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Original article

The secondary impact of mining on primates and other medium to large mammals in forest reserves in southwestern Ghana

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ABSTRACT

The upsurge of mining in Africa promises substantial economic development opportunities, but poses serious threats to the continent's natural environment and rich biodiversity. We assessed the impact of mining on medium to large mammals in the Western Region of Ghana. We surveyed mammals in the project area and two forest reserves (FRs) before the commencement of mining operations and 10 years after mine closure and forest rehabilitation. The methodology involved direct and indirect observations along transects as well as focus group discussions. We found declines in species diversity of primates and other medium to large mammals in the core mining areas and within FRs. Forest rehabilitation after mine closure did not allow recovery of mammals in the core areas to previous levels in the FRs, as potential sources of colonisers from the FRs were removed. The discussants consumed bushmeat regularly, and agreed that mammal diversity in the area had declined due to noise from mining operations and hunting within FRs. Our data suggest that mining impacted negatively on medium to large mammal diversity. Greater management effort is needed to regulate hunting in forest reserves adjoining mining areas to avoid extirpation of primates and other wildlife species from Ghana's rainforest.

1. Introduction

Globally, natural ecosystems have been destroyed or degraded with increasing human impact and land-use changes (Butchart et al., 2010). Anthropogenic influences like mining, intensification of agriculture and forestry, large-scale industrialization, unsustainable hunting, invasive species and climate change have led to population declines and species level extinctions (Pimm and Raven, 2000; Pimm et al., 2006; Brook et al., 2008; Krauss et al., 2010). Increasing concern over human-induced environmental degradation and biodiversity loss has elicited international, regional and local responses to protect the natural environment and conserve biodiversity. At the global scale, the Convention on Biodiversity (CBD) aims at safeguarding biodiversity and ecosystem services (Kullberg and Moilanen, 2014). In 2002, the CBD mandated its member states to institute strategies to reduce environmental degradation and the rate of biodiversity loss dramatically by 2010 (COP 6 Decision VI/26).

In line with the CBD (2002) directive, member states developed biodiversity action plans and strategies, including the establishment of protected areas (PAs) to conserve biodiversity and the natural environment (Watson et al., 2014). Although PAs have been around for millennia (Chape et al., 2005), their number and extent have increased dramatically in the past few decades. Currently, terrestrial PAs cover about 12.5% of the earth's surface, with almost every country in the world having some form of legally-designated national protected area (Geldmann et al., 2013; Watson et al., 2014). The Strategic Plan for Biodiversity and the Aichi Biodiversity Targets (http://www.cbd.int/decision/cop) recognize PAs as cornerstones and mainstays of *in situ* biodiversity conservation, calling for an increase in the coverage of global PAs to at least 17% of terrestrial and inland water areas, and 10% of coastal and marine areas by 2020 (Target 11).

Although increasing the number and/or size of PAs is laudable and must continue, the physical extent of PAs is not a measure of their effectiveness (Rodrigues et al., 2004; Chape et al., 2005), as they may fail to achieve their goals if the surrounding landscape matrix is poorly managed (Beaumont and Duursma, 2012; Gray et al., 2016). Protected areas are integral parts of larger ecosystems and therefore depend on adjoining landscapes to maintain the flow of matter and energy (DeFries et al., 2005; Gray et al., 2016). The effectiveness of PAs in conserving biodiversity can be strongly influenced by land use practices and changes in the surrounding landscapes (Laurance, 2012; León-Ortega et al., 2017). The ever-increasing human populations and standard of living, as well as demand for multiple ecosystem services in developing tropical countries have intensified the scramble for lands

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surrounding PAs (Newmark, 2008). Fragmentation of landscapes adjacent to PAs can lead to increased exposure of PAs to negative human impacts (Beaumont and Duursma, 2012).

The booming mining industry in Africa presents enormous economic growth and development opportunities as extraction and processing of minerals provide important sources of employment and wealth creation (Hilson, 2014; Virah-Sawmy et al., 2014). However, mining poses serious risks to the continent's natural environment and exceptionally rich biodiversity (Yelpaala and Ali, 2005; Deikumah et al., 2014; Abernethy et al., 2016; Attuquayefio et al., 2017). The negative impacts of mining on the environment and biodiversity may be direct or indirect. Direct negative impacts include habitat loss and fragmentation, killing of wildlife during land clearance, disruption of hydrological systems and air and water pollution within and beyond the immediate confines of the mining operations (Durán et al., 2013). The indirect impacts of mining result from the consequences of mining infrastructure and associated socioeconomic changes (Osti et al., 2011; Abernethy et al., 2016).

