academicJournals

Vol. 6(9), pp. 681-701, September 2014
DOI: 10.5897/IJBC2014.0739
Article Number: 642B73847885
ISSN 2141-243X

http://www.academicjournals.org/IJBC

International Journal of Biodiversity and Conservation

Full Length Research Paper

The state of biodiversity in Ghana: Knowledge gaps and prioritization

Kwame Oppong HACKMAN

Center for Earth System Science, Tsinghua University, Beijing 100084, China.

Received 22 June 2014; Accepted 21 August, 2014

Biodiversity conservation in tropical countries is of great importance due to high levels of endemism. Over the past century, Ghana has reserved over 300 ecologically important areas for biodiversity conservation, and a national strategy for this purpose has been developed under the framework of the Convention on Biological Diversity. However, inadequate relevant information has been a drawback to implementation. This paper synthesizes relevant occurrence records of species, together with recently published data, and provides a current overview of the country's biodiversity. A map of the distribution of biodiversity study sites in recent years, the taxa studied, total richness of each taxonomic group (except microbes) and list of the species, are presented. The results indicate that in addition to insufficient off-reserve biodiversity knowledge, its acquisition over the past two decades covers only less than 40% of the protected reserves. It is argued that, with the current low-level of protection in protected areas, it is necessary to prioritize agro-ecological studies in order to obtain the baseline data needed for developing effective land-use strategies, as well as the right information to attract the voluntary participation of the public in biodiversity conservation.

Key words: Ghana, biodiversity, conservation, species richness, off-reserve, protected areas, land-use.

INTRODUCTION

Biodiversity loss and conservation have been a global focus for at least two decades, mainly addressing issues of prioritization for efficient fund allocation (Myers et al., 2000; Mace et al., 2000; O'Connor et al., 2003; Brooks et al., 2006). At the national and local levels where all biodiversity driving forces converge, and where conservation needs to be implemented, prioritization is often biased by parochialism due to poor data availability (Hunter and Hutchinson, 1994; da Fonseca et al., 2000). Over the past century, different human activities especially in agriculture have degraded Ghana's biological resources significantly. Exactly 80 years ago, 63% of the country's forests were in pristine or near-pristine condition in the forest zone (Dickson, 1969). Today, the landscape is mostly human-dominated with forest patches covering ~15% of the country's land area. This is mainly due to land conversion to agriculture, a phenomenon which may continue to biodiversity losses until the economy grows and becomes less dependent on agriculture (Beier et al., 2002). This trend can however be reversed, or at least stabilized, under land-use management regimes in which crop production is maximized with no significant losses to

E-mail: kaupong@gmail.com. Tel: +8618811583917.

biodiversity (Tscharntke et al., 2012). Essentially, every efficient management plan is driven by quality agro-ecological data, and should gravitate towards increasing ecological complexity through the cultivation of multiple resource-efficient crop varieties under enhanced fertilization while allowing some less-competitive native flora (Kumaraswamy and Kunte, 2013).

Like other African countries (da Fonseca et al., 2000), Ghana lacks location and landscape-scale ecological data, a setback to biodiversity conservation. The currently available biodiversity information has been described as scanty with inaccuracies and gaps, and lacking up-to-date knowledge (Ministry of Environment and Science, 2002; Ghana Report, 2009). Fortunately, a large collection of species occurrence data exists in different museums and online databases (see sources of information). This can be synthesized, together with data and results from recent studies, to obtain the baseline information needed to promote the development of new, effective strategies necessary for the conservation and sustainable use of the country's biological resources (da Fonseca et al., 2000). The objectives of this study were to: (i) compile relevant occurrence records of species, and together with recently published data, synthesize them to provide a current view of biodiversity, (ii) map the distribution of protected and non-protected areas previously studied, along with their corresponding studied taxa, for directing future studies, and (iii) identifying and discussing existing knowledge gaps.

MATERIALS AND METHODS

Study area

Ghana is located in West Africa (4.7° - 11.2°N, 3.3°W - 1.2°E), with its southern part lying on the coast of the northeast Atlantic Ocean (Gulf of Guinea) (Figure 1). To the north is Burkina Faso, to the west is Côte d'Ivoire and to the east is Togo. The country extends over two unique ecosystem zones; Eastern Guinean Forests and West Sudanian Savanna, with a transitional Guinean Forest-Savanna Mosaic ecosystem zone. It encompasses a total land area of 238,761 km^2, and has an annual bimodal rainfall distribution between 900 and 2,100 mm (Ntiamoa-Baidu et al., 2001). The current population is 24,658,823 (2010 estimate) with an annual population growth rate of 2.5% (Ghana Statistical Service, 2013). Divided into 10 regions, the country has ~15% of land under protection, the largest of which is in the Western Region where 32.3% of land is protected (Table 2 in Supplementary Information – Tables 1-3).

Sources of information

Species data totaling 296 (Table 1) was obtained from 73 peer-reviewed literature and several databases. The SCI-Web of Science was consulted for data on Ghana's biodiversity in November 2013. A search for Ghana species occurrence data was also conducted in large species databases like the Global Biodiversity Information Facility (GBIF) on Ghana, comprising 90 different organizations, AVIBASE (Lepage 2014), African Bird Club (Dowsett et al., 2014), Amphibia Web (University of California, Berkeley), The Reptile Database (Uetz and Hošek 2014), African Butterfly Database (Sáfián et al., 2009), Afromoth (De Prins and De Prins, 2014), Orthoptera Species File (Eades et al., 2014) and the IUCN's Red List of Threatened Species. Finally, web pages of researchers working on different aspects of the country's biodiversity were visited for published literature containing additional information. Diversity data (species richness) and study locations were recorded for six taxonomic groups (birds, insects, mammals, amphibians, reptiles and plants) in three habitat systems: protected areas (forest and wildlife reserves, etc.), non-protected areas and sacred groves (Table 1; Table 1 in Supplementary Information – Tables 1-3) (Aalangdong, 2009; Ryan and Attuquayefio, 2000). Each article included in this review reported species richness of particular taxa for at least one site. In cases where different articles on the same location reported different species richness values for the same taxa, the maximum was used. Species lists were compiled from the records obtained fSurom the databases and literature.

Data analysis

Box and whisker plotting were used to indicate differences in species richness across different habitat types for each taxonomic group. In addition, a combined map of the spatial distribution of sites where recent (1994 – 2013) taxonomic studies have been undertaken was generated for visual assessment of the present knowledge and possible gaps.

RESULTS

Birds

A total of 794 bird species belonging to 101 families have been recorded, of which 494 (65%) are resident, and 16 species (14 of which are resident) are globally endangered (Table 2; Supplementary Information - Birds). The Mole National Park, probably due to its large size, has the highest bird species richness of 314 (Ntiamoa-Baidu et al., 2001), while the Afrensu Brohuma Forest Reserve has the lowest richness of 44 species (Manu 2011). Table 2 shows the regional distribution of bird species in Ghana. A summary of the distribution of bird species richness for protected and non-protected areas of the country is presented graphically in Figure 2.

Studies on birds, like other species, have concentrated more on the protected areas (87.5%), with little attention to non-protected areas (11.25%) and sacred groves (1.25%) (Table 1). The Brong-Ahafo Region, with only one Important Bird Area (IBA) of ~1,830 km^2 has the highest bird species richness (533), while the Western Region with 18 of the 36 IBAs (total area ~3,850 km^2) in the country, has a richness of 495 (Ntiamoa-Baidu et al., 2001; Table 2). This is surprising considering the fact that the Western Region occupies the largest portion of the richest biodiversity area of the country (Myers et al., 2000; Ministry of Environment and Science, 2002). Beier et al. (2002) gives strong evidence of a positive correlation between habitat size and species richness of birds, which offers some explanation on the basis of island biogeography. Moreover, the low diversity of birds in the

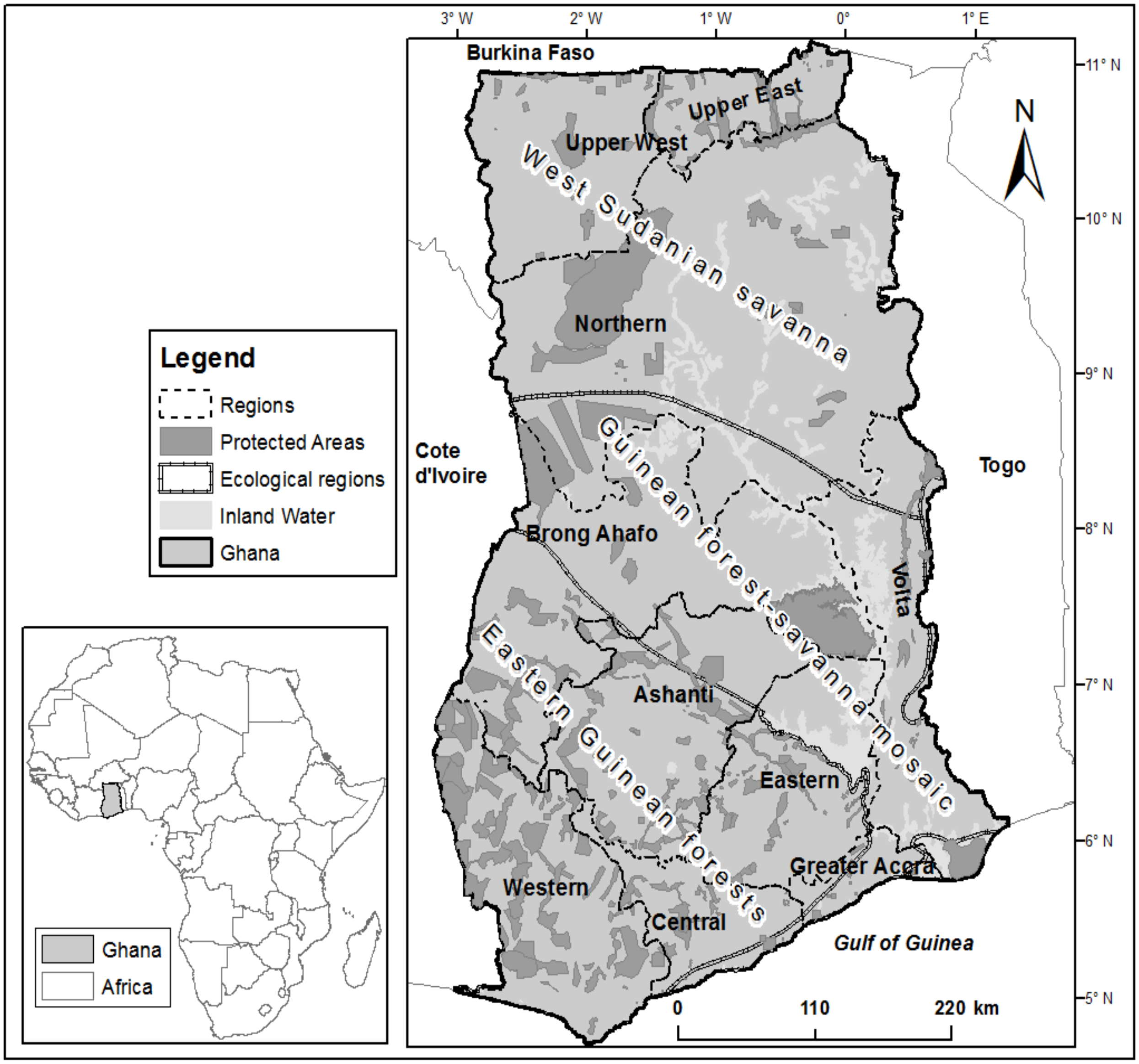

Figure 1. The map of Ghana.

Table 1 Summary of dataset distribution from literature for different taxa groups and habitat types in Ghana.

Taxa	**Habitat type**			**Total**	**Percentage occurrence**
	Protected	**Non-Protected**	**Sacred groves**		
Birds	70	9	1	80	27.0
Butterflies	42	0	7	49	16.6
Small mammals	27	12	4	43	14.5
Amphibians	25	12	0	37	12.5
Plants	22	11	0	33	11.1
Large mammals	25	0	0	25	8.4
Other insects	11	6	0	17	5.7
Reptiles	9	3	0	12	4.1
Total	231	53	12	296	
Proportions	78.0%	17.9%	4.1%		

Table 2. Summary of bird species per region.

Region	Richness	Proportion (%)	Rare Species	IBAs	GE	IN
Brong-Ahafo	533	70.4	11	1	10	2
Central	528	69.7	13	3	10	2
Eastern	528	69.7	10	2	7	2
Volta	526	69.5	16	2	5	3
Greater Accra	518	68.4	19	4	6	4
Ashanti	515	68.4	10	2	8	2
Western	495	65.4	12	18	9	2
Northern	472	62.4	15	2	8	0
Upper East	390	51.5	18	2	6	1
Upper West	375	49.5	13	0	5	2
Total	794*	100	-	36	16	-

Data source – Lepage (2014). GE- Globally endangered species, IN- Introduced species, IBAs - Important bird areas. *additional information used.

