African Journal of Ecology

Comparing survey methods to assess the conservation value of a community-managed protected area in western Tanzania

Yves Hausser*, Romain Tagand, Eric Vimercati, Sandy Mermod and Claude Fischer

Natural Resource Management Department, University of Applied Sciences of Western Switzerland, Hepia, 150 route de Presinge, 1254, Jussy, Switzerland

Abstract

The ability of low-status protected areas under community management to achieve a conservation objective is frequently questioned, particularly in developing countries. The lack of sound, scientific-based biodiversity monitoring frequently undermines attempts to evaluate the extent to which these areas are contributing to biodiversity conservation. Based on data collected between 2008 and 2010 in a Forest Reserve under community management in western Tanzania, our study tested fives methods: camera trapping, walking line transects, vehicle transects, opportunistic encounters and indirect signs, to find the most appropriate for future monitoring. Method comparisons confirmed a higher performance of camera trapping compared to other methods for the ability to detect species. However, our results identified the need of a better survey design to ensure a sound monitoring in the future. Besides method comparisons, our study provides the first fine-scale data on mammal communities in such a low-status protected area. Combined methods allow the identification of 49 species of medium and large mammals, a surprisingly high diversity for such area. These findings outline the potential conservation value of this type of protected area and call for better biodiversity monitoring throughout complexes of protected areas of different statuses and management regimes.

Key words: camera traps, Community Conserved Area, large mammals, miombo woodland, surveys, Tanzania

Résumé

La capacité des aires protégées de faible statut sous gestion communautaire è atteindre des objectifs de conservation est souvent remise en question, spécialement dans les pays en développement. Le manque de suivi efficace et scientifique de la biodiversité empêche souvent toute tentative d'évaluer dans quelle mesure ces aires contribuent à la conservation de la biodiversité. En se basant sur des données collectées entre 2008 et 2010 dans une réserve forestière gérée de façon communautaire dans l'ouest de la Tanzanie, notre étude a testé cinq méthodes : pièges photographiques, transects parcourus à pied, en véhicule, rencontres opportunistes et signes indirects, afin de voir laquelle est la plus appropriée pour un suivi à venir. La comparaison des méthodes a confirmé que les pièges photographiques avaient de meilleures performances que les autres méthodes pour pouvoir détecter les espèces. Cependant, nos résultats ont identifié le besoin d'une étude mieux conçue pour garantir un suivi correct à l'avenir. En plus de la comparaison des méthodes, notre étude apporte les premières données fines sur des communautés animales dans une aire à faible statut de protection. La combinaison des méthodes a permis l'identification de 49 espèces de moyens et grands mammifères une diversité surprenante pour une telle aire. Ces résultats soulignent la valeur de conservation potentielle de ce type d'aire protégée et soulignent la nécessité d' un meilleur suivi de la biodiversité dans les complexes d'aires protégées bénéficiant de différents statuts et régimes de gestion.

Introduction

The conservation value of 'low-status' protected areas (IUCN categ. IV–VI) has been subjected to renewed interest in the light of various factors, such as the development of landscape ecology, which has clearly demonstrated weaknesses of the current strictly protected areas (Categ. I–III) if

---

*Correspondence: E-mail: yves.hausser@hesge.ch

the aim is to protect species with large seasonal home ranges. Some recent studies have suggested that even strictly protected areas, such as national parks (NP), may be missing the conservation target, despite considerable costs (Estes, Atwood & Estes, 2006; Caro & Scholte, 2007; Caro, 2008; Craigie *et al.*, 2010), and that alternative management regimes involving local users may perform better in terms of conservation (Hayes, 2006; Western, Russell & Cuthill, 2009; Nelson & Chomitz, 2011; Persha, Agrawal & Chhatre, 2011). Moreover, other recent studies equally demonstrated that these protected areas may serve not only as seasonal dispersal areas for wildlife from the parks but may also host distinct communities of species of less studied taxonomic groups (Fitzherbert *et al.*, 2006, 2007; Gardner *et al.*, 2007a), emphasizing the need for combined conservation strategies (Caro *et al.*, 2009). If the biodiversity of NPs is relatively well known, this is not the case for most low-status protected areas. Hence, there is a lack of documented data about the biodiversity harboured by these areas and a need for reliable data on wildlife populations in areas where wildlife and greater resource use is allowed.

The aim of this article was to contribute to filling this gap by providing and analysing data from medium and large mammal surveys conducted using five different methods in a community-managed protected area of western Tanzania from 2008 to 2010. We selected the community of medium and large mammals in recognition of the economic and ecological value of these species in Tanzania and consider them as a proxy of the conservation value (Li *et al.*, 2012). To evaluate the relative conservation value of our study area, we combined the species richness, Red List status and spatial distribution of our observations.

Material and methods

Study site

Mlele Forest Reserve (FR) is a governmental reserve that lies within the north-western extent of the miombo woodland ecosystem of Tanzania. Located in Mpanda District, Inyonga Division (6°40′S–31°45′E), the FR borders the northern boundary of Katavi NP and Rukwa Game Reserve (GR) and represents a potential connection to Ugalla GR (Fig. 1). Mlele FR is characterized by a double-status situation, as discussed in earlier papers (Hausser & Mpuya, 2004; Hausser, Weber & Meyer, 2009), as the FR is also a Game Controlled Area (GCA). We conducted surveys in the portion demarcated as a community-managed beekeeping zone (BKZ), accounting for 850 km^2 of the total 2350 km^2 of Mlele FR (Fig. 2).

