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# Mammal Depletion Processes as Evidenced From Spatially Explicit and Temporal Local Ecological Knowledge

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## Abstract

In the face of increased defaunation in tropical regions, embracing the complexity of wildlife population trends is important to guide the development of effective conservation and restoration strategies. Here, based on a case study in Democratic Republic of the Congo, we use an ethnozoological approach, with a protocol that captures spatially explicit and temporal ecological knowledge on defaunation. Our case study evidences the overall depletion profile for the majority of mammal species in the whole landscape and particularly for red colobus, orycterope, and chimpanzee. The elephant has already disappeared locally, and okapi and forest buffalo only persist in the northern part of the landscape. On the other hand, postdepletion sustainability seems to characterize Yangambi Reserve, with more stable populations of fast-reproducing/small-sized species. Local extinctions or sharp declines in mammal populations in our landscape are either the direct consequence of conflict or the result of cascading effects that have their origins in the rebellions between 1996 and 2002. From a conservation perspective, the challenge is to understand how the depletion process can be reversed in a postconflict context and to identify the levers that can inverse the cascading effect to allow species recovery. We encourage the use of our methodology in regions that are regularly used by a significant number of observers. The proposed methodology provides cost-effective, reliable, and spatially explicit data on population trends, covering for a wide range of species and allows to understand the historical pattern of defaunation as well the wider context in which changes occurred.



## Keywords

ethnozoology, wildlife trends, spatially explicit, historical perspective, local ecological knowledge, mammals, wildlife management


## Introduction

Biological diversity is experiencing an unprecedented rate of decline worldwide (Butchart et al., 2010; Tittensor et al., 2014). Among terrestrial vertebrates, 322 species have become extinct since 1500, and populations of the remaining species show a 25% average decline in abundance (Dirzo et al., 2014). Sixty percent of the large herbivores are threatened with extinction or experiencing range contractions (Ripple et al., 2015). In tropical forest landscapes, this defaunation process is often considered the direct impact of overhunting (Benítez-López et al., 2017; Koerner et al., 2017; Sinclair, 2017; Sousa, & Srbek-Araujo, 2017).

It is, however, well known that defaunation is driven by a range of anthropogenic and environmental factors acting in combination (de Araujo Lima Constantino, 2016; Ducatez & Shine, 2017). Untangling the effect of each factor is unrealistic and probably useless. However, embracing the complexity explaining wildlife population

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trends is important to enable more accurate predictions of when and where collapses will occur and to guide the development of effective conservation and restoration policies (McNamara et al., 2015). When considering the hunting system as a social-ecological system, the focus is on the resilience of the whole system, which requires an understanding of the complex and dynamic relationships between the hunting ground, its resources, the stakeholders in play, and the different exogenous drivers of change that affect the components of the system (van Vliet, Fa, & Nasi, 2015).

In practice, while useful information can be gained from the comparison of a hunted wildlife landscape with a reference landscape using surveys (the so-called space for time approach; Pickett, 1989), our understanding of wildlife persistence or change depends on our ability to learn from the past (de Silva, 2016). The contemporary situation is nothing but the result of a complex combination of pressures and responses from the past, shaping the evolution of wildlife populations. As opposed to one-time surveys, longitudinal research requires efforts to study a particular system in a sustained and systematic way over a long or repeated period of time. However, with the exception of a few places that have been monitored and studied over several years (Dornelas et al., 2014, Hoppe-Dominik, Kühl, Radl, & Fischer, 2015; Magurran et al., 2010; Taig-Johnston et al., 2017), most tropical forest landscapes suffer from a lack of longitudinal data (de Silva, 2016). Where longitudinal wildlife surveys exist, they are often limited in scope as the range of species that can be covered is dependent on the survey protocol used and cryptic species are often overlooked (Turvey et al., 2013). Observed trends are often difficult to interpret because of the lack of information on the broader context in which changes have occurred. Understanding wildlife depletion is not only about providing information on changes in wildlife composition but also on the rate and trajectory (i.e., linear and nonlinear) of temporal and spatial change and about the mechanisms driving these changes (Thurstan et al., 2015).

In this article, we hypothesize that local knowledge can be a powerful and inexpensive alternative to wildlife surveys for better understanding of defaunation within changing socioecological systems. While local knowledge has already proved to provide robust ecological information on wildlife presence or abundance (Parry & Peres, 2015; Pillay, Johnsingh, Raghunath, & Madhusudan, 2011; Turvey et al., 2013; Brittain, Bata, Ornellas, Milner-Gulland, & Rowcliffe, 2018, van Vliet et al., 2018) or on population trends (Duda, 2017; Gray, Phommachak, Vannachomchan, & Guegan, 2017), the originality of our approach lies in its capacity to embrace both geographic and historical dimensions of defaunation, with a protocol that captures spatially explicit and temporal local ecological knowledge. Based on a case study in the Yangambi landscape (Democratic Republic of the Congo [DRC]), we use a combination of participatory mapping, group discussions, and semi-structured interviews directed to hunters to describe changes observed in species abundance and distribution, and the explanatory variables in the social and ecological system that explain the changes observed.

## Methods

### *Study Site*

Yangambi is a town located in the North-East of the DRC, about 100 km West of Kisangani City in the Tshopo Province (Figure 1). As it is typically observed in the Congo Basin forests, the landscape around Yangambi is characterized by a superposition of land tenures combining the existence of the Yangambi Man and Biosphere Reserve created in 1979, the Ngazi Forest Reserve which belongs to INERA (Institut National des Etudes et Recherches Agronomiques), a logging concession and customary land. In practice, due to the lack of human and financial resources, both reserves (Yangambi and Ngazi) have no official management plan; their limits are contested and are not under any specific form of management. Our focus within this landscape are both the Yangambi Biosphere Reserve given its protection status and the Ngazi Forest Reserve, as the main source of bushmeat for the neighboring town of Yangambi.

The climate is marked by two dry seasons (from December to mid-March and from June to July) that alternate with two rainy seasons (from April to May and from August to November). The landscape is covered by old secondary forests, semideciduous dense forests, young secondary forests, and dense evergreen forests. The rest is covered by a mosaic of agriculture, marshy forests, and agroforestry systems. While several botanic surveys carried out since colonial times have provided a good understanding of the vegetation, there is no such data concerning mammals, resulting in a complete black box in terms of wildlife population data within and around the biosphere reserve.