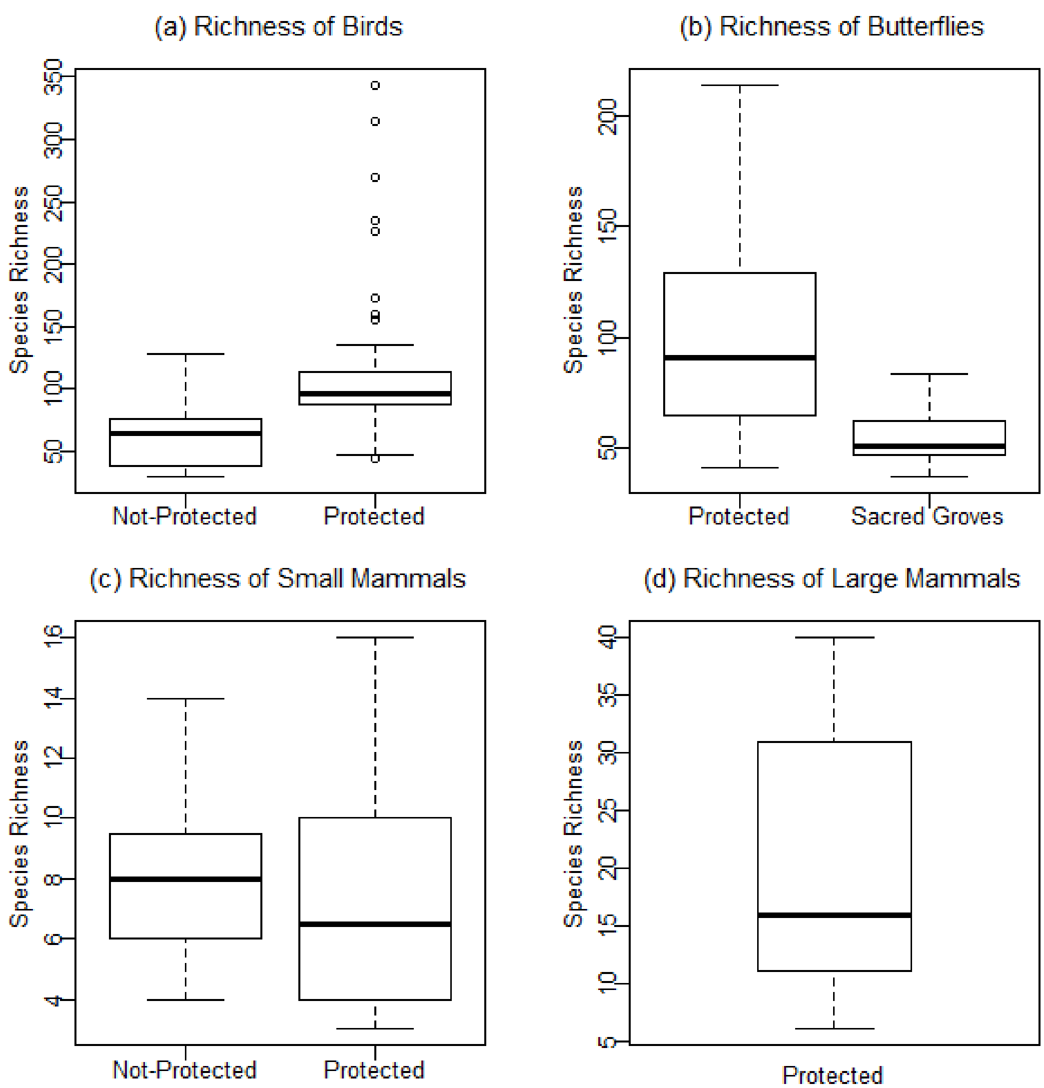

Figure 2. Richness of birds, butterflies, small and large mammals.

Table 3. Butterfly species richness and distribution according to rainfall and vegetation cover, produced based on estimated proportions in Larsen (2006). The proportions were calculated using the total butterfly richness (983) of the country.

Vegetation/Land-use	Annual rainfall (mm)	Richness (estimated)	Proportion
Forest			
Wet evergreen	1 900 – 2 100	718	0.73
Upland evergreen	1 700 – 1 800	688	0.70
Moist evergreen	1 600 – 1 700	629	0.64
Dry	1 300 – 1 600	511	0.52
Lightly logged wet evergreen	1 900 – 2 100	688	0.70
Secondary growth evergreen	1 600 – 2 100	462	0.47
Wholly-cleared evergreen	1 600 – 2 100	88	0.09
Savanna			
Guinea savanna	1 000 – 1 300	197	0.20
Sudan savanna	800 – 1 000	118	0.12
Wholly-cleared savanna	800 – 1 300	79	0.08

Western Region could suggests that, despite birds being the best studied taxa in terms of spatial coverage, the present knowledge on their diversity, distribution and abundance is still insufficient (Weckstein et al., 2009).

Despite the small sizes of the sacred groves, they may conserve small populations of forest-specialist without local extinction threats because, unlike butterflies (Larsen et al., 2009), birds from nearby source habitats can recolonize them. Attuquayefio (2008) found no species common to all five forest reserves in the Brong-Ahafo Region. This may suggest that (i) each forest-specialist bird species has a strict set of habitat requirements, and (ii) those forest reserves have different ecological conditions probably related to the different degrees of degradation within them. Details of the distribution of forest and savanna restricted species in the IBAs is given elsewhere (Ntiamoa-Baidu et al., 2001).

Butterflies and other insects

Out of a total of 983 butterfly species belonging to six families – Lycaenidae (349), Nymphalidae (336), Hesperiidae (216), Pieridae (53), Papilionidae (26) and Riodinidae (3) (Supplementary Information – Insects), 33 are endemic to the Mount Afadjato area of the Volta Region, Atewa Range Forest Reserve and the wet forests of the area extending from western Ghana to eastern Côte d'Ivoire (Larsen, 1994, 2006; Larsen et al., 2009). There are 1,328 moth species belonging to 35 families with one (*Zekelita shamssiae*) being endemic.

The Atewa Range Forest Reserve has recorded the highest cumulative butterfly richness of 575 (Aduse-Poku and Doku-Marfo, 2007), followed in decreasing order by Kakum Conservation Area (496 species) (Larsen et al., 2009), Bobiri Wildlife Sanctuary (454 species) (Larsen et al., 2009), Bia Biosphere Reserve (453 species) (Aduse-Poku et al., 2012), Kyabobo National Park (401 species) (Larsen, 2006), Ankasa, Wli Falls area, Boabeng-Fiema and Aburi Botanical Gardens (390, 328, 288 and 267 species, respectively) (Larsen et al., 2009). A summary of the rest of the data, mostly from single, short-period assessments of different sites, is presented in Figure 2.

Using the habitat distribution ratios obtained from Larsen (2006), the number of forest-centered, savanna-centered and ubiquitous butterfly species are estimated at 798, 177 and 39, respectively. Table 3 shows the distribution of butterflies in different vegetation types and rainfall bands. About 20% of the butterfly species, including 16 endemics, are located within the human dominated areas and have not yet been recorded in the protected areas (Larsen, 2006). These species, unless they are ubiquitous, need conservation attention regardless of their endemic status. This is because land-use activities such as bush burning and insecticide application can potentially cause local extinctions due to their low mobility, especially if they are restricted to small geographic areas. For example, even though rare, all the three species (*Abisara intermedia*, *Abisara tantalus* and *Abisara gerontes*) of the Riodinidae, were recorded only in non-protected areas (Larsen, 2006).

More than three-quarters of Ghana's butterfly fauna is located within the forest zone, which stretches from the southwest to the mid-regions (Larsen, 2006). Concentration is unusually high in the southwest wet forests in the Western Region, upland moist forests within the Atewa-Range Forest Reserve and the forest areas of the Volta region (Emmel and Larsen, 1997). For example, even though the Atewa Range Forest Reserve covers only an area of ~232 km^2, it is home to ~580 species of butterflies with a projected estimate of over 700 species (Aduse-Poku and Doku-Marfo, 2007), which is more than

Table 4. Summary of species richness of invertebrates (excluding Lepidoptera (2,311 species).

Order	Total richness
Hymenoptera	404*
Coleoptera	382#
Diptera	128
Orthoptera	73
Mantodea	45
Hemiptera	34
Dermaptera	16
Neuroptera	12
Blattodea	8
Total	1,102

#Source: Browne (1963); *Source: Kolo and Hormenyo (2009).

the butterfly species richness of Western Europe, and more than the butterfly richness of any state in the USA (Larsen, 2005). This suggests that land-use activities that promote the encroachment of savanna vegetation into the forest zone can potentially cause the loss of many savanna-hostile butterfly species. Both vegetation and rainfall are known to affect butterfly richness with an approximately linear relationship (Larsen, 1994). Thus, any long-term perturbations, distributional shifts, and declines in rainfall may lead to loss of biodiversity and rapid turn-over of species (Dornelas et al. 2014).

Butterflies are the best studied fauna in the country's sacred groves, with at least 7 sacred groves studied. However, due to Larsen's (2006) estimated habitat area requirement of 200 km^2 for butterfly conservation, the continued local survival of some forest-specialists is doubtful in sacred groves (and even in some forest reserves) because of their small areas. This follows directly from the observation of Larsen et al. (2009) that local extinction of butterfly species in Boabeng-Fiema, an isolated reserve of ~ 4.4 km^2 area, cannot be reversed because there is no opportunity for continued gene-flow through re-colonization from nearby subpopulations, a process which is important for the continued local survival of butterflies than the surface areas of the habitats they occupy.

The total species richness of non-lepidopteran arthropods recorded under nine taxonomic orders is 1,102 (Table 4). The species richness of arthropods belonging to the Coleoptera (382 species from 130 genera) was based on Browne's (1963) estimate. However, 118 species belonging to the Scolytidae and Platypodidae which Browne omitted from his paper are not presented in the species list (Supplementary Information – Insects). Similarly, for Hymenoptera, only 221 of the species richness of 404 reported by Kolo and Hormenyo (2009) are listed. Recent studies (Davis and Philips, 2005; Lachat et al., 2006; Norris et al., 2010; Kolo et al., 2011) have indicated that human land-use has negatively affected non-lepidopteran arthropods in West Africa. Larsen (2005), however, acknowledges that the population of savanna and adventive species has increased significantly within the forest zone, and Belshaw and Bolton (1993) believe that the change may not be significant.

Mammals

Currently, 327 species of terrestrial mammal have been recorded, of which four are endangered, eight are vulnerable and 15 are near threatened (IUCN, 2013; Table 5). Studies on mammals have concentrated primarily on small and medium-sized (or large) mammals with a ratio of about 3:1 (Table 1). Small mammals are the best studied in terms of species distribution and abundance on different land-use systems in the country. Small mammal diversity is high in areas that have stable habitats with dense vegetation, sufficient food availability and increased ground cover (Attuquayefio and Wuver, 2003; Ofori et al., 2013). Jeffrey (1977) also reported that the abundance of small mammals is determined by food availability, while richness is determined by availability of dense ground cover.

Diversity of small mammals has been found to be low in most forest reserves but high in built-up areas and other human dominated land-use systems (Jeffrey, 1977; Vordzogbe et al., 2005). Small mammals confronted by unfavorable food conditions in primary forests with sparse ground cover migrate to adjacent human-disturbed habitats with denser ground covers and sufficient food availability (Vordzogbe et al., 2005). Rainfall, being an agent for ground cover densification and food availability, also causes increases in small mammal diversity (Attuquayefio and Wuver, 2003). This explains why, sometimes, the diversity of small mammals is higher in human dominated land-use systems than in protected areas. The above observations suggest that the abundance and diversity of small mammals are less dependent on level of pristineness of habitats, even though other studies have found the opposite (Ofori et al., 2012). The species richness data available from recent single assessments of both small and large mammals in protected and non-protected areas are shown in Figure 2.

At habitat level, small mammal diversity depends on habitat size, distance from a colonization source, and the presence of suitable migration corridors (Decher, 1997). Hunting is the main cause of biodiversity decline in large and medium-sized mammals (Curry-Lindahl, 1969; Asibey, 1974; Vordogbe et al., 2005), while bush burning is the worst threat to small mammals (Decher and Bahian, 1999; Attuquayefio and Wuver, 2003; Vordzogbe et al., 2005).

Table 5. Summary of mammal species in Ghana. The terms near threatened, vulnerable and endangered are as defined by the IUCN.

Order	Richness	Near Threatened	Vulnerable	Endangered
Chiroptera	124	6		
Rodentia	86			1
Carnivora	30	2	3	1
Artiodactyla	29	1	2	
Primates	26	1	3	2
Soricomorpha	18	2		
Pholidota	5	2		
Hyracoidea	4			
Lagomorpha	2			
Erinaceomorpha	1			
Proboscidea	1		1	
Tubulidentata	1			
Total	327	14	9	4

Table 6. Summary of amphibian species in Ghana grouped according to families. NT- Near Threatened, CR- Critically Endangered (Conraua derooi), EN- Endangered, VU - Vulnerable (IUCN 2013).

Family	Richness	NT	CR	EN	VU
Hyperoliidae	34	4		2	3
Phrynobatrachidae	21	2		3	1
Arthroleptidae	17	2			
Ptychadenidae	14	1			
Bufonidae	13	1			
Ranidae	11	1	1		
Pipidae	4				
Dicroglossidae	2				
Hemisotidae	2				
Pyxicephalidae	2				
Caeciliidae	1				
Microhylidae	1				
Rhacophoridae	1				
Total	123	11	1	5	4

Herpetofauna

The terrestrial herpetofaunal richness of the country presently stands at 377 species (Supplementary Information – Amphibians; Supplementary Information – Reptiles) comprising a total of 119 species of amphibians belonging to 13 families (including six endemics), and 259 species of reptiles belonging to 18 families (Tables 6 and 7).

