African Journal of Ecology

On the merits and feasibility of wildlife monitoring for conservation: a case study from Katavi National Park, Tanzania

Tim Caro[1,2]*

[1]*Department of Wildlife, Fish and Conservation Biology, University of California, 1 Shields Avenue, Davis, CA 95616, U.S.A., and* [2]*Tanzania Wildlife Research Institute, PO Box 661, Arusha, Tanzania*

Abstract

Although long-term monitoring is viewed as an essential part of conserving wildlife populations, it is currently carried out in surprisingly few protected areas in Africa. Here, data from a 16-year vehicle transect monitoring programme in Katavi National Park, western Tanzania, are presented. These data provide information on large mammal densities, identify declines in populations of several large mammal species as based on encounter rates, support worrying trends observed in aerial census data and shed light on the effectiveness of recent changes in legal protection. Ground and aerial surveys confirmed that waterbuck, topi, warthog, lion and spotted hyaena populations are all in decline and that this should be a cause for concern. Counting animals by driving vehicle transects is relatively easy and inexpensive to carry out, and data here show that such counts have several pay-offs for conservation managers especially in identifying population declines; counts should be employed more often in East Africa and elsewhere.

Key words: census, Katavi–Rukwa, large mammal, population decline, survey

Résumé

Alors que l'on considère qu'un suivi de longue durée est une part essentielle de la conservation de populations de faune sauvage, cela ne se fait que dans un nombre d'aires protégées étonnamment réduit. Nous présentons ici un programme d'une durée de 16 ans de suivi à partir d'un véhicule sur transect dans le Parc National de Katavi, dans l'ouest de la Tanzanie. Ces données présentent des informations sur la densité de grands mammifères, identifient des déclins de population de plusieurs espèces de grands mammifères basés sur des taux d'observations, étayent des tendances inquiétantes déjà observées dans des données résultant de recensements aériens, et mettent en lumière l'efficacité de récents changements de protection légale. Des études aériennes et au sol ont confirmé que les populations de waterbucks, de topis, de phacochères, de lions et d'hyènes tachetées sont toutes en diminution et que cette situation doit nous inquiéter. Compter les animaux à partir de véhicules le long de transects est relativement facile et peu coûteux, et ici, les données montrent que ces comptages ont plusieurs avantages pour les gestionnaires de la conservation, spécialement pout identifier des déclins de populations; des dénombrements devraient être employés plus souvent, en Afrique de l'Est et ailleurs.

Introduction

To understand the consequences of legal protection and management actions, wildlife populations need to be monitored over time (Yuccoz, Nichols & Boulinier, 2001; Nichols & Williams, 2006; Marsh & Trenham, 2008; Lindenmayer & Likens, 2010a; Peters, 2010). Surprisingly, however, across the world renowned network of protected areas in East Africa, there are few active monitoring programmes. In Tanzania, for example, long-term ground surveys of large and medium-sized mammals are carried out only in two national parks: Serengeti (e.g. Hofer & East, 1995) and Katavi. In contrast, mammal populations across Tanzania are counted intermittently using systematic reconnaissance flights although the resulting information is rarely examined over a long time period; instead, the most recent surveys are usually compared with the previous two

---

**Correspondence:* E-mail: tmcaro@ucdavis.edu

surveys in unpublished reports that are for limited distribution only (but see Sinclair *et al.*, 2007; Caro, 2008). This is unfortunate because it is important to estimate animal population sizes in protected areas to which management authorities can refer in the future (e.g. Scholte, Adam & Bobo, 2007), to track population trends to forewarn of upcoming problems (e.g. Ogutu & Owen-Smith, 2005), to examine any consequences of management activities on wildlife populations (e.g. Remis & Kpanou, 2011) and to relate ground and aerial surveys to each other (e.g. Jachmann, 2002; Waltert *et al.*, 2008). Here, these four issues are addressed with a 16-year time series derived from vehicle transects in Katavi National Park (NP) that were carried out between 1995 and 2010 over a period when the park was doubled in size (Katavi-Rukwa Ecosystem Management Plan, 2002). This long-term data set provides an empirical justification for the importance of wildlife monitoring in African protected areas. The purpose of this paper is not to compare methods of monitoring wildlife populations but to encourage the establishment of new monitoring programmes in African protected areas especially in the light of widespread population declines across the continent (Caro & Scholte, 2007; Craigie *et al.*, 2010).

Material and methods

Study area

The Katavi–Rukwa ecosystem lies in the Great Lakes Region of East Africa north of Lake Rukwa in Mpanda District, Rukwa Region, Tanzania (Katavi-Rukwa Ecosystem Management Plan, 2002; Fig. 1). The area is part of the central Zambezi miombo woodlands ecoregion (Burgess *et al.*, 2004) but, unusually for miombo, is characterized by trees of the *Terminalia* and *Combretum* genera (Banda, Schwartz & Caro, 2006; Banda *et al.*, 2008). A great diversity and abundance of large mammals occur in this area (Caro, 1999a,b, 2003) which is currently under five different forms of protection. First, a 4279-km^2 NP is administered and patrolled by Tanzania National Parks (TANAPA); no settlements or exploitation are allowed within NP boundaries. Established in 1974, Katavi NP was half this size until 1998 but was then extended to the south-east (Fig. 1) and now constitutes the country's third largest NP. To the east and south of the park lies the 4323-km^2 Rukwa Game Reserve (GR); Lwafi GR lies to the west; both are administered by the Wildlife Division but patrolled infrequently. No settlements are allowed in these two GRs but hunting companies operate there during the dry season, July to November. To the west of the park lies the Nkamba Forest Reserve (FR) which is administered by the Forestry Department; it also doubles as a hunting block. To the north of the park there is the Msanginia FR. No settlements are allowed in FRs but legal and illegal loggings occur in these two areas. To the north-east of the park sits Mlele Game Controlled Area (GCA) also administered by the Wildlife Division but it is effectively a multiple-use area (Caro, 1999b). To the south of Katavi NP and Rukwa GR lies Usevya Open Area (OA) also called Mpimbwe. There Sukuma, Pimbwe and Fipa live in and around 22 villages where they graze cattle and practice agriculture (principally sorghum, maize, millet, cassava, peanut and rice cultivation, Borgerhoff Mulder, Caro & Msago, 2007). It is illegal to hunt animals in the OA without a license but in practice illegal subsistence hunting is widespread.

Surveys

Ground surveys were conducted by regularly driving four vehicle transects along minor tracks in Katavi NP (Fig. 1). Transect A was along the Park Extension – Mlele GCA border ('Kapapa' 23.6 km in length); transect B was through the western edge of the NP Extension ('X' 6.0 km); transect C went through the eastern portion of the original NP ('North Chada' 22.1 km); and transect D went through the centre of the NP Extension ('Paradise' 28.7 km). Transects were driven nearly every year between 1995 and 2010, always early in the morning, always in the dry season and usually twice per year (range 1–3) (transects driven a total of 88 times amounting to 1692 km).

