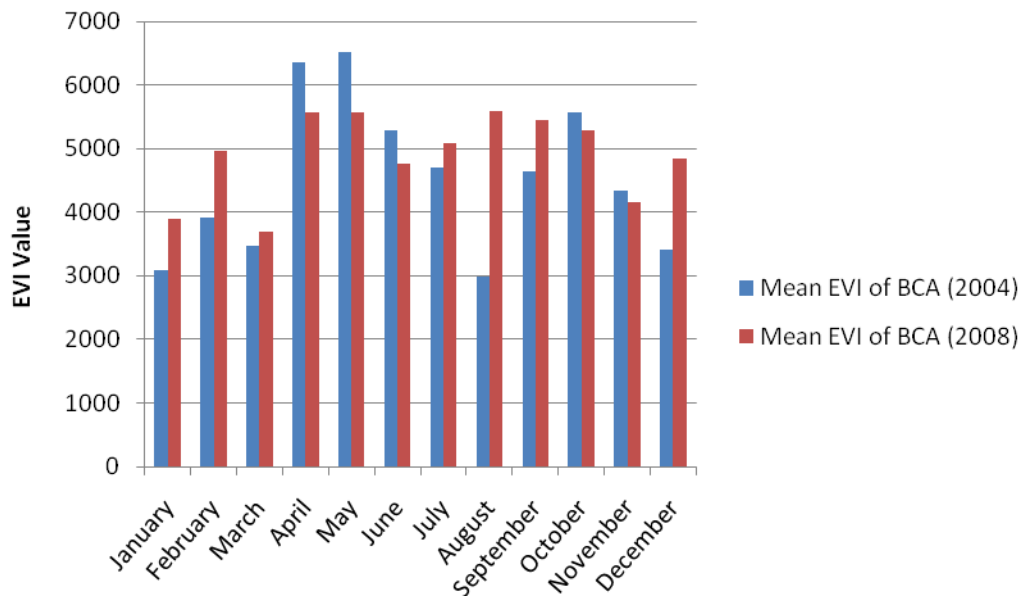


Figure 7: Mean monthly Enhanced Vegetation Index (EVI) values of Bia Conservation Area for 2004/08

Table 2: Monthly change in mean Enhanced Vegetation Index (EVI) value of Bia Conservation Area in 2004/08

Month	Change in mean EVI of BCA (2004)	Change in mean EVI of BCA (2008)
Jan-Feb	828.62	1074.52
Feb-Mar	-445.16	-1267.68
Mar-Apr	2887.65	1869.67
Apr-May	166.09	14.46
May-Jun	-1230.11	-811.66
Jun-Jul	-579.93	315.76
Jul-Aug	-1708.30	514.06
Aug-Sep	1648.47	-147.75
Sep-Oct	929.21	-161.34
Oct-Nov	-1236.87	-1121.47
Nov-Dec	-917.40	675.92

Similar trends in mean 2004 EVI fluctuations were observed in the 10 km² crop-raiding blocks around Bia Conservation Area (Fig. 8). In general, the mean EVI increased rapidly from March, peaked in May and steadily decreased from May to August. EVI values were lowest in August. The rapid decrease in mean EVI occurred in the same months as crop-raiding, namely July and August (Figs. 5 and 8). The mean EVI increased from August to October, a second peak, and decreased again from October to December (Fig. 8). The mean EVI of BCA in 2004 was less than all crop-raiding blocks (with the exception of Block 8) from the beginning of July to mid-August. The mean EVI of BCA was consistently lower than the mean EVI of most crop-raiding blocks around BCA throughout 2004 (Fig. 8). The mean EVI of blocks in the south and south-eastern area around BCA were not found to noticeably differ from the mean EVI of blocks in the north and north-western area around BCA (Appendix 4 and Fig. 8).

In 2008, similar trends in mean EVI fluctuations were observed from January to April (Fig. 9). Whilst 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, simultaneous to decreases in the mean EVI (Figs. 5 and 9). The mean EVI of BCA was consistently lower than the mean EVI of most crop-raiding blocks around BCA from January to June and October to December (Fig. 9). The mean EVI of blocks in the south and south-eastern area around BCA were not found to noticeably differ from the mean EVI of blocks in the north and north-western area around BCA (Appendix 4 and Fig. 9).