PAs are supposedly spared from mining activities, but when they coincide with mineral deposits, they may be downgraded, downsized or degazetted (PADDD), to allow mining prospecting and development (Edwards et al., 2014). This is a worrying phenomenon, particularly in Africa, where most PAs harbour mineral resources (Abernethy et al., 2016) and about 44% of major mining sites are situated inside or within a few kilometres outside PAs (Durán et al., 2013).

By creating and improving infrastructure networks, mining can strongly influence the economy and demography of mining communities (Virah-Sawmy et al., 2014), which are often rural and sparsely populated (Edwards et al., 2014). Mining operations and infrastructure may encourage and facilitate migration of people into mining areas in search of mining-related jobs or to undertake small-scale artisanal mining outside the boundaries of the "official mine". This rapidly increases the populations and pressure from land clearing and bushmeat hunting for local consumption (Edwards et al., 2014; Abernethy et al., 2016). Roads may constructed through hitherto inaccessible forests and PAs, creating an influx of commercial bushmeat hunters and illegal loggers (Espinosa et al., 2014; Laurance et al., 2017). Also, local people displaced from their lands by mining activities may encroach on protected forests in their quest for economic spaces, threatening wildlife and their habitats in the process.

The conflict between economic benefits of mining and conservation initiatives is becoming increasingly acute. This is particularly evident in developing countries, where the material needs of an ever-increasing population compete with diminishing tropical rainforests (Fiori and Zalba, 2003; Suarez et al., 2009; Durán et al., 2013). Mining and associated infrastructural development promise economic opportunities that seem too good to part with, even when it imperils irreplaceable ecosystems. The expansion of mining industries in developing tropical countries has failed to provide the expected and much-needed development (Hilson, 2014). Indeed, the exploitation of mineral and oil resources has impacted negatively on the economy and governance outcomes of many developing countries (Busse and Gröning, 2013; Corrigan, 2014). This "resource curse" is believed to be due to host governments' inability to manage the sudden influxes of revenue from mineral exploitation (Mehlum et al., 2006; Robinson et al., 2006; Boschini et al., 2007; Collier, 2008; Corrigan, 2014; Hilson, 2014). This coupled with corruption has exacerbated pre-existing societal inequalities, nepotism and social injustice, thereby perpetuating conflicts, political instability and despotic governments in many developing countries (Bhattacharyya and Hodler, 2010; Corrigan, 2014; Hilson, 2014; Kelly, 2014). It is however worth acknowledging that some developing countries endowed with huge mineral resources are performing very well in terms of economic development and quality of governance (Corrigan, 2014).

The need for economic growth and improved living standards of ever-growing human populations in developing countries and the magnitude of global rise in demand for mineral resources mean that plans for large scale mining will continue unabated in developing tropical countries. Given the environmental concerns of mining, it can be expected that operators will increasingly be required to reduce their levels of environmental impacts. A number of environmental assessment tools and methodologies have been developed by the international community to help mitigate the negative impacts of mining on biodiversity and the natural environment (Norgate et al., 2007). Among these are environmental impact assessment (EIA) and biodiversity offsets. The EIA is a legal requirement prior to mining operations, and characterizes the potential impacts of mining projects on the environment. This results of the EIA is used to prepare an environmental impact statement (EIS), which stipulates measures to be implemented to reduce or offset the potential negative effects of mining (Morgan, 1998; Attuquayefio et al., 2017). The basic approach of biodiversity offset is to quantify biodiversity loss caused by mining projects, which occur even after implementation of impact mitigation measures, and then to generate biodiversity benefits through compensatory activities that offset the impacts (Maron et al., 2012; Bull et al., 2013a; Gardner et al., 2013). Biodiversity offset schemes generally aim to achieve an overall no net loss of biodiversity (McKenney and Kiesecker, 2010; Bull et al., 2013b). Although the secondary impacts of mining may have far-reaching ramifications for local and regional biodiversity, these are rarely addressed in EIA and biodiversity offset processes.

The rainforest of Ghana harbours a spectacular diversity of plants and animals, provide myriad of natural products and services to local communities, and plays key roles in the hydrological cycle, as well as being rich in gold and other precious minerals (Akabzaa, 2000; Rajaee et al., 2015). Unfortunately, the country's rainforest is being degraded and fragmented by large-scale land-use change and other environmental alterations (Damnyag et al., 2012; Hackman and Gong, 2017). Mining in Ghana's rainforest poses enormous risks to the nation's biodiversity and natural environment with large tracts of intact forest being cleared, topsoil removed and mine waste dumped into water bodies (Hilson and Nyame, 2006; Schueler et al., 2011). In many areas, loggers, migrant workers and commercial hunters attracted by the mines further stress the forest resources by poaching wild animals (normally medium to large mammals and birds) for bushmeat (Ntiamoa-Baidu, 1998; Ofori and Attuquayefio, 2010).