Available data on recent, single herpetological assessments of some protected and non-protected areas are presented graphically in Figure 4. Ghana's amphibian diversity is highest in the Western Region of the Country (Rödel et al., 2005). Before the beginning of the 21st century, the highest amphibian richness recorded for a single site was 20 species (Rödel and Adjei, 2003). In recent years, however, higher values have been recorded, the highest being 40 species for the Ankasa Conservation Area (Rödel et al., 2005). The diversity of amphibians correlates negatively with elevation and density of ground litter (Wiafe and Adjei, 2013). Reptiles have also been studied in recent years, and like amphibians, the studies are few and not comprehensive. So far, protected areas studied include Kyabobo National

Table 7. Summary of reptile families in Ghana.

Family	Richness
Lizards	
Scincidae	42
Gekkonidae	21
Agamidae	10
Chamaeleonidae	7
Lacertidae	7
Gerrhosauridae	2
Varanidae	2
Polychrotidae	1
Snakes	
Colubridae	80
Atractaspididae*	18
Elapidae	14
Lamprophiidae	14
Viperidae	11
Leptotyphlopidae	10
Typhlopidae	6
Boidae	5
Chelonians	
Testudinidae	5
Amphibians	
Amphisbaenidae	4
Total	**259**

Source: The Reptile Database (2014). *_Aparallactus lineatus_- near threatened (IUCN, 2013).

Park (Leaché et al., 2006), Gyemira and Gyeni River Forest Reserves (Yahaya et al., 2013), and Draw River and Krokosua Hills Forest Reserves (Ernst et al., 2005).

Plants

The current total plant species richness of the country is 5,429, comprising 5,217 angiosperms (1,257 monocots, 3,959 dicots and a single species of magnoliids), 147 pteridophytes (ferns), 46 bryophytes (35 mosses and 11 liverworts), 12 lycophytes (club and spike mosses), and seven gymnosperms (Supplementary Information – Plants). Of these species, 121 are threatened, including three (*Talbotiella gentii*, *Salacia fimbrisepala* and *Aubregrinia taiensis*) critically endangered, 19 endangered, four near threatened and 95 vulnerable species (IUCN, 2013). Historically, apart from *S. fimbrisepala* which was recorded at only two sites, *T. gentii* and *A. taiensis* appear to have had much wider geographic ranges in the forest zone (Figure 3).

Occurrence records between 1908 and 1974 indicate that *T. gentii*, despite being concentrated near Somanya (Eastern Region) and spread along the north-west direction into the Ashanti Region, was recorded in a few other parts of the country. Specifically, in the years 1952, 1960 and 1970, the species was sparsely recorded at different locations within the Guinea Savanna vegetative zone of the country. Also in 1952, *T. gentii* was recorded near Amisano in the Central Region. By extracting and examining the elevation and slope of each of the 102 sites where *T. gentii* was observed between 1908 and 1999, it has become clear that the species occurred more at lower and medium elevations ($<$300 m AMSL) than at higher elevations. The species occurred on flat and gentle-sloped terrains because 50% of the records were obtained from slopes from 0 to 7°. Recently, it has been reported that *T. gentii* occurs on high elevations and on rocky slopes (Anyomi et al., 2008), which is possibly due to overexploitation of the species that occurred at lower elevations. Despite earlier reports that the species is geographically restricted to Bandai Hills, Sapawsu and Yongwa Forest Reserves (Anyomi et al., 2008; Boshier et al., 2011), there is a strong indication of its occurrence in the other forest reserves within the area defined by the following coordinates: i. 0.273°E, 6.375°N; ii. 0.022°W, 5.744°N; iii. 1.362°W, 6.434°N; iv. 1.047°W, 7.084°N, especially Dome River, Southern Scarp, Afram Headwaters, Volta River and Bomfoum (Figure 3).

Similarly *A. taiensis*, known to occur only in Ghana and Côte d'Ivoire, appears to occur within the Eastern Guinean Forest block extending from the Sassandra River (Côte d'Ivoire) to the Volta River. In Ghana, its concentration is within the Atewa Range Forest Reserve area, and spreads towards the wet evergreen forest zone in the Western Region. The historical distribution range of *A. taiensis* is slightly different from that of *T. gentii* because it recorded only in the Eastern Guinean Forests ecoregion. The last record of the species was made in the Aiyaola Forest Reserve (0.95°W, 6.15°N) in March 1970 which should be a starting point towards establishing its conservation status. The last critically endangered species, *S. fimbrisepala* is believed to be endemic to Ghana and Cameroun. In Ghana, only two records of the species have been filed in the University of Ghana Herbarium; one of which was recorded ~1.25 km, 026° from Anhweam in the Western Region in 1935 while the other (date unknown) was recorded near Ahinsan, ~2.5 km, 031° from Dompoase in the Ashanti Region. Unfortunately, both sites occur in human dominated land-use areas; however, search for the existence and conservation status of the species in the nearby Subuma and Bosomtwi Range Forest Reserves respectively could yield some positive results.

For the protected areas, the average species richness of 22 reserves whose data were recorded in recent studies is 306. Single study records on the richness of groups of plants species are presented in Figure 4. Plant

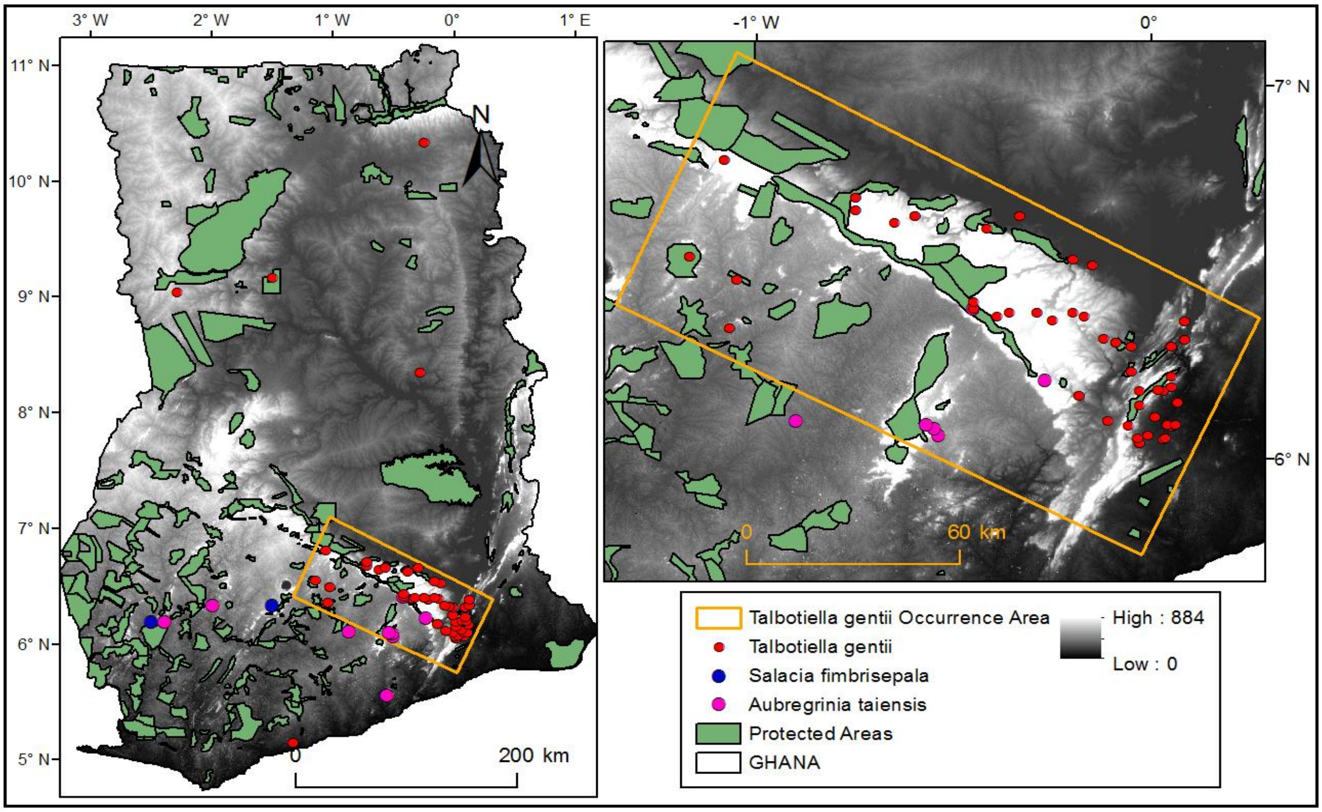

Figure 3. Historical distribution of the critically endangered species *T. gentii*, *S. fimbrisepala* and *A. taiensis*. Spatial distribution of *T. gentii* (an endemic species to Ghana) is highlighted. Data sources: Aster GDEM data (http://gdem.ersdac.jspacesystems.or.jp/), protected areas of Ghana (IUCN and UNEP-WCMC 2013) and species occurrence data (GBIF).

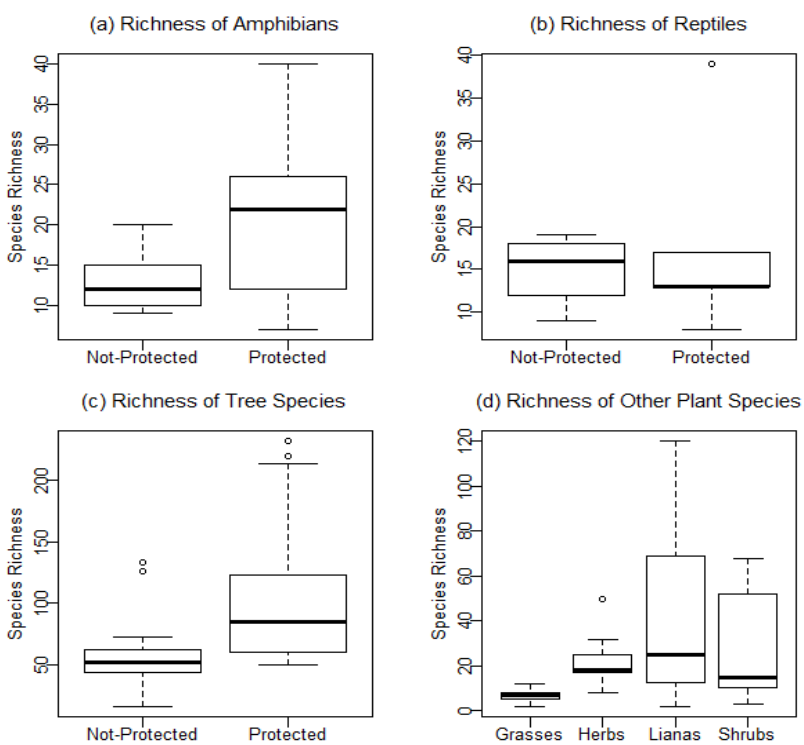

Figure 4. Richness of amphibians, reptiles and plants.

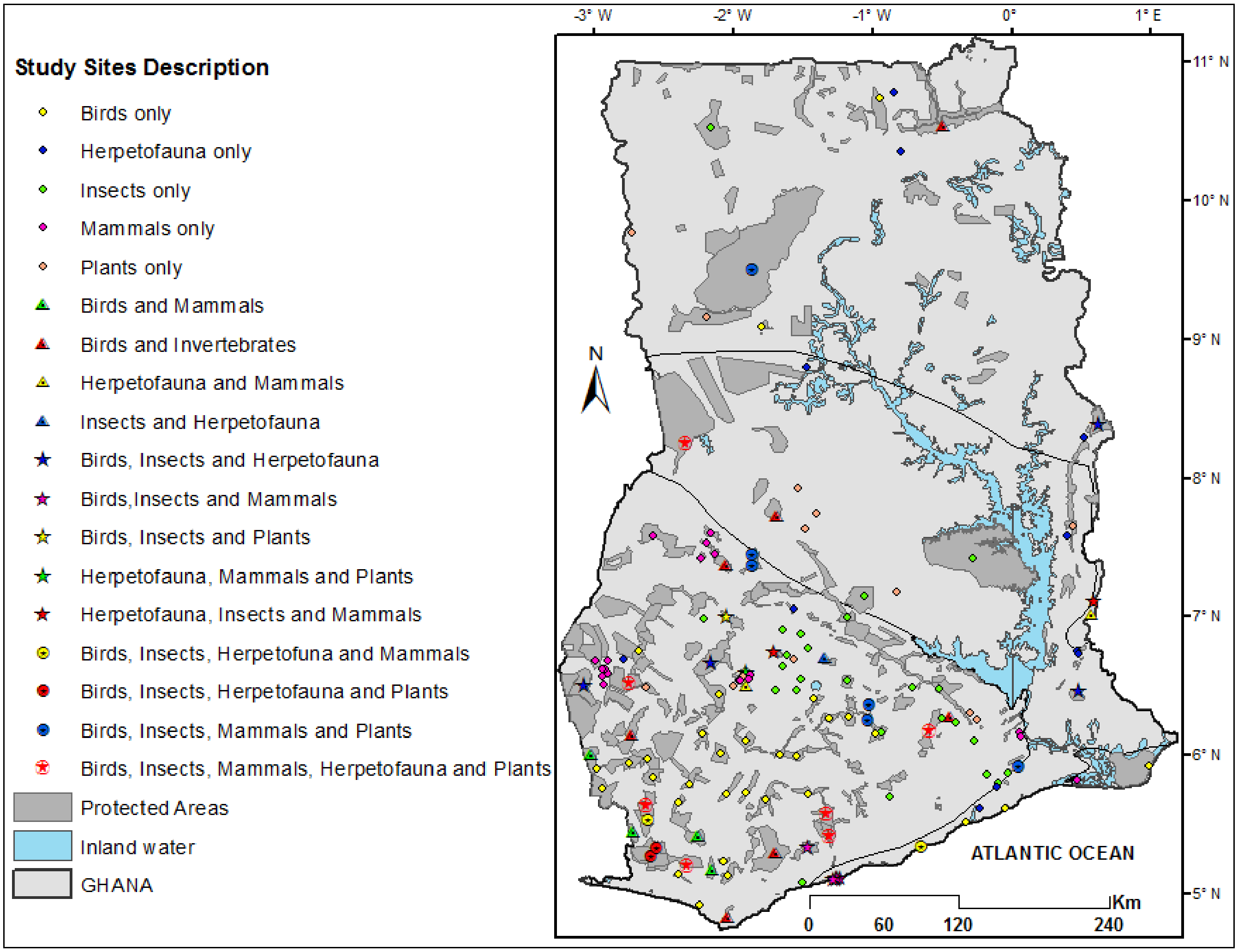

Figure 5. Spatial distribution of sites studied and the taxa of interest.