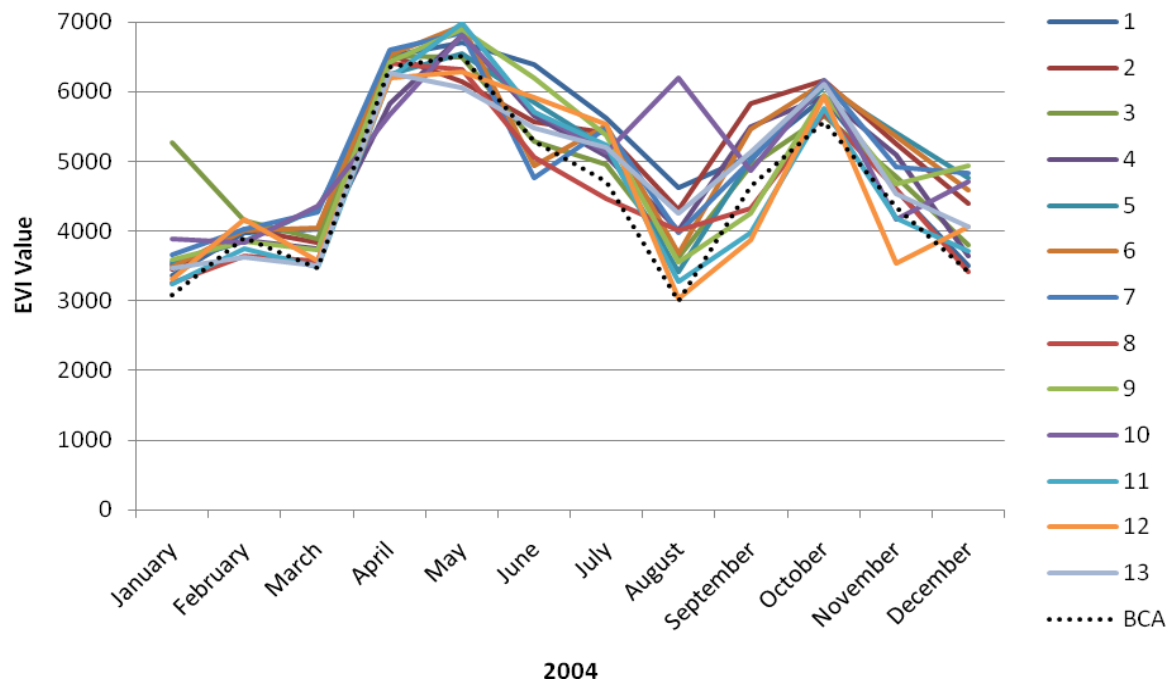


Figure 8: Mean Enhanced Vegetation Index (EVI) values of each block around Bia Conservation Area in which crop-raiding occurred (n = 13), 2004

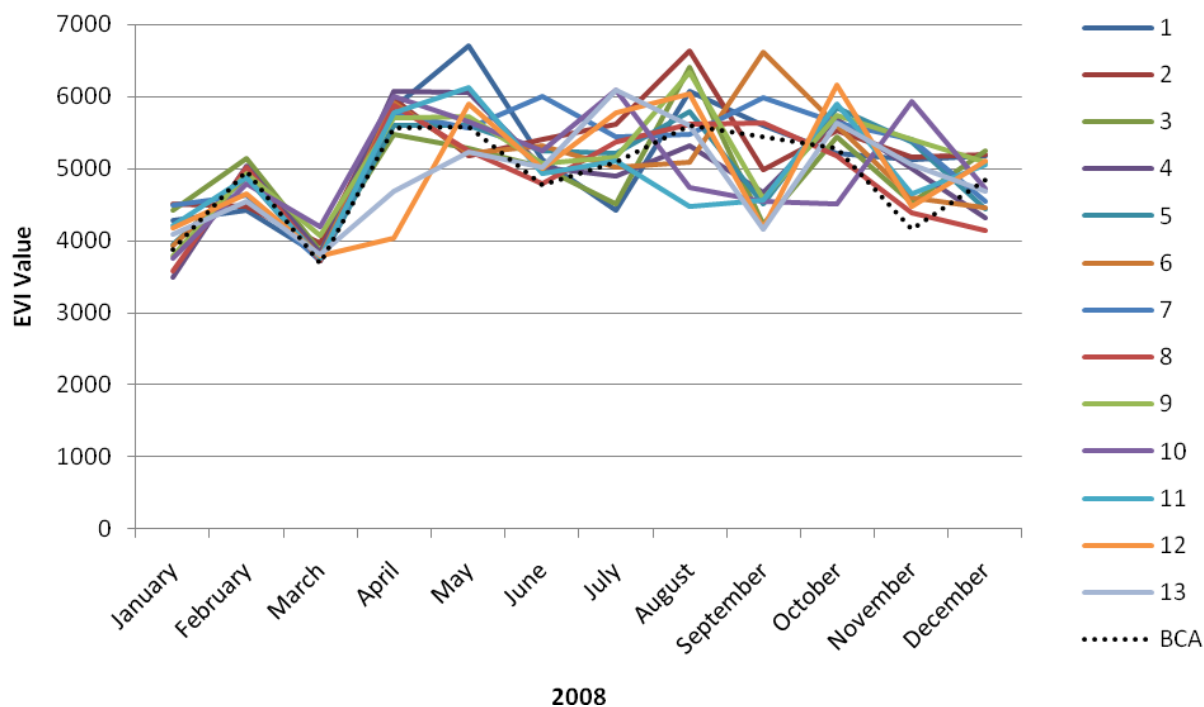


Figure 9: Mean Enhanced Vegetation Index (EVI) values of each block around Bia Conservation Area in which crop-raiding occurred (n = 13), 2008

5.3 Principal Components Analysis (PCA)

The PCA found the first three components to represent the greatest relative contribution of the components (80.21%) of total variance) (Table 3).

Table 3: Relative contribution of each component to the explanation of the total variation in the 10 km² data

Component	Eigenvalue	% of Total Variance	Cumulative % of Total Variance
1	2.75934	39.42	39.42
2	1.97040	28.15	67.57
3	0.88505	12.64	80.21
4	0.70041	10.01	90.22
5	0.41077	5.87	96.09
6	0.20284	2.90	98.98
7	0.07120	1.02	100.00

The eigenvectors of the first three components showed mean distance to BCA, mean farm size and EVI difference between block and BCA to have the greatest weightings (Table 4). The PCA plot showed the greatest correlation between HEC intensity and mean farm size, mean EVI and mean distance to BCA. Correlation between the number of raids and mean farm size, mean EVI and mean distance to BCA were also greatest (Fig. 10).

Table 4: Eigenvectors of the first three components of the 10 km² data

Variable	Component		
	1	2	3
HEC intensity (%)	0.20641	0.58959	-0.07512
No. of raids	0.24120	0.47603	0.46483
Mean farm size (acres)	-0.46201	-0.18451	0.44658
Mean distance to BCA (m)	-0.55389	0.18593	0.06209
Mean distance to human settlement (m)	0.10870	-0.50905	0.32010
Mean EVI index	-0.38084	0.04585	-0.62931
EVI difference between block and BCA	0.47129	-0.30974	-0.27660