The population living within the Yangambi landscape is of about 141,643 inhabitants and includes the urban population of Yangambi (10 districts) and villages in the sectors of Turumbu (Yawenda, Yelongo, Weko, and Yambau groups) and Bamanga (Bamanga Yambuya and Bamanga Bengamisa groups) and along the Weko-Yambelo road. The population living in and around the Yangambi Man and Biosphere Reserve belong mainly to the Turumbu ethnical group. In the town of Yangambi, several ethnic groups coexist. In the rural area, hunting and fishing are the two most important activities immediately after traditional agriculture. In Yangambi, which

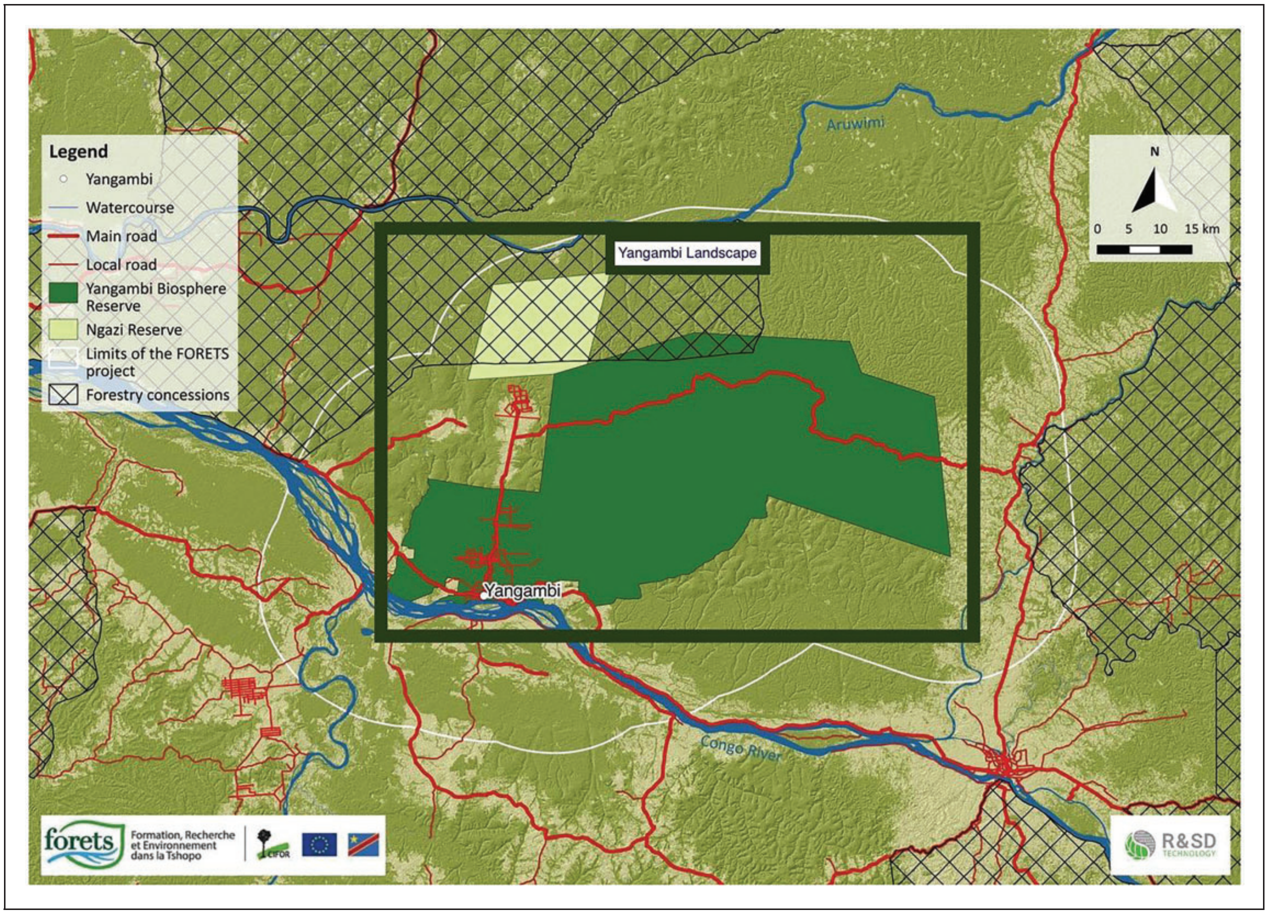


**Figure 1.** Map of the Yangambi Landscape.

evolved from being a research campus during the colonial period into a real town, most families still rely on salaries from the different national research institutes or on small business. Food security is poor in the region, and forest products (particularly bushmeat) significantly contribute to household food security and nutrition (van Vliet et al., 2017). In a recent assessment, van Vliet et al. (2017) evidenced a vibrant bushmeat trade from neighboring forests (including from protected areas) to the town of Yangambi, equivalent to about 145 tons of smoked bushmeat sold annually. The meat originates from the Ngazi Reserve for about 66% of the biomass, the rest either from Yangambi Reserve or from the logging concession located to the West outside the boundaries of what is defined as the Yangambi landscape. The main species sold are small monkeys (38% of the carcasses) and red duikers (31%), followed by blue duikers, bush pigs, and brush-tailed porcupines (van Vliet et al., 2017). While hunters living around Ngazi specialize in commercial hunting (more than 80% of the biomass is sold), hunters living around the Yangambi Reserve state that wildlife is no longer as abundant and obtaining a surplus for sale is becoming increasingly difficult.

## Data Collection

We followed an ethnozoological approach that combines participatory mapping of the hunting landscape, semistructured interviews, and group interviews. Our methodology captures both spatial and temporal trends and accounts for the dynamics of the social and ecological dimensions of the landscape. Field work was carried out from January to May 2018.

*Participatory mapping.* Given the lack of previous fine-scale geographical data of the hunting grounds within the Yangambi landscape, we carried out several participatory mapping exercises in Weko, Ngazi, Lumumba, Bangala, Yaselia, Bossukulu, Yaliboto, Lokeli, and Bandele. Within each village, the working group consisted of about 10 hunters, selected depending on their availability and willingness to participate in the activity, with a fair representation of different age groups. With support from colored pens and an A4 piece of paper where key features were indicated in advance (such as the main road, villages and the main rivers [Arwimi and Congo rivers]), hunters were able to locate more fine-scale features such as main hunting trails, hunting camps, streams, marshy areas, and other landscape features they identified as key elements used by them to refer to spatial locations within their hunting grounds. We combined this information with the GPS geolocation of all the features mentioned in the previous exercises. To do so, numerous field trips (about 60 consecutive days) were organized by the research team (two researchers) with guidance from two hunters (selected for their knowledge of the areas to be mapped). With this hands-on experience of the area by the research team and discussions with the hunters on the maps that were generated, it was possible to ensure that both the research team and the hunters shared a common understanding of the landscape and could both locate main landscape features on the produced map.

*Historical trend analysis.* To understand the co-evolution of the wider social and ecological context and the dynamics of mammal populations in our study site, the same working groups described above were used to carry out a historical trend analysis. In each of the group sessions, participants were invited to: (a) List the main mammal species present in the studied landscape or locally extirpated in the period 1995–2018. Local names were matched with scientific names using the images of the Kingdon's mammal guide of Africa (Kingdon, 1995) to corroborate the information provided by the hunters; (b) Discuss the evolution of mammal populations during the analyzed period (trends in species presence/absence, behavior, distribution, abundance); (c) Describe and place chronologically the main factors explaining the observed changes (hunting pressure, demography, socioeconomic changes, climatic, ecological and biological factors, etc.). The period was chosen so as to cover a period for which older participants could have sufficiently clear memories, from 1995 to the present day.