diversity and distribution in the forest zone have been well documented (Thompson, 1910; Hall and Swaine, 1976) even though the studies were carried out several decades ago. In recent years, studies have declined considerably in all vegetative zones. Tree and liana species richness of human-dominated land-use areas decrease with increasing years of continuous human activity (Asase and Tetteh, 2010; Anyomi et al., 2011; Anglaaere et al., 2011; Addo-Fordjour et al., 2012). Secondly, perhaps due to the differences in structure and management, plant species diversity increases from seedling through sapling to tree stages in natural forests, while the reverse is true for agroforestry systems (Addo-Fordjour et al., 2009; Boakye et al., 2012). As a result, undisturbed forests in the country are characterized by high tree diversity, low herb diversity and medium sapling diversity; disturbed (logged) forests are characterized by low tree diversity, high sapling diversity and medium herb diversity; and disturbed-invaded forests are characterized by high herb diversity, low sapling diversity and medium tree diversity (Fordjour et al., 2009). Thirdly, for highly degraded areas undergoing regeneration, plant diversity transitions in time is from grass-dominating through shrub-dominating to tree-dominating (Campbell, 2005).

Study coverage

The dataset on study sites comprises species richness data (mainly from 1994 – 2013) on single or multiple taxa covering 146 different locations scattered over the country (Figure 5). Of this number, 88 (~60%) sites are protected areas, 48 sites are off-protected (including wetlands) and 10 sites are sacred groves. With the exception of two sites (Muni-Pomadze Ramsar site and Wli/Agumatsa proposed protected area) which have had multiple taxonomic studies on multiple taxa, the remaining non-protected sites have been studied only once for single taxa. Eight out of 10 sacred groves were solely studied for butterflies, with Okyem and Prako sacred groves being studied for small mammals. While acknowledging that several unpublished studies (for example, student thesis, etc.) may be available, this study reveals that only about 32% of the protected areas have had taxonomic studies over the past two decades. Fifty-four of the protected sites have had single taxa studies (33 birds-only, 11 insects-only, six small mammals-only and four plants-only). Atewa Range, Tano-Nimiri, Krokosua Hills and Draw River Forest Reserves, Bui National Park and Kakum-Assin Attandanso Conservation Area have had studies (multiple for except for herpetofauna) in all taxonomic groups and are thus considered the best known sites.

DISCUSSION

Knowledge gaps

Unlike moths which, despite the availability of large collections of incidence data, has received no systematic study in the country, butterflies in the country have been well-studied (examples are Larsen, 2005; Bossart et al., 2007; Merek and Doku-Marfo, 2009; Larsen et al., 2009; Bossart and Opuni-Frimpong, 2009; Nganso et al., 2012; Aduse-Poku et al., 2012). Butterfly studies have concentrated on only 42 protected areas and seven sacred groves (Table 1). Apart from the rough estimates of butterfly richness for different vegetation types (Table 3), the effects of many anthropogenic land-use systems on the diversity of butterflies still remain unknown.

Despite the new findings available, wide knowledge gaps still exist in all taxonomic groups as previously highlighted in the literature (Ministry of Environment and Science, 2002; Ghana's Report, 2009). In particular, non-lepidopteran insects need to be prioritized in biodiversity studies. These insects, apart from being good indicators of environmental change (Ansah, 2005; Larsen, 2005; Naskrecki, 2007; Kolo et al., 2011), play immense roles in nutrient recycling through wood and leaf litter degradation, soil turnover, dung and carrion disposal, as well as serving as primary food for many animals (Ansah, 2005). However, although a large collection of occurrence data is available in different museum collections outside the country, only a few studies have been conducted on these insects over the last two decades because of taxonomic difficulties (Ansah, 2005; Naskrecki, 2007; Oteng-Yeboah et al., 2009). The fact that approximately 84% of the occurrence records were made more than three decades ago indicates that these arthropods have generally become less popular in recent biodiversity studies. The Coleoptera (largest insect order), for example, has been studied only once over the last decade, and only the Ankasa Conservation Area was covered (that is, Davis and Philips, 2005). Similarly, for Orthoptera, the only recent studies are that of Naskrecki (2007, 2009) which recorded 61, 50 and 33 species of Tettigonioidea from Atewa Range, Ajenjua Bepo and Mamang River Forest Reserves, respectively.

The order Hymenoptera has also had only two recent studies. Belshaw and Bolton (1994) recorded 197 species from 20 different sites with varying vegetation types throughout the forest and transition zones of the country, while Kolo and Hormenyo (2009) recorded 125 species comprising of 98 species from Ajenjua Bepo and 101 species from Mamang River forest reserves. In addition, Deikumah and Kudom (2010) sampled over 15000 individuals from forest patches in Cape Coast and classified them into 52 families, while Ansah (2005) recorded 60, 54 and 49 species from Boin-Tano, Krokosua Hills and Draw River forest reserves, respectively. The other taxonomic orders have not been studied in recent years.

Reptiles and amphibians have also recorded mostly single studies in very few areas of the country and thus need to be given more attention in future studies. Plant diversity, though considered well-known on the basis on extensive work done several decades ago, needs to be studied with particular attention to the savanna zone which is poorly known (Ayensu et al., 1996). With the exception of Asase and Oteng-Yeboah (2007) and Tom-Dery et al. (2012; 2013), no other recent, relevant studies on plant diversity in the savanna zone are available. Already, some studies have looked at the plant conservation roles of land-use systems such as mixed crop and cocoa agroforestry by comparing species richness of plants in these systems with species richness of plants in adjacent protected areas (examples are Asase and Tetteh, 2010; Anglaaere et al., 2011; Boakye et al., 2012). However, despite being limited to only few land-use systems, the proximity of these agroforestry systems to the protected areas enhances easy colonization of native species, and hence their outcomes may have been biased towards agroforestry systems since species richness of most widespread species increases significantly in disturbed land-use systems (Waltert et al., 2011).

Birds are also well-known, but unlike plants, knowledge regarding their diversities and distribution over human-dominated land-use systems is almost non-existent. Having lost virtually all forests outside the protected areas which, for centuries past, supported the traditional shifting cultivation system of farming, efforts towards documenting and managing biodiversity in off-reserve areas for continued provision of goods and services for human well-being has become necessary. This knowledge gap is also stated in Ghana Report (2009) as follows: "It is hoped that the other areas, such as in off-reserves where no management regimes or plans are in place, will receive adequate attention to become good sources for national indication of successful implementtation of the convention. This achievement will clearly show how biodiversity has been mainstreamed into the society". At present, biodiversity knowledge in off- reserve

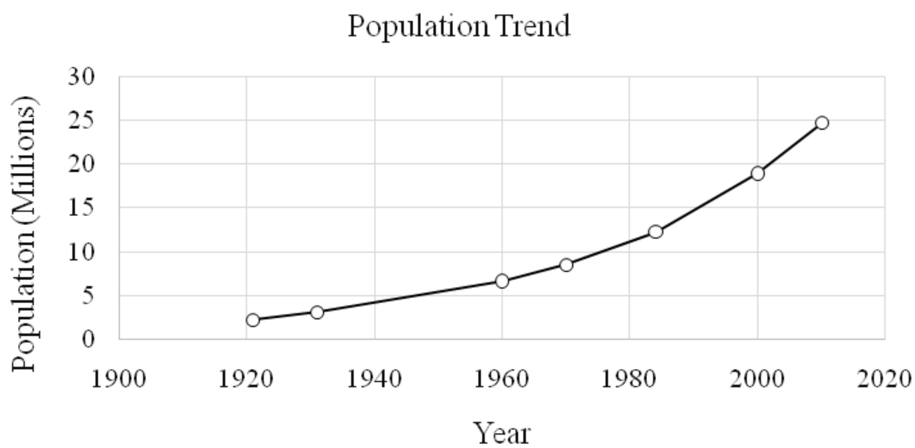

Figure 6. Ghana's population trend 1921–2013. Data Source: Ghana Statistical Service (2013).

Table 8. Land-use share of Ghana's land area.

Land-use	Share of area (km^2)	Cover
Protected Areas	35 814.14[#]	15.0%
Area under cultivation	155 000.00[*]	64.9%
Inland water area	11 000.00[§]	4.6%
Others (Fallow, pastures, sacred groves, etc.)	36 946.64	15.5%
Total	238 760.78[+]	100.0%

Sources: [*]CountryStat Ghana (2014); [#]IUCN and UNEP-WCMC (2013); [§]Ministry of Food and Agriculture (2011); [+]Maplibrary (2013).

areas is too poor and needs attention.

Drivers of biodiversity loss

Ghana is no exception to the present global crisis of biodiversity loss (Myers et al., 2000; Brook et al., 2006). First of all, the population of the country has been increasing (Figure 6) and this has negative effects on biodiversity (Sarkar, 1999; Luck, 2007; Cincotta et al., 2000; McKee et al., 2003; Laurance et al., 2012; Cai and Pettenella, 2013; Bamford et al., 2014). Between 1960 and 2010, for example, the population of the country more than tripled with an average annual population growth between 1921 and 2010 of 3.3% (Ghana Statistical Service, 2013). Presently, the country's populations stands at 25.9 million (CountryStat Ghana, 2014) and is fed mainly from food production on ~65% of terrestrial land (Table 8).

Agriculture is the largest and the most important sector of the country (Benhin and Barbier, 2001) and has been the main agent of deforestation and land-use intense-fication since the beginning of the 19th Century (Thompson, 1910; Dickson, 1969; Curry-Lindahl, 1969; Benhin and Barbier, 2001). Food production was low and declining between 1960 and 1983 (Figure 7), and domestic food production was supplemented by food imports. Overall increase in the production of the seven major crops over this period was very small, a factor of 1.1. However, following efforts through the Economic Recovery Program to attain self-sufficiency in food production after the 1983 drought (Ofori-Sarpong, 1986; Attuquayefio and Fobil, 2005), the country has seen an increasing annual trend in food production (Figure 7). In contrast to the period prior to 1983, food production over the same number of years increased substantially by a factor 4.1. This increase in food production correspond-dingly resulted in the expansion of the agricultural land area which accelerated the rate of forest loss (Attuquayfio and Fobil, 2005). Twenty-eight years ago, land under cultivation of 30,000 km^2 (Ofori-Sarpong, 1986) which represented only 12.5% of the country's terrestrial land is today 5.2 times more. From FAO's 52-year time-series for the period 1960 - 2012, the country's annual crop yield and harvested area which indicate increasing trends are shown in Table 9, Figures 7 and 8.

Of the present land under cultivation, cocoa (24%),

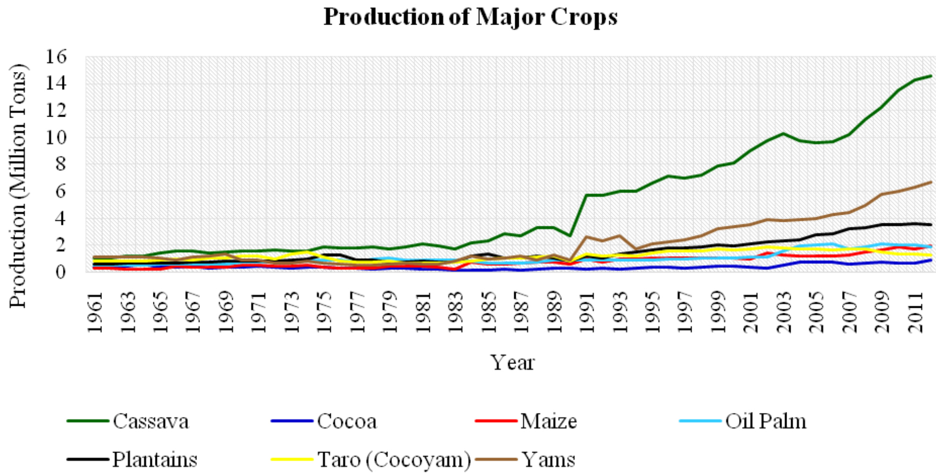

Figure 7. Trends in annual production of major crops in Ghana (Source of data: FAO 2014).