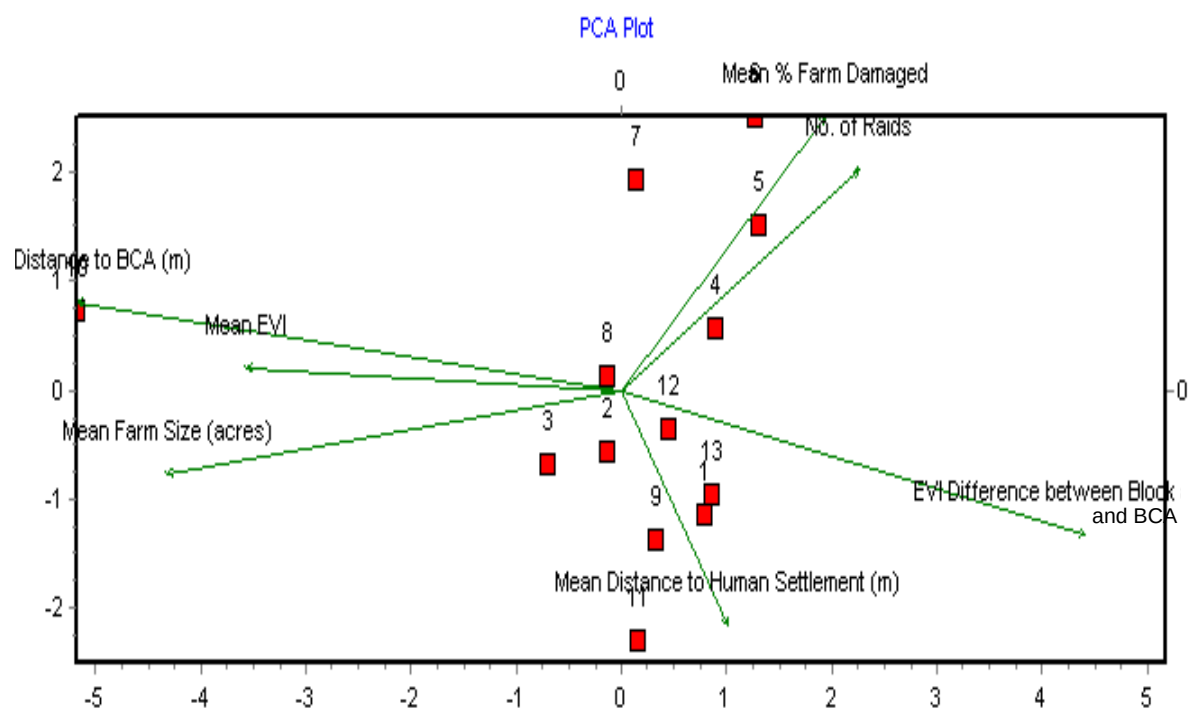


Figure 10: Principal Components Analysis plot of the eigenvector values of the first component of the 10 km² data

5.4 Spearman's Rank Correlations

The variables selected from the PCA for further analysis were mean farm size, mean distance to BCA, mean EVI and EVI difference between block and BCA. No significant relationships were found between HEC intensity and the selected variables (Table 5). There were no significant relationships between the number of raids and the selected variables (Table 5).

Table 5: Spearman's rank correlations for associations between four variables and HEC intensity and number of crop-raiding incidents in 10 km² blocks (2004 and 2008, n = 13), NS = not significant at a 95% level

	HEC Intensity (%)	No. of Raids
	<i>r_s</i> Values	<i>r_s</i> Values
Mean farm size (acres)	-0.391 (NS)	-0.391 (NS)
Mean distance to BCA (m)	0.868 (NS)	0.253 (NS)
Mean EVI	-0.193 (NS)	-0.528 (NS)
EVI difference between block and BCA	-0.231 (NS)	-0.157 (NS)

In 2004, at the individual crop-raiding incident scale the intensity of HEC was negatively correlated with mean farm size ($r_s = -0.458$, $p < 0.01$; Table 6 and Fig. 11). Intensity of HEC was positively correlated with mean distance to BCA ($r_s = 0.392$, $p < 0.05$; Table 6 and Fig. 12). In 2008, no significant relationships were found (Table 7). Due to the limited data available and the possibility of spatial autocorrelation, all statistical results should be considered with caution.

Table 6: Spearman's rank correlations for associations between two variables and HEC intensity at the incident scale in 2004 ($n = 32$), NS = not significant at a 95% level

2004	HEC Intensity (%)
	r_s Values
Farm size (acres)	-0.458 ($p < 0.01$)
Distance to BCA (m)	0.392 ($p < 0.05$)

Table 7: Spearman's rank correlations for associations between two variables and HEC intensity at the incident scale in 2004 ($n = 13$), NS = not significant at a 95% level

2008	HEC Intensity (%)
	r_s Values
Farm size (acres)	-0.393 (NS)
Distance to BCA (m)	-0.209 (NS)

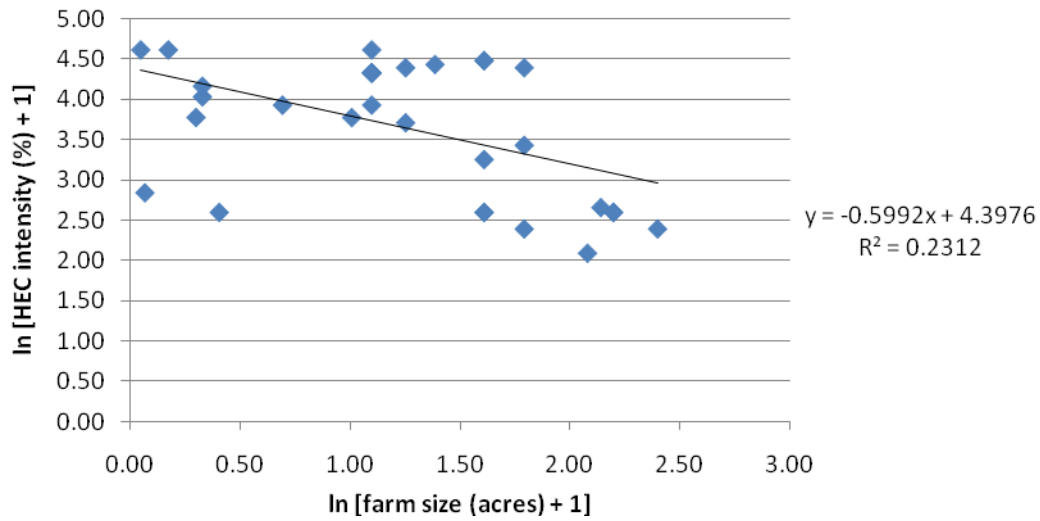


Figure 11: Relationship between HEC intensity and farm size for 2004 crop-raiding incidents