*Semistructured interviews.* From March to May 2018, we conducted semistructured interviews with a sample of 234 hunters (99 hunters in Ngazi and 135 in Yangambi), representing about 30% of the total number of active hunters within the Yangambi landscape (van Vliet et al., 2017). To ensure spatial representativeness, the sample was geographically distributed among the different villages and neighborhoods of Yangambi town (Table 1). Within each location, a sample of hunters was chosen representing about 30% of the total number of active hunters identified. Hunters were selected based on their availability and willingness to participate in the interview. The objective of the semistructured hunter interviews was to (a) spatially locate the last observation made by each hunter for each mammal species listed in the group discussions, (b) understand perceptions of change in species abundance according to the hunters (extirpated, sharply declined, declined, stable, increased, sharply increased), and (c) assess the importance of the different factors explaining the observed trends. The questionnaire used was administered using Kobocollect on Android and consisted in three main sections:

**Table 1.** Sampling for Semistructured Interviews With Hunters Across the Different Locations in Our Study Site.

| Name of village or neighborhood | Number of hunters interviewed |
|---|---|
| Bakobi | 10 |
| Bandele | 10 |
| Bangala | 12 |
| Bayangene | 10 |
| Bosukulu | 21 |
| Lokeli | 10 |
| Lumumba | 11 |
| Ngazi | 45 |
| Lumumba | 1 |
| Weko | 54 |
| Yakombe | 7 |
| Yaliboto | 11 |
| Yalungu | 1 |
| Yaselia | 31 |
| Total | 234 |

1. A general section about the hunter: age, ethnicity, hunting frequency, number of years of hunting experience, and most used hunting technique.
2. A section concerning the last observations made for each species in the list: place, date, type of observation (heard, seen, footprints, feces, nests, and carcass). Here we asked the hunters interviewed to locate the last observation on the printed map developed during the participatory mapping exercise covered by a $4 \times 4$ km grid, where each cell could be identified by a number ($Y$ axis) and a letter ($X$ axis).
3. A section on the status and evolution of each of the mammal species in the list: population trends and main explanatory factors.

## Data Analysis

To evaluate current status (abundance and distribution) in mammal species, all observations of wildlife that occurred in 2018 (January to April) and 2017 (the whole year) were lumped into the same category to represent the current situation. The number of observations per species was used as an indication of mammal composition across the whole landscape: The higher the percentage of hunters that had observed a given species in 2017/2018, the more abundant the species was supposed to be in the area. We calculated the topmost observed species in 2017–2018 (observed by more than 80% of the hunters), the number of observations for vulnerable species (including near threatened, vulnerable, endangered, or critically endangered according to International Union for Conservation of Nature [IUCN] red list; Ripple et al., 2016), the ratio between rodents and ungulates (Rowcliffe, Cowlishaw, & Long, 2003), and the ratio between blue duikers and red duikers (Yasuoka et al., 2015), as indicators of depletion. We compared Ngazi Forest Reserve and Yangambi Biosphere Reserve for the aforementioned indicators.

To trace the evolution of wildlife since 1995, we used the number of last observations for vulnerable species per year across the study period as an indication of timing and trend of depletion process. A high number of last observations dating back in time represented rarefaction events. An inverse exponential curve was expected for vulnerable species indicating a sufficient proof for depletion. To interpret trends on a species by species basis and facilitate interpretation, the dates of the last observations per species since 1995 were grouped into five classes (before 1999, between 1999 and 2003, between 2004 and 2008, between 2009 and 2013, and between 2014 and 2018). We established a species depletion profile for Ngazi and Yangambi, through a graphical representation of the evolution of observations per species and time period using darker red colors for more ancient observations and lighter red color for more recent observations. A profile with a darker red color indicated a more pronounced depletion process as opposed to a profile dominated by lighter red color. Species listed at the bottom of the pyramid were typically common and abundant species, while species listed at the top of the pyramid represented rare species.

In addition, we analyzed the perceptions according to the hunters about the evolution of mammal species and calculated for each species the percentage of hunters that perceived a sharp decline, decline, stability, increase, or sharp increase. The evolution profile of mammals was compared between Ngazi and Yangambi Reserves.

The factors mentioned by the hunters to explain the observed wildlife trends were grouped into two categories: (a) intrinsic factors related to the ecology or biology of the species and (b) human factors related to social and economic pressures. For each of the trends identified (extirpated, sharply declined, declined, stable, increased, and sharply increased), we assessed the intrinsic and human factors that were most mentioned to explain the trend observed. In addition, to understand the relationship between changes in the general socioeconomic context of the study area and the evolution of wildlife, the information from the group interviews was corroborated and compiled into a single timeline.

## Results

The hunters interviewed were mostly from the Turumbo ethnical group (98% in Ngazi and 56% in Yangambi) and most hunted with guns (73% in Ngazi; 60% in Yangambi). The rest hunted using cable snares, spears, and dogs or other techniques. Ages ranged from 15 to 80 years but 80% of the hunters were 30 years old or older and 90% of the hunters had more than 10 years of experience in hunting. More than 90% of the hunters interviewed spent more than 10 days per month in hunting activities. The semistructured questionnaire generated 8,190 events for mammal observations (234 hunters * 35 species), among which 45% corresponded to positive observations (animal was observed), 53% corresponded to negative observations (animal was never observed), and 2% were "don't know" answers. For the positive observations, 7% were unable to provide the date of last observation and less than 1% were unable to locate the observation in the map (either because they did not know or because the observation was made outside the borders of the map).

### Current Status of Mammals in the Yangambi Landscape

Thirty-four species (or group of species) of mammals were cited by hunters as being present in the study site (Table 2). Among those species, six are vulnerable (classified in one of the IUCN critical categories: near threatened, vulnerable, endangered, and critically endangered): *Pan troglodytes*, *Okapia johnstoni*, *Smutia gigantea*, *Panthera pardus*, *Aonix congicus*, and *Piliocolobus badius*. In 2017–2018, the composition of mammal species differed between Ngazi and Yangambi Reserves. In Ngazi, the most abundant species (those observed by more than 80% of the hunters) were *Philantomba monticola*, *Cephalophus dorsalis*, *Cercopithecus ascanius*, *Crycetomis emini*, *Atherurus africanus*, and *Potamochoerus porcus*. In Yangambi Reserve, the most abundant species were the *Crycetomis emini*, *Atherurus africanus*, *Protoxerus stageri*, *Dendrohyrax sp.*, and *Philantomba monticola*. In Ngazi, the proportion of observations for vulnerable species, the ratio between rodents and ungulates, and the ratio between blue duikers and red duikers were all higher than in Yangambi Reserve, indicating a less depleted profile for Ngazi as compared with Yangambi (Table 3).