In 1996, we conducted a baseline survey as a basis for an Environmental Impact Assessment (EIA) for a proposed development of an open-pit gold mine, ore processing plant and associated infrastructure at Damang, near Tarkwa in the Western region of Ghana. We surveyed medium to large mammals in the proposed mining operation areas and two adjoining forest reserves (FRs). As part of mitigation efforts, the mining company initiated forest regeneration and rehabilitation programmes after mine closure. To assess the effect of mining on medium to large mammals and the success or otherwise of the reclamation and forest regeneration initiative, we conducted a second survey in the mining area and the two FRs previously surveyed in 2007 after mine closure and forest rehabilitation. To enable comparison of results, we followed the same protocols used in the baseline study. We hypothesized that abundance and species richness of medium to large mammal species will decline in the mining area and adjoining forest reserves due to direct and indirect impacts of mining in the core mining area and FRs, respectively. We also expect mammal community composition in the core mining area and FRs to change due to influx of disturbance-tolerant species in the core mining area and loss of hunting sensitive species from FRs as local hunters direct hunting expeditions toward the FRs.

2. Materials and methods

2.1. Study area and sites

The study area in the Western Region of Ghana (Fig. 1) has been

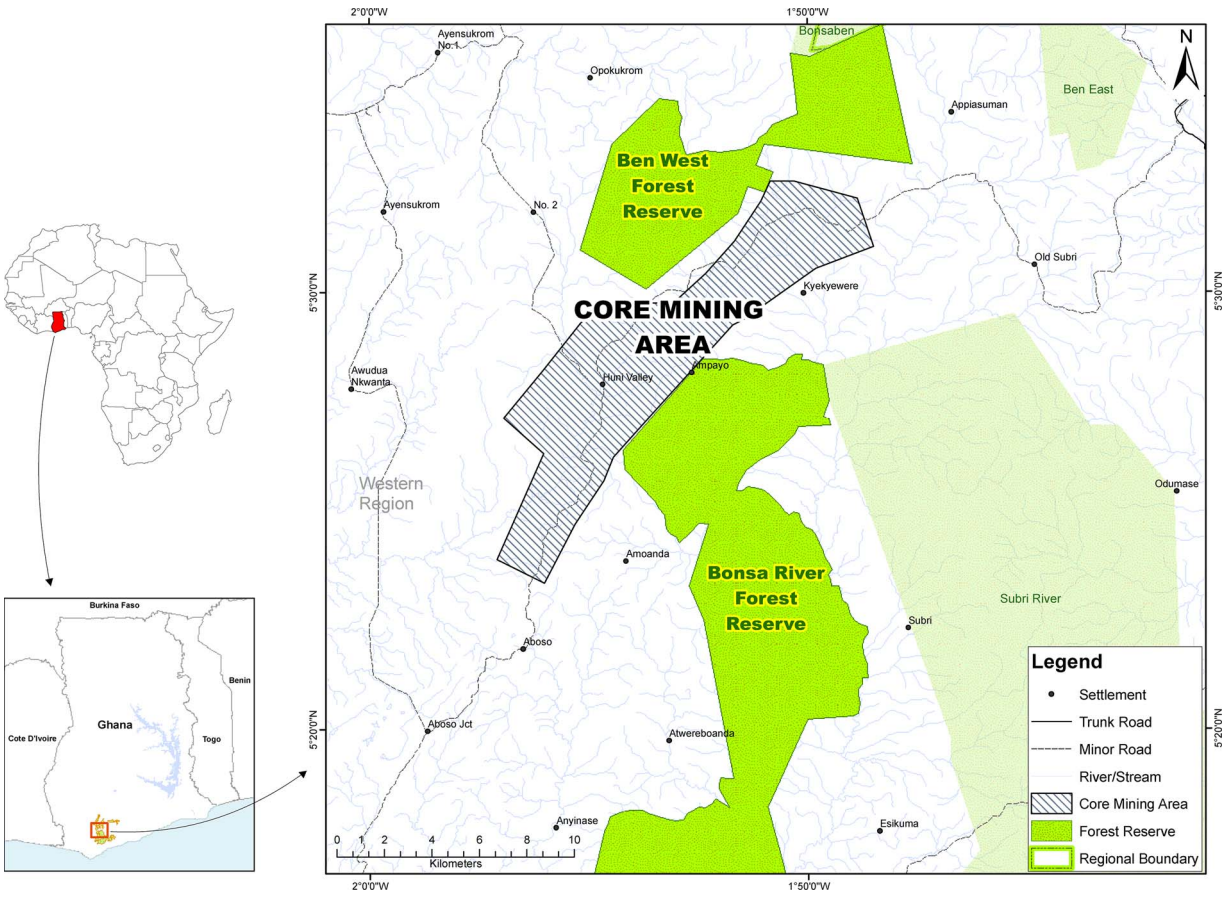

Fig. 1. Map of study area.

described in detail elsewhere (Attuquayefio et al., 2017). Mammal surveys were undertaken in four areas within the Abosso mining concession, two each in the core area and adjoining protected areas. The mining concession itself is located in the Wassa West District (4°–5°40′N; 1°45′–2°10′W), with a total land area of 2354 km^2 and the largest concentration of mines in a single district in the country.