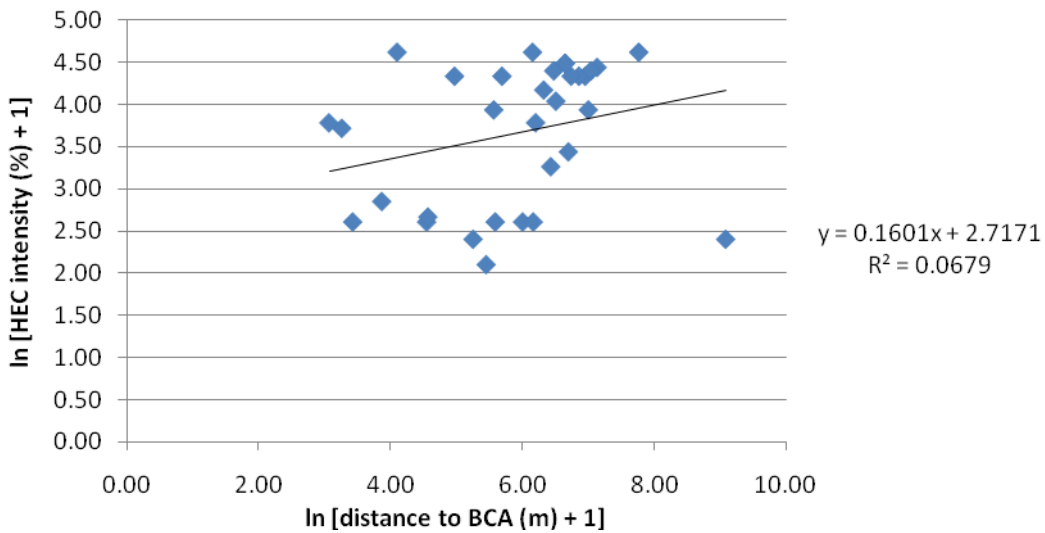


Figure 12: Relationship between HEC intensity and distance to BCA for 2004 crop-raiding incidents

6. DISCUSSION

Despite a decrease in the number of raids and the intensity of crop-raiding incidents from 2004 to 2008, elephant crop-raiding around BCA remains a problem and the Wildlife Division (WD) is under pressure from local farmers to mitigate HEC. The large decrease in the number of raids between 2004 and 2008 may be attributed to farmers reporting crop-raiding events less rather than an actual decrease in crop-raiding events. According to the data collected by the wildlife guards, elephant behaviour has changed between 2004 and 2008. Whereas in 2004, all raiding occurred in the south and south-eastern boundary of BCA there has since been a dramatic shift of all crop-raiding incidents to the north and north-western boundary of BCA. Whilst 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 BCA 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).

Sam (2000) found the distribution of elephants in BCA to be influenced by poaching. The shift in crop-raiding from the southern to the northern boundary could be in response to an increase in poaching in the southern sectors of BCA, either for ivory or in retaliation to crop-raiding. Griebenow (2006) reported that farmers hire specialized poachers to eliminate the “problem” and secretly divide and consume the meat, sell the ivory and bury the carcasses in the forest. Cocoa farming in the northern sectors has also increased during the course of the decade (Wildlife Division, 2000) and Griebenow (2006) found a strong correlation between the spatial distribution of elephants and cocoa farms. The mean EVI values of the crop-raiding blocks around BCA did not noticeably differ (Appendix 4). This can be attributed to the agroforestry and intercropping which is common practice throughout the area. However the proportion of crop types cultivated in these blocks may differ causing the shift in crop-raiding from the southern to the northern boundary. Whilst data on the crop types damaged was available, data on the crop types and the proportion of those crop types grown on each farm should be collected to investigate the relationship between crop-raiding and crop types.

Between 2004 and 2008 there has been an increase in the size of crop-raiding elephant groups. In 2008, family groups consisting of adult males, females and sub-adults were largely responsible for crop-raiding. In 2004 lone adult males and adult male and female pairs accounted for nearly half of crop-raiding incidents. This is similar to the findings of Sam *et al.* (2005) and Oppong *et al.* (2008) who also noted increasing elephant group sizes and a shift to family groups being the major culprits. These findings could relate to the 'male behaviour hypothesis' theory. Males are more tolerant to human disturbance which allows them to live near the natural vegetation/settlement interface and take more risks to maximize reproductive success through better nutrition (Hoare, 1999a). If males are successful in the new behaviour females may then copy that behaviour, in this case, crop-raiding. Whilst there is very little evidence to suggest that crop-raiding intensity is dependent on elephant densities in savannah environments (Hoare, 1999a; Hoare, 2001b), the increasing elephant population and decreasing elephant range in BCA (WD, 2000) could be forcing family groups to crop-raid in response to limited forage availability. The apparent increase in family groups being responsible for crop-raiding should be further investigated as the findings of this study are limited by the small number of incidents in which the elephants responsible were recorded. As crop-raiding usually occurs during the night (Hillman Smith *et al.*, 1995; Sitati *et al.*, 2003; Kioko *et al.*, 2006; Jackson *et al.*, 2008) the identification of crop-raiding elephants is difficult. Furthermore, lone males or male and female pairs are far harder to detect than large family groups especially in forest habitats which may have skewed the data.

The onset of crop-raiding in 2004 and 2008 can be attributed to seasonal variation in vegetation biomass. Decreases in EVI values are matched with crop-raiding incidents. In 2004, crop-raiding was highest 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 for mature crops high in nutritional content. In BCA crops mature from May to October (Sam, 2000) thus the vegetation quality outside BCA is most likely higher during those months. In December and January, whilst the vegetation biomass is low, the vegetation quality inside BCA may equal or exceed that outside BCA. Thus crop-raiding during those months does not provide nutritional benefits. 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 of the late minor wet season to the early dry season (October to January) resulted in the highest intake of forest fruits and limited the intake of cultivated crops. In contrast, in the major wet season consumption of cultivated crops was highest and the availability and intake of fruit lowest.