### Local Extirpations

The elephant (*Loxodonta Africana*) is known as the only mammal species to have disappeared from the entire study landscape over the period from 1995 to 2018, the last observation (direct and indirect observations combined) dating from 2007. The last observations of

**Table 2.** List of Mammal Species Listed by the Hunters and Used for the Semistructured Interviews.

| Order | Family | Scientific names | Local names in Turumbo |
|---|---|---|---|
| Afrosoricidé | Tanricidae | Potamogale velox (Du Chaillu, 1860) | Bowengele |
| Arctiodactyle | Bovidae | *Tragelaphus scriptus* (Pallas, 1766) | Kenge |
| | | *Tragelaphus spekii* (P.L. Scaler, 1863) | Mbulimasuwa |
| | | *Cephalophus nigrifrons* (Gray, 1871) | Mbengela |
| | | *Cephalophus leucogaster* (Gray, 1873) | Koto |
| | | *Cephalophus dorslis* (Gray, 1846) | Koto |
| | Giraffidae | *Okapia johnstoni* (Sclater, 1901) | Okapi |
| | Suidae | *Potamochoerus porcus* (Linnaeus, 1758) | Ngulu |
| | Tragulidae | *Hyemoschus aquaticus* (Ogilby, 1845) | Elebe, Bolafi |
| Carnivore | Felidae | *Panthera pardus* (Linnaeus, 1758) | Nkoy |
| | Herpestidae | *Crossarchus alexandri* (Thomas & Wroughton, 1907) | Liende |
| | Mustelidae | *Aonyx congicus* (Lönnberg, 1910) | Bohoso |
| | Viverridae | *Genetta servalina* (Pucheran, 1855) | Isisimba |
| | | *Genetta victoriae* (Thomas, 1901) | Bolende |
| | | *Civettictis civetta* (Schreber, 1915) | Libobi (Limbuta) |
| | | *Nandinia binotata* (Gray, 1830) | Alela |
| Cetarctiodactyle | Bovidae | *Syncerus caffer* (Sparrman, 1779) | Nzayi |
| | | *Philantomba monticola* (Thunberg, 1789) | Mboloko |
| Hyracoidae | Procaviidae | *Dendrohyrax sp* (Fraser, 1855) | Eloka |
| Macroscelidea | Macroscelididae | *Rhynchocyon cirnei* (Peters, 1847) | Ifini |
| Pholidota | Manidae | *Smutsia gigantea* (Illiger, 1815) | Liha |
| Primate | Cercopithecidae | *Piliocolobus badius* (Kerr, 1792) | Ekota |
| | | *Papio anubis* (Lesson, 1827) | Abula |
| | | *Cercopithecus ascianus* (Audebert, 1799) | Kidekide |
| | | *Cercopithecus neglectus* (Schlegel, 1876) | Funga |
| | | *Cercopithecus wolfi* (Meyer, 1891) | Bongande |
| | | *Cercopithecus hamlyni* (Pocok, 1907) | Kputuko |
| | Hominidae | *Pan troglodytes (Blumenbach, 1776)* | Mukomboso |
| | Lorisidae | *Perodicticus potto* (Müller, 1766) | Efombé |
| Proboscidea | Elephantidae | *Loxondota africana* (Anonym, 1827) | Nzoku |
| Rongeur | Hystricidae | *Atherurus africanus* (Gray, 1842) | Nziko |
| | Nesomydae | *Cricetomys emini* (Wroughton, 1910) | Lotomba |
| | Sciuridae | *Protoxerus stangeri* (Waterhouse, 1843) | Bokoma |
| | Thrynomyidae | *Thrynomys swinderianus* (Temmick, 1827) | Simbiliki |
| Tubulidentata | Orycteropidae | *Orycteropus afer* (Pallas, 1766) | Tumba, Libongo |

**Table 3.** Depletion Indicators for Yangambi Biosphere Reserve and Ngazi Reserve.

| | Whole landscape | Ngazi Reserve | Yangambi Reserve |
|---|---|---|---|
| Species observed at least by 80% of the hunters in 2017/2018 | African pouched rat, brush-tailed porcupine, blue duiker, eastern tree hyrax | Blue duiker, bay duiker, black-cheecked white nose monkey, African pouched rat, brush-tailed porcupine, bush pig | African pouched rat brush-tailed porcupine, African giant squirrel, eastern tree hyrax, blue duiker |
| Proportion of observations for near threatened to critically endangered species in 2017/2018 | 9% | 10% | 4% |
| Ratio rodents/ ungulates in 2017/2018 | 0.64 | 0.94 | 0.52 |
| Ratio bleu duikers/red duikers in 2017/2018 | 0.77 | 0.82 | 0.75 |

*Loxodonta africana* in the study landscape (in total five observations since 1999) are located north of the Ngazi Reserve and were observed between 2004 and 2008. In the Yangambi Reserve, the last sightings of *Loxodonta africana* (3 direct observations) date from before 1995. Two species of small diurnal monkeys (*Cercocebus agilis* and *Colobus angolensis*) locally called Atamba and Atelu have also disappeared locally but prior to 1995.

In Ngazi, *Okapia johnstoni*, *Piliocolobus badius*, and *Tragelaphus spekii* were the only species that accounted for an "extirpated" response. However, they represented a minority of the hunters (3%, 4%, and 2% of the hunters, respectively) and these three species were last observed in 2017–2018 (by 1, 27, and 30 hunters, respectively), indicating that these species are actually still present. Over the last 20 years, observations for *Okapia johnstoni* (13 sightings since 1999, most of which are direct sightings) and for *Syncarus caffer nanus* (36 since 1999) are located north of the Ngazi Reserve.

In Yangambi, *Okapia johnstoni* is said to have disappeared by 29% of the hunters, *Syncarus caffer nanus* according to 17% of them, and *Piliocolobus badius* according to 12% of the hunters. The last direct observations of these species in Yangambi Reserve date from 2015 for *Okapia johnstoni*, from 1996 for *Syncarus caffer nanus* (only one direct observation in 1996, although it was heard in 2004 and its footprint observed in 2018), and from 2017 to 2018 for *Piliocolobus badius* (12 direct observations). As such, okapi and buffalo can be considered locally extinct or close to extinction in Yangambi. Figure 2(a), (b), and (c) shows the geographical distribution of the last observations (by type and date) for the three species that have locally disappeared or are likely to have disappeared from the Yangambi Reserve.

## *Trends in Mammal Populations Since 1995*

The profile of last observations of vulnerable mammals since 1995 points out the following characteristics (Figure 3):

1. As opposed to our hypothesis, we observed no indication of inverse exponential trend for vulnerable species, providing no sufficient proof for a generalized depletion process for all vulnerable species.
2. Three picks in last observations were observed: before 1995, in 2000, and in 2005 pointing out three rarefaction events.

The species depletion profile pictured Yangambi with a more severe depletion profile than Ngazi (Figure 4(a) and (b)). In Yangambi, besides the local extirpation of the three species already mentioned earlier, a pronounced depletion is observed for *Orycteropus afer*, *Piliocolobus badius*, *Papio anubis*, and *Pan troglodytes*. In Ngazi, a pronounced depletion profile is observed for *Okapia johnstoni* and *Syncerus caffer nanus*.

According to the hunters, the trend in mammal abundance in the study area is generally characterized by a gradual decline for all mammal species. In Ngazi, the majority of the hunters perceive either a sharp decline in mammal species (23% of hunters) or a decline (68%), whereas in Yangambi, the majority of the hunters perceive either a stability in all mammal species (50%) or a stability (41%) in mammal abundance. Figure 5(a) and (b) shows the number of hunters that perceive a given trend in mammal abundance in Ngazi and Yangambi, respectively. In Ngazi, the three species which received greatest rate of response for "drastic decline" were *Okapia johnstoni* (88% of the hunters), *Piliocolobus badius* (65%), and *Pan troglodytes* (61%). In Yangambi, the three species with the highest score for the "drastic decline" category were *Cercopithecus hamlyni* (41%), *Orycteropus afer* (39%), and *Piliocolobus badius* (37%). In Yangambi, the three species with the highest rate of "stability" responses were *Dendrohyrax sp*. (77%), *Thryonomys swinderianus* (60%), and *Protoxerus stangeri* (57%), whereas no species obtained a "stable" response by a majority of hunters in Ngazi.