Overall, mammal densities were calculated by dividing the total number of animals seen each time a given transect was driven by the area over which animals were visible based on a continuous record of visibility estimated by eye and taken along the length of each transect up to a maximum of 500 m (see Caro, 1999a,b,c for details). This method is suitable for the patchy woodland–grassland mosaic that characterizes this area (Caro, 1999c, 2008). For each of the four transects, a mean figure for the area that could be seen was estimated (area/times transect were driven) because strip width estimates differed slightly each time transects were driven owing to observer error.

When comparing numbers of individuals counted over time along the same transect, however, numbers of animals counted were simply divided by the length of transect in order to circumvent having to use area estimates which

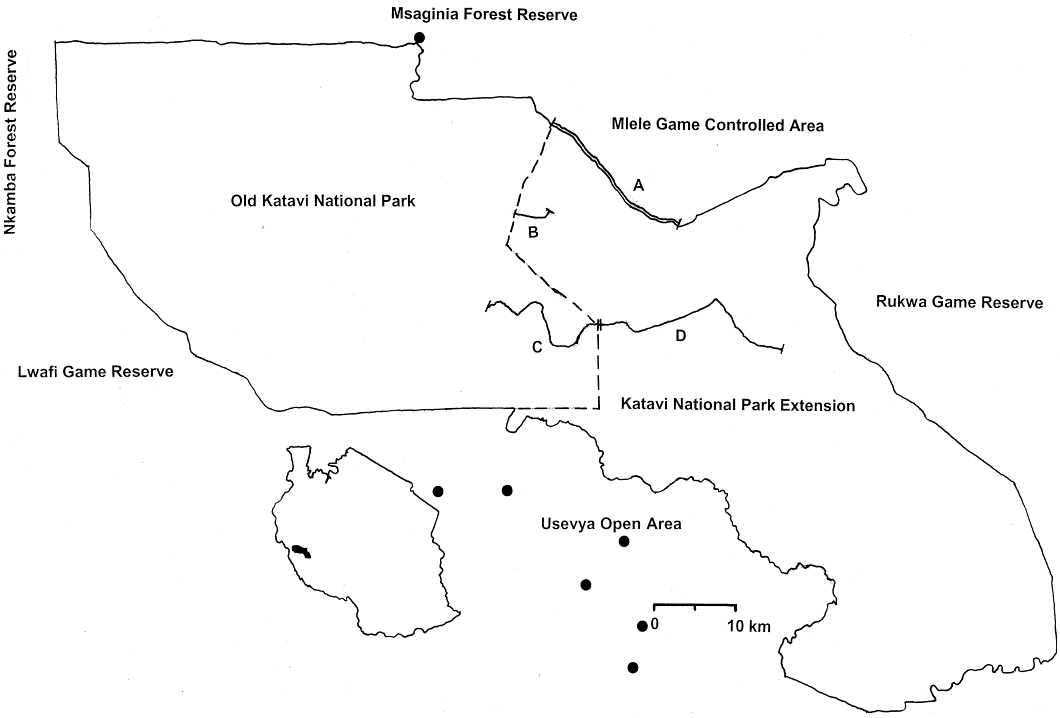


Fig 1 Map of Katavi National Park showing the location of the four ground transects and legally protected areas mentioned in the text. A (Kapapa); B (transect X); C (North Chada); D (Paradise). Dashed line shows boundary of the old NP and NP Extension; filled ovals show locations of important villages. Inset shows location of Katavi NP (filled in) in Tanzania.

involve error. DISTANCE sampling was not used because there were insufficient numbers of individuals of many of the rarer species to derive a suitable detection function and these species are particularly interesting from a conservation perspective. The resulting population indices (individuals per km) should nevertheless be robust because detection probabilities are very unlikely to have changed over years. These (1–3) population indices were then averaged for each year and correlated against years that transects were driven. These indices were highly correlated with densities derived from the strip transect visibility method (Spearman rank correlation coefficients for all 25 species, including humans, ranged between +0.825 and +1.000 across 12 years, $0 < P < 0.001$).

Aerial census data for the whole of the Katavi–Rukwa ecosystem were obtained from Serengeti Ecological Monitoring Programme (SEMP), Tanzania Wildlife Conservation Monitoring Programme (TWCM) and Conservation Information Monitoring Unit (CIMU) reports of repeated systematic reconnaissance flights of an area of approximately 12,000 km^2 (see SEMP, 1988, 1989; TAWIRI, 2002; TAWIRI/CIMU, 2004, 2007, 2010; TWCM, 1992, 1999 for data, and Stoner *et al.*, 2007a,b; Caro, 2008 for further details). Densities of sixteen species of ungulates were calculated by dividing the total population estimate by total area surveyed. Densities were plotted against the year that the survey was conducted between 1977 and 2009.

Results

Estimated densities of large and medium-sized mammals in Katavi National Park differed considerably according to whether animals were encountered in thick miombo woodland, in sparse miombo parkland or on floodplains in the dry season. Table 1 shows that densities observed on floodplain transects (C and D) were considerably higher for most species of artiodactyls, carnivores and primates although some ungulates such as greater kudu (*Tragelaphus strepsiceros* Blyth) and hartebeest (*Alcelaphus buselaphus* Peters) were principally found along transects that did not pass near rivers or areas that flood in the wet season

Table 1 Estimated mean densities (individuals per km^2) of large and medium-sized mammals obtained from four ground transects in Katavi NP conducted between 1995 and 2010. A (Kapapa) is almost entirely thick miombo woodland, B (transect X) is scattered parkland, C (North Chada) is principally riverine habitat and floodplain in the original KNP, D (Paradise) is principally riverine habitat, floodplain and both thick and open miombo in the Park Extension. Also shown are mean densities and associated standard deviations (SD) across the four transects. Mammals are listed in the order of descending body weight and taxonomic affiliation