The high number of crop-raiding incidents in 2004 could be attributed to the large fluctuations and overall higher values in vegetation biomass in comparison to 2008. Whilst rainfall data were not included in this study, an analysis of the relationship between rainfall and vegetation biomass could assist in predicting the onset of crop-raiding.

The frequency of crop-raiding of each crop type varied between 2004 and 2008 which could indicate a shift in the preference of crop-raiding elephants or merely differences in the proportion of each crop type grown in the southern and northern sectors of BCA. Overall, cocoa, cassava, plantain and yam were the most raided crops in accordance with the findings of Sam (2000), Sam *et al.* (2005) and Oppong *et al.* (2008). 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. Furthermore, knowledge of the crops grown on farms not raided would have enabled a deduction of the relationship, if any, of crop types grown and crop-raiding. The growing of mono-crops has been recommended to reduce crop-raiding risk as farms with high crop diversity have a higher tendency to be raided than those with low crop diversity (Sam *et al.*, 2005). The implementation of mono-cropping may not be feasible around BCA as farmers rely on cocoa as a source of income and the remaining crops as sources of food. Furthermore cultivation of tree crops amongst cocoa ensures a productive, diverse system beneficial to cocoa production and the food crops serve to shade and protect young cocoa seedlings and ensure food security (www.new-ag.info).

This study is the first of its kind to analyse the spatial patterns of HEC in a forest habitat using a systematic, grid-based approach. Crop-raiding was spatially clustered. No clear relationships were apparent between HEC intensity and mean farm size and proximity to BCA at the 10 km² scale. Similar to Sam *et al.* (2005) and Oppong *et al.* (2008), at the individual farm scale HEC intensity in 2004 was inversely influenced by the size of raided farms. Thus, the smaller a farm the greater the intensity of the crop-raiding, that is

the greater the percentage of the crops damaged. This result is expected as crop-raiding elephants likely spend the same amount of time on each farm so damage is high on small farms. The high edge to area ratio also makes small farms more vulnerable. No relationship was found between HEC intensity in 2008 and the size of raided farms. This is likely due to the small data sample for that year and no conclusions can be drawn.

At the individual farm scale in 2004, HEC intensity was positively correlated with distance from the BCA boundary. Animals searching for food in heterogeneous environments act in response to three questions, namely, when to forage, what to forage and where to forage (Menzel, 1981). It is expected that animals preferentially use areas where gain is maximized and travel costs between patches of high gain are minimized (Blake and Inkamba-Nkulu, 2004). Once a source of food is located elephants are likely to maximize the amount ingested to justify the energy expended on travelling.

Barnes *et al.* (1995) states that the improved nutritional intake from foraging on secondary forest and agriculture is likely to increase reproductive success which in turn, increases the elephant population at a faster rate. In previous studies it has been found that crop raiding is negatively correlated against distance from human settlement indicating that elephants avoid areas of human settlement (Hillman Smith *et al.*, 1995; Sitati *et al.*, 2003). In this study the relationship between HEC intensity and distance to human settlement was insignificant. The inclusion of human density data is 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/ km².

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 km² scale, no significant relationships between HEC intensity and mean EVI and EVI difference between the blocks and BCA were found. Whilst 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 area bordering BCA are minor. The vegetation biomass of BCA and the blocks in which crop-raiding occurred was found to be similar in

both 2004 and 2008 (Appendix 4). 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 BCA 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 be also be due to agricultural areas having higher soil mineral contents than BCA.

This study was greatly limited by the small amount of crop-raiding data available and would have benefitted from a suite of crop-raiding data over several years with corresponding satellite images. The limited data made the inference of statistical relationships difficult and results from the statistical analyses must be considered with caution. Due to the small sample it was not possible to test for spatial autocorrelation which should be included in future studies. This study has highlighted the need for accurate and complete crop-raiding data to be recorded for every incident if analysis is to be accurate.

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 dry 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? Lastly, what is the relationship between human density and HEC intensity? Whilst 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 km² grid is recommended to generate spatial units for GIS-based HEC analysis in forest habitats. Used in combination with data on nutritional content, soil mineral content,

human density and crop type proportions a greater understanding of the factors influencing HEC intensity could be achieved.

7. CONCLUSIONS

This study was the first to use a grid-based GIS system to evaluate several environmental factors that may be influencing HEC intensity in forest habitats in Africa. Whilst previous studies have been undertaken in the area, the purpose of this research was to highlight the value of using GIS to generate unique data and spatial units for HEC analysis. The onset of crop-raiding in BCA can be attributed to the seasonal variation in vegetation biomass as shown by the EVI values derived from remotely sensed data. The insignificant relationship found between EVI values and HEC intensity indicates that crop-raiding intensity is not influenced by vegetation biomass but more likely vegetation quality.

Grid-based analysis of HEC intensity not only contributes to predicting HEC intensity but aids the accurate deployment of mitigation measures to those areas that are most vulnerable to crop-raiding. The existence of distinct crop-raiding blocks simplifies mitigation strategies by enabling those farms most at risk to have measures implemented first.

It is recommended that a study is conducted to determine the current density of elephants in BCA using the line transect method. Data on the seasonal fluctuations in nutritional content of available forage in BCA and crops cultivated is necessary to analyse the relationship between HEC intensity and vegetation quality. A study should also be conducted to assess the influence of mineral content on elephant distribution using GPS telemetry and soil analyses. The results of these studies would deepen understanding of the behaviour of crop-raiding elephants enabling a more accurate prediction of which areas are at risk and effective deployment of mitigation measures. The shift of crop-raiding from the south and south-eastern boundary to the north and north-western boundary of BCA also requires further investigation to ascertain whether it is a response to increased poaching in the south or if the vegetation quality (related to crop types cultivated) in the northern areas now exceeds that of the southern areas.