## *Drivers of Wildlife Dynamics*

*Extirpation.* Political conflicts related to successive rebellions between 1996 and 2003 are presented as being the source of many cascading effects on the social, economic, and ecological system of the study area, with significant direct and indirect impacts on wildlife (Figure 6). The local extirpation process was explained by most of the hunters (67%) as resulting from the presence of armed groups. During these periods of rebellion, many soldiers of the Armed Forces of the DRC (FARDC) passed through the forest in order to control the progress of various armed groups (Congolese, Rwandans, and Ugandans from eastern DRC). To feed themselves, the troops practiced hunting and controlled access to weapons by the villagers. In addition to hunting for meat, military groups also trafficked ivory, skins, and meat. During this period, many soldiers used the forest, without asking permission from the rights holders eroding the customary rules of access to resources. Okapi, leopard, buffalo, and elephant are the species that were most affected by the presence of these armed groups in the forest.

*Defaunation.* According to the hunters, the sharp decline and the decline of mammal species is due, in order of importance, to the increased number of hunters, the increased trade in bushmeat, the increase in night hunting, and other changes in hunting techniques (Figure 6).

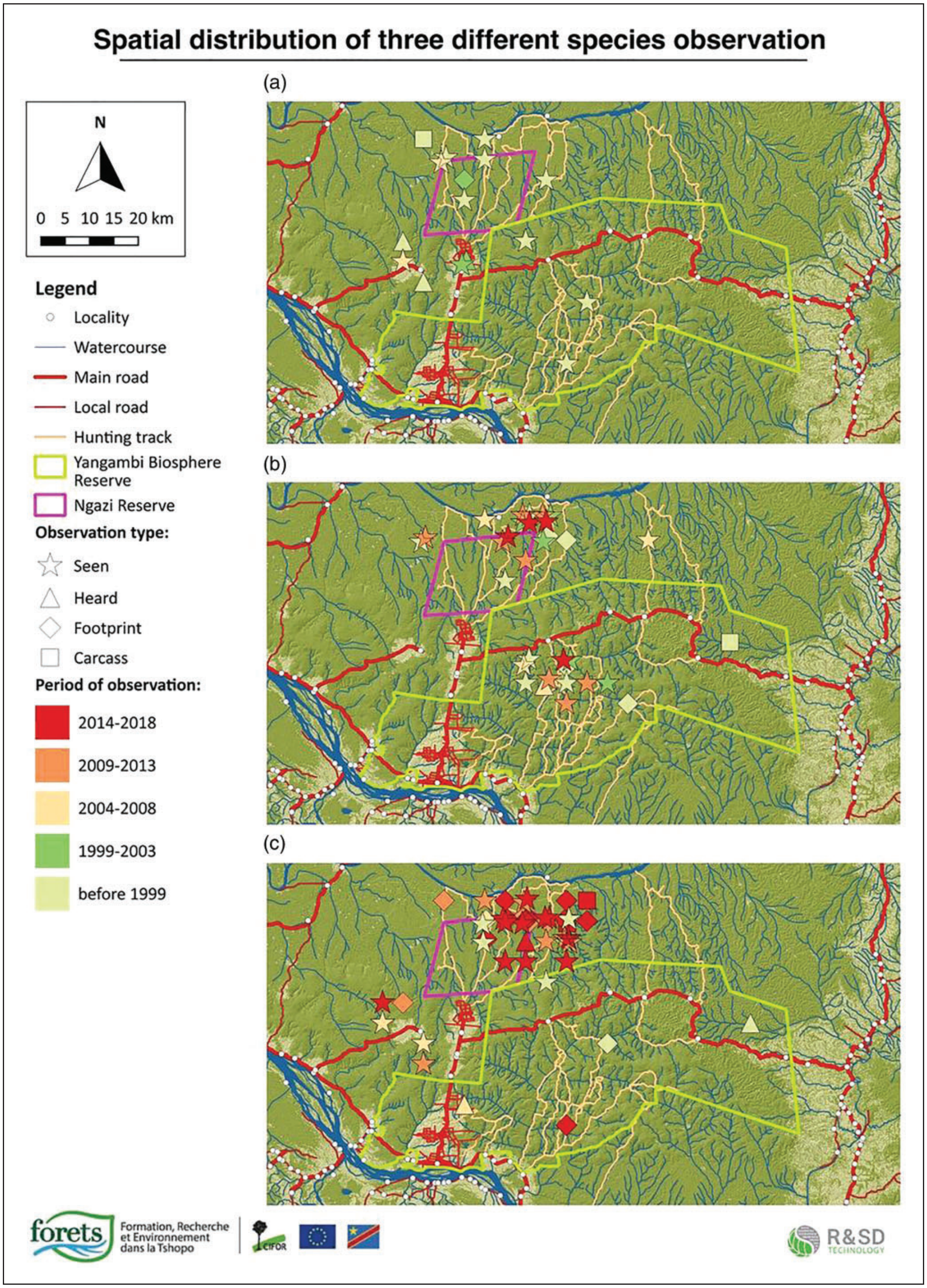


**Figure 2.** Spatial distribution of the last observations of (a) Loxondonta Africana, (b) *Okapia Johnstoni,* and (c) *Syncerus caffer nanus*.