Species	A	B	C	D	$\bar{X}$	SD
Number of times driven	25	21	23	19		
Elephant	0.25	0.15	0.46	0.21	0.269	±0.133
Hippopotamus	0	0	6.60	11.34	4.484	±5.528
Giraffe	1.28	2.82	0.44	1.04	1.396	±1.012
Buffalo	0.23	2.36	39.03	42.79	21.104	±22.941
Eland	0	0.53	0.08	0.62	0.307	±0.313
Roan antelope	0	0.08	0	0.27	0.087	±0.129
Burchell's zebra	0.34	1.45	7.62	30.09	9.874	±13.851
Waterbuck	1.65	0	0.47	5.07	1.797	±2.288
Greater kudu	0.30	0.08	0	0	0.093	±0.141
Hartebeest	0.87	1.75	0	0.03	0.663	±0.830
Topi	0.16	3.43	2.91	1.27	1.943	±1.502
Bush pig	0.02	0.30	0	0.03	0.088	±0.145
Warthog	0.73	0.38	0.74	1.08	0.734	±0.284
Reedbuck	0.07	0	0.04	2.27	0.593	±1.117
Impala	0.05	1.07	9.67	4.63	3.853	±4.347
Bushbuck	0.09	0	0.02	0.06	0.043	±0.043
Common duiker	0.21	0.46	0	0.07	0.183	±0.202
Lion	0	0	0.18	0.06	0.060	±0.084
Spotted hyaena	0	0	0.04	0.03	0.019	±0.023
Assorted carnivores[a]	0	0	0.03	0.02	0.013	±0.015
Mongoose[b]	0.07	0.08	0.26	0.53	0.234	±0.216
Yellow baboon	0.34	0	0.04	0.36	0.185	±0.193
Vervet monkey	0.82	0.53	0.86	2.03	1.060	±0.661
Small mammals[c]	0	0	0	0.02	0.005	±0.007
Human[d]	1.78	0	0	0.04	0.456	±0.886

[a] Cheetah *Acinonyx jubatus*, ratel *Mellivora capensis*, side-striped jackal *Canis adustus* combined.

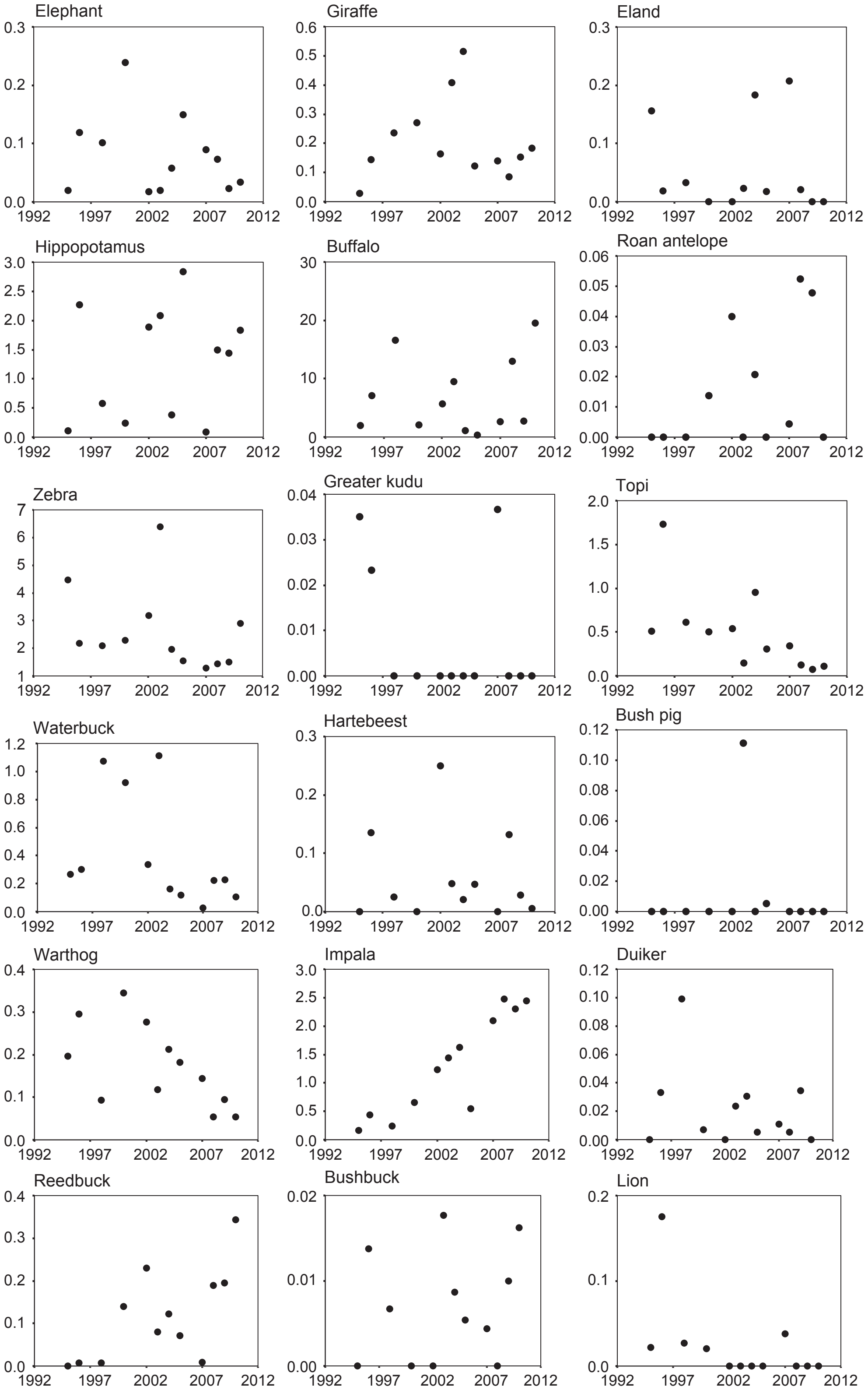
[b] Dwarf *Helogale parvula*, banded *Mungos mungo*, Egyptian *Herpestes ichneumon* and marsh mongoose *Atilax paludinosus* combined.

[c] Greater cane rat *Thryonomys swinderianus* and hare *Lepus crawshayi* combined.

[d] Humans on foot.

(A and B). Average densities of mammals are shown for the four transects and establish preliminary 1995–2010 estimates for this, Tanzania's third largest, national park.