Human-elephant conflict remains a problem in BCA. The abandonment of agriculture as a source of income and food are not viable options for most farmers, thus the implementation of cheap, experimental mitigation measures such as bee-keeping, chilli buffer crops and chilli grease fences should be introduced. These mitigation measures

provide alternative livelihoods and have been highly successful in savannah habitats and should therefore be tested in forest habitats. As HEC is limited to specific seasons the cost and effort of maintaining such mitigation measures is reduced.

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APPENDIX 1: Elephant Damage Report Form

Region _____ Form No. _____
District _____
Subdivision _____
Village _____ Map Grid Reference _____
Enumerator Name _____ Date of Incident _____
Complainant(s) Name _____
Date of Complaint _____

Crop	Damage Type	Quality Before Damage (Tick one category)			Age of Crop (Tick one category)		
		Good	Medium	Poor	Seedling	Interm.	Mature
Crop 1	_____	_____	_____	_____	_____	_____	_____
Crop 2	_____	_____	_____	_____	_____	_____	_____
Crop 3	_____	_____	_____	_____	_____	_____	_____
Crop 4	_____	_____	_____	_____	_____	_____	_____
Crop 5	_____	_____	_____	_____	_____	_____	_____

Dimensions (Paces) of Total Field Where Damage Occurred

Length _____ paces

Width _____ paces

Dimensions (Paces) of Actual Damaged Portion of Field

Length _____ paces

Width _____ paces

Other Damage Tick and Specify Detail

Food Store _____
Water Supply _____
Threat to Life _____
Human Injury _____
Human Death _____
Other Specify _____

Elephants Involved	Number	Visual ID	Track ID
Group Size (Total)	_____	_____	_____
Adult Male	_____	_____	_____
Adult Female	_____	_____	_____
Sub-adult/Calf	_____	_____	_____

Your Comments:

Was This Report Forwarded?

To Whom? _____

Where? _____

When? _____

How? _____

APPENDIX 2: HEC Data from Elephant Damage Report Forms for 2004 and 2008

HEC INCIDENTS 2004												
Date	GPS Co-Ordinates	Farm Area (acres)	Damage Area (acres)	% Farm Damaged	Cocoa	Cassava	Maize	Cocoyam	Plantain	Yam	No. of Elephants	Dist. to BCA (m)
01/07/2004	6.38715 -2.98852	0.02	0.01	53.33	n	y	n	n	n	N	2	625.42
01/07/2004		0.01	0.01	100.00	n	y	n	n	n	N		
04/07/2004		0.08	0.03	41.56	n	n	y	n	n	N	2	
04/07/2004		0.12	0.02	18.64	y	n	n	n	n	N		
04/07/2004		0.09	0.02	25.58	y	y	n	n	n	N	1	
05/07/2004		0.04	0.01	32.56	n	y	y	n	n	N	5	
05/07/2004		0.03	0.02	72.00	n	y	y	n	n	N	3	
07/07/2004		0.11	0.01	7.96	y	n	n	n	banana	N	2	
07/07/2004		0.17	0.05	32.12	n	n	y	n	n	N	1	
08/07/2004		4.00	1.00	25.00	n	y	n	n	y	N	1	
10/07/2004		6.38639 -2.99194	1.00	50.00	n	y	n	n	y	N		
11/07/2004		6.33500 -2.98500	0.19	100.00	y	y	n	n	y	N	6	
11/07/2004			0.05	36.54	y	n	n	n	n	veg.	4	
12/07/2004		6.35333 -2.98889	2.00	75.00	n	n	y	n	n	Y		
12/07/2004		6.35167 -2.99889	2.50	40.00	n	y	n	n	y	N	3	
13/07/2004			0.09	60.67	y	n	n	n	y	N	1	
13/07/2004			0.05	36.00	n	n	y	y	y	N	4	
13/07/2004			0.06	28.07	n	n	n	n	y	N	1	
14/07/2004		6.34917 -2.99111	5.00	80.00	n	y	y	n	y	N		
16/07/2004		6.40350 -2.99908	0.05	100.00	n	n	y	n	y	N		
16/07/2004		6.40283 -2.99663	0.39	55.53	n	y	y	n	n	N		
18/07/2004			0.02	42.86	n	y	n	n	n	N	1	
19/07/2004		6.34917 -2.98694	5.00	30.00	y	y	y	n	y	N	1	816.73

30/07/2004	6.39902 -2.99567	0.39	0.25	63.50	n	n	y	n	y	N	6	561.79
05/08/2004		6.00	3.00	50.00	y	n	n	n	n	N	10	
07/08/2004	6.41492 -3.00942	0.07	0.01	16.22	n	y	n	n	y	N	4	47.17
07/08/2004	6.41343 -3.00858				y	n	n	n	n	N	6	65.27
07/08/2004	6.41180 -3.00815	1.74	0.74	42.71	y	n	y	n	n	N	8	20.63
10/08/2004	6.38611 -3.05750	5.00	0.50	10.00	y	y	n	n	n	N		191.75
10/08/2004	6.34806 -2.98361	2.00	1.50	75.00	n	n	n	n	n	Y		1053.79
11/08/2004	6.40147 -2.99773	0.35	0.15	42.77	n	y	n	n	y	N		496.87
12/08/2004	6.34861 -3.02611	4.00	0.50	12.50	y	y	n	n	n	Y		408.12
12/08/2004	6.35083 -3.02361	8.00	1.00	12.50	y	n	n	n	n	N	2	30.01
12/08/2004	6.34861 -3.02694	8.00	1.00	12.50	y	n	n	n	n	N	2	478.79
14/08/2004	6.39444 -3.06778	7.00	0.50	7.14	y	n	n	n	n	N	2	234.05
14/08/2004	6.34611 -3.01028	4.00	0.50	12.50	n	y	n	n	y	Y	1	94.33
14/08/2004	6.35083 -2.98389	4.00	3.50	87.50	n	y	n	n	y	N		773.08
14/08/2004	6.34944 -2.98361	2.00	1.50	75.00	n	y	n	n	y	N		958.55
15/08/2004	6.35470 -2.99000	7.50	1.00	13.33	y	n	n	n	n	Y		96.10
15/08/2004	6.34583 -2.98389	3.00	2.50	83.33	n	y	n	n	y	N		1264.92
15/08/2004	6.35000 -2.98500	4.00	3.50	87.50	n	y	n	n	y	N		782.62
17/08/2004	6.35468 -2.98875	2.00	1.50	75.00	n	y	n	n	y	N	4	144.32
17/08/2004	6.34944 -2.98528	2.00	1.50	75.00	n	y	n	n	y	N		851.97
17/08/2004	6.34694 -2.98417	2.50	2.00	80.00	n	y	n	n	y	Y		1151.86
20/08/2004	6.37165 -3.15632	10.00	1.00	10.00	y	n	y	n	y	Pawpaw		8898.50
21/08/2004	6.34611 -2.98694	2.00	1.00	50.00	y	n	n	n	n	N	10	1106.28
22/08/2004	6.44972 -3.15632	2.00	2.00	100.00	y	y	n	y	y	N	10	
22/08/2004	6.50302 -2.90435	4.00	4.00	100.00	n	y	n	n	y	N	10	
24/08/2004		7.04	0.15	2.19	y	n	n	n	n	N	6	
25/08/2004		2.00	2.00	100.00	y	y	n	y	y	N	10	
25/08/2004	6.35378 -2.98825	4.00	0.50	12.50	n	y	n	y	y	N	10	268.90