2.1.1. Core mining area

This is the active mining area, which covers an area of 0.32 km^2 and comprises degraded forests, secondary growth, abandoned farmlands, and active crop farms (cocoa, oil palm, maize, plantain, cassava, and pineapples). Two sites within the Core Area were chosen for the study: (i) North East Waste Dump (NEWD) and (ii) South Tailings Storage Facility (STSF). The NEWD comprised of remnants of secondary forest with thick undergrowth, with *Alchornia cordifolia* and *Chromolaena odorata* ("Acheampong"/Siam weed) as dominant species. Emergent tree species like *Celtis milbraedii, Pycnanthus angolense, Albizia* sp., *Parkia bicolor* and *Musanga cecropioides* were also present, as well as few remnants of oil palm and cassava farms. The STSF covered an area of approx. 0.52 km^2 adjoining secondary forest with thick undergrowth of *Chromolaena odorata* and emergent species like *Celtis milbraedii* and *Terminalia superba*. Both active and abandoned oil palm and cassava farms were present (Attuquayefio et al., 2017).

2.1.2. Forest reserves

The two forest reserves surveyed were the Ben West Block Forest Reserve (FR1) and Bonsa River Forest Reserve (FR2). The FR1 is located northeast of the core mining area and covered an area of 161 km^2. It comprised both primary and mature secondary forests in Moist Evergreen Forest. Dominant timber tree species were *Heritiera utilis, Piptadeniastrum africanum, Cynometra ananta,* and *Celtis milbraedii*. The FR2 is located northwest of the core mining area and covered an area of 22 km^2. The vegetation comprised disturbed moist evergreen forest with primary and mature secondary forest. The degraded forest is colonized by *Musanga cercropoides, Alchornea cordifolia* and *Chromolaena odorata,* with dominant trees including *Entandrophragma olivieri*, *Celtis milbraedii* and *Piptadeniastrum africanum* (Attuquayefio et al., 2017). Both FRs had no direct mining influence, but are at reachable distances from the core mining area.

2.2. Mammal survey

We surveyed mammals from 7th to 18th May 1996 (i.e., before mining) and 17th to 29th May 2007 (after mine closure and forest rehabilitation). We employed standard field techniques including direct and indirect observations, as well as focus group discussions with the local people. Direct and indirect observations of medium to large mammals were conducted along transects (trails, footpaths and other access routes) selected to cut through the various vegetation types and levels of disturbance in the study area. Two transects, each 2.5 km long and positioned about 1 km apart, were established at each sampling site. In the core mining area, one transect was located in the NEWD and the other in the STSF. Transects were walked by a team of at least three observers, including one experienced local hunter. Observers positioned themselves five metres apart to search for, and record direct sighting of animals and/or indirect evidence of their presence, such as tracks, footprints, faecal pellets, feeding sites, nests, calls, etc. Night surveys were also conducted to record nocturnal mammals. Evidence of recent hunting, farming and logging activities in the forest reserves were also recorded. Mammal nomenclature followed Wilson and Reeder (2005).

Focus group discussions were conducted in the study area (after mine closure and forest rehabilitation) to better understand the local

Table 1
Abundance, species richness and diversity in the core mining areas (NEWD and STSF) and two adjacent forest reserves (FR1 and FR2) recorded during the baseline survey in 1996.

SCIENTIFIC NAME	COMMON NAME	SAMPLING SITE				TOTAL
		FR1	FR2	NEWD	STSF	
PRIMATE						
Galagidae						
Galagoides demidoff	Dwarf galago	2(3.3)	0	0	0	*2*
Lorisidae						
Perodicticus potto	Bosman's potto	1(1.6)	0	0	0	*1*
Cercopithecidae						
Cercopithecus petaurista	Spot-nosed monkey	0	1(2.0)	0	0	*1*
Cercopithecus mona	Mona monkey	2(3.3)	0	0	0	*2*
RODENTIA						
Sciuridae						
Protoxerus stangeri	Giant forest squirrel	0	3(6.1)	0	0	*3*
Heliosciurus gambianus punctatus	Gambian sun squirrel	0	3(6.1)	0	0	*3*
Funisciurus pyrrhopus	Fire-footed squirrel	0	4(8.2)	4(57.1)	7(63.6)	*15*
Euxerus erythropus	Striped ground squirrel	0	0	2(28.6)	1(9.1)	*3*
Nesomyidae						
Cricetomys gambianus	Giant rat	3(4.9)	0	0	0	*3*
Hystricidae						
Atherurus africanus	Brush-tailed porcupine	11(18.0)	7(14.3)	0	0	*18*
HYRACOIDEA						
Procavidae						
Dendrohyrax arboreus	Tree hyrax	7(11.5)	0	0	0	*7*
CARNIVORA						
Herpestidae						
Atilax paludinosus	Marsh mongoose	0	3(6.1)	0	0	*3*
Herpestes sanguinea	Slender mongoose	6(9.8)	10(20.4)	0	1(9.1)	*17*
Nandiniidae						
Nandinia binotata	Two-spotted palm civet	3(4.9)	0	0	0	*3*
Viverridae						
Viverra civetta	African Civet cat	0	1(2.0)	0	1(9.1)	*2*
ARTIODACTYLA						
Suidae						
Potamochoerus porcus	Red river hog	15(24.6)	1(2.0)	0	0	*16*
Bovidae						
Cephalophus niger	Black duiker	3(4.9)	0	0	0	*3*
Cephalophus dorsalis	Bay duiker	0	4(8.2)	0	0	*4*
Tragelaphus scriptus	Bushbuck	2(3.3)	1(2.0)	1(14.3)	0	*4*
Philantomba maxwelli	Maxwell's duiker	5(8.2)	11(22.4)	0	1(9.1)	*17*
PHOLIDOTA						
Manidae						
Phataginus tricuspis	Tree pangolin	1(1.6)	0	0	0	*1*
Total number of individuals		*61*	*49*	*7*	*11*	*128*
Total number of species		*13*	*12*	*3*	*5*	*21*
Shannon-Wiener index (H)		*2.25*	*2.18*	*0.96*	*1.16*	*2.62*
Margalef's index (D)		*2.92*	*2.83*	*1.03*	*1.67*	*4.12*

people's perception of the presence and relative abundance of mammal species in the study area, and how mining operation impacted on their socio-economic activities and interaction with wildlife. Five focus group discussion sessions with seven to 15 individuals were conducted. In total, discussants included 19 hunters (all male) 23 farmers (13 male and 10 female), chop-bar operators (5 female) and six opinion leaders (3 male and 3 female). The age range of the discussants was 25 to 60 years. Discussions followed a semi-structured questionnaire format, and were conducted in "Twi", the local language of the study area and recorded and transcribed verbatim.

2.3. Data analysis

We computed the species richness from the number of species observed both directly and indirectly, and estimated abundance from direct sightings only. Abundance was estimated as the number of individuals encountered per 2.5 km of transect walked. We used Margalef's (D) and Shannon-Wiener (H) indices for species richness and species diversity respectively, as follows:

$$\text{Margalef's Index } (D) = (s\text{-}1)/\ln N \quad (1)$$

$$\text{Shannon-Wiener index } (H) = -\Sigma p_i \ln p_i \quad (2)$$

Where: s = number of species in the sample,N = number of individuals in the sample,pi = relative abundance of each species recorded.

We compared the species composition between sites "before" and "after" mining using the Sorensen's Similarity Index (*S),* which measures the commonness of species between two sites on a scale of 0–1. A similarity index of 0 between any two sites indicates that the sites have no species in common, whereas a similarity index of 1 means the sites have the same set of species. This analysis included species observed both directly and indirectly.

$$\text{Sorensen's Similarity Index } (S) = 2c/(a + b) \quad (3)$$

Where: c = species common to sites A and B,a and b = total number of species recorded at sites A and B, respectively.

We used Fisher's exact test with 0.05 level of significance to analyse the difference of species abundance and richness between "before" and "after" mining surveys for the study sites. The underlying assumption was that all the medium to large mammals in the study area were equally detectable. The conservation status of the species recorded were determined using the IUCN Red List of Threatened Mammals (IUCN Red

List 2017, www.redlist.org/mammals) and the Wildlife Conservation Regulation of Ghana (LI 685, 1971). For the focus group discussions, patterns that emerged based on perceptions regarding species presence and their relative abundance, and how mining activity has impacted on the socio-economic activities of local people and their interaction with wildlife are presented.