Over a 16-year period from 1995 to 2010, there were declines in numbers of individuals counted for 14 of the 24 species or species groups (Fig. 2). In particular, waterbuck (*Kobus ellipsiprymnus* Ogilby), topi (*Damaliscus lunatus* Burchell), warthog (*Phacocherus africanus* Pallas), lion (*Panthera leo* Linnaeus), spotted hyaena (*Crocuta crocuta* Erxleben) and possibly zebra (*Equus quagga burchellii* Gray) declined significantly, while numbers of reedbuck (*Redunca redunca* Pallas) and impala (*Aepyceros melampus* Lichenstein) increased significantly as based on ground transects. The increase in impala is marked. (It is to be noted that although regular ground transects in the Park Extension were not started until 1998, the findings presented above were replicated almost precisely when only years 1998–2010 were considered.) There was great variability in encounter rates over time for a number of species. Comparatively rare species such as greater kudu and lion might only be seen if they were encountered by chance; common but secretive species such as bushpig (*Potamochoerus porcus* Linnaeus) and small mammals were not usually seen; whereas species that live in large herds such as buffalo (*Syncerus caffer* Sparrman) and hippopotamus (*Hippopotamus amphibius* Linnaeus) generated high numbers but only


Elephant
0.0
0.1
0.2
0.3
Giraffe
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Eland
0.0
0.1
0.2
0.3
Hippopotamus
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Buffalo
0
10
20
30
Roan antelope
0.00
0.01
0.02
0.03
0.04
0.05
0.06
Zebra
1
2
3
4
5
6
7
Greater kudu
0.00
0.01
0.02
0.03
0.04
Topi
0.0
0.5
1.0
1.5
2.0
Waterbuck
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Hartebeest
0.0
0.1
0.2
0.3
Bush pig
0.00
0.02
0.04
0.06
0.08
0.10
0.12
Warthog
0.0
0.1
0.2
0.3
0.4
Impala
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Duiker
0.00
0.02
0.04
0.06
0.08
0.10
0.12
Reedbuck
0.0
0.1
0.2
0.3
0.4
Bushbuck
0.00
0.01
0.02
Lion
0.0
0.1
0.2
1992
1997
2002
2007
2012

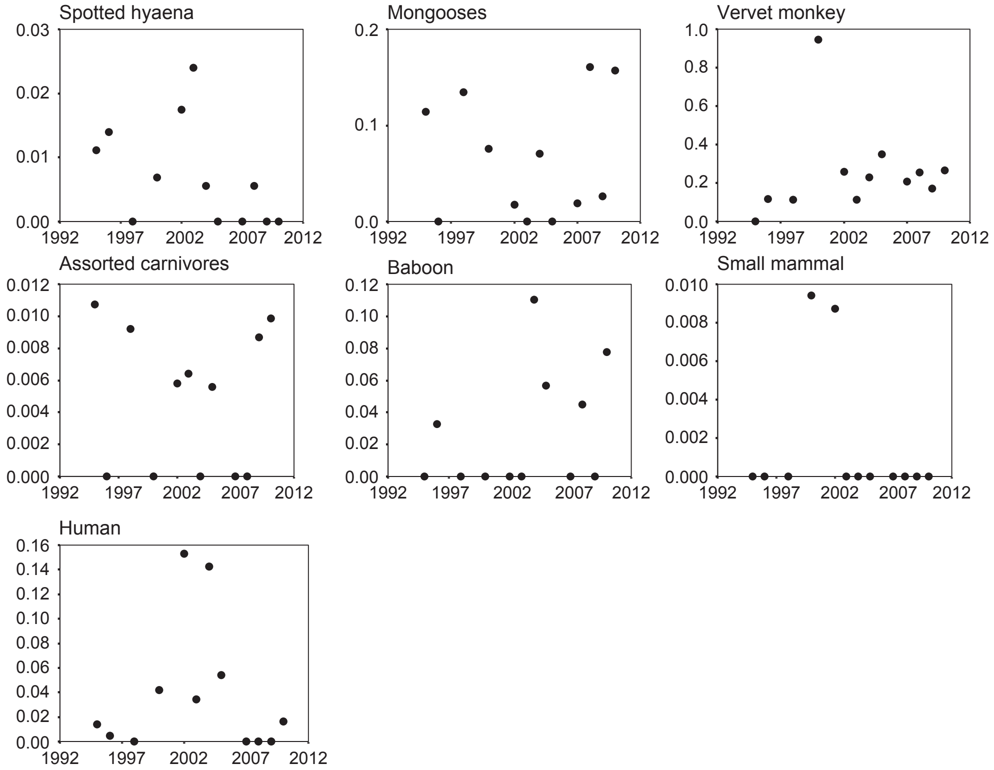


Fig 2 (Continued)

when the groups were encountered. Outlying data points in species such as vervet monkeys (*Cercopithecus aethiops* Linnaeus) are more difficult to explain. It is worth noting that correlations using densities derived from strip transect visibility showed a significant decline over time for lion ($N = 12$ years, $r_s = -0.586$, $P = 0.045$) and significant increases in reedbuck and impala ($N = 12$ years, $r_s = 0.652$, $P = 0.021$ and $r_s = 0.901$, $P < 0.0001$, respectively).

Findings obtained on the ground differed somewhat from those obtained from aerial censuses carried out over a longer period of time and across a much larger area. Aerial data uncovered declines in every species with significant declines in densities of buffalo, eland (*Taurotragus oryx* Pallas), waterbuck, topi, warthog, reedbuck and impala and possibly giraffe (*Giraffa camelopardalis* Linnaeus) and hartebeest, with no significant increases in the population densities of any species (Fig. 3). There was variability in the aerial census data as well, again in herd living species such as buffalo and hippopotamus and in rarer species such as roan (*Hippotragus equinus* Desmarest) and sable antelope (*Hippotragus niger* Harris) and puku (*Kobus vardonii* Livingstone) even though aircraft coverage was more comprehensive. In conclusion, while both types of monitoring showed declines in many species, these differed either because of the method itself, the time period over

---

Fig 2 Encounters rates taken from ground surveys in Katavi National Park conducted between 1995 and 2010. Panels show the numbers of large and medium-sized mammals per km of transect driven in Katavi NP plotted against year ($N = 12$ years for all). Each year, mean numbers of animals seen on a given transect repeated that year were averaged across the four transects. Spearman rank correlation coefficients: elephant $r_s = -0.112$, NS; hippopotamus $r_s = 0.098$, NS; giraffe $r_s = -0.014$, NS; buffalo, $r_s = 0.189$, NS; eland $r_s = -0.249$, NS; roan antelope, $r_s = 0.403$, NS; zebra $r_s = -0.510$, $P = 0.090$; waterbuck $r_s = -0.650$, $P = 0.022$; greater kudu $r_s = -0.349$, NS; hartebeest $r_s = -0.007$, NS; topi $r_s = -0.783$, $P = 0.003$; bushpig $r_s = 0.054$, NS; warthog $r_s = -0.636$, $P = 0.026$; reedbuck $r_s = 0.685$; $P = 0.014$; impala $r_s = 0.902$, $P < 0.001$; bushbuck $r_s = 0.256$, NS; duiker $r_s = -0.106$, NS; lion $r_s = -0.600$, $P = 0.039$; spotted hyaena $r_s = -0.587$, $P = 0.045$; assorted carnivores $r_s = -0.051$, NS; mongooses $r_s = 0.197$, NS; yellow baboon $r_s = 0.398$, NS; vervet monkey $r_s = 0.455$, NS; small mammals $r_s = -0.263$, NS (see Table 1 footnote).

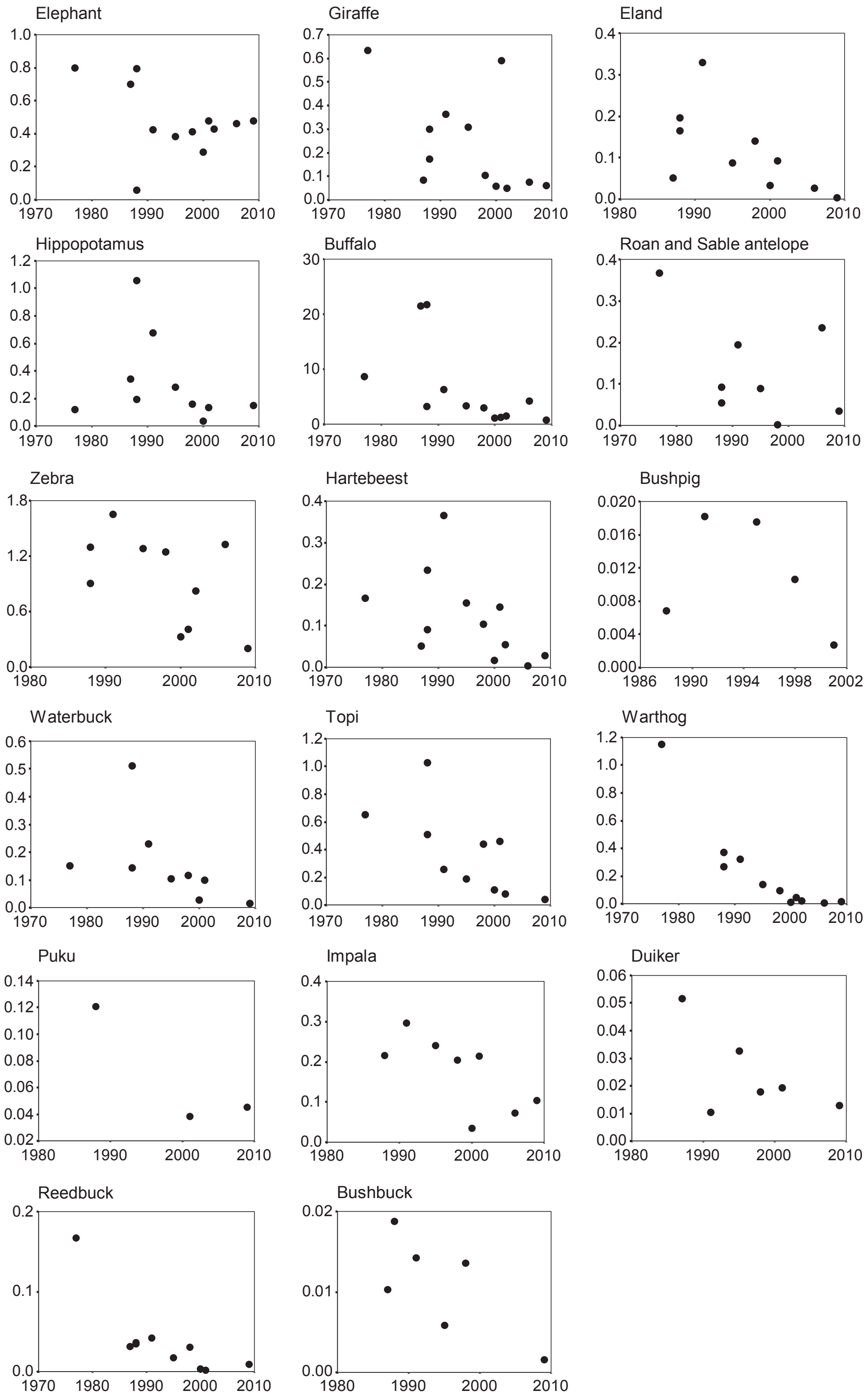

Elephant
1.0
0.8
0.6
0.4
0.2
0.0
1970
1980
1990
2000
2010
Giraffe
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1970
1980
1990
2000
2010
Eland
0.4
0.3
0.2
0.1
0.0
1980
1990
2000
2010
Hippopotamus
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1970
1980
1990
2000
2010
Buffalo
30
20
10
0
1970
1980
1990
2000
2010
Roan and Sable antelope
0.4
0.3
0.2
0.1
0.0
1970
1980
1990
2000
2010
Zebra
1.8
1.2
0.6
0.0
1980
1990
2000
2010
Hartebeest
0.4
0.3
0.2
0.1
0.0
1970
1980
1990
2000
2010
Bushpig
0.020
0.016
0.012
0.008
0.004
0.000
1986
1990
1994
1998
2002
Waterbuck
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1970
1980
1990
2000
2010
Topi
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1970
1980
1990
2000
2010
Warthog
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1970
1980
1990
2000
2010
Puku
0.14
0.12
0.10
0.08
0.06
0.04
0.02
1980
1990
2000
2010
Impala
0.4
0.3
0.2
0.1
0.0
1980
1990
2000
2010
Duiker
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1980
1990
2000
2010
Reedbuck
0.2
0.1
0.0
1970
1980
1990
2000
2010
Bushbuck
0.02
0.01
0.00
1980
1990
2000
2010

Fig 3 Densities taken from aerial surveys over the Katavi–Rukwa ecosystem conducted between 1997 and 2009. Panels show densities of large and medium-sized mammals (individuals per km^2) plotted against year. Spearman rank correlation coefficients: elephant $N = 12$ surveys, $r_s = -0.203$, NS; hippopotamus N = 10, $r_s = -0.383$, NS; giraffe $N = 12$, $r_s = -0.571$, $P = 0.053$; buffalo $N = 12$ years, $r_s = -0.750$, $P = 0.005$; eland $N = 10$, $r_s = -0.632$, $P = 0.05$; roan and sable antelope combined $N = 8$, $r_s = -0.455$, NS; zebra $N = 10$, $r_s = -0.474$, NS; waterbuck $N = 9$, $r_s = -0.862$, $P = 0.003$; hartebeest $N = 12$, $r_s = -0.571$, $P = 0.053$; topi $N = 10$, $r_s = -0.821$, $P = 0.004$; bushpig $N = 5$, $r_s = -0.400$, NS; warthog $N = 11$, $r_s = -0.911$, $P < 0.001$; puku $N = 3$ too few to test; reedbuck $N = 10$, $r_s = -0.839$; $P = 0.002$; impala $N = 8$, $r_s = -0.714$, $P = 0.047$; bushbuck $N = 6$, $r_s = -0.543$, NS; duiker $N = 6$, $r_s = -0.371$, NS.

which surveys were conducted, or the area that was covered, or a combination of these, with only significant declines in waterbuck, topi and warthog being common to both methods. Some species such as impala and reedbuck showed an increase in the centre of the ecosystem as based on ground transects but a decline in the ecosystem as a whole judged from aerial transects (Table 2).