Selected logging, regulated hunting and beekeeping are allowed within the FR under permit systems, and thus, human pressure and disturbance are considered to be high compared to NPs and GRs (Stoner *et al.*, 2007). The area is comanaged by the District and the Inyonga Beekeepers Association, which conduct joint antipoaching patrols in the area 10 days per month on a yearly basis. A trophy hunting company is located in the GCA and conducts antipoaching activities during the hunting season (July to December).

The topography is characterized by the presence of two plateaus divided by a steep escarpment. Several intermittent and a few permanent streams run down the escarpment. The altitude varies from 900 to 1500 m. Most of the area is covered by the Central Zambezian miombo woodland (Banda *et al.*, 2008), with limited floodplains and riverine forests along the main watercourses. The climate is bimodal, with rains occurring from November to April (900–1200 mm year^{-1}), and the average temperature varies from 15 to 25°C.

Considering the study area and the local constraints [no professional village game scouts (VGS), only one car available, poor road network], we chose to test and compare five different survey methods: (i) camera trapping; (ii) direct observations by car (day and night); (iii) direct observations by foot; (iv) opportunistic encounters; and (v) the use of indirect signs. The results were used to establish a first inventory and select the most appropriate scientifically robust methods that could be implemented by the VGS in an autonomous manner to conduct monitoring in the future. These methods were tested during field sessions from 2008 to 2010.

Cameras and trapping sites

Camera traps are increasingly used as a noninvasive method for monitoring wildlife (Rowcliffe & Carbone, 2008). Applications range from species inventories (Silveira, Jacomo & Diniz-Filho, 2003; Tobler *et al.*, 2008) to abundance estimates that are made through the capture–recapture of species characterized by individually recognizable coat patterns (Karanth & Nichols, 1998; Kelly *et al.*, 2008). Modern systems are simple to use, even for people with limited access to modern technology. The

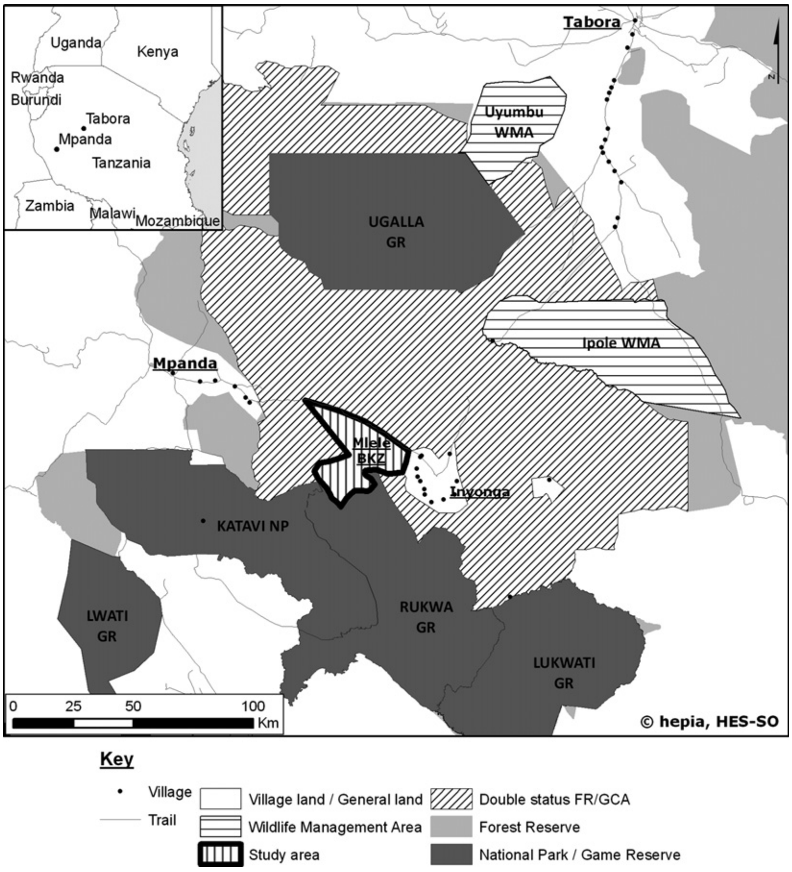

Fig 1 Map showing the location of the study area in the complex of protected areas in western Tanzania: the Katavi–Rukwa–Ugalla ecosystem

method has been successfully used in a diverse set of ecosystems, from rainforests to arid ecosystems (Henschel & Ray, 2003; Kauffmann *et al.*, 2007). In Tanzania, the method was used in different studies covering an important part of the protected areas network (Bowkett, Rovero & Marshall, 2008; Rovero & Marshall, 2009; Pettorelli *et al.*, 2010) in both savannah and forest ecosystems.