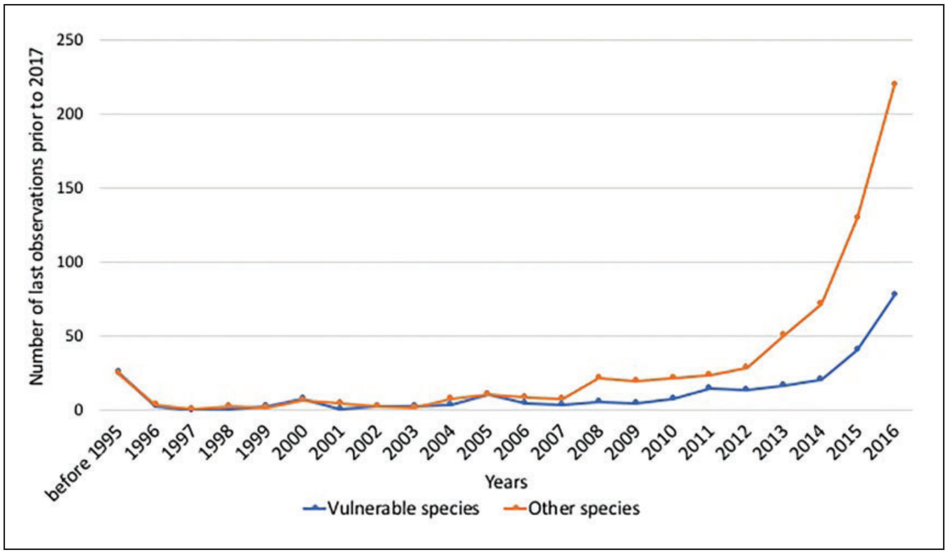


**Figure 3.** Number of last observations for vulnerable mammals and other mammal species from 1995 to 2016.

The most affected species are the large-sized ones and those with gregarious behaviors (Figure 7). In fact, the decline in wildlife is the result of cascading effects triggered by the degradation of the economic and social context following the political transitions and the armed rebellions. Indeed, already weakened by the independence and the stopping of the Belgian public and private investment, the economy of the region was significantly affected with the political instability which settled in the routine between 1996 and 2003. During this period, the transport of goods was limited by insecurity, and the movement of people and exchange networks were greatly diminished. The existing factories for export products (cocoa, sugar, rubber, etc.) managed by foreign capital, closed one after the other (see also Takamura, 2015). The number of employees as well as the salary levels in the Yangambi and Ngazi research centers gradually decreased (e.g., at the Ngazi station from INERA the number of employees increased from 600 in 1998 to 25 in 2018), leaving many families without stable income. Given the lack of employment opportunities and population growth, more families became dependent on forest resources for food security. In addition, with the population growth in the city of Yangambi, and the lack of production and supply of meat from domestic animals, the trade in bushmeat increased steadily during the last 20 years as attested by the increase in the number of bushmeat traders in the Yangambi central market (from 15 traders in 1998 to more than 200 in 2018). As the population increased, the area under cultivation also increased reducing suitable habitat for most prey at a close vicinity from the villages. The number of hunters in the villages gradually doubled in 20 years from about 300 hunters in 1998 to 600 active hunters in 2018. This is explained by the increase in population but also by the decrease in the average age of entry into hunting: In the late 90s, hunters began to hunt from the age of 23 years onwards, but currently young people become independent hunters at the age of 15 years.

This overall context resulted in changes in hunting practices. Before the rebellions, firearms were controlled and subject to permits. As a result, only a small number of hunters had a rifle. Hunting was practiced mainly with traps and spear. Since the early 2000s, with access to locally manufactured weapons and cartridges, and the lack of gun control, the number of rifles increased. With guns, hunting pressure on small monkeys increased, and in the last decade, birds (e.g., hornbill, turaco, guinea fowl, pigeons) have also become prey for hunters. For trappers, to offset lower trap productivity, the number of traps per hunter has increased: around 30 traps per hunter in 1995 to about 100 traps per hunter since the year 2000. Prior to 1995, hunting was practiced from the village on short trips during the day, but nowadays, hunting is practiced mainly from camps located more than 10 to 15 km and hunting trips last 1 to 2 weeks. With the availability of headlamps since 2008, night hunting has become a common practice: Hunting is practiced at any time, day or night. Hunting therefore affects nocturnal animals that were previously not included as game: *Dendrohyrax sp.*, *Thryonomys swinderianus*, *Protoxerus stangeri*, *Bdeogale nigripes*, *Atilax paludinosus*, *Orycteropus afer*, *Perodictitus potto*, and bats.

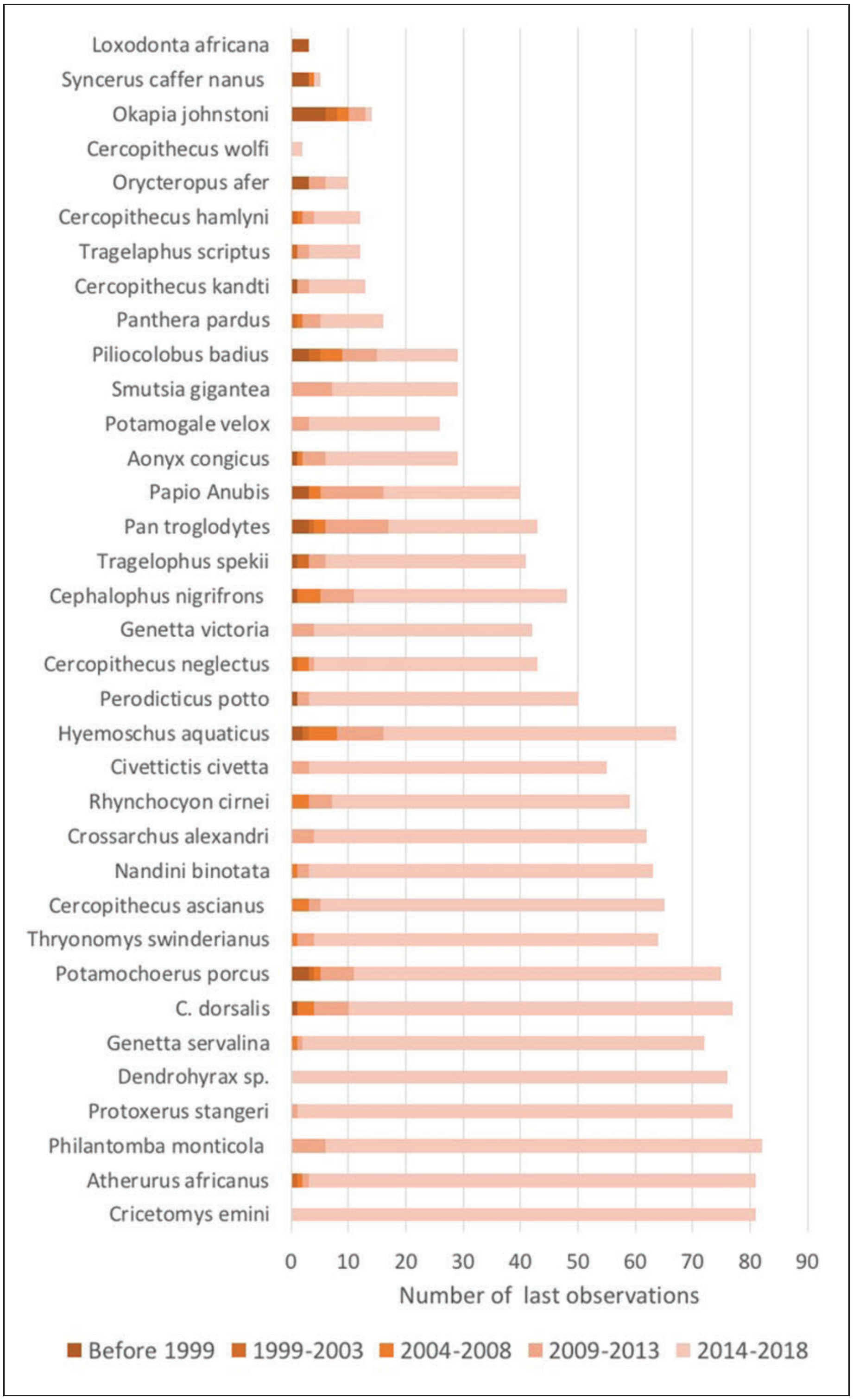


**Figure 4.** Species profile for Yangambi Reserve (the number of last observations of each species in 2017–2018 provides an indication of the current composition of mammals and the number of observations prior to 2017–2018 informs about the depletion process for each species across time).