Because ground surveys were carried out over a period of time during which the NP was extended in size, it is instructive to examine whether mammal populations increased following legal upgrading of the Extension from a GCA to a NP. Accordingly, comparisons were made between the two ground transects in which large numbers of mammals were often seen. Of 23 species or species-groups observed and counted from the ground in the Park Extension, nine showed increases, three of which were significant – buffalo, impala and assorted carnivore species (Table 3). Fourteen, however, showed decreases, two of which were significant, giraffe and waterbuck, and lion showed a decreasing trend. Of the nine population increases in the Extension, only hippopotamus, impala and baboons (*Papio hamadryas cyanocephalus* Linnaeus) showed parallel increases in the old portion of the park suggesting that increased legal protection was having some specific effect on the six remaining species, namely buffalo, eland, roan antelope, hartebeest, reedbuck and assorted carnivores. In contrast, and more pessimistically, of the fourteen decreases, four, namely bushbuck (*Tragelaphus scriptus* Pallas), lion, vervet monkey and mongoose species, showed declines while populations in the adjacent old NP increased.

Table 2 Summary of changes in mammal population sizes between 1995 and 2010 for ground surveys and 1977 and 2009 for aerial surveys in the Katavi-Rukwa Ecosystem. Note these different methods target different areas. +denotes increase, −denotes decline. $^*P < 0.1$, $^{**}P < 0.05$, $^{***}P < 0.01$, $^{****}P < 0.001$

Species	Ground	Aerial
Elephant	−	−
Hippopotamus	+	−
Giraffe	−	− (*)
Buffalo	+	− (****)
Eland	−	− (**)
Roan antelope	+	−[a]
Burchell's zebra	− (*)	−
Waterbuck	− (**)	− (***)
Greater kudu	−	Not counted
Hartebeest	−	− (*)
Topi	− (***)	− (***)
Bush pig	+	−
Warthog	− (**)	− (****)
Reedbuck	+ (**)	− (****)
Impala	+ (****)	− (**)
Bushbuck	+	−
Common duiker	−	−
Lion	− (**)	Not counted
Spotted hyaena	− (**)	Not counted
Assorted carnivores[b]	−	Not counted
Mongoose[c]	+	Not counted
Yellow baboon	+	Not counted
Vervet monkey	+	Not counted
Small mammals[d]	−	Not counted

[a] roan and sable antelope combined.
[b] Cheetah, ratel, side-striped jackal combined.
[c] Dwarf, banded, Egyptian and marsh mongoose species combined.
[d] Greater cane rat and hare combined.

Discussion

It is widely acknowledged that ecological monitoring is important in protected areas (Jachmann, 2001; Spellerberg, 2005; Lindenmayer & Likens, 2010b). For example, in Tanzania, there is a TANAPA ecologist in most of the country's national parks and periodic workshops are held on how to monitor wildlife populations effectively. Ground surveys of large mammals using vehicles are advocated in national parks (although not in game reserves) because these are cheaper to carry out than aerial censuses, require less organization and can cover reasonably large distances.

Table 3 Spearman rank order correlation coefficients between numbers of individuals of large and medium-sized mammals seen per km along transect D (28.3 km) in the new NP Extension, and transect C (22.3 km) in the original KNP against time. $N = 10$ years over which transects were conducted between 1998 and 2010

Number of times driven	Park Extension		Original Park	
	19		23	
Species	r_s	P	r_s	P
Elephant	−0.372	NS	−0.152	NS
Hippopotamus	+0.527	NS	+0.152	NS
Giraffe	−0.638	0.047	−0.365	NS
Buffalo	+0.733	0.016	−0.067	NS
Eland	+0.127	NS	None seen	
Roan antelope	+0.213	NS	None seen	
Sable antelope	None seen		None seen	
Burchell's zebra	−0.139	NS	−0.359	NS
Waterbuck	−0.697	0.025	−0.896	<0.001
Greater kudu	None seen		None seen	
Hartebeest	+0.406	NS	None seen	
Topi	−0.091	NS	−0.855	0.002
Bush pig	−0.174	NS	None seen	
Warthog	−0.139	NS	−0.709	0.022
Reedbuck	+0.576	0.082	−0.138	NS
Impala	+0.685	0.029	+0.830	0.003
Bushbuck	−0.252	NS	+0.406	NS
Common duiker	−0.335	NS	None seen	
Lion	−0.574	0.083	+0.174	NS
Spotted hyaena	−0.415	NS	−0.240	NS
Carnivores[a]	+0.683	0.029	−0.487	NS
Mongoose[b]	−0.043	NS	+0.601	0.066
Yellow baboon	+0.321	NS	+0.290	NS
Vervet monkey	−0.018	NS	+0.636	0.048
Small mammals[c]	−0.290	NS	−0.406	NS

[a] Cheetah, ratel, side-striped jackal combined.
[b] Dwarf, banded, Egyptian and marsh mongoose species combined.
[c] Greater cane rat and hare combined.

Yet, regular ground transects are difficult to maintain over long periods because of changing personnel, vehicle availability, sufficient fuel and other pressing needs. Data presented here, however, emphatically show that important trends in wildlife populations can be uncovered over quite short time scales by means of ground transects using vehicles. The disadvantage of this sort of survey is that there is great variability between counts because large herds of ungulates may be seen along transects in some years because of grass suddenly greening following a fire, for instance; because rare or secretive species are sometimes sighted along a transect but not at other times; because wide ranging species such as elephants (*Loxodonta africana* Blumenbach) move on and off transects; and because of chance encounters. The problem of variability can be tackled to some extent by increasing the frequency with which transects are driven and by increasing the number of transects and hence the area covered each year (Brashares & Sam, 2005); both increase the costs and effort of monitoring, however.