3. Results

3.1. Abundance, species diversity and conservation status

Direct and indirect observations and interviews with local people before the mining operations in 1996 indicated that 40 species of medium to large mammalian species belonging to 15 families occurred in the study areas. These included nine species of global conservation concern. The Bongo is "Endangered", the White collared Mangabey and Diana monkey are "Vulnerable", the Olive Colobus and Yellow-backed duiker are "Rare", and the Bay duiker, Royal antelope, Water chevrotain and Palm squirrel are "Insufficiently known" species. In addition, six species including the clawless otter, Tree pangolin, Long-tailed pangolin, Bushbaby, Bossman's potto and Western black-and-white colobus monkey are wholly protected, while four species, Red river hog, Maxwell's duiker, Bushbuck and the Common genet are partially protected under the Ghana Wildlife Conservation Regulation (LI 685, 1971).

One hundred and twenty-eight individual mammals belonging to 13 families and 21 species were directly sighted. Sixty-one individuals of 13 species (species richness $D = 2.92$, diversity $\acute{H} = 2.25$) were recorded at FR1, while 49 individuals belonging to 12 species ($D = 2.18$; $\acute{H} = 2.83$) were recorded at FR2. At STSF, 11 individuals of five species ($D = 1.67$; $\acute{H} = 1.16$) were recorded, while at NEWD, only seven individuals comprising three species ($D = 1.03$; $\acute{H} = 0.96$) were recorded. Red river hog, Slender mongoose, Brush-tailed porcupine and Maxwell's duiker were the dominant species in the forest reserves, while the Fire-footed squirrel was the dominant species in the core mining area (Table 1).

After mining and forest rehabilitation in 2007, a total of 154 individuals belonging to six families and nine species was directly sighted in the study area: Fire-footed squirrel, Striped ground squirrel, Cane rat, Slender mongoose, Common genet, Red river hog, Bushbuck and Maxwell's duiker. With the exception of the Red river hog, Maxwell's duiker and Bushbuck, all the species recorded are generally associated with woodland, forest edges and degraded areas and/or areas under intense hunting pressure. In general, there was no difference in the numbers of species recorded at STSF, NEWD, FR1 and FR2. However, the number of individuals recorded at STSF and NEWD were about three times more than those recorded at FR1 and FR2 (Table 2). The Red river hog was recorded at FR1 and FR2 only. At FR1, Bushbuck and Striped ground squirrel codominated with each forming 22.7% of the recorded individuals, while at FR2, the Striped ground squirrel was the dominant species with 41.2% of the recorded individuals. At STSF, the Cane rat was the commonest species with 32.2% of the recorded individuals, while Bushbuck dominated the NEWD with 30.4% of the recorded individuals (Table 2).

Impact of mining operations on mammals: comparing species composition between sites before and after mining operation

There were varying degrees of commonness of species between sites before and after mining operations. The two forest reserves appeared to have lost about half of their medium to large mammal species richness and about two-thirds of the number of individuals during the 10 years of mining operation. The observed changes in abundance and species richness, however, were not statistically significant (Fisher's exact test, $P > 0.05$). In the core mining area, the number of individuals increased from seven to 59 and from 11 to 56 for the TSF and NEWD, respectively, with relatively no change in species richness. Again, the difference in abundance was not statistically significant (Fisher's exact test, $P > 0.05$). The Bay duiker, Black duiker, Brush-tailed porcupine and the primate species sighted in the reserves during the survey before the mining operation in 1996 were not sighted during the survey conducted after the mining operation in 2007. The similarity of species composition (Sorensen's index S) between the "before mining" and "after mining" surveys was lower for the forest reserves (S = 0.53 for FR1, 0.32 for FR2) than the core mining area (S = 0.83 for STSF and 0.6 for NEWD).

Table 2
Abundance, species richness and diversity in the core mining areas (STSF and NEWD) and two adjacent forest reserves (FR1 and FR2) recorded during the "after mining and forest rehabilitation" survey in 2007.

SCIENTIFIC NAME	SAMPLING SITE				TOTAL
	FR1	FR2	STSF	NEWD	
RODENTIA					
Sciuridae					
Funisciurus pyrrhopus	4 (18.2%)	0	8 (13.6%)	8 (14.3%)	*20 (13%)*
Euxerus erythropus	5 (22.7%)	7 (41.2%)	13 (22%)	14 (25%)	*39 (25.3%)*
Thryonomyiidae					
Thryonomys swinderianus	0	1 (5.9%)	19 (32.2%)	11 (19.6%)	*31 (20.1%)*
CARNIVORA					
Herpestidae					
Herpestes sanguinea	1 (4.5%)	0	3 (5.1%)	2 (3.6%)	*6 (4%)*
Viverridae					
Genetta genetta	2 (9.1%)	1 (5.9%)	2 (3.4%)	2 (3.6%)	*7 (4.5%)*
ARTIODACTYLA					
Suidae					
Potamochoerus porcus	2 (9.1%)	2 (11.8%)	0	0	*4 (3%)*
Bovidae					
Tragelaphus scriptus	5 (22.7%)	2 (11.8%)	12 (20.3%)	17 (30.4%)	*36 (23.4%)*
Philantomba maxwelli	3 (13.6%)	4 (23.5%)	2 (3.4%)	2 (3.6%)	*11 (7.1%*
Total number of individuals	*22*	*17*	*59*	*56*	*154*
Total number of species	*7*	*6*	*7*	*7*	*8*
Shannon-Wiener index (H)	*1.83*	*1.54*	*1.67*	*1.66*	*1.83*
Margalef's index (D)	*1.94*	*1.76*	*1.47*	*1.49*	*1.39*