In the BKZ, we conducted three sessions of camera trapping during the dry seasons of 2008, 2009 and 2010. Because we only had six camera traps during the first two sessions, we set up the devices based on opportunistic observations. In 2010, we had enough camera traps (twelve) to use a transect strategy. For the third session, camera traps were set along transects of 4–5 km, at intervals of 0.5–1 km. The transects either followed water courses or were along animal paths in the different types of habitat. Across the three sessions, camera traps were established in 36 locations in the Mlele BKZ (Fig. 2). The camera trap stations were not baited or lured. Cameras were operational 24 h a day, with a time lag between pictures of 1 min. The research effort is measured by the cumulative number of camera trap days (CT days). We used the 'capture' model (Cuddeback Digital; Non Typical, Inc., Green Bay, WI), a 3.0 megapixel resolution with a passive infrared motion detector that detects in the infrared spectrum as well as motion. The detection sensibility is not adjustable.

Direct observations: vehicle transects

Surveys based on direct observations are often made on a line transect strategy. Transects can be run using various means of transport. In Tanzania, Tanzania Wildlife Conservation Monitoring, with support from partner organizations, is using aerial transect surveys (Stoner *et al.*, 2007). This method, however, is especially suited for open

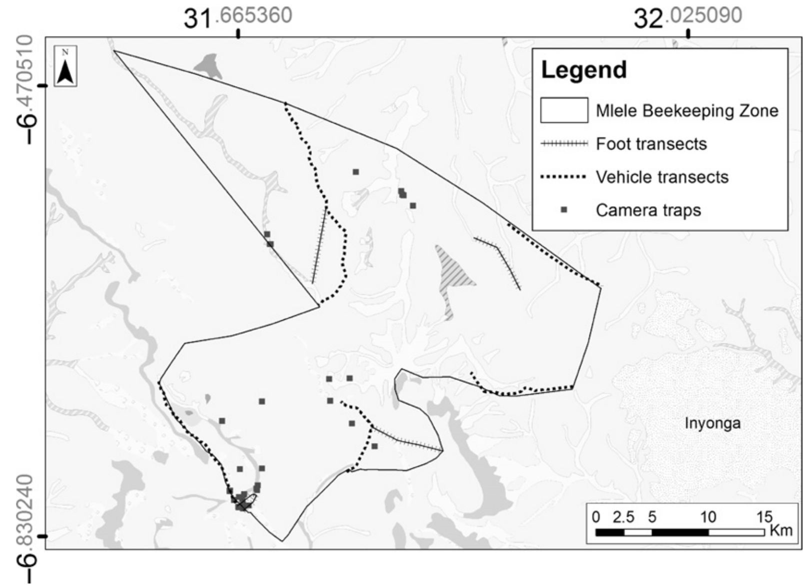

Fig 2 Location of camera traps and transects within the Mlele Beekeeping Zone

habitats and for larger species (Caro, 2011); thus, it is not suitable in a forested habitat, such as the miombo. Hence, we chose to test direct observations on transects run either by car or by foot.

The use of a car enables a larger area to be covered, given that there are enough suitable roads. Currently, there are five dirt roads in the BKZ. We selected five transects of 20 km in length, one on each of these roads, for transects conducted in the morning (between 7.30 and 10.30 AM) at an average speed of 20 kph. We also conducted surveys with spotlights at night (between 20.00 and 23.00 PM) on the same five transects to consider nocturnal species.

Direct observations: foot transects

As large areas of the BKZ are not sampled if we only consider transects situated on roads, we selected four transects of 4 km in length on existing beekeeper's paths on which transects were conducted by walking during the day (early morning and late afternoon).

Indirect observations

We principally considered foot prints and faeces as indirect signs, following Stuart & Stuart (2013). In a forested habitat, such as the miombo, where the ground is often covered with grasses or leaves and where foot prints are difficult to identify during the dry season, indirect signs were principally used to obtain qualitative data regarding species occurrence in the study area. Indirect signs were recorded whenever they were encountered in the BKZ.

Opportunistic encounters

In addition, we recorded all of the individuals that were observed and all of the signs identified in the BKZ by foot or by car during displacements. These observations contributed to the inventory and the spatial distribution of the species.

Data treatment and analysis

As outlined by Tobler *et al.* (2008), evaluating the completeness is key to estimating the number of extra species that might be detected by a larger sampling effort. To do so, we elaborated a predictive model based on the literature (Kingdon, 1997; East, 1999) and records from the Tanzania mammal atlas (http://www.tanzaniamammals.org/). We excluded data supported by only one record in the atlas and that was not supported by other scientific records. The predictive model reached an estimate of 60 species of medium to large mammals (Table 1). Records from the five methods were aggregated to create a first inventory list. Regarding the data treatment and analysis of the camera traps, we considered a capture event as each

Table 1 Species predictive model and the detected species

N	Order	Common name	Latin name	Obs. type
1	Primates	Yellow baboon	*Papio cynocephalus*	a, b, c, d, e
2	Primates	Silver monkey cluster	*Cercopithecus (n.) mitis*	a
3	Primates	Vervet monkey	*Cercopithecus (a.) pygerythrus*	a, b, e
4	Primates	Lesser galago	*Galago moholi*	c, e
5	Primates	Greater galago	*Otolemur crassicaudatus*	c
6	Insectivora	Four toed Elephant shrew	*Petrodromus tetradactylus*	e
7	Lagomorpha	Cape hare	*Lepus capensis*	a, b, c, e
8	Lagomorpha	Scrub hare	*Lepus saxatilis*	no observation
9	Rodentia	Spring hare	*Pedetes capensis*	a, c, d, e
10	Rodentia	African Porcupine	*Hystrix cristata*	a, d
11	Rodentia	Cane rat	*Thryonomys swinderianus*	c
12	Rodentia	Giant pouched rat	*Crycetomys gambianus*	e
13	Carnivora	Side-striped jackal	*Canis adustus*	a
14	Carnivora	Black backed jackal	*Canis mesolemas*	no observation
15	Carnivora	Wild dog	*Lycaon pictus*	d, e
16	Carnivora	Aardwolf	*Proteles cristatus*	no observation
17	Carnivora	Spotted hyena	*Crocuta crocuta*	a, d, e
18	Carnivora	Serval	*Leptailurus serval*	e
19	Carnivora	Caracal	*Felis caracal*	no observation
20	Carnivora	Wild cat	*Felis sylvestris*	c, d
21	Carnivora	Leopard	*Panthera pardus*	a, c, d, e
22	Carnivora	Lion	*Panthera leo*	c, d, e
23	Carnivora	African palm civet	*Nandinia binotata*	c
24	Carnivora	African civet	*Civettictis civetta*	a
25	Carnivora	Unidentified large genet	*Genetta sp.*	a
26	Carnivora	Miombo genet	*Genetta angolensis*	a, c, e
27	Carnivora	Large spotted genet	*Genetta maculata*	no observation
28	Carnivora	Honey badger	*Mellivora capensis*	a, d, e
29	Carnivora	Banded mongoose	*Mungus mungo*	b, c, e
30	Carnivora	Bushy tailed mongoose	*Bdeogale crassicauda*	a
31	Carnivora	Dwarf mongoose	*Helogale parvula*	b, c, e
32	Carnivora	Marsh mongoose	*Atilax paludinosus*	a, d
33	Carnivora	Slender mongoose	*Herpestes sanguinea*	e
34	Carnivora	White tailed mongoose	*Ichneumia albicauda*	a, c
35	Carnivora	Egyptian mongoose	*Herpestes ichneumon*	no observation
36	Tubulidentata	Aardvark	*Orycteropus affer*	a, d
37	Hyracoidea	Bush hyrax	*Heterohyrax brucei*	no observation
38	Hyracoidea	Tree hyrax	*Dendrohyrax arboreus*	no observation
39	Proboscidea	African elephant	*Loxodonta africana*	a, d
40	Perissodactyla	Plain zebra	*Equus q. boehmi*	a, b, c, d, e
41	Artiodactyla	Hippopotamus	*Hippopotamus amphibius*	d
42	Artiodactyla	Bushpig	*Potamochoerus larvatus*	a, c, d, e
43	Artiodactyla	Warthog	*Phacochoerus aethiopicus*	a, b, c, d, e
44	Artiodactyla	Girafe	*Giraffa camelopardalis*	a, b, c, d, e
45	Artiodactyla	African buffalo	*Syncerus caffer*	a, d, e
46	Artiodactyla	Common eland	*Taurotragus oryx*	d
47	Artiodactyla	Greater kudu	*Tragelaphus strepsiceros*	a, c, d, e
48	Artiodactyla	Bushbuck	*Tragelaphus scriptus*	a, d, e
49	Artiodactyla	Defassa waterbuck	*Kobus ellipsiprymnus*	no observation

(continued)

Table 1 *(continued)*

N	Order	Common name	Latin name	Obs. type
50	Artiodactyla	Southern reedbuck	*Redunca aurundinum*	b, c, e
51	Artiodactyla	Impala	*Aepyceros melampus*	a, c, d
52	Artiodactyla	Lichtenstein's hartebeest	*Alcelaphus b. lichtensteinii*	a, b, c, d, e
53	Artiodactyla	Topi	*Damaliscus lunatus*	a, c, d, e
54	Artiodactyla	Roan antelope	*Hippotragus equinus*	a, b, d, e
55	Artiodactyla	Sable antelope	*Hippotragus niger*	a, b, c, d, e
56	Artiodactyla	Common duiker	*Sylvicapra grimmia*	a, b, c, d, e
57	Artiodactyla	Sharpe's grysbok	*Raphicerus sharpei*	e
58	Artiodactyla	Ourebi	*Ourebia ourebi*	no observation
59	Artiodactyla	Kirk's dik dik	*Madoqua kirkii*	b, c, d, e
60	Artiodactyla	Klipspringer	*Oreotragus oreotragus*	no observation

a: camera trap; **b**: foot transect; **c**: car transect; **d**: indirect observation; **e**: opportunistic direct observation

independent capture. If it was not possible to differentiate individuals of the same species, we used an interval of 30 min to consider them as independent (O'Brien, Kinnaird & Wibisono, 2003).

Results

Species richness

The combined methods resulted in the identification of 49 species of medium and large mammals (Table 2), with a comparatively modest research effort (e.g. 726 days of camera traps, transects repeated 5–6 times). In terms of species richness, the result represented 82% of the species that were potentially present according to the predictive model. As shown in Table 2, the species detected by each method varied from 31 (63%) for camera traps (726 trap days) to 14 (29%) for foot transects (five replicates each), with car transects reaching a performance close to camera traps, with 26 species (53%, 5–6 replicates).