Table 9. Summarized statistics on major crops in Ghana

Crop	2012 Yield (tons)	2012 Harvested area (Square km)	Mean annual change (1961 – 2012) (%)	
			Yield	Harvested area
Cassava	14 547 279	8 685.50	+6.3	+4.4
Yams	6 638 867	4 263.43	+6.8	+4.2
Plantains	3 556 524	3 372.93	+4.5	+3.1
Maize	1 949 897	10 420.83	+10.3	+4.8
Oil Palm	1 900 000	3 500.00	+3.2	+4.0
Taro (Cocoyam)	1 270 266	1 963.28	+2.1	+5.5
Cocoa	879 348	16 003.00	+3.1	+0.6

Source: FAO, 2014.

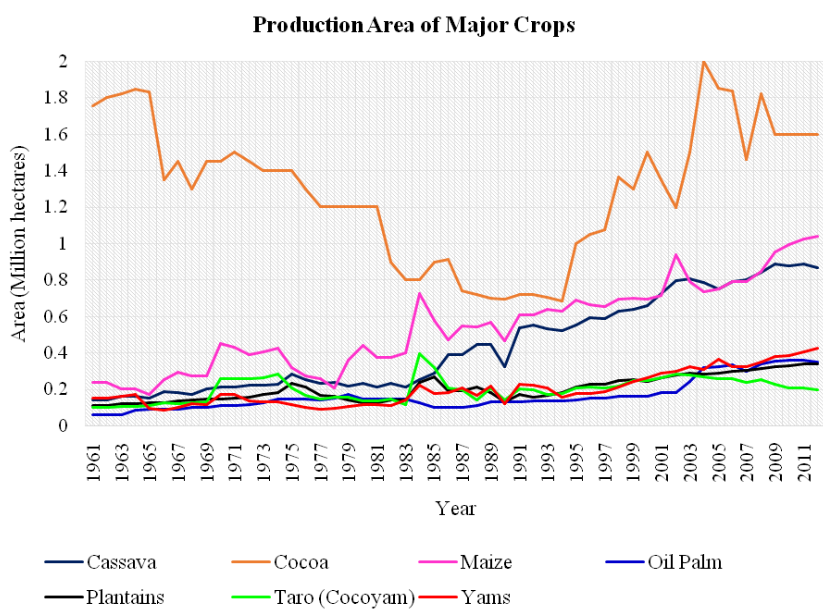

Figure 8. Trends in harvested area of major crops in Ghana (Source of data: FAO 2014).

maize (18%), cassava (13%) and yam (9%) alone occupy 63% (CountryStat Ghana, 2014). Despite the forest loss (Benhin and Barbier, 2001; Laurance et al., 2012), land-use intensification (Benton et al. 2003; Hansen and DeFries 2007; Cai and Pettenella 2013), bush burning (Birnin-Yauri and Aliero, 2008; Thompson, 1910), etc. associated with annual food crop cultivation, cocoa cultivation, the dominant agricultural activity in terms of land coverage, is problematic to biodiversity conservation because of its associated farming practices such as insecticide spraying (Padi and Owusu, 2003; Afrane and Ntiamoah, 2011; Tscharntke et al., 2012; Schiesari et al., 2013) and the elimination of other water-competing or pest-hosting plants (N'goran, 1998). Crop production has been restricted to the forest and the forest-savanna transition regions of the country due to land suitability. However, comparison between land under crop cultivation and suitable land indicates that in the future, production increases in crops cannot depend on area expansion (Breisinger et al., 2008). With no hope of expansion in cropland, further land-use intensification is expected if food sufficiency is to be attained.

Further land-use intensification could potentially have ecological (taxonomic and functional) decay consequences on both off-reserve biodiversity and on biodiversity inside protected reserves (Baillie et al., 2000; Hansen and DeFries, 2007; Laurance et al., 2012; Cai and Pettenella, 2013; Hamilton et al., 2013). Land-use effects on protected areas include reduction in effective size and alteration of ecological flows (Curran et al., 2004; Hansen and DeFries, 2007), and disruption of source-sink dynamics of ecosystems though the elimination of unique source habitats (Hansen and Rotella, 2002; Hansen and DeFries, 2007), edge effects (Hansen and DeFries, 2007; Bossart and Opuni-Frimpong, 2009; Laurance et al., 2012), increasing reserve isolation (Laurance et al., 2012) and reduction in habitat amount (Fahrig, 2013). In human-dominated land-use systems, ecological processes such as dispersal which naturally promote biodiversity could lead to population reduction and subsequently range contraction (Baillie et al., 2000; Benton et al., 2003) as well as landscape homogeneity. This is because dispersal could transport range-restricted species to poor-quality, unfavorable habitats (Benton et al., 2003) and widespread, invasive species to new, favorable habitats where they can spread rapidly. Thus, prioritizing studies that properly map land-use effects on biodiversity is necessary to ensure systematic conservation planning inside and outside protected reserves.

Restoration of degraded forest reserve through natural regeneration

It has been reported that biological recovery and regeneration is high not only for plants in highly degraded areas of the country (Lugo et al., 1993; Decher, 1997; Anyomi et al., 2011; Appiah, 2011; Boakye et al., 2012) including areas that have consistently experienced annual bushfires (Tom-Dery et al., 2013), but also animals (Curry-Lindahl, 1969) in both the savanna and forest zones (Decher and Bahian, 1999). Within a period of 30 to 40 years, forests area which have completely degraded into savanna can be re-established provided those areas are protected from wildfires (Lugo et al., 1993; Decher, 1997). There is sufficient evidence that without further human interferences, degraded areas of the country's forest reserves can potentially undergo natural restoration into forest habitats. This notwithstanding, reforestation of degraded forest reserves is important to speed up biodiversity recovery. However, when exotic species are highly represented, it defeats the purpose of the reserves and violates some of the guidelines contained in the Forestry and Wildlife Policy (Ministry of Lands and Forestry, 1994) of the country.

McCullough et al. (2005) has already described as inappropriate, an attempt to replant degraded parts of the Krokosua Hills Globally Significant Biodiversity Area with *Cedrela odorata*. Larsen (2005) has also described this practice as a means of creating vegetative areas which are effectively biodiversity deserts, for which reason it should not be tolerated. While acknowledging that this practice has some historical support, it should not be considered at this time because there are several studies available on cheaper methods for restoring degraded tropical forests (Lamb et al., 2005; Shono et al., 2007; Holl, 2013).

Conservation campaigns should lead to voluntary participation

For over a century, the desire to preserve wilderness (Sarkar, 1999) and knowledge that loss of natural forest cover causes biodiversity loss, have driven conservation activities worldwide. Protected area systems of conser-vation are examples but their benefits are hardly noticed due to insufficient public knowledge, lack of alternative livelihood support for nearby communities, and the fact that there is almost zero interaction between a majority of the people and these reserves. Often, attempts to involve fringe communities in conservation efforts fail due to biased selection of co-management members, corruption in management and exclusion of locals from promised benefits (Songorwa, 1999; Sarker and Røskaft, 2011). Thus, residents of these communities usually engage in farming activities of varying intensities which gradually extend the agricultural frontier uncontrollably into the buffer zones (Bamford et al., 2014), leaving the protected areas as isolated islands (Sarkar, 1999).

Already, since the year 2000, The Rufford Foundation, a charitable organization based in the UK, has funded over 40, one-year duration biodiversity conservation projects costing over £260000 in the country (http://www.rufford.org/projects/byCountry/GH) (Table 10). These projects, together with several other short and

Table 10. Summary of conservation projects sponsored by The Rufford Foundation. The number of studies under each item is in brackets.

Target Audience	Conservation Target
Community conservation (24)	Habitat conservation/restoration (12)
General public (14)	Amphibians (11)
Students (6)	Primates (4)
Commercial drivers (1)	Medicinal plants (3)
	Bats (3)
Conservation Status	Conservation conflict resolution (2)
Threatened species (16)	Birds (2)
Non-threatened species (18)	Reptiles (2)
Not applicable (11)	Other plants (2)
	Fungi (1)
Study Area Type	Pangolins (1)
Reserved forests (26)	General (8)
Ramsar site (3)	
Plant garden (3)	
Others (13)	

long-term biodiversity conservation projects including the Northern Savanna Biodiversity Conservation Project, Ghana High Forest Biodiversity Conservation Project and the West African Primate Conservation Action, are reported to have achieved varying degrees of success. However, only a handful of them included alternative livelihood programs. Certainly, this deficiency makes them unsustainable because they would not get the continued local support (Songorwa, 1999; Sarker and Røskaft, 2011). In local communities, most people (perhaps greater than 90%) depend fully on farming for food, and resource extraction for other needs related to fuel, shelter and health. Therefore, running educational campaigns of “no-entry” into reserves contribute very little, if not nothing, to conversation because no one without the basic survival needs will truly show interest in such conservation messages (Sarker and Røskaft, 2011). There is the need to build a better conservation strategy which attracts the voluntary participation of the least-income earners (Kumaraswamy and Kunte, 2013).

As long as off-reserve biological resources remain inadequate to meet basic needs like meat, firewood, roofing materials, etc, of the poor, no amount of protection can prevent them from illegally operating within the protected areas as already observed (Belshaw and Bolton, 1994; Ntiamoa-Baidu et al., 2001; Decher et al., 2005; Rödel et al., 2005; McCullough et al., 2005; Abeney et al., 2008; Addo-Fordjour et al., 2009; Naskrecki, 2009; Larsen et al., 2009; Ghana Report, 2009; Demey, 2009; IUCN/PACO, 2010; Buzzard and Parker, 2012; The Proforest Initiative, 2012; Tollenaar, 2012; Tom-Dery et al., 2013). This should be expected because the people will naturally continue to eke out their living from nature in order to survive. The evidence in support of this is the scarcity of small and medium-sized mammals within the country (Curry-Lindahl, 1969; Asibey, 1974; Ntiamoa-Badu et al., 2001; Larsen, 2005).

Given the present low protection of protected areas, alternative solutions which allow quota-based hunting (Songorwa, 1999; Kangalawe and Noe, 2012), firewood and other resource extraction in legally-designated areas (Sarker and Røskaft, 2011), as well as financial incentives for reserve protection (Sarker and Røskaft 2011) should be considered. The need to monitor and rid such systems of improper management and corruption (Songorwa, 1999; Sarker and Røskaft, 2011) is also essential. Moreover, there is the need to support studies which seek to identify threatened species and their distribution ranges so that location-based educational campaigns could be launched. Such campaigns should educate the target groups to properly understand the consequences of their continued dependence on such species using relevant research findings as well as similar cases from other locations. As a long-term project, primary, secondary and tertiary educational institutions should be considered effective vehicles for promoting the spirit of biodiversity conservation (Anyomi et al., 2008). Without these measures, it would be difficult to attract peoples’ voluntary participation in conservation projects and all efforts will break down at some point as population increases.

Insects need to be prioritized in biodiversity studies

As discussed above and also in previous publications (Anyomi et al., 2008; Boshier et al., 2011), the situation of *T. gentii* and *S. fimbrisepala* brings into focus the thought that the country, like other tropical countries, could be experiencing several unknown losses, and perhaps mass extinctions (Sodhi et al., 2009), of several important species because of the present gaps in relevant information. Already, Larsen (2006) has reported that one out of 10 insect species found in Ghana could be new to science, and thus significant effort need to be put into finding out the ecological status of the insect groups whose ecology and distribution across different land-use systems in the country is largely unknown.

The lack of insect taxonomists as already reported (Ansah, 2005; Naskrecki, 2007; Oteng-Yeboah, et al. 2009) deserves urgent consideration but should not be a setback to ecological knowledge acquisition. As Hobson (2014) points out "the first step to solving any problem is to not hide from it…" and besides, insects have a myriad of characteristics which make them strong candidates as species surrogates in studies that quantify the effects of environmental changes on biological systems. Insects are globally ubiquitous (Bossart and Opuni-Frimpong, 2009), are highly sensitive to anthropogenic and climatic disturbances (Kremen et al., 1993; Oliver and Beattie, 1996; Ward and Lariviere, 2004; Natural Resources Canada, 2010; Koch et al., 2013) and have large species assemblages (Beccaloni and Gaston, 1995; Natural Resources Canada, 2010) which allows them to broaden the scope of ecosystem factors that can be perceived (Kremen et al., 1993). They also contribute more than 90% of genetic variability (Duelli, 1997), they are tractable study species (Morris, 2010), they provide early warning of ecological changes (Kremen et al., 1993), they have high rate of endemism and speciation (Bossart and Opuni-Frimpong, 2009), and their diversity is highly correlated with that of vertebrates (Caro, 2010).

Besides the many desirable characteristics of insects, the taxonomic impediment could be overcome by identifying individuals to genus level (Caro, 2010). For rapid assessments (and in cases of financial constraints), careful identification to morphospecies by non-experts with basic training has been tested and proved to be sufficient (Oliver and Beattie, 1993, 1996, 1997; Ward and Lariviere, 2004; Obrist and Duelli, 2010; Derraik et al., 2002, 2010), even though this method has been criticized (Goldstein, 1997; Krell, 2004). Fortunately, countries such as Switzerland, Australia, New Zealand, Canada, etc., have already made great advances in using insects for biodiversity monitoring and their experience is an asset.

The need for data-driven conservation plans

The need to seek knowledge on the state of biodiversity in human-dominated land-use systems cannot be overem-phasized (Kumaraswamy and Kunte, 2013), even though diversity is generally known to be low in these systems (Larsen, 2005; Davis and Philips, 2005; Bossart and Opuni-Frimpong, 2009). Landscape-scale studies which describe changes across different biodiversity groups in relation to land-use have become necessary in order to fill in knowledge gaps (Norris et al., 2010; Kumaraswamy and Kunte, 2013). Because it takes years of observation to record a significant amount of species, focus should be on the effects of the interaction between these systems and biodiversity (Ntiamoa-Baidu et al., 2000; Larsen, 2005). The outcome of such studies is the identification of a set of land-use activities for different areas which conserve different sets of ecologically-important species (Kumaraswamy and Kunte, 2013). This knowledge is necessary for off-reserve biodiversity conservation. Essentially, as areas get degraded some species adapt to the changes while others do not, and enrichment of these areas is possible under better land-use management (Tscharntke et al., 2012).

It is increasingly becoming clear that the protected area system of biodiversity conservation needs to be complemented by off-reserve conservation in order to make it more effective (Hansen and DeFries, 2007; Anand et al., 2010; Brussaard et al., 2010; Plieninger and Gaertner, 2011; Cai and Pettenella, 2013; Fahrig, 2013; Kumaraswamy and Kunte, 2013). Innovative land-use programmes for both crop yield improvement and farmland biodiversity conservation based on well-formulated policies should therefore be pursued (Benton et al., 2003; Anand et al., 2010; Kumaraswamy and Kunte, 2013; Baral et al., 2014). This naturally leads to a system in which food security for all people and biodiversity conservation are jointly achieved (Brussaard et al., 2010; Tscharntke et al., 2012). Thus, the problem of biodiversity conservation is a constrained optimization problem which cannot be solved in a vacuum, but must be linked with the food security of the lowest income earners (Tscharntke et al., 2012).

Adequate quality agro-ecological data is needed (Kumaraswamy and Kunte, 2013). Fortunately, the freely available high-resolution global land-use/cover products (for example, Gong et al., 2013; (http://data.ess.tsinghua.edu.cn/); Wang et al. 2014, etc) can be utilized in landscape-scale ecological assessments (for example, Fuller et al., 1998; Reidsma et al., 2006; Baral et al., 2014) to obtain the necessary ecological data, despite the belief that variability in farmland size make this pursuit difficult (Kumaraswamy and Kunte, 2013). Given data on agricultural variables, a locally-suitable, optimized land-use management solution can be developed. Already, the traditional systems of farming practiced predominantly in the northern regions of the country and Burkina Faso, in which native woody plants are interspersed with crops, and cocoa farming systems in the forest zone have ideal features that could facilitate easy integration into optimized land-use plans (also known as offset mechanisms; Kumaraswamy and Kunte, 2013). As Tscharntke et al. (2012) have indicated, biodiversity conservation and environmental cost minimization are achievable in the tropics amidst agro-ecological intensification.

Conflict of Interests

The author(s) have not declared any conflict of interests.

ACKNOWLEDGEMENTS

Many thanks to the managements of Global Biodiversity Information Facility, AVIBASE, African Bird Club, AmphibiaWeb, The Reptile Database, African Butterfly Database, Afromoth, Orthoptera Species File and the IUCN's Red List of Threatened Species, and all their numerous contributors for making their data freely available. Thanks also go to two anonymous reviewers for their useful comments and suggestions. The author was supported by a research grant from Tsinghua University.

REFERENCES

Aalangdong OI (2009). Rapid Assessment of Large Mammals in the Ajenjua Bepo and Mamang River Forest Reserves in the Abirem North District, Eastern Region, Ghana. Conserv. Int.

Abeney EA, Obiri BD, Nutakor E, Oduro W, Boateng GO (2008). Social and environmental impact assessment of the FORM agro-forestry project in Asubima Forest Reserve, Ghana. Form International, The Netherlands.

Addo-Fordjour P, Anning AK (2008). Diversity and distribution of climbing plants in a semi-deciduous rain forest, KNUST Botanical Garden, Ghana. Int. J. Bot. 4(2):186-195.

Addo-Fordjour P, Obeng S, Anning AK, Addo MG (2009). Floristic composition, structure and natural regeneration in a moist semi-deciduous forest following anthropogenic disturbance and plant invasion. International. J. Biodivers. Conserv. 1(2):21-37.

Addo-Fordjour P, Rahmad ZB, Amui J, Pinto C, Dwomoh M (2012). Patterns of liana community diversity and structure in a tropical rainforest reserve, Ghana: effects of human disturbance. Afr. J. Ecol. 51:217-227.

Aduse-Poku K, Doku-Marfo E (2007). A rapid survey of butterflies in the Atewa Range Forest Reserve, Ghana. In: McCullough et al (eds) A Rapid Biological Assessment of the Atewa Range Forest Reserve, Eastern Ghana. RAP Bulletin of Biological Assessment 47. Conservation International. Arlington, VA

Aduse-Poku K, Oduro W, Oppong SK, Larsen T, Ofori-Boateng C, Molleman F (2012). Spatial and temporal variation in butterfly biodiversity in a West African forest: lessons for establishing efficient rapid monitoring programmes. Afr. J. Ecol. 50:326-334.

Afrane G, Ntiamoah A (2011). Use of pesticides in the cocoa industry and their impact on the environment and the food chain. In: Stoytcheva (eds) Pesticides in the modern world – risks and benefits. InTech, Rijeka, Croatia.

AmphibiaWeb (2014). Information on amphibian biology and conservation [online]. Berkeley, California. Available from: http://amphibiaweb.org/. Accessed 18 Feb 2014.

Anand MO, Krishnaswamy J, Kumar A, Bali A (2010). Sustaining biodiversity conservation in human-modified landscapes in the Western Ghats: Remnant forests matter. Biol. Conserv. 143:2363-2374.

Anglaaere LCN, Cobbina J, Sinclair FL, McDonald MA (2011). The effect of land use systems on tree diversity: farmer preference and species composition of cocoa-based agroecosystems in Ghana. Agroforest. Syst. 81:249-265.

Ansah F (2005). Rapid assessment of insects (excl. butterfly) of Draw River, Boi-Tano and Krokosua Hills. In: McCullough et al (eds) A biological assessment of the terrestrial ecosystems of the Draw River, Boi-Tano, Tano Nimiri and Krokosua Hills forest reserves, southwestern Ghana. RAP Bulletin of Biological Assessment 36. Conservation International, Washington, DC

Anyomi KA, Anthony EK, Kpodo E, Amoaku S (2008). Beyond protective status; what next? Current knowledge on Talbotiella gentii (Hutch & Greenway), an endemic species in Ghana. The Rufford Foundation, UK

Anyomi, KA, Pelz, DR, Kyereh, B, Anglaaere, LCN (2011). Influence of age and cropping system on tree population structure in South West Ghana. Afr. J. Agric. Res. 6(4):873-881.

Appiah M (2011). Changes in plant species composition in within a planted forest in a deciduous agroecosystem in Ghana. Agroforestry Systems, DOI 10.1007/s10457-011-9459-3.

Appiah M (2013). Tree population inventory, diversity and degradation analysis of a tropical dry deciduous forest in Afram Plains, Ghana. Forest Ecol. Manag. 295:145-154.

Asase A, Oteng-Yeboah AA (2007). Assessment of plant biodiversity in Wechiau Community Hippopotamus Sanctuary in Ghana. Journal of the Botanical Research Institute of Texas 1(1):549-556.

Asase A, Tetteh DA (2010). The role of complex agroforestry systems in the conservation of forest tree diversity and structure in southeastern Ghana. Agrofor. Syst. 79:355-368.

Asibey EOA (1974). Ghana.'s Progress. Oryx. 11:470-475.

Attua EM, Paddi O (2013). Tree species composition, richness and diversity in the northern forest-savanna ecotone of Ghana. J. Appl. Biosci. 69:5437-5448.

Attuquayefio DK (2008). Biodiversity assessment (rodents and avifauna) of five forest reserves in the Brong Ahafo Region, Ghana. Ghana. J. Sci. 48:37-45.

Attuquayefio DK, Fobil JN (2005). An overview of biodiversity conservation in Ghana: challenges and prospects. West Afri. J. Appl. Ecol. 7:1-18.

Attuquayefio DK, Ryan JM (2006). Taxonomic report of small mammals from two coastal wetland (Ramsar) sites in Ghana. West Afr. J. Appl. Ecol. 10(1).

Attuquayefio DK, Wuver AM (2003). A study of bushfires in a Ghanaian coastal wetland: impact on small mammals. West Afr. J. Appl. Ecol. 4:1-11.

Ayensu ES, Adu A, Barnes E (1996). Ghana: biodiversity and tropical forestry assessment. USAID Report (Contract P1O/T641-0110-3-50035), Accra, Ghana.

Baillie SR, Sutherland WJ, Freeman SN, Gregory RD, Paradis E (2000). Consequences of large-scale processes for the conservation of bird populations. J. Appl. Ecol. 37:88-102.

Bamford AJ, Ferrol-Schulte D, Wathan J (2014). Human and wildlife usage of a protected area buffer zone in an area of high immigration. Oryx. 1-10.

Baral H, Keenan RJ, Sharma SK, Stork NE, Kasel S (2014). Spatial assessment and mapping of biodiversity and conservation priorities in a heavily modified and fragmented production landscape in north-central Victoria, Australia. Ecological Indicators 36:552-562.

Barrière P, Nicholas V, Oduro LK (2009). Rapid Survey of the Small Mammals of Ajenjua Bepo and Mamang River Forest Reserves, Ghana. Pages 54-57 In: A Rapid Biodiversity Assessment of the Ajenjua Bepo and Mamang River Forest Reserves, Ghana. Conserv. Int.

Beccaloni GW, Gaston KJ (1995). Predicting Species Richness of Neotropical Forest Butterflies: Ithomiinae (Lepidoptera: Nymphalidae) as Indicators. Biol. Conserv. 71:77-86.

Beier P, Van Drielen M, Kankam BO (2002). Avifaunal collapse in West African forest fragment. Conservation Biology 16(4):1097-1111.

Belshaw R, Bolton B (1993). The effect of forest disturbance on the leaf litter ant fauna in Ghana. Biodiver. Conserv. 2:656-666.

Belshaw R, Bolton B (1994). A survey of leaf litter ant fauna in Ghana., West Africa (Hymenoptera: Formicidae). J. Hymenoptera Res. 3:5-16.

Benhin JKA, Barbier EB (2001). The effects of the structural adjustment program on deforestation in Ghana. Agric. Res. Econ. Review 30(1):66-80.

Benton TG, Vickery JA, Wilson JD (2003). Farmland biodiversity: is habitat heterogeneity the key? Trends Ecol. Evol. 18(4):182-188.

Birnin-Yauri YA, Aliero BL (2008). Implications of bush burning on weed species diversity, population density and organic matter content of the soil in Birnin-Yauri, Kebbi, Nigeria. J. Appl. Sci. Environ. Manag. 12(1):53-55.

Boakye EA, van Gils H, Osei EM, Asare VNA (2012). Does forest restoration using taugya forster tree species diversity? The case of Afram Headwaters Forest Reserve in Ghana. Afr. J. Ecol. 50:319-325.

Boshier D, Dompreh D, Swaine M (2011). Talbotiella gentii: genetic variation and conservation. A case study and teacher's notes In: Boshier, D, Bozzano, M, Loo, J, Rudebjer, P (eds), Forest Genetic Resources Training Guide. Biodiversity International, Rome, Italy.