3.2. Focus group discussions

The discussants stated that they used to consume bushmeat regularly prior to the mining operation, but they do so less frequently now because of declines in mammal abundance in the area. According to them, 14 mammalian species which were previously (i.e., before the mining operation) common in the area were now very rare. They attributed the declines in mammalian species richness and abundance in the area to high noise levels from the mining and machinery used in logging operations, and overhunting due to the increased human population in the area. Maxwell's duiker, Grasscutter and Brush-tailed porcupine were ranked by the hunters as the most common species in the area prior to mining operations (Table 3). Although all medium to large mammal species in the area were used as bushmeat, the most preferred animals were Grasscutter, Maxwell's duiker, Bay duiker, Black duiker, Royal antelope and monkeys (Spot-nosed monkey, Mona monkey, Diana monkey, White-collared Mangabey, Olive Colobus

Table 3
Hunters' perceptions of the relative abundance (on an ordinal scale of 1–14) of commonly hunted mammals in the study area.

Species	Relative abundance
Maxwell's duiker	14
Grasscutter	11
Brush-tailed porcupine	8
Black duiker	7
Giant rat	6
Bushbuck	4
Bay duiker	4
Red river hog	3
Tree pangolin	3
Spot-nosed monkey	2
Civet	2
Mona monkey	2
Tree hyrax	1
Royal antelope	1

monkey). According to the hunters and chop-bar operators, monkey meat was a special delicacy but very expensive because monkeys were difficult to get. The discussants confirmed that they farmed and hunted in the mining area before the mining operation. They also admitted that hunting was occasionally done in forest reserves before mining operations commenced in the area. When asked about where they currently farm and hunt, the discussants openly said they farmed and hunted in surrounding forests, including forest reserves.

4. Discussion

The FR1 and FR2 recorded higher medium to large mammal abundance, species richness and species diversity before than after mining operations, although our survey effort was not enough to make the observed differences statistically significant. In the core mining area, we recorded higher mammal abundance after the mining operations and forest rehabilitation than before mining operations. However, this was dominated by three disturbance-tolerant species, *Euxerus erythropus*, *Thryonomys swinderianus* and *Tragelaphus scriptus*. Species diversity in the core mining area has not recovered to the state in which the forest reserves were before mining. Our data support the hypothesis that mining impacted negatively on medium to large mammal abundance, diversity and composition in the study area.

Both FR1 and FR2 recorded low levels of similarity of species composition between the "before" and "after" mining surveys. The decline in abundance and species diversity in the reserves could be attributed to indirect impacts of mining. Mining activity placed extra stress on the forest reserves, even though they were already being exploited by the local people. The granting of a mining lease meant that the core mining area, which served as a farming and hunting ground for the local people, was no more available to them. The displaced people therefore resorted to exploitation of the forest reserves for non-timber forest products (NTFPs) and bushmeat. As revealed during the focus group discussions, migrant mine workers also hunted in the reserves and surrounding non-protected forests, further causing declines in numbers of medium to large mammals in the area.

None of the primates recorded in the area before the mining operation was recorded after the mining survey. These are the most prized bushmeat species, and therefore might have been overexploited by commercial hunters in particular, who usually sell the majority of their produce in urban markets (Robinson and Bennett, 2004; Wilkie et al., 2011). The construction of access roads to mine sites have opened up the area, providing access to illegal loggers and commercial bushmeat hunters to exploit the forest reserves. The secondary effects of access roads into hitherto inaccessible forests have been extensively demonstrated in the logging literature (Bowen-Jones and Pendry, 1999; Walsh et al., 2003; Robinson and Bennett, 2004; Laurance et al., 2006; Laporte et al., 2007; Poulsen et al., 2009; Wilkie et al., 2011; Abernethy et al., 2013).During the survey, we found direct evidence of recent hunting and logging activities (e.g., spent cartridges, wire snares, remains of chain-sawed lumber, etc.) in the two forest reserves. It appeared that hunters and illegal loggers had unrestricted access to the forest reserves.