Globally, the most represented groups were the carnivores and the ungulates, with eighteen species detected for each group. Primates were represented by three species, with two species for prosimians. Afrotherians accounted for three species. Finally, we recorded one species of lagomorph and four species of rodents.

Most of the rare species that are usually found in NPs were present, including IUCN Red Listed species, such as the wild dog (*Lycaon pictus*, critically endangered) and the leopard (*Panthera pardus*, near threatened) or the African elephant (*Loxodonta africana*) and the lion (*Panthera leo*), both of which are classified as vulnerable. None of the methods ensured the detection of the total number of species. Even the most 'powerful' method in terms of detection, the camera traps (Table 2), only recorded 52% of the species potentially present.

Camera traps and spatial distribution

Camera traps were established for an average 8 days in the same location. The low average result was due to battery problems encountered during the first session. In 726 CT days, we collected 1713 pictures. Out of these pictures, we excluded 1089 failures and 53 pictures with human beings labelled as 'users', which left 571 pictures of 31 medium and large mammal species and four bird species. Most of the pictures allowed species identification, with some difficulties for taxa, such as *Genetta* and *Lepus*, which necessitated confirmation by independent experts. The most represented groups were the ungulates (twelve species belonging to ten genera) and carnivores (eleven species belonging to nine genera). Several species were detected only by camera traps, particularly nocturnal species, such as the aardvark (*Orycteropus afer*), but also some diurnal ones, such as Moloney's monkey (*Cercopithecus m. moloneyi*) (Davenport, Nowak & Perkin, 2013). The species detection accumulation curve tended to take an asymptotic form at the end of the study period (Fig. 3), which suggested that few species remained to be detected with an increase in research effort.

The most widely distributed ungulates were the warthog, captured in fourteen CT stations (38.8%), followed by the common duiker (ten CT stations, 27.8%), giraffe (nine CT stations, 25.0%), plain zebra (eight CT

Table 2 Comparison of the detection performances between methods

	Camera trap	Indirect observations	Car transect	Foot transect	Car opportunistic	Foot opportunistic	Shared by all methods	All methods pooled
Number of detected species	31	28	26	14	23	16	9	49
Number of species detected by one method only	5	2	3	0	2	3	–	–
In percent of the 49 detected species, %	52	47	43	23	38	27	15	100
In percent of the 60 expected species, %	63	57	53	29	47	33	18	82

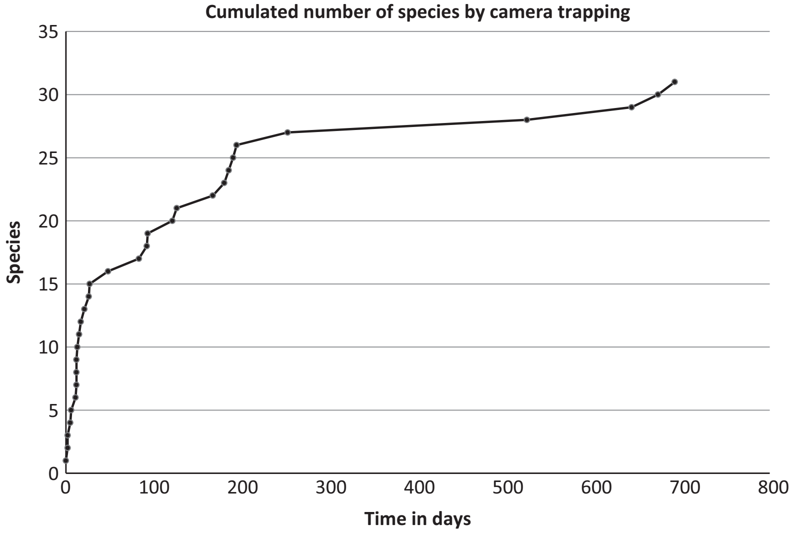

Fig 3 Camera traps species accumulation curve

stations, 22.2%), bushpig (seven CT stations, 19.4%), bushbuck (six CT stations, 16.7%) and Lichtenstein's hartebeest (five CT stations, 13.9%). Among primates, the baboon was the most widely distributed and captured species (eleven CT stations, 30.6%). Among carnivores, the most distributed species were the Hyaena, captured in twelve CT stations (33.3%), followed by leopard (nine CT stations, 25%), the miombo genet (six CT stations; 16.7%) and marsh mongoose (*Atilax paludinosus*) (four CT stations; 11.1%).

Line transects on foot

In 32 h over transects that were each surveyed five times, we made 35 observations of fourteen species of mammals. Compared to the other methods, foot transects presented poor performance in terms of detection, as we observed only a quarter of the species present according to the predictive model and none by this method alone.

Vehicle transects

In 33 h of vehicle transects by day, each repeated 5–6 times, we recorded 66 observations of 22 species of mammals. At night, the same method allowed us to make 276 observations of 22 species in 33 h, with transects repeated between four and five times. Combining night and day observations, the method supported the identification of 26 species, which is slightly lower than the camera trap, with 31 species. In terms of detection, the vehicle transect method supported the identification of species not detected by other methods, such as the lion, observed twice by day and once by night. Regarding nocturnal species, vehicle transects detected the serval (*Leptailurus serval*), two species of galago and the wild cat (*Felis sylvestris*).