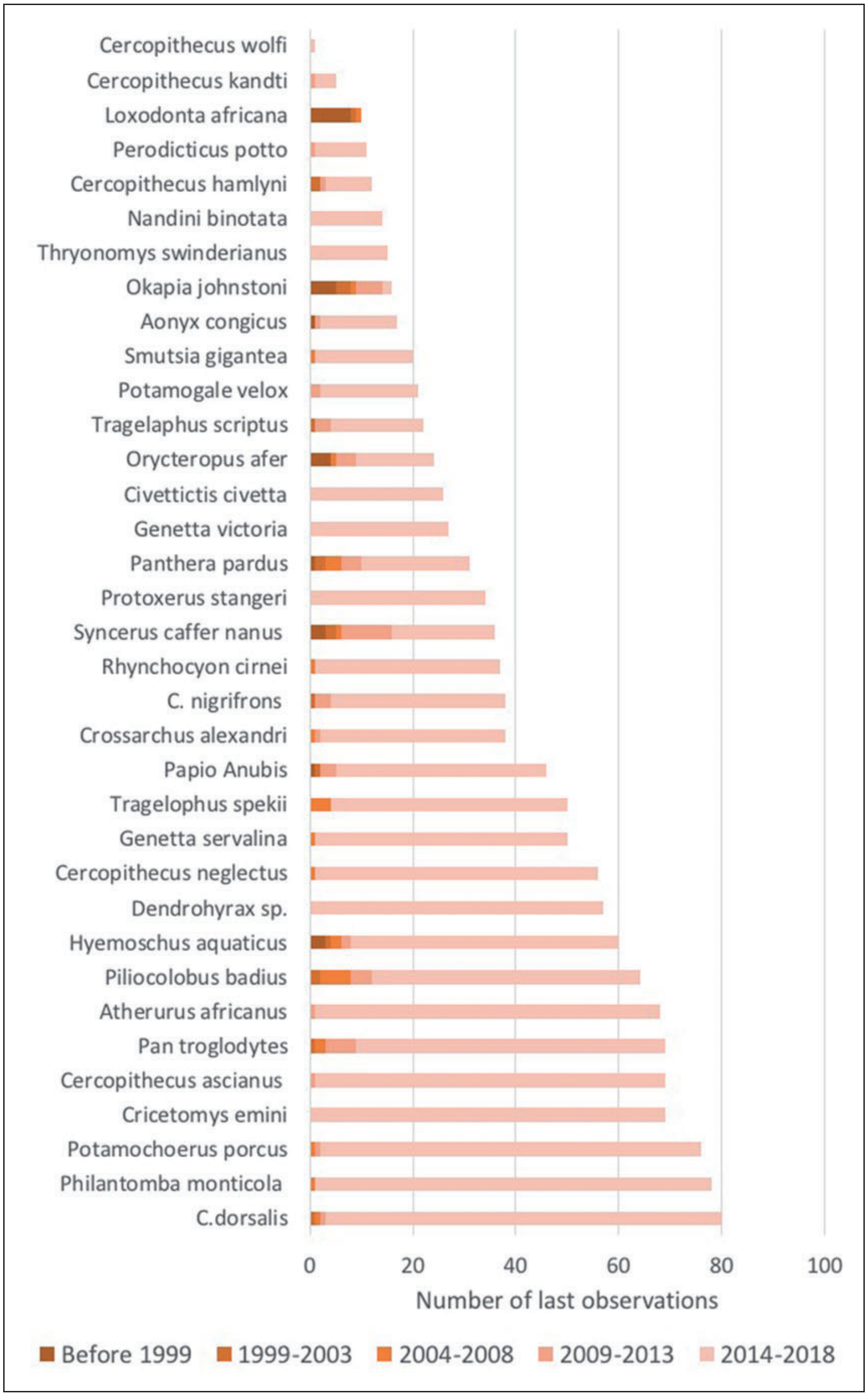


**Figure 5.** Species profile for Ngazi Reserve (the number of last observations of each species in 2017– 2018 provides an indication of the current composition of mammals and the number of observations prior to 2017–2018 informs about the depletion process for each species across time).

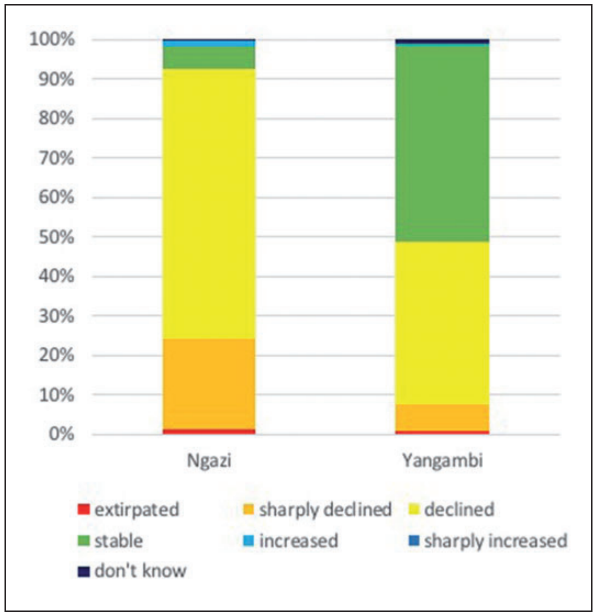


**Figure 6.** Mammal population trends in Yangambi and Ngazi (the *Y* axis represents the percentage of responses that indicated the local extirpation, sharp decline, decline, stability, increase, sharp increase for each species).

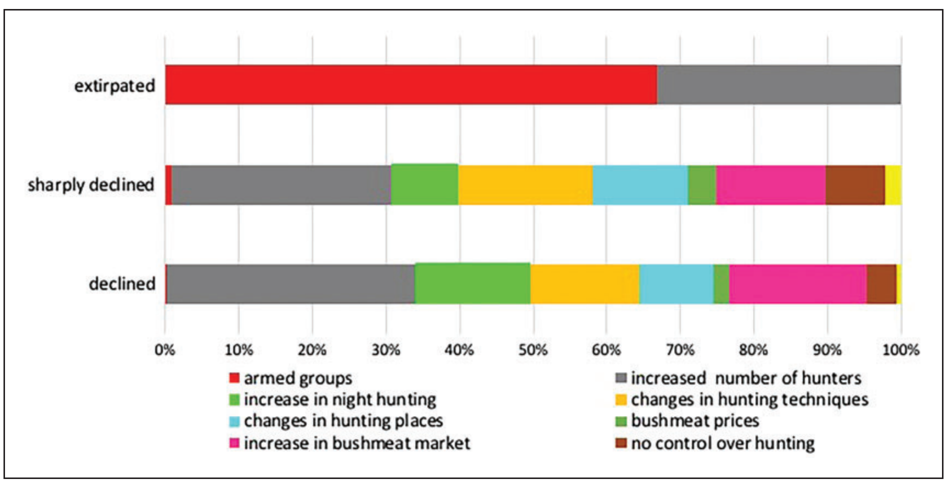


**Figure 7.** Human-induced drivers of mammal population change according to the hunters.

*Persistence.* According to the hunters, species that are considered stable have an ecological and behavioral profile that allows them to adapt to the hunting pressure. Hunters report that species with stable populations have a large number of young per year, a short gestation period or a preferred habitat that is not easily accessible to hunters (and their hunting dogs; e.g., *Tragelaphus spekii* which prefers swampy areas; Figure 8). In addition, species with a nocturnal activity or a cryptic behavior (as opposed to curious or daring behavior) have had better chances to persist in hunted areas. Some species, well adapted to anthropogenic environments, have actually thrived with the expansion of crop fields (e.g., *Thryonomys swinderianus*) and are more abundant than in the past.