Averaging densities along several different transects or along one transect over time generates information on the densities of species within an area. In Katavi National Park, it can be seen (Table 1) that buffalo and zebra live at high densities whereas greater kudu and roan antelope live at low densities. Three points are worthy of note. First, these densities cannot be taken as axiomatic for Katavi NP because the Park is extremely heterogeneous with species living at substantially different densities in different types of habitat. For example, Table 1 shows that reedbuck and zebra are found at high densities in certain floodplains, greater kudu are not found in the central part of the park, lions often are seen near floodplains, and hippopotamus are only found along watercourses, just to mention a few examples. Transects set-up in other areas of the NP generate different densities (see Caro, 1999a), and transect location has a great influence on density estimation. Therefore, multiplying the densities of these species by the area of the park to get an overall density is foolhardy. Inferring absolute animal densities from sample surveys would clearly require a randomized sampling design. Second, the different methods of counting populations yield different densities. Jachmann (2002) showed that aerial censuses considerably underestimate mammal populations in comparison with foot transect data. Waltert *et al.* (2008) showed that foot transects in general yield lower estimates than vehicle transects. Low densities of bushbuck and common duiker (*Sylvicapra grimmia* Linnaeus) reported in Table 1 are likely due to these species hiding at the approach of a vehicle; they can be more easily seen (and counted) on foot (Waltert *et al.*, 2008). Caro (2008) argued that aerial censuses give appropriate values for large species, vehicle surveys are appropriate for medium-sized species and foot surveys best for small species of mammal. Densities generated from vehicle transects for some species, such as lion, do seem to agree with densities obtained from more suitable (call-back) methods (0.060 per km^2 this study versus 0.048 per km^2, Kiffner *et al.*, 2009), and confirm that lions are living at a low density in Katavi possibly as a result of high lion offtake by foreign tourist hunters (Packer *et al.*, 2010) as well as Sukuma hunting lions for commercial reasons (Borgerhoff Mulder *et al.*, 2009). Third, some species of large mammals were never seen during transects but do occur in the ecosystem; namely sable antelope, puku, wild dog (*Lycaon pictus* Brookes) and leopard *Panthera pardus* (Linnaeus). Despite these provisos, Table 1 gives density estimates for 24 species or species groups of mammal to which future counts along these four transects can be compared.

Encounter rates from ground surveys show that while ten species of mammal are increasing in the centre of the Katavi–Rukwa ecosystem over time, only two are increasing significantly. On the other hand, fourteen species show declines with five of these being significant over the 16-year time period and one other showing a declining trend (Fig. 2). In contrast, aerial censuses conducted over a longer time frame and over a wider area paint a far more pessimistic picture of wildlife populations in the Katavi ecosystem. They show populations of all seventeen herbivore species are in decline, seven of these are declining significantly and two show a marginally significant decline. These aerial censuses extend those reported in Caro (2008) by another seven years (to 2009); those earlier findings also reported widespread population declines. Warthog in particular appear to be faring very badly in this ecosystem. The picture that emerges is of continuing declines of many large and medium-sized mammal populations throughout the ecosystem as well as in the central portion (where the ground transects are conducted). Some species are holding their own in the central, photographic tourist areas, but even here species such as lions are becoming more difficult to find. Preliminary calculations, as well as elimination of competing hypotheses, suggested that large herbivores are declining in Katavi NP as a result of high levels of illegal hunting on the periphery and in adjacent lightly patrolled areas (Caro, 2008; A. Martin, T. Caro and M. Borgerhoff Mulder, unpublished data; see also Waltert, Meyer & Kiffner, 2009). Although data on illegal hunting are still being collected, declines seen across the ecosystem as a whole but less in the central better-patrolled tourist area are consistent with the idea that illegal hunting is a significant problem in this ecosystem. Changing hydrology may be involved as well (Manase, Gara & Wolanski, 2011) but we cannot yet determine the relative roles of illegal hunting and reduced water flow in this ecosystem. Whatever the reason for wildlife declines, the Katavi–Rukwa ecosystem is experiencing a marked reduction in numbers of its large mammals and this should be a cause of serious concern for the authorities that can be partially countered through greater protection on the ground as outlined in the Katavi-Rukwa Ecosystem Management Plan (2002) and expansion of the area under full protection (Caro, 2010).

Upgrading the legally protected status of the Park Extension from a GCA to a NP has not resulted in uniform increases in population sizes of large and medium-sized mammals in that area. Some populations have shown increases, although few of these have been significant – perhaps this is not surprising given that the area achieved NP status only 12 years ago. On the other hand, over 60% of the species showed decreases and four of these were specific to the Extension. One of these species, lion, is of particular concern because it is known that lions are favoured quarry of both tourist hunters and young Sukuma men. Declines in the other species, bushbuck, mongooses and vervet monkeys are more difficult to explain.

Conclusion

A large mammal ground monitoring programme set-up in Katavi NP, one of only two long-term programmes in Tanzania, has provided temporal data on population sizes of over twenty species of mammals, has uncovered widespread declines in many of these species, has verified worrying trends seen in aerial census data and has shed light on the effectiveness of recent changes in legal protection. Driving transects is simple, relatively easy to carry out, comparatively cheap and has pay-offs for conservation managers because it can forewarn of population extirpation; it should be employed more often in East Africa and elsewhere. Nonetheless, protected area managers starting on a regular monitoring programme of driving transects should bear in mind the following: transects should be located in a number of different habitats, should be located in both core and peripheral parts of the protected area, should be driven frequently (at least four times per year), rangefinders should be used to measure distances from the road, DISTANCE should be used in analysis of common species if possible and money should be set aside exclusively for regular population monitoring. Vehicle transects can be used to calibrate more commonly used aerial censuses and should not be used to the exclusion of other methods of monitoring including camera trapping, call-backs and foot transects. All are valuable.

Acknowledgements

I thank the Tanzania Wildlife Research Institute, Commission for Science and Technology, and Tanzania National Parks for permissions; TANAPA wardens at Katavi NP HQ at Sitalike for their continuing support; Columbus Zoo, National Geographic Society and University of California for funding; Monique Borgerhoff Mulder, Andrew Bower, Barnabas Caro, Emily Fitzherbert, Toby Gardner, Peter Mgawe, Ayubu Msago, Osca Ulaya for help in the field; Mzee and Jafert Gama, Linus Mwitwa and Toby Mumbi for keeping the cars running in Rukwa Region; Simon Mduma, Honori Maliti and Chantal Stoner for access to aerial census data; and Christian Kiffner and four anonymous referees for comments on the manuscript.

References

Banda, T., Schwartz, M.W. & Caro, T.M. (2006) Woody vegetation structure and composition along a protection gradient in a miombo ecosystem of western Tanzania. *For. Ecol. Mgmt* **230,** 179–185.

Banda, T., Mwanngulango', M., 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. Mgmt* **255,** 3382–3395.

Borgerhoff Mulder, M., Caro, T.M. & Msago, O.A. (2007) The role of research in evaluating conservation strategies in Tanzania: the case of the Katavi-Rukwa ecosystem. *Conserv. Biol.* **21,** 647–658.

Borgerhoff Mulder, M., Fitzherbert, E.B., Mwalyolo, J. & Mahenge, J. (2009) The national Sukuma expansion and Sukuma-lion conflict. Unpublished report for Panthera Fund.