Bossart JL, Fetzner JF, Rawlins JE (2007). Ghana Butterfly Biodiversity Project [online]. Available from: http://iz.carnegiemnh.org/ghanaBFly/

Accessed: 2 December 2013.
Bossart JL, Opuni-Frimpong E (2009). Distance from edge determines fruit-feeding butterfly community diversity in Afrotropical forest fragments. Environ. Entomol. 38(1):43-52.
Breisinger C, Diao X, Kolavalli S, Thurlow J (2008). The role of cocoa in Ghana.'s future development, Ghana Strategy Support Program Background Paper NO GSSP 0011, International Food Policy Research Institute, USA
Brooks TM, Mittermeier RA, da Fonseca GAB, Gerlach J, Hoffmann M, Lamoreux JF, Mittermeier CG, Pilgrim JD, Rodrigues ASL (2006). Global Biodiversity Conservation Priorities. Science. 313:58-61.
Browne, FG, 1963. Notes on the habits and distribution of some Ghanaian bark beetles and ambrosia beetles (Coleoptera: Scolytidae and Platypodidae). Commonwealth Agricultural Bureaux, 1963.
Brussaard L, Caron P, Campbell B, Lipper L, Mainka S, Rabbinge R, Babin D, Pulleman L (2010). Reconciling biodiversity conservation and food security: scientific challenges for a new agriculture. Environ. Sust. 2:34-42.
Buzzard, PJ, Parker, AJA (2012). Surveys from the Subri River Forest Reserve, Ghana. African Primates 7(2):175-183.
Cai M, Pettenella D (2013). Protecting biodiversity outside protected areas: can agricultural landscapes contribute to bird diversity conservation on Natura 2000 in Italy? J. Environ. Engr. Landscape Manag. 21(1):1-11.
Campbell MO (2005). Sacred groves for forest conservation in Ghana's coastal savanna: addressing ecological and social dimensions. Singapore J. Tropical Geograph 26(2):151-169.
Caro T (2010). Conservation by proxy: indicator, umbrella, keystone and other surrogate species. Island Press, Washington, DC
CountryStat Ghana (2014). Ghana. [online]. Available from: http://www.countrystat.org/homeaspx?c=GHA Accessed 10 Feb 2012, Ghana. Statistical Service, Ghana.
Curran, LM, Trigg, SN, McDonald, AK, et al (2004). Lowland Forest Loss in Protected Areas of Indonesian Borneo. Science (303)1000-1003.
Curry-Lindahl K (1969). Report to the government of Ghana on conservation, management and utilization of Ghana.'s wildlife resources. IUCN, Morges, Switzerland.
Da Fonseca GAB, Balford A, Bibby C, Boitani L, Corsi F, Brooks T, Gascon C, Olivieri S, Mittermeier RA, Burgess N, Dinerstein E, Olson D, Hannah L, Lovett J, Moyer D, Rahbek C, Stuart S, Williams P (2000). …following Africa's lead in setting priorities. Nature 405:393-394.
Davis, ALV, Philips, TK (2005). Effect of deforestation on a southwest Ghana dung beetle assemblage (Coleoptera: Scarabaeidae) at the periphery of Ankasa Conservation Area. Environmental Entomology 34(5):1081-1088.
De Prins J, De Prins W (2014). Afromoths, online database of Afrotropical moth species (Lepidoptera). World Wide Web electronic publication (www.afromots.net) Accessed 24 April 2014.
Decher J, Fahr J (2007). A conservation assessment of bats (Chiroptera) of Draw River, Boi-Tano, Krokosua Hills forest reserves in the Western Region of Ghana. Myotis 43:5-30.
Decher J, Kilpatrick CW, Bahian KL (2001). Small mammal zoogeography and diversity in West African forest remnants. Progress report, Ghana. Wildlife Division.
Decher J, Oppong J, Fahr J (2005). Rapid assessment of small mammals at Draw River, Boi-Tano, Krokosua Hills. In: McCullough et al (eds). A biological assessment of the terrestrial ecosystems of the Draw River, Boi-Tano, Tano Nimiri and Krokosua Hills forest reserves, southwestern Ghana. RAP Bulletin of Biological Assessment 36. Conserv. Int. Washington, DC.
Decher, J (1997). Conservation, small mammals, the future of sacred groves in West Africa. Biodivers Conserv. 6:1007-1026.
Decher, J, Bahian, LK (1999). Diversity and structure of terrestrial small mammal communities in different vegetation types on the Accra Plains of Ghana. J. Zool. 247:395-408.
Deikumah JP, Kudom AA (2010). Biodiversity status of urban remnant forests in Cape Coast, Ghana. J. Sci. Technol. 30(3):1-8.
Demey R (2009). Rapid survey of the birds of Ajenjua Bepo and Mamang River forest reserves, Eastern Region of Ghana. Pages 50-53, In: A Rapid Biodiversity Assessment of the Ajenjua Bepo and Mamang River Forest Reserves, Ghana. Conserv. Int.
Demey R, Ossom W (2007). A rapid assessment of the birds of the Atewa Range Forest Reserve, Ghana. In: McCullough et al (eds) A Rapid Biological Assessment of the Atewa Range Forest Reserve, Eastern Ghana. RAP Bulletin of Biological Assessment 47. Conservation International, Arlington, VA
Derraik JGB, Early JW, Closs GP, Dickinson KJM (2010). Morphospecies and Taxonomic Species Comparison for Hymenoptera. J. Insect Sci. 10:1-7.
Derraik, JGB, Closs, GP, Dickinson, KJM, Sirvid, P, Barratt, BIP, Patrick, BH (2002). Arthropod morphospecies versus taxonomic species: a case study with Araneae, Coleoptera, Lepidoptera. Conservation Biology 16:1015-1023.
Deschner T, Kpelle DG (2005). Rapid assessment of the primates of Draw River, Boi-Tano and Krokosua Hills. In: McCullough et al (eds). A biological assessment of the terrestrial ecosystems of the Draw River, Boi-Tano, Tano Nimiri and Krokosua Hills forest reserves, southwestern Ghana. RAP Bulletin of Biological Assessment 36. Conservation International, Washington, DC
Dickson, KB (1969). A historical geography of Ghana. Cambridge University Press, London.
Dornelas M, Gotelli NJ, McGill B, (2014). Assemblage Time Series Reveal Biodiversity Change but Not Systematic Loss. Science 344:296-299.
Dowsett RJ, Atkinson PW, Caddick JA (2014). Checklist of the birds of Ghana. [online]. Available from www.africanbirdclub.org Accessed 15 April 2014
Dowsett-Lemaire F, Dowsett RJ (2010). Avifauna of Bui National Park in western Ghana. Malimbus. 32:1-21.
Duelli P (1997). Biodiversity evaluation in agricultural landscapes: An approach at two different scales. Agriculture, Ecosystems and Environment 62 (2-3):81-91.
Eades DC, Otte D, Cigliano MM, Braun H (2014). Orthoptera Species File. Version 5.0/5.0. http://orthoptera.speciesfile.org. Accessed 24 April 2014.
Ekpe P (2005). Rapid assessment of plant biodiversity of sections of Draw River, Boi-Tano and Krokosua Hills forest reserves in Ghana. In: McCullough et al (eds). A biological assessment of the terrestrial ecosystems of the Draw River, Boi-Tano, Tano Nimiri and Krokosua Hills forest reserves, southwestern Ghana. RAP Bulletin of Biological Assessment 36. Conservation International, Washington, DC
Emmel TC, Larsen TB (1997). Butterfly diversity in Ghana, West Africa. Tropical Lepidoptera 8 (Suppl. 3):1-13.
Ernst R, Agyei AC,
Fahrig L (2013). Rethinking patch size and isolation effects: the habitat amount hypothesis. J. Biogeograph. 40:1649-1663.
Garshong RA, Attuquayefio DK, Holbech LH, Adomako JK (2013). Distribution and abundance of small mammals of small mammals in different habitat types in the Owabi Wildlife Sanctuary, Ghana. J. Ecol. Nat. Environ. 5(5):83-87.
Ghana Report (2009). CBD fourth national report – Ghana. Secretariat of the Convention on Biological Diversity, Montreal, Canada.
Ghana Statistical Service (2013). 2010 Population and Housing Census: National Analytical Report. Ghana Statistical Service, Ghana.
Goldstein PZ (1997). How Many Things Are There? A Reply to Oliver and Beattie, Beattie and Oliver, Oliver and Beattie, Oliver and Beattie. Conservation Biology 11(2):571-574.
Gong P, Wang J, Yu L, Zhao YC, Zhao YY, Liang L, Niu Z, Huang X, Fu H, Liu S, Li C, Li X, Fu W, Liu C, Xu Y, Wang X, Cheng Q, Hu, L, Yao W, Zhang H, et al. (2013). Finer resolution observation and monitoring of global land cover: first mapping results with Landsat TM and ETM+ data. Int. J. Remote Sensing, 34(7):2607-2654.
Granier N, Awotwe-Pratt V (2007). A rapid assessment of primates from Atewa Range Forest Reserve, Ghana. In: McCullough et al (eds) A Rapid Biological Assessment of the Atewa Range Forest Reserve, Eastern Ghana. RAP Bulletin of Biological Assessment 47. Conservation International, Arlington, VA
Hall JB, Swaine MD (1976). Classification and ecology of closed-canopy forest in Ghana. J. Ecol. 64(3):913-951.
Hansen AJ, DeFries R (2007). Ecological mechanisms linking protected areas to surrounding lands. Ecological Applications 17(4):974-988.
Hansen AJ, Rotella JJ (2002). Biophysical factors, land use, species

variability in and around nature reserves. Conserv. Biol. 16(4):1112-1122.
Hillers A, Boateng CO, Agyei AC, Rödel MO (2007). Assessment of endangered and endemic amphibians in the forests of southern Ghana [online]. Available at: http://www.cepf.net/Documents/final_Hillersetal_amphibians_southernGhana.pdf Accessed 10 Jan 2014.
Hobson M (2014). Color blind or color brave? [Online video]. Available at: https://www.ted.com/talks/mellody_hobson_color_blind_or_color_brave (Accessed 15 April 2014).
Holbech LH (2005). The implications of selective logging and forest fragmentation for the conservation of avian diversity in evergreen forests of south-west Ghana. Bird Conserv. Int. 15:27-52.
Holl KD (2013). Restoring Tropical Forest. Nature Education Knowledge 4(4).
Hughes B (1988). Herpetology in Ghana. (West Africa). British Herpetological Society Bulletin 25:29-38.
Hunter ML, Hutchinson A (1994). The Virtues and Shortcomings of Parochialism: Conserving Species That Are Locally Rare, but Globally Common. Conservation Biology 8(4):1163-1165.
IUCN (2013). IUCN Red List of Threatened Species. Version 2013.2 [online]. Available from: www.iucnredlist.org Accessed 18 Feb 2014.
IUCN and UNEP-WCMC (2013). The World Database on Protected Areas (WDPA) [On-line]. Cambridge, UK: UNEP-WCMC Available at: www.protectedplanet.net Accessed 10 November 2013.
IUCN/PACO (2010). Parks and reserves of Ghana: Management effectiveness assessment of protected areas. Ouagadougou, Burkina Faso, IUCN/PACO
Jeffrey SM (1977). Rodent ecology and land use in Western Ghana. J. Appl. Ecol. 14:741-755.
Jongkind CCH (2007). The botanical diversity of the Atewa Range. In: McCullough et al (eds) A Rapid Biological Assessment of the Atewa Range Forest Reserve, Eastern Ghana. RAP Bulletin of Biological Assessment 47. Conservation International, Arlington, VA
Kangalawe RYM, Noe C (2012). Biodiversity conservation and poverty alleviation in Namtumbo District, Tanzania. Agric. Eco. Environ. 162:90-100.
Koch K, Wagner C, Sahlen G (2013). Farmland verses forest: comparing changes in Odonata species composition in western and eastern Sweden. Insect Conservation and Diversity, doi: 10.1111/icaD12034
Kolo Y, Hormenyo A (2009). Rapid Survey of the Ants of Ajenjua Bepo and Mamang River Forest Reserves, Ghana. Pages 27 – 29, In: A Rapid Biodiversity Assessment of the Ajenjua Bepo and Mamang River Forest Reserves, Ghana. Conserv. Int.
Kolo Y, Konate S, Tiho S, Camara SK (2011). Impacts of land use types on ant communities in a tropical forest margin (Oumé – Côte d'Ivoire). Afr. J. Agric. Res. 6(2):260-274.
Krell FT (2004). Parataxonomy vs taxonomy in biodiversity studies – pitfalls and applicability of 'morphospecies' sorting. Biodiver. Conserv. 13:795-812.
Kremen C, Colwell RK, Erwin TL, Murphy DD, Noss RF (1993). Terrestrial Arthropod Assemblages: Their Use in Conservation Planning. Conserv. Biol. 7 (4):796-808.
Kumaraswamy S, Kunte K (2013). Integrating biodiversity and conservation with modern agricultural landscapes. Biodivers. Conserv. 22:2735-2750.
Lachat T, Attignon S, Djego J (2006). Arthropod diversity in Lama Forest reserve (South Benin), a mosaic of natural, degraded and plantation forests. Biodivers. Conserv. 15:3-23.
Lamb D, Erskine PD, Parrotta JA (2005). Restoration of degraded tropical forest landscapes. Science 310:1628-1632.
Larsen TB (1994). The butterflies of Ghana and their implications for conservation and sustainable use. Ghana butterfly report, Wildlife Department, Ghana.
Larsen TB (2005). Rapid assessment of butterflies on Draw River, Boi-Tano and Krokosua Hills. In: McCullough, et al (eds) (2005) A biological assessment of the terrestrial ecosystems of the Draw River, Boi-Tano, Tano Nimiri and Krokosua Hills forest reserves, southwestern Ghana. RAP Bulletin of Biological Assessment 36. Conservation International, Washington, DC
Larsen TB (2006). The butterflies of Kyabobo National Park, Ghana and those of the Volta Region. Ghana. Wildlife Division Support Project (WDSP Report NO 64).
Larsen TB, Adusei-Poku K, Sáfián Sz (2009). The Butterflies of Boabeng-Fiema Monkey Sanctuary - Biodiversity and Extinction in a Forest Fragment in Ghana. Afr. Entomol. 17(2):131-146.
Laurance WF, Useche DC (2012). Averting biodiversity collapse in tropical forest protected areas. Nature, doi:10.1038/nature11318.
Leaché AD, Rödel MO, Linkem CW, Diaz RE, Hillers A, Fujita MK (2006). Biodiversity in a forest island: reptiles and amphibians of the West African Togo Hills. Amphibian and Reptile Conservation 4(1):22-45.
Leaché, AD (2005). Results of a Herpetological Survey in Ghana and a New Country RecorD Herpetological Review 36(1):16:19.
Lepage D (2014). Checklist of birds of Ghana. [online]. Avibase, the world bird database. Available from: http://avibase.bsc-eoc.org/avibasePDF/checklist.pdf?region=gh&list=clements&lang=EN&obs=no&format=2 (Accessed 17 Feb 2014).
Luck GW (2007). A review of the relationships between human population density and biodiversity. Biological Reviews 82(4):607-645.
Lugo AE, Parrotta JA, Brown S (1993). Loss in Species Caused by Tropical Deforestation and Their Recovery through Management. Ambio 22(2-3):106-109.
Mace GM, Balford A (2000). It's time to work together and stop duplicating conservation efforts…. Nature 405, 393.
Manu AP (2011). Biodiversity monitoring of Asubima and Afrensu Brohuma Forest Reserves, Ghana. Form International, The Netherlands.
Maplibray (2013). Ghana. [online]. Available from: www.maplibrary.org [Accessed: 15 Nov 2013].
McCullough J, Decher J, Kpelle DG (2005). A biological assessment of the terrestrial ecosystems of the Draw River, Boi-Tano, Tano Nimiri and Krokosua Hills forest reserves, southwestern Ghana. RAP Bulletin of Biological Assessment 36. Conservation International, Washington, DC
Mckee JK, Sciulli PW, Fooce CD, Waite TA (2003). Forecasting global biodiversity threats associated with human population growth. Biological Conservation 115(1):161-164.
Ministry of Environment and Science (2002). National Biodiversity Strategy for Ghana. Ministry of Environment and Science, Republic of Ghana.
Ministry of Food and Agriculture (2011). Agriculture in Ghana: facts and figures 2010. Ministry of Food and Agriculture, Ghana.
Ministry of Lands and Forestry (1994). Forest and Wildlife Policy. Ministry of Lands and Forestry, Ghana.
Monney KA, Darkey ML, Dakwa KB (2011). Diversity and distribution of amphibians in the Kakum National Park and its surrounding. International Journal of Biodiversity and Conservation 3(8):358-366.
Morris RJ (2010). Anthropogenic impacts on tropical forest diversity: A network structure and ecosystem functioning perspective. Philosophical Transactions of the Royal Society B 365:3709-3718.
Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GAB, Kent J (2000). Biodiversity hotspots for conservation priorities. Nature 403:853-858.
N'goran GK, Boateng CO, Rödel MO (2007). A rapid survey of amphibians from the Atewa Range Forest Reserve, Eastern Region, Ghana. In: McCullough et al (eds) A Rapid Biological Assessment of the Atewa Range Forest Reserve, Eastern Ghana. RAP Bulletin of Biological Assessment 47. Conservation International, Arlington, VA
N'goran K (1998). Reflections on a durable cacao production system: the situation in Ivory Coast, Africa [online]. Available at: http://nationalzoo.si.edu/scbi/migratorybirds/research/cacao/koffi1.cfm Accessed: 29 December 2013.
Naskrecki P (2007). The katydids of the Atewa Range Forest Reserve, Ghana. In: McCullough et al (eds) A Rapid Biological Assessment of the Atewa Range Forest Reserve, Eastern Ghana. RAP Bulletin of Biological Assessment 47. Conservation International, Arlington, VA
Naskrecki P (2009). A survey of katydids (Insecta: Orthoptera: Tettigonioidea) of Ajenjua Bepo and Mamang River Forest Reserves, Eastern Region of Ghana. Conserv. Int.
Natural Resources Canada (2010). Using insects as biodiversity indicators for the boreal forest. Branching out 62, Canadian Forest Services. Catalog Number Fo113-1/62-2010E-PDF