Indirect signs

Indirect signs enabled the identification of species rarely or never detected by other methods. This was the case for the porcupine and the aardvark, until they were captured by the camera traps during the last camera trap days. Currently, two species are still undetected but definitely present, as revealed by indirect signs: the Cape eland (*Taurotragus oryx*) and the hippopotamus (*Hippopotamus amphibius*). Both species might be present on a seasonal basis (Table 3).

Discussion

The discussion will be articulated around three points: performance comparisons between methods, the incidence of camera trap use in wildlife research and the conservation value of lightly protected areas.

Regarding performance comparisons, our survey confirms that camera trapping appears to be the best method regarding species detection in the miombo ecosystem, particularly when taking into account cost efficiency and data validity. The apparent poor performances of the walked transects, besides the low effort of our survey, may be linked to hunting pressure and to the sensitivity of animals to human disturbance. As mentioned by Caro (1999b), flight distances appear more important in the FR and GCA than in the neighbouring Katavi NP. In this context, the method appears to be inadequate, and we suggest that it should be abandoned.

Driven transects represent a complementary method to camera trapping and are useful for the detection of nocturnal species.

Indirect signs were important to confirm the presence of some secretive species during the first years of the project, but the method requires expertise to validate the identification of tracks and spoors. We suggest that this method be abandoned.

Opportunistic encounters played a significant role regarding the inventory. They confirmed the presence of four species: the wild dog, Sharpe's grysbok, the four toed elephant shrew (*Petrodromus tetradactylus*) and the serval.

Table 3 Camera traps: Spatial distribution of the capture events and the number of independent pictures per species

N	Common name	No. of CT stations	No. of independent pictures
1	Warthog	14	35
2	Spotted hyena	12	47
3	Yellow baboon	11	41
4	Common duiker	10	25
5	Leopard	9	19
6	Giraffe	9	24
7	Plain zebra	8	21
8	Bushpig	7	13
9	Bushbuck	6	12
10	Miombo genet	6	11
11	Hare sp.	5	23
12	Lichtenstein's hartebeest	5	12
13	African buffalo	4	14
14	Spring hare	4	11
15	Honey badger	4	8
16	Marsh mongoose	4	4
17	Bushy tailed mongoose	3	3
18	Sable antelope	2	9
19	African Porcupine	2	4
20	African civet	2	3
21	Side-striped jackal	2	2
22	African elephant	2	2
23	Roan antelope	2	2
24	Vervet monkey	1	3
25	Topi	1	3
26	Silver monkey cluster	1	1
27	White tailed mongoose	1	1
28	Un-identified large genet	1	1
29	Aardvark	1	1
30	Greater kudu	1	1
31	Impala	1	1

Finally, we suggest to continue regular surveys with two methods, camera trapping, using systematic sampling with a grid approach, and regular driven counts on defined transects. The repetition of data collection using these two methods will help to detect changes in population dynamics at the landscape level.

Regarding the incidence of camera trap use in wildlife research, several studies using other methods have covered the larger Katavi-Rukwa ecosystem, including our study area, although none focused exclusively on Mlele FR and its diversity of wildlife. The relative research effort in our study area remained low, with only a few data collection points or transects within the area for each studied group (Caro, 1999a,b, 2008; Gardner *et al.*, 2007b). Most of the studies concluded that low-status areas (FR and GCA) were harbouring fewer big game populations than protected core areas. Stoner *et al.* (2007) concluded, from the analysis of a decade of monitoring data, that strictly protected areas were clearly more effective in conserving large mammal populations than multiple-use areas with fewer restrictions on resource use.

Besides our method comparisons, our results provide the first fine-scale data on medium and large mammal communities in Mlele FR. The results reveal that this low category protected area of western Tanzania harbours diversified populations of medium and large mammals, despite a low level of law enforcement activities compared to NPs and GRs. Despite the low coverage of our sampling strategy, the recorded mammal community appears to be higher than the average recorded in FRs countrywide, which are considered to be depleted of wildlife (Durant & Foley, 2009). Most of the large- and medium-sized mammal species potentially hosted by the miombo habitat were proven to be present. Compared with existing data recorded in the area by the Tanzania Wildlife Research Institute (TAWIRI) using aerial counts and vehicle transects (Caro, 1999a, 2008; Stoner *et al.*, 2007), our data present a much more diverse mammal community. The presence of this community, with all sizes of carnivores (eighteen species), indicates the existence of a well-structured ecosystem (Fischer, Tagand & Hausser, 2013) in which most of the ecological niches are occupied. Our results are consistent with TAWIRI findings during a camera trap survey conducted in the Selous-Niassa Corridor (TAWIRI, 2010), and the method is efficient in detecting species difficult to observe from aerial surveys such as the carnivores and night active species.

In the aforementioned context of wildlife decline in strictly protected areas, our study suggests contrasting results. This, we hypothesize, may be linked to the fact that our study is the first to use camera traps in the Katavi–Rukwa ecosystem. As underlined by Caro (2011), both aerial and vehicle counts may underestimate wildlife populations in the miombo ecosystem. The contribution of lightly protected areas to conservation strategies remains disputed. If numerous studies concluded that lightly protected areas are efficient at reducing habitat loss (Hayes, 2006; Leroux *et al.*, 2010; Persha, Agrawal & Chhatre, 2011), the ability of this type of protected area to ensure the conservation of medium and large mammals would remain debated. Some researchers, such as Caro (2015), simply consider them to be inadequate to contribute to the conservation of medium and large mammals, while Geldmann *et al.* (2013) found inconclusive results regarding the ability of lightly protected areas to maintain the populations of medium and large mammals. In contrast, Leroux *et al.* (2010) found that category VI IUCN protected areas might have an unexpectedly high degree of naturalness – based on the human footprint index, which is inversely correlated to degree of naturalness – compared with strictly protected areas, such as NPs. Our data demonstrated a high diversity of species, but we cannot infer from our results quantitative data regarding population estimates. It is therefore not possible to address a clear answer to the question of the value of lightly protected areas compared to strict protected areas. We have now to confirm this supposition through more systematic and standardized camera trapping surveys that will allow us to quantify population estimates. All these elements call for more research on the occurrence and persistence of medium and large mammals in the landscape of various types of protected areas, including lightly protected areas.

Acknowledgements

We thank TAWIRI and COSTECH for permission to conduct research at the national level and District staff for their support at the local level. We thank the Inyonga Beekeepers Association and ADAP for field support and partnership. We thank the SDC-KfH Program and the UASWS for funding. We thank C. Foley, B. Chardonnet, B. Bergerot, J. Felix and three anonymous reviewers for comments on earlier versions of the manuscript.

References

Banda, T., Mwangulango, N., Meyer, B., Schwartz, M.W., Mbago, F., Sungula, M. & Caro, T.M. (2008) The woodland vegetation of the Katavi-Rukwa ecosystem in western Tanzania. *For. Ecol. Manage.* **255**, 3382–3395.

Bowkett, A.E., Rovero, F. & Marshall, A.R. (2008) The use of camera trap data to model habitat use by antelope species in the Udzungwa mountains forests, Tanzania. *Afr. J. Ecol.* **46**, 479–497.

Caro, T.M. (1999a) Densities of mammals in partially protected areas: the Katavi ecosystem of western Tanzania. *J. Appl. Ecol.* **36**, 205–217.

Caro, T.M. (1999b) Demography and behaviour of African mammals subject to exploitation. *Biol. Conserv.* **91**, 91–97.

Caro, T. (2008) Decline of large mammals in the Katavi - Rukwa ecosystem of western Tanzania. *Afr. Zool.* **43**, 99–116.

Caro, T.M. (2011) On the merits and feasibility of wildlife monitoring for conservation: a case study from Katavi National Park, Tanzania. *Afr. J. Ecol.* **49**, 320–331.

Caro, T. (2015) Conservation in the African Anthropocene. In: *Protecting the Wild. Parks and Wilderness the Foundation for Conservation* (Eds G. Wuerthner, E. Crist and T. Butler). Published by Foundation for Deep Ecology, San Francisco, Island Press, Washington.

Caro, T. & Scholte, P. (2007) When protection falters. *Afr. J. Ecol.* **45**, 233–235.

Caro, T.M., Gardner, T., Stoner, C., Fitzherbert, E. & Davenport, T. (2009) Assessing the effectiveness of protected areas: paradoxes call for pluralism in evaluating conservation performance. *Divers. Distrib.* **15**, 178–182.

Craigie, I.D., Baillie, J.E.M., Balmford, A., Carbone, C., Collen, B., Green, R.E. & Hutton, J.M. (2010) Large mammals population declines in Africa's protected areas. *Biol. Conserv.* **143**, 2221–2228.

Davenport, T., Nowak, K. & Perkin, A. (2013) Priority primates areas in Tanzania. *Oryx* **48**, 39–51.

Durant, S. & Foley, C. (Eds.) (2009) A National Plan for Mammal Conservation in Tanzania. Final report to Darwin Initiative. November 1st 2005 – February 7th 2009. Tanzania Mammal Atlas Project. ZSL, TAWIRI.

East, R. (Ed.) (1999) African Antelope Database 1998. IUCN/SSC Antelope Specialist Group, IUCN Gland (Switzerland) and Cambridge (UK).

Estes, R.D., Atwood, J.L. & Estes, A.B. (2006) Downwards trends in Ngorongoro crater ungulate population 1986–2005: conservation concerns and the need for ecological research. *Biol. Conserv.* **131**, 106–120.

Fischer, C., Tagand, R. & Hausser, Y. (2013) Diversity and distribution of small carnivores in a miombo woodland within the Katavi region, Western Tanzania. *Small Carniv. Conserv.* **48**, 60–66.

Fitzherbert, E., Gardner, T., Davenport, T. & Caro, T. (2006) Butterfly species richness and abundance in the Katavi ecosystem of western Tanzania. *Afr. J. Ecol.* **44**, 353–362.

Fitzherbert, E., Gardner, T., Caro, T. & Jenkins, P. (2007) Habitat preferences of small mammals in the Katavi ecosystem of Western Tanzania. *Afr. J. Ecol.* **45**, 249–257.

Gardner, T., Fitzherbert, E., Drewes, R.C., Howell, K. & Caro, T. (2007a) Spatial and temporal patterns of abundance and diversity of an East African Leaf Litter amphibian fauna. *Biotropica* **39**, 105–113.