25/08/2004	6.50302 -2.90435	4.00	0.50	12.50	n	y	n	n	y	N	10	
25/08/2004	6.35505 -2.98967	2.00	2.00	100.00	n	y	y	y	y	N	10	59.77
		Mean Farm Area (acres)	Mean Damage Area (acres)	Mean % Farm Damaged	% Incidents w/cocoa	% Incidents w/cassava	% Incidents w/maize	% Incidents w/ cocoyam	% Incidents w/ plantain	% Incidents w/yam	Mean No. Elephants	Mean Dist. to BCA (m)
		2.53	0.96	49.32	39.62	58.49	26.42	9.43	52.83	11.32	5	795.60

HEC INCIDENTS 2008												
Date	GPS Co-Ordinates	Farm Area (acres)	Damage Area (acres)	% Farm Damaged	Cocoa	Cassava	Maize	Cocoyam	Plantain	Yam	No. of Elephants	Dist. to BCA (m)
11/05/2008	6.56758 -3.12547	4.00	0.50	12.50	y	y	y	n	y	y	12	31.01
24/05/2008	6.61620 -3.05752	1.73	0.15	8.55	n	n	n	y	y	y	5	20.43
24/05/2008	6.66653 -3.05812	2.50	0.50	20.00	y	y	y	n	y	n	5	
24/05/2008	6.61653 -3.05812	1.85	0.09	5.02	y	y	y	n	y	n	5	33.72
26/05/2008	6.57178 -3.12451	4.50	0.75	16.67	y	y	y	n	n	y		61.89
27/05/2008	6.58551 -3.12592	6.00	0.50	8.33	y	y	y	y	n	y		63.31
03/06/2008	6.56478 -3.12742	12.00	0.50	4.17	n	y	n	y	y	y	1	167.72
04/06/2008	6.55273 -3.13269	9.00	0.50	5.56	y	y	n	y	n	y		305.98
05/06/2008	6.54309 -3.13423	5.00	0.50	10.00	y	y	y	y	n	y	17	125.35
13/09/2008	6.56000 -3.12974	2.00	0.50	25.00	y	y	n	y	n	y	10	213.82
13/09/2008	6.58401 -3.12715	2.00	0.75	37.50	y	y	n	y	y	y		177.15
14/09/2008	6.57503 -3.12451	1.00	0.75	75.00	n	y	n	n	n	y		41.63
28/09/2008					y	n	n	n	n	n		
02/10/2008	6.61543 -3.05231	2.22	0.07	3.33	y	n	n	n	n	y	2	266.85
03/10/2008	6.60015 -3.03917	6.92	1.04	15.00	y	n	n	n	y	y	1	23.83
19/10/2008	6.50880 -3.15070		1.00		y	y	n	y	y	y	4	544.30
21/10/2008	6.51043 -3.14785				n	y	n	n	banana	y	4	296.19
		Mean Farm Area (acres)	Mean Damage Area (acres)	Mean % Farm Damaged	% Incidents w/cocoa	% Incidents w/cassava	% Incidents w/maize	% Incidents w/cocoyam	% Incidents w/plantain	% Incidents w/yam	Mean No. Elephants	Mean Dist. To BCA (m)
		4.34	0.54	17.62	76.47	76.47	35.29	47.06	47.06	82.35	6	158.21

APPENDIX 3: Principal Components Analysis (PCA) Results

COMPONENT	C 1	C 2	C 3	C 4	C 5
% Variance	79.088253	15.919502	3.215672	1.009266	0.767303

LOADING	C 1	C 2	C 3	C 4	C 5
Band 1	0.411166	0.321214	0.708687	-0.009733	0.474796
Band 3	0.641606	0.558512	0.487205	0.016754	-0.196863
Band 4	0.553448	-0.819275	0.118494	0.089951	-0.018736
Band 5	0.995080	-0.037489	-0.030882	-0.086321	0.002516
Band 7	0.939970	0.293133	-0.099551	0.142159	0.020215