## Discussion

Based on an ethnozoological approach, we provide a spatial and temporal description of the depletion/persistence process characterizing mammal species in a heavily hunted landscape around Yangambi. Understanding defaunation through the eyes of wildlife users is emerging as an important field for ethnozoological research because the symbolic, social and cultural

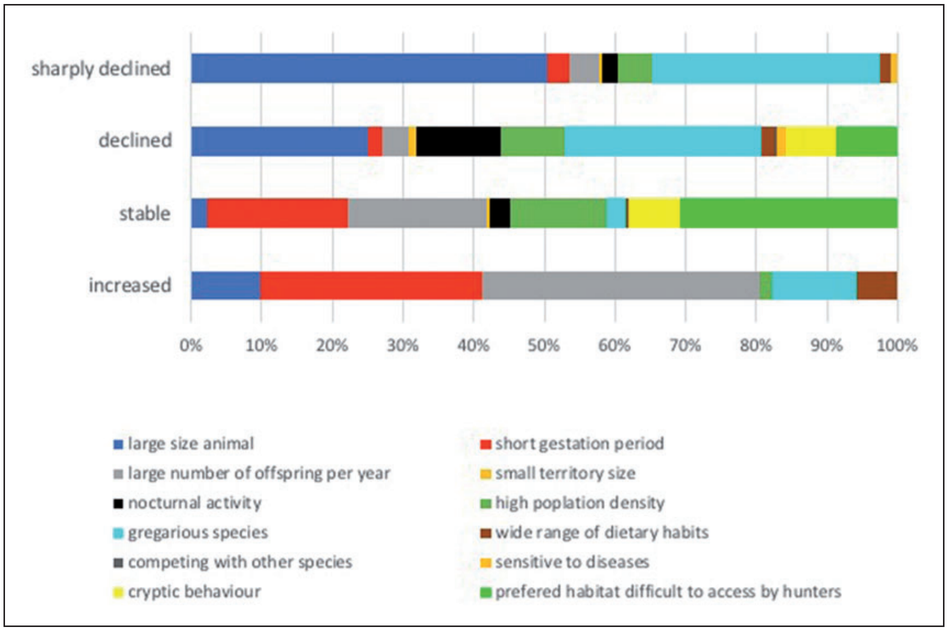


**Figure 8.** Ecological and biological variables explaining mammal population trends according to the hunters.

dimensions of defaunation are of direct relevance to any initiative aiming for sustainable wildlife management (Fernández-Llamazares, 2017).

Our case study evidences the depletion process that characterizes the landscape in Yangambi. While Yangambi Reserve shows a postdepletion sustainability pattern in line with what Cowlishaw et al. (2005) described for the Takoradi market in Ghana and evidenced by stable populations of fast-reproducing/small-sized species (*Crycetomis emini*, *Atherurus africanus*, *Protoxerus stageri*, *Dendrohyrax sp*., and *Philantomba monticola*), Ngazi Reserve appears less depleted (dominated by ungulates and small monkeys) but shows a severe and continued decline in mammal populations. Over the time period of our study, one species disappeared locally (*Loxodonta Africana*), and *Okapia johnstoni* and *Syncerus caffer nanus* only persist in the northern part of the landscape (North of Ngazi Reserve). In addition, *Piliocolobus badius*, *Orycteropus affer*, and *Pan troglodytes* evidence severe depletion profiles. Local extinctions and sharp declines in mammal species in our landscape are either the direct consequence of conflict or the result of cascading effects that have their origins in the rebellions between 1996 and 2002. The collapse of the local governance systems, the disruption of the economic vitality of the region, and the in-migration resulting from conflict are all factors that triggered increased hunting pressure. Independently from conflict, innovations in hunting practices (either local, such as the local confection of fire arms and cartridges; or external, such as the head lamps used to hunt at night) also explain increased pressure particularly for nocturnal and arboreal species.

Nevertheless, the observation that vulnerable and emblematic species are still present (*Pan troglodytes*, *Okapia johnstoni*, *Smutia gigantea*, *Panthera pardus*, *Aonix congicus*, and *Piliocolobus badius*) and that wildlife is still able to provide food for about 141,643 humans (about 145 tons of bushmeat extracted per year according to van Vliet et al., 2017) provides a demonstration of the resilience of natural systems facing sustained and increased anthropogenic pressures. This is not to underevaluate the continued decrease in wildlife as perceived and evidenced through local knowledge but rather to provide a positive vision about the likelihood to reverse trends as long as critical functions are preserved. The conceptual framework around which we frame our understanding of hunting socioecological systems does not view the depletion process as a linear irreversible trend, and our challenge is now to understand how the depletion process can be reversed in a postconflict context. Our capacity to identify the levers that can reverse the cascading effect to allow species recovery will determine our success in conservation efforts. In the region, local societies have already shown their capacity to reorganize through emerging alternative distribution systems utilizing indigenous knowledge, the ecological environment and access to globalized technology (Takamura, 2015). The gradual recovery of urban–rural distribution systems and the subsequent stimulation of activities that allow rural people to accumulate wealth is an example of this adaptation capacity

(Takamura, 2015) and might provide opportunities to downsize dependency on bushmeat. Ultimately, the sustainability of bushmeat harvest in the region will also be dependent on the availability of affordable substitutes for ensuring sustainable food systems in support of the peace building process (van Vliet et al., 2017).

Our methodology is limited to regions that are regularly used by a significant number of hunters (or other observers) covering the whole landscape of interest. Areas that are less used or never visited by hunters or habitats that are not accessible to hunters are likely to be underestimated through this methodology. Here, we were interested in the historical trends and rarefaction patterns. Instead, if the interest is on current wildlife abundance and distribution, then a variation of this methodology could be used to focus on mammal observations during last hunting trip. If location and duration of last hunting trip can be assessed, then the bias for less visited areas can be reduced through the production of occupancy models (Brittain et al., 2018).

## Implications for Conservation

Despite the aforementioned limitations, our results support previous studies showing that local knowledge can provide reliable and cost-effective scientific data if well designed (Alves & Albuquerque, 2017), particularly for small populations or low encounter rates (Gaidet et al., 2003; Humber et al., 2017). Indeed, our methodology provided data for a wide range of species (diurnal or nocturnal, small sized or large sized, arboreal or terrestrial, abundant or rare), therefore competing with most of the available mammal survey protocols used in ecological sciences. Besides, this methodology provides fine-scale local and spatially explicit details, and historical context to detect changes yet undocumented and understand drivers of change. Our methodology incorporates cross-generational knowledge acquired not only through individual experience but also through inherited culture that one-off ecological assessments are unable to provide. The species depletion profile suggested in our study represents both current abundance and depletion process and can therefore be used to compare sites with different hunting pressures or monitor changes observed in one single location. Being based on a very friendly graphic representation of local knowledge and requiring no complex statistical skills, this species depletion profile can be considered as a handy support to discuss management options with local stakeholders.

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