Gardner, T., Caro, T., Fitzherbert, E., Banda, T. & Lalbhai, P. (2007b) Conservation value of multiple use areas in Eastern Africa. *Conserv. Biol.* **21**, 1516–1525.

Geldmann, J., Barnes, M., Coad, L., Craigie, D., Hockings, M. & Burgess, N.D. (2013) Effectiveness of terrestrial protected areas in reducing habitat loss and populations declines. *Biol. Conserv.* **161**, 230–238.

Hausser, Y. & Mpuya, P. (2004) When the bees get out of the woods: an innovative cross – sectoral approach to community based natural resource management. *Game Wild. Sci.* **21**, 291–312.

Hausser, Y., Weber, H. & Meyer, B. (2009) Bees, farmers, tourists and hunters: conflict dynamics around western Tanzania protected areas. *Biodivers. Conserv.* **18**, 2679–2703.

Hayes, T. (2006) Parks, people, and forest protection: an institutional assessment of the effectiveness of protected areas. *World Dev.* **34**, 2064–2075.

Henschel, P. & Ray, J. (2003) Leopards in African Rainforests: Survey and Monitoring Techniques. Global carnivores programme, Wildlife Conservation Society.

Karanth, K.U. & Nichols, J.D. (1998) Estimation of tiger densities in India using photographic captures and recaptures. *Ecology* **79**, 2852–2862.

Kauffmann, M.J., Sanjayan, M., Lowenstein, J., Nelson, A., Jeo, R.M. & Crooks, K.R. (2007) Remote camera-trap methods and analyses reveal impacts of rangeland management on Namibian carnivore communities. *Oryx* **41**, 70–78.

Kelly, M.J., Noss, A.J., di Bitetti, M.S., Maffei, L., Arispe, R.L., Paviolo, A., de Angelo, S.D. & di Blanco, Y. (2008) Estimating puma densities from camera trapping across three study sites: Bolivia, Argentina and Belize. *J. Mammal.* **89**, 408–418.

Kingdon, J. (1997) *The Kingdon Field Guide to African Mammals.* A&C Black Publishers Ltd., London.

Leroux, S. J., Krawchuk, M. A., Schmiegelow, F., Cumming, S. G., Lisgo, K., Anderson, L. G. & Petkowa, M. (2010) Global protected areas and IUCN designation: do the categories match the conditions? *Biol. Conserv.* **143**, 609–616.

Li, S., McShea, W.J., Wang, D., Lu, Z. & Gu, X. (2012) Gauging the impact of management expertise on the distribution of large mammals across protected areas. *Divers. Distrib.* **18**, 1166–1176.

Nelson, A. & Chomitz, K.M. (2011) Effectiveness of strict vs. multiple use protected areas in reducing tropical forest fires: a global analysis using matching methods. *PLoS ONE* **6**, e22722.

O'brien, T.G., Kinnaird, M.F. & Wibisono, H.T. (2003) Crouching tigers, hidden prey: Sumatran tiger and prey populations in a tropical forest landscape. *Anim.Conserv.* **6**, 131–139.

Persha, L., Agrawal, A. & Chhatre, A. (2011) Social and ecological synergy: local rulemakings, forest livelihoods and biodiversity conservation. *Science* **331**, 1606–1607.

Pettorelli, N., Lobora, A.L., Msuha, M.J., Foley, C. & Durant, S.M. (2010) Carnivore diversity in Tanzania: revealing distribution patterns of secretive mammals using camera traps. *Anim. Conserv.* **13**, 131–139.

Rovero, F. & Marshall, A.R. (2009) Camera trapping photographic rate as an index of density in forest ungulates. *J. Appl. Ecol.* **46**, 1011–1017.

Rowcliffe, J.M. & Carbone, C. (2008) Surveys using camera-traps: are we looking to a brighter future? *Anim. Conserv.* **11**, 185–186.

Silveira, L., Jacomo, A.T.A. & Diniz-Filho, J.A.F. (2003) Camera trap, line transect census and track surveys: a comparative evaluation. *Biol. Conserv.* **114**, 351–355.

Stoner, C., Caro, T., Mduma, S., Mlingwa, C., Sabuni, G. & Borner, M. (2007) Assessment of effectiveness of protection strategies in Tanzania based on a decade of survey data for large herbivores. *Conserv. Biol.* **21**, 635–646.

Stuart, C. & Stuart, M. (2013) A Field Guide to the Tracks and Signs of Southern, Central and East African wildlife. Struik Nature.

TAWIRI (2010) Small Fauna Survey of the Selous-Niassa Wildlife Protection Corridor. Study Report N°9, Tanzania Wildlife Research Institute.

Tobler, M.W., Carrillo-Percastegui, S.E., Leite Pitman, R., Mares, R. & Powell, G. (2008) An evaluation of camera traps for inventorying large- and medium-sized terrestrial rainforest mammals. *Anim. Conserv.* **11**, 169–178.

Western, D., Russell, S. & Cuthill, I. (2009) The status of wildlife in protected areas compared to non-protected areas of Kenya. *PLoS One* **4**, e6140.

(*Manuscript accepted 10 January 2016*)

doi: 10.1111/aje.12301