Brashares, J.S. & Sam, M.K. (2005) How much is enough? Estimating the minimum sampling required for effective monitoring of African reserves *Biodiv. Conserv.* **14,** 2709–2722.

Burgess, N., Hales, J., Underwood, E., Dinerstein, E., Olson, D., Itoua, I., Schipper, J., Ricketts, T. & Newman, K. (2004) *Terrestrial Ecoregions of Africa and Madagascar: a Conservation Assessment*. Island Press, World Wildlife Fund.

Caro, T.M. (1999a) Abundance and distribution of mammals in Katavi National Park, Tanzania. *Afr. J. Ecol.* **37,** 305–313.

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

Caro, T.M. (1999c) Conservation monitoring: estimating mammal densities in woodland habitats. *Anim. Conserv.* **2,** 305–315.

Caro, T. (2003) Umbrella species: critique and lessons from East Africa. *Anim. Conserv.* **6,** 171–181.

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

Caro, T. (2010) *Katavi National Park: Roads, Economic Development and Protected Area Boundaries*. Unpublished Report, University of California, Davis, USA.

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

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

Hofer, H. & East, M. (1995) Population dynamics, population size, and the commuting system of Serengeti spotted hyenas. In: *Serengeti II: Dynamics, Management, and Conservation of an Ecosystem* (Eds A.R.E. Sinclair and P. Arcese), pp. 332–363. of Chicago Press, Chicago.

Jachmann, H. (2001) *Estimating Abundance of African Wildlife: An Aid to Adaptive Management*. Kluwer Academic Publishers, Dordrecht.

Jachmann, H. (2002) Comparison of aerial counts with ground counts for large African herbivores. *J. Appl. Ecol.* **39,** 841–852.

Katavi-Rukwa Ecosystem Management Plan (2002) United Republic of Tanzania, Ministry of Tourism and Natural Resources, Tanzania National Parks. Unpublished Report.

Kiffner, C., Meyer, B., Mühlenberg, M. & Waltert, M. (2009) Plenty of prey, few predators: what limits lions *Panthera leo* in Katavi National Park, western Tanzania? *Oryx* **43,** 52–59.

Lindenmayer, D. & Likens, G.E. (2010a) *Effective Ecological Monitoring*. CSIRO publishing, Collingwood, Victoria, Australia.

Lindenmayer, D. & Likens, G.E. (2010b) The science and application of ecological monitoring. *Biol. Conserv.* **143,** 1317–1328.

Manase, E., Gara, J.I. & Wolanski, E. (2011) A review of the water crisis in Tanzania's protected areas, with emphasis on the Katuma River – Lake Rukwa ecosystem. *Ecohydrol. Hydrobiol.* DOI: 10.2478/v10104-011-0001-2.

Marsh, D.M. & Trenham, P.C. (2008) Current trends in plant and animal population monitoring. *Conserv. Biol.* **22,** 647–655.

Nichols, J.D. & Williams, B.K. (2006) Monitoring for conservation. *Trends Ecol. Evol.* **21,** 668–673.

Ogutu, J.O. & Owen-Smith, N. (2005) Oscillations in large mammal populations: are they related to predation or rainfall? *Afr. J. Ecol.* **43,** 332–339.

Packer, C., Brink, H., Kissui, B.M., Maliti, H., Kushnir, H. & Caro, T. (2010) Effects of trophy hunting on lion and leopard populations in Tanzania. *Conserv. Biol.*. DOI: 10.1111/j.1523-1739.2010.01576.x.

Peters, D.P.C. (2010) Accessible ecology: synthesis of the long, deep, and broad. *Trends Ecol. Evol.* **25,** 592–601.

Remis, M.J. & Kpanou, J.B. (2011) Primate and ungulate abundance in response to multi-use zoning and human extractive activities in a Central African reserve. *Afr. J. Ecol.* **49,** 70–80.

Scholte, P., Adam, S. & Bobo, K. (2007) Population trends of antelopes in Waza National Park (Cameroon) from 1960-2001:

the interacting effects of rainfall, flooding and human interventions. *Afr. J. Ecol.* **45,** 431–439.

Serengeti Ecological Monitoring Programme(1988) Programme Report: March 1988. Serengeti Wildlife Research Centre. Unpublished Report.

Serengeti Ecological Monitoring Programme (1989) Katavi-Rukwa Reconnaissance Survey December 1988. Serengeti Wildlife Research Institute. Unpublished Report.

Sinclair, A.R.E., Mduma, S.A.R., Hopcraft, J.G.C., Fryxell, J.M., Hilborn, R. & Thirgood, S. (2007) Long-term ecosystem dynamics in the Serengeti: lessons for conservation. *Conserv. Biol.* **21,** 580–590.

Spellerberg, I.F. (2005) *Monitoring Ecological Change.* Cambridge University Press, Cambridge.

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

Stoner, C., Caro, T.M., Mduma, S., Mlingwa, C., Sabuni, G., Borner, M. & Schelten, C. (2007b) Changes in herbivore populations across large areas of Tanzania. *Afr. J. Ecol.* **45,** 202–215.

Tawiri (2002) Aerial Census for the Katavi-Rukwa Ecosystem. October 2000 & May 2001. Unpublished Report.

Tawiri/Cimu (2004) Aerial Census in the Katavi-Rukwa Ecosystem. Dry Season 2002. Unpublished Report.

Tawiri/Cimu (2007) Aerial census in the Katavi-Rukwa Ecosystem, Dry Season 2006. Tanzania Wildlife Research Institute. Unpublished Report.

Tawiri/Cimu (2010) Aerial Census in the Katavi-Rukwa Ecosystem. Dry Season 2009. Unpublished Report.

Twcm (1992) Wildlife-Census. Katavi-Rukwa. November 1991. Unpublished Report.

Twcm (1999) Aerial Census in Katavi National Park and surrounding areas. Dry season December 1995. Unpublished Report.

Waltert, M., Meyer, B. & Kiffner, C. (2009) Habitat availability, hunting or poaching: what affects distribution and density of large mammals in western Tanzania woodlands? *Afr. J. Ecol.* **47,** 737–746.

Waltert, M., Meyer, B., Shanyangi, M.W., Balozi, J.J., Kitwara, O., Qolli, S., Krischke, H. & Mühlenberg, M. (2008) Foot surveys of large mammals in woodlands of western Tanzania. *J. Wildl. Mgmt* **72,** 603–610.

Yuccoz, N.G., Nichols, J.D. & Boulinier, T. (2001) Monitoring of biological diversity in space and time. *Trends Ecol. Evol.* **16,** 446–453.

(*Manuscript accepted 11 April 2011*)

doi: 10.1111/j.1365-2028.2011.01268.x