Nganso BT, Kyerematen R, Obeng-Ofori D (2012). Diversity and abundance of butterfly species in the Abiriw and Odumante sacred groves in the Eastern Region of Ghana. Res Zool. 2(5):38-46.

Norris K, Asase A, Collen B, Gockowski J, Mason J, Phalan B, Wade A (2010). Biodiversity in forest-agriculture mosaic – the changing face of West African rainforests. Biol. Conserv. 143:2341-2350.

Ntiamoa-Baidu Y, Owusu EH, Asamoah S, Owusu-Boateng K (2000). Distribution and abundance of forest birds in Ghana. Ostrich: J. Afr. Ornithol. 71(1-2):262-268.

Ntiamoa-Baidu Y, Owusu EH, Daramani DT, Nuoh AA (2001). Ghana. In: Fishpool, LDC and Evans, MI (eds). Important Bird Areas in Africa and associated islands: Priority sites for conservation. Newbury and Cambridge, UK: Pisces Publications and BirdLife International. (BirdLife Conservation Series NO 11).

O'Connor C, Marvier M, Kareiva P (2003). Biological vs social, economic and political priority-setting in conservation. Ecology Letters 6:706-711.

Obrist M, Duelli P (2010). Rapid biodiversity assessment of arthropods for monitoring average local species richness and related ecosystem services. Biodiver. Conserv. 19:2201-2220.

Ofori BY, Attuquayefio DK, Gbogbo F (2013). Terrestrial small mammal community structure in an anthropogenically-altered moist semi-deciduous forest zone of Ghana. Int. J. Dev. Sust. 2(2):1156-1168.

Ofori BY, Attuquayefio DK, Owusu EH (2012). Ecological status of large mammals of a moist semi-deciduous forest of Ghana: implications for wildlife conservation. J. Biodiver. Environ. Sci. 2(2):28-37.

Ofori-Sarpong E (1986). 1981 – 1983 draught in Ghana. Singapore J. Tropical Geograp. 7(2):108-127.

Oliver I, Beattie AJ (1993). A Possible Method for the Rapid Assessment of Biodiversity. Biodiver. Conserv. 7(3):562-568.

Oliver I, Beattie AJ (1996). Designing a cost-effective invertebrate survey: a test of methods for rapid assessment of biodiversity. Ecological Applications 6 (2), 594 – 607.

Oliver I, Beattie AJ (1997). Future taxonomic partnerships: reply to Goldstein. Conserv. Biol. 11:575-576.

Oteng-Yeboah A, Kwapong P, Cobblah MA, Smith R, Lyal CHC (2009). Ghana's taxonomic needs: the information and expertise required to support agriculture, biodiversity, environment, fisheries and forestry management. BioNET International.

Owusu EH (2007). The ornithological importance of the Amansuri Community Nature Reserve in the Western Region of Ghana. Journal of Science and Technology 27(3).

Owusu EH, Ekpe EK, Asamoah A (2005). Large mammal fauna of the Afadjato and Agumatsa Range in Ghana.: an important bird area. West Afr. J. Appl. Ecol. 8(1).

Padi B, Owusu GK (2003). Towards an integrated pest management for sustainable cocoa production in Ghana. [online]. Available at: http://nationalzoo.si.edu/scbi/migratorybirds/research/cacao/padi.cfm Accessed 30 Dec 2013.

Plieninger T, Gaertner M (2011). Harnessing degraded lands for biodiversity conservation. J. Nat. Conserv. 19:18-23.

Quansah YK (2011). A survey of medium-sized mammals in Asubima Forest Reserve. Form International, BV

Rainey HJ, Asamoah A (2005). Rapid assessment of the birds of Draw River, Boi-Tano and Krokosua Hills. In: McCullough, et al (eds). A biological assessment of the terrestrial ecosystems of the Draw River, Boi-Tano, Tano Nimiri and Krokosua Hills forest reserves, southwestern Ghana. RAP Bulletin of Biological Assessment 36. Conservation International, Washington, DC

Raxworthy CJ, Attuquayfio DK (2000). Heptofaunal communities at Muni Lagoon in Ghana. Biodivers. Conserv. 9:501-510.

Reidsma, P, Tekelenburg, T, van den Berg, M, Alkemade, R, Impacts of land-use change on biodiversity: An assessment of agricultural biodiversity in the European Union. Agriculture, Ecosystems and Environment 114:86-102.

Rödel MO (2005). Herpetological assessment of Draw River, Boi-Tano and Krokosua Hills. In: McCullough, et al (eds). A biological assessment of the terrestrial ecosystems of the Draw River, Boi-Tano, Tano Nimiri and Krokosua Hills forest reserves, southwestern Ghana. RAP Bulletin of Biological Assessment 36. Conservation International, Washington, DC

Rödel MO, Agyei AC (2003). Amphibians of the Togo – Volta highlands, Eastern Ghana. Salamandra, Rheinbach 39(3/4):207-234.

Rödel MO, Gil M, Agyei AC, Leaché AD, Diaz RE, Fujita MK, Ernst R (2005). The amphibians of the forested parts of south-western Ghana. Salamandra, Rheinbach 41(3):107-127.

Ryan JM, Attuquayefio D (2000). Mammal fauna of the Muni-Pomadze Ramsar site, Ghana. Biodivers. Conserv. 9:541-560.

Sáfián Sz, Collins, SC, Kormos B, Siklósi A (2009). African Butterfly Database [Version 1.0]. www.abdb-africa.org [Accessed 23/04/2014].

Sam MK, Lokko KO, Akom E, Nyame J (2007). A rapid survey of large mammals from the Atewa Range Forest Reserve, Eastern Region, Ghana. In: McCullough et al (eds) A Rapid Biological Assessment of the Atewa Range Forest Reserve, Eastern Ghana. RAP Bulletin of Biological Assessment 47. Conservation International, Arlington, VA

Sarkar S (1999). Wilderness preservation and biodiversity conservation – keeping divergent goals distinct. BioScience 49(5):405-412.

Sarker AHMR, Røskaft E (2011). Human attitudes towards the conservation of protected areas: a case study from four protected areas in Bangladesh. Oryx 45(3):391:400.

Shono K, Cadaweng EA, Durst PB (2007). Application of assisted natural regeneration to restore degraded tropical forestlands. Restoration Ecology 15(4):620-626.

Songorwa AN (1999). Community-Based Wildlife Management (CWM) in Tanzania: Are the Communities Interested? World Development 27(12):2061-2079.

The Proforest Initiative (2012). Reducing cocoa and palm oil expansion into Ghanaian forests: analysis of implementation and financing gaps The Prince's Rainforests Project.

Thompson HN (1910). Gold Coast Report on Forests. Darling and Sons, London.

Tollenaar M (2012). Social and environmental impact assessment of Afrensu Brohuma Forest Reserve, Ghana. Form International, The Netherlands.

Tom-Dery D, Boakye P, Asante WJ (2012). Woody species richness and abundance in a tropical savanna of Northern Ghana. J. Bot. Res. Inst Texas 6(1):131- 141.

Tom-Dery D, Hinneh P, Asante WJ (2013). Biodiversity in Kenikeni Forest Reserve of Northern Ghana. Afr. J. Agric. Res. 8(46):5896-5904.

Tscharntke T, Clough Y, Wanger TC (2012). Global food security, biodiversity conservation and the future of agricultural intensification. Biol. Conserv. 151:53-59.

Uetz P, Hošek J (2014). The reptile database [online]. Available at: http://reptile-database.reptarium.cz/ Accessed 4 February 2014.

Vordzogbe VV (2011). Mapping of the Kabo River Forest Reserve in Ghana towards Community-Based Fire Management. West Afr. J. Appl. Ecol. 19:119-137.

Vordzogbe VV, Attuquayefio DK, Gbogbo F (2005). The flora and Mammals of the Moist Semi-Deciduous Forest Zone in the Sefwi-Wiawso District of the Western Region, Ghana. West Afr. J. Appl. Ecol. 8(1):40- 54.

Waltert M, Bobo KS, Kuapa S, Montoya ML, Nsanyi MS, Fermon H (2011). Assessing conservation values: biodiversity and endemicity in tropical land use systems. PLoS ONE 6 (1), e16238. doi:10.1371/journaLponE0016238.

Wang J, Zhao Y, Li C, Yu L, Liu D, Gong P (2014). Mapping global land cover in 2001 and 2010 with spatial-temporal consistency at 250m resolution. ISPRS J. Photogrammetry and Remote Sensing. http://dXdoi.org/10.1016/j.isprsjprs.2014.03.007 .

Ward DF, Lariviere MC (2004). Terrestrial invertebrate surveys and rapid biodiversity assessment in New Zealand: lessons from Australia. New Zealand J. Ecol. 28 (1):151-159.

Weber N, Fahr J (2007). A rapid assessment of small mammals from the Atewa Range Forest Reserve, Eastern Region, Ghana. In: McCullough et al (eds) A Rapid Biological Assessment of the Atewa Range Forest Reserve, Eastern Ghana. RAP Bulletin of Biological Assessment 47. Conservation International, Arlington, VA

Weckstein JD, Marks BD, Moyle RG, Johnson KP, Meyer MJ, Braimah J, Oppong J, Amponsah J (2009) Birds recorded from surveys in Ghana's Central and Brong-Ahafo regions. Malimbus. 31:28-46.

Wiafe ED, Agyei D (2013). Species richness, diversity and distribution of amphibians along elevational gradient on Mountain Afadjato, Ghana. Eur. J. For. Sci. 1(2):68-76.

Yahaya M, Attuquayefio DK, Owusu EH, Holbech LH, Ofori BY (2013). A conservation assessment of herpitofauna of a well deciduous forest in Ghana. J. Biodiver. Environ. Sci. 3(1):186-197.

Further links to supplementary information: http://goo.gl/Z95QTC