APPENDIX 4: EVI Data for 10 km² Blocks

EVI VALUES 2004												
Block No.	January	February	March	April	May	June	July	August	September	October	November	December
1	3366.23	3967.60	4021.82	6521.10	6704.12	6383.46	5613.55	4627.54	5082.58	5922.48	4594.29	3506.15
2	3453.25	4024.10	3837.50	6537.98	6151.11	5568.05	5416.30	4307.53	5836.99	6167.50	5250.17	4388.28
3	5271.91	4152.79	3890.47	6519.31	6497.56	5283.89	4960.75	3621.37	4940.52	5659.76	4782.14	3800.32
4	3517.36	3874.03	3747.32	5831.69	6802.26	5649.07	5079.51	4017.33	5504.17	5937.51	5087.88	3639.12
5	3553.62	3847.47	4332.08	6250.98	6539.14	5841.64	5199.10	3417.17	5031.26	6073.79	5401.82	4763.50
6	3480.06	4017.20	4052.28	6531.03	6942.64	4944.41	5509.25	3683.46	5454.50	6132.30	5355.71	4590.81
7	3655.09	4028.12	4264.76	6608.62	6837.02	4765.69	5484.31	3973.83	5012.84	6158.29	4921.55	4835.49
8	3264.39	3648.27	3578.70	6410.04	6327.65	5052.07	4460.30	4002.41	4326.02	5689.82	4613.47	3416.97
9	3582.54	3848.71	3730.83	6418.42	6903.38	6191.71	5366.65	3550.03	4250.56	5960.03	4683.45	4931.01
10	3893.59	3832.88	4365.68	5664.27	6804.00	5708.43	5126.20	6201.51	4874.04	6140.78	4167.39	4718.05
11	3245.25	3749.61	3482.21	6190.43	6981.90	5711.13	5240.45	3272.90	3974.75	5760.66	4185.02	3710.59
12	3316.85	4160.74	3575.67	6197.18	6280.05	5924.81	5527.37	3029.34	3864.57	5937.10	3538.52	4055.90
13	3465.60	3634.36	3500.07	6270.15	6065.56	5476.90	5204.44	4248.77	5136.72	6116.86	4536.74	4067.21
Block Mean	3620.44	3906.61	3875.34	6303.94	6602.80	5577.02	5245.24	3996.40	4868.42	5973.61	4701.39	4186.42
BCA Mean	3078.25	3906.87	3461.71	6349.36	6515.44	5285.34	4705.41	2997.11	4645.57	5574.79	4337.91	3420.52
Difference	-542.19	0.26	-413.63	45.42	-87.36	-291.68	-539.83	-999.29	-222.85	-398.82	-363.48	-765.90

2008												
Block No.	January	February	March	April	May	June	July	August	September	October	November	December
1	4289.94	4426.07	3781.65	5837.26	6704.12	5125.04	4415.98	6071.21	5595.00	5219.01	5117.57	5170.48
2	4505.20	4471.40	3960.89	5966.85	5172.07	5406.68	5607.12	6634.59	4982.73	5527.59	5162.55	5197.89
3	4421.08	5141.78	3865.52	5482.72	5282.70	5014.43	4508.58	6411.80	4227.06	5436.95	4527.62	5241.91
4	3491.08	5034.48	3826.30	6071.99	6061.28	5013.73	4887.20	5319.89	4666.08	5685.96	5000.62	4311.44
5	3945.19	4883.74	3715.60	5589.59	5595.24	5239.69	5206.50	5797.81	4508.73	5839.72	5374.76	4435.26
6	3922.97	4898.51	3779.38	5909.85	5206.75	5311.94	5014.04	5086.58	6607.60	5604.34	4595.86	4448.57
7	4495.55	4627.36	3725.36	5774.75	5562.90	6008.36	5440.47	5469.79	5985.81	5641.75	5403.36	4537.52
8	3574.58	5010.12	3718.10	5874.28	5253.20	4795.62	5369.89	5611.74	5635.65	5174.74	4394.43	4136.20
9	3782.27	4933.26	4076.25	5710.83	5720.09	5079.27	5166.88	6335.52	4571.74	5730.31	5400.81	5084.99
10	3749.75	4799.21	4199.53	6002.82	5652.29	5239.77	6086.28	4738.86	4543.64	4509.52	5932.35	4727.94
11	4208.69	4877.83	3758.15	5777.92	6119.49	4931.94	5108.22	4466.35	4556.54	5898.55	4642.82	5057.86
12	4173.96	4654.89	3790.65	4043.52	5902.94	4993.22	5775.30	6036.07	4179.59	6152.53	4478.34	5112.80
13	4083.17	4551.86	3809.61	4680.62	5236.16	5019.12	6084.68	5599.00	4158.98	5634.60	5058.53	4689.13
Block Mean	4049.49	4793.12	3846.69	5594.08	5651.48	5167.60	5282.39	5659.94	4939.93	5542.73	5006.89	4780.92
BCA Mean	3885.73	4960.25	3692.57	5562.24	5576.70	4765.04	5080.80	5594.86	5447.11	5285.77	4164.29	4840.21
Difference	-163.77	167.13	-154.12	-31.84	-74.78	-402.56	-201.59	-65.08	507.18	-256.97	-842.60	59.29

APPENDIX 5: HEC Data for 10km² Blocks

HEC Incidents in 10 km ² Blocks							
Block No.	Mean % Farm Damaged	No. of Raids	Mean Farm Size (acres)	Mean Distance to BCA (m)	Mean Distance to Human Settlement (m)	Mean EVI	Block/BCA EVI Difference
1	6.79	2	1.79	27.09	466.20	5066.48	510.22
2	3.33	1	2.22	266.85	210.90	5527.59	-241.83
3	15.00	1	6.92	23.83	222.00	5436.95	-151.18
4	29.47	3	0.91	33.90	199.80	4017.33	-1020.22
5	56.05	6	1.03	516.18	177.60	4308.14	-456.88
6	64.70	14	3.32	566.87	288.60	4596.36	-745.10
7	77.78	3	1.73	1584.27	144.30	5484.31	-778.90
8	12.50	4	6.00	252.81	114.30	4002.41	-1005.30
9	8.57	2	6.00	425.80	588.30	3550.03	-552.92
10	10.00	1	10.00	8898.50	193.75	6201.51	-3204.00
11	10.00	1	5.00	125.35	987.50	4931.94	-166.90
12	23.15	6	5.42	137.01	455.10	5025.25	237.70
13	22.92	2	4.00	120.23	432.90	4697.57	814.33