Intensive hunting is known to cause the extirpation of species with low reproduction rates like primates and other large-bodied mammals (Alvard et al., 1997; Laurance et al., 2000; Robinson and Bennett, 2004; Wilkie et al., 2011). Also, because primates live in the canopies of the tall timber tree species often targeted by loggers (Struhsaker, 1999), this may have indirectly contributed to the decline or disappearance of primates in the study area. This corroborates studies that identified commercial hunting and logging as the primary cause of primate declines (Walsh et al., 2003; Robinson and Bennett, 2004; Wilkie et al., 2011; Abernethy et al., 2013).

The core mining areas were basically farmlands at the time of the baseline study. Persistent high hunting pressure had already reduced the medium to large mammals of the area to only a few remnant species prior to the commencement of the mining operation. The clearing of the core mining area for gold extraction and its related activities might have caused further declines in the mammalian fauna of the area. Wildlife diversity in the core mining areas appears not to have recovered after mine closure and forest rehabilitation. However, two additional species, *Genetta genetta* and *Thryonomys swinderianus*, have entered the area, probably as a result of the habitat change caused by the mining operations. It is most likely that the depletion of wildlife species in the forest reserves from hunting during the 10 years of mining, also might have impeded recovery of the core mining areas, as a potential source of populations was removed.

Species that tolerate human-modified landscapes persist in fragmented and regenerating forests, whereas those that avoid matrix-habitat usually decline or disappear (Gascon et al., 1999). The medium-sized mammal species recorded in the core mining area, including the slender mongoose, fire-footed squirrel, striped ground squirrel and the common genet have relatively broad habitat tolerances and are less sensitive to ecological changes in forest fragments. Consequently, these matrix-tolerant species tend to be the remnant species in highly degraded areas and regenerating forests. The other two large mammals (Maxwell's duiker and Bushbuck) recorded in the area are forest species which normally exploit open habitats and degraded areas within forest landscapes. Such species are usually not affected to the same extent as primates when forests are fragmented and modified, but are rather favoured by opening of mature forest and regenerating forest (Struhsaker and Oates, 1995; Ofori et al., 2012). Although hunting might have reduced the population density of bushbuck and Maxwell's duikers in the study area, these species probably may have withstood hunting pressure better than the more susceptible primates that dwell in the canopies of tall timber tree species often targeted by loggers (Struhsaker, 1999).

Observations from this survey suggested a change in the physical conditions of the vegetation in the area. While the observed changes in the vegetation of the core mining area may be a direct consequence of mining operations, the current state of the two forest reserves could have resulted from the indirect impacts of mining. In particular, the development of the mine has exposed the Bonsa River Forest Reserve to the intrusion of edge species into the reserve (edge effect). Mining activities in the area have further fragmented the already degraded area, but there has been improvement in the patches of secondary forests, particularly at higher elevations. The area degraded by mining operations has been rehabilitated using mainly fast growing exotic species, such as *Acacia mangium*, *Eucalyptus* sp., *Leucena leucocephala* and *Gliricidia sepium*. The rehabilitation of the mined area appears to focus on plant biomass per unit area rather than diversity of species. Consequently, the rehabilitation process is progressively leading to the establishment of exotic monocultures rather than the recovery of local

flora, which will eventually lead to declines in the floral and faunal diversity of the area.

Ten years of hunting directed toward the FRs and away from the core mining areas appear to have reduced the diversity of medium to large mammals in the study area. This did not allow recovery of the core mining areas toits previous state as the potential sources of colonisers were removed. Thus, the landscape suffers net loss despite the forest rehabilitation programme. Poor enforcement of wildlife legislation due to inadequate wildlife staffing (e.g. guards, rangers and officers), finance and logistics, has resulted in uncontrolled hunting and the bushmeat trade in Ghana (Ayivor et al., 2013). The situation is further compounded by lax wildlife laws which do not adequately motivate wildlife guards and rangers to arrest illegal commercial hunters (Ofori and Attuquayefio, 2010).

The findings of this study indicate negative indirect impacts of mining on the medium to large mammals in the forest reserves adjoining a mine site in the Western Region of Ghana. This situation is likely to be replicated in most, if not all, forest reserves adjacent (within about 10–20 km) to mine sites in Ghana and elsewhere in the Western and Central African subregion. As the mineral extraction industry has come to stay and will continue to flourish in Ghana, we foresee an intensification of hunting pressure and habitat destruction in both reserves and off-reserve areas. Without serious and aggressive enforcement of hunting and logging laws and investment in protected area management, the next few decades will push medium to large mammals, particularly primates, to the brink of local and potentially global extinction.

Declaration of interest

Authors declare no financial interest.

Authors contribution

All authors contributed equally to the data collection, analysis and preparation of the manuscript.

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