Ebola and the decline of gorilla *Gorilla gorilla* and chimpanzee *Pan troglodytes* populations in Minkebe Forest, north-eastern Gabon

Bas Huijbregts, Pauwel De Wachter, Louis Sosthène, Ndong Obiang and Marc Ella Akou

Abstract During 1998–2000 extremely low densities of gorillas *Gorilla gorilla gorilla* and chimpanzees *Pan troglodytes troglodytes* were found in the Minkebe Forest block in north-eastern Gabon. When compared with data collected before 1994, these data suggest a catastrophic decline in ape populations in the area. We believe that this decline was caused by a disease epidemic. The period of decline corresponds with the Ebola outbreaks of 1994 and 1996 that occurred in the human population in the same area. Deaths of gorillas and chimpanzees were associated with both Ebola outbreaks. Data from nearby sites indicate that the epidemic was limited to the Minkebe Forest. Occurrence of such epidemic die-offs should be taken into account in conservation strategies for the long-term survival of ape populations. At the time of writing, an Ebola epidemic among humans in the Zadié Department east of Minkebe Forest has resulted in 53 deaths. In the neighbouring Republic of Congo, authorities have reported 43 deaths and at least 12 other cases of Ebola. These epidemics are believed to be linked to the handling and eating of dead apes.

Keywords Chimpanzees, Ebola, Gabon, *Gorilla gorilla*, great apes, Minkebe, *Pan troglodytes*.

Introduction

Population crashes in large mammal populations due to catastrophic disease epidemics are not uncommon. There are numerous examples of parasites and diseases posing major threats to populations of endangered species (McCallum & Dobson, 1995). Young (1994) identified 21 die-offs of large mammals caused by disease, of which four were in the tropical forest biome. These 21 events probably represent only a small fraction of the severe mammalian die-offs that have occurred recently (Young, 1994). Die-offs amongst tropical forest mammals are most probably under-represented due to the difficulty of detection (Glanz, 1982, and Milton, 1990, in Young, 1994; McCallum & Dobson, 1995). Disease as a threat to ape populations remains a neglected issue (Butynski, 2001). Because chimpanzees and gorillas are phylogenetically close to humans, they are highly susceptible to numerous infectious diseases of humans, especially viruses such as Ebola (Butynski, 2001; Tutin, 2001). Several small, threatened populations of apes are being exposed to additional risk of disease through frequent close contact with large numbers of tourists, guides, security personnel, researchers and local people (Adams *et al.*, 2001; Butynski, 2001; Woodford *et al.*, 2002). Small populations of apes in fragmented, unstable ecosystems may be at particular risk (Butynski, 2001; Woodford *et al.*, 2002). The sporadic occurrence of epidemic outbreaks therefore have important consequences for biological conservation planning in general and for the conservation of endangered primate populations in particular.

In this paper we provide evidence of extremely low chimpanzee *Pan troglodytes troglodytes* and gorilla *Gorilla gorilla gorilla* populations in the Minkebe Forest block in Gabon, a large stable ecosystem with relatively little human pressure. These low densities are apparently linked with two outbreaks of Ebola that occurred amongst humans in the same area in 1994 and 1996.

Study area

The Minkebe Forest (32,382 km^2) is located in extreme north-eastern Gabon (Fig. 1). It is bordered by the Lalara-Makokou road to the south, the Lalara-Minvoul road to the west, the Kom and Ayina Rivers to the north (which form the border between Gabon and Cameroon), and the Ivindo River to the east (part of which is the border between Gabon and Congo). The Minkebe Forest has no permanent human settlements and contains a 14,000 km^2 core area almost devoid of any human disturbance. The area is generally flat, with hills and inselbergs in some areas, and altitudes of 450–900 m. The river valleys are often seasonally flooded. The annual rainfall of 1,500–1,800 mm is one of the lowest in Gabon; the average

Bas Huijbregts (Corresponding author) **Pauwel De Wachter** and **Marc Ella Akou** WWF-Central Africa Regional Program Office, P.O. Box 9144, Libreville, Gabon. E-mail: bas.h@inet.ga

Louis Sosthène, **Ndong Obiang** Ministry of Water and Forests, Gabon, P.O. Box 9144, Libreville, Gabon.

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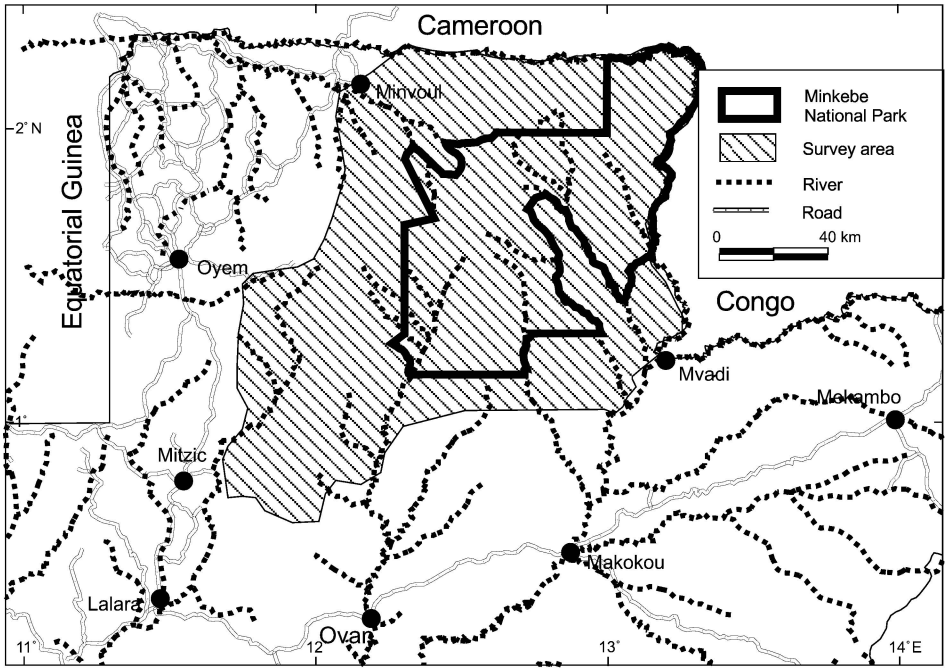

Fig. 1 The location of the Minkebe National Park and the survey area in north-eastern Gabon

temperature is 24°C. The habitats in Minkebe include dense humid evergreen forest, riverine and swamp forest, raffia swamps, monospecific stands of *Gilbertiodendron dewevrei* forest, open canopy Marantaceae forest, open marsh (*bai*) with Cyperaceae, seasonally flooded prairies, and prairie habitat on inselbergs. The Minkebe Forest block is probably the least disturbed large area of rain-forest remaining in equatorial Africa (Barnes *et al.*, 1991).

Methods

The Minkebe project teams used reconnaissance ('recce') walks, or 'path of least resistance' methodology, in which a compass bearing is followed along the path of least resistance in order to move relatively fast across large remote areas. The walks are used to assess animal populations and evaluate human activities over surveys in large and remote zones, and to map vegetation types (White & Edwards, 2000). A recce team consists of five people, the transect cutter and compass bearer followed at an interval of about 20 minutes by three observers. Observer 1 looks for signs on the ground, including ape nests, elephant dung and human signs. Observer 2 looks for ape nests in trees, and Observer 3 notes changes in vegetation type and writes down all the data. Where the transect cutter or compass bearer sights an animal, they wait for Observer 3. Distance walked is measured with a hip chain meter with thread. All team leaders were trained in data collection and had survey experience before starting the Minkebe surveys. The data generated by recce walks include indices of abundance of animal species and human activities, and information on the distribution of vegetation types.

Although a compass bearing is followed during a recce walk, obstacles such as large swamps and very dense vegetation are avoided, and perpendicular distances to observed animals are not measured. This method differs from transects in that the path followed is not independent of the environment and provides an index of abundance rather than an estimation of density, which is therefore of limited use for comparison between sites. However, recent studies in several sites have shown that, at least for elephant dung and gorilla nests, there is a good correlation between data collected during recce walks and transect data collected in the same area (White & Edwards, 2000).

Results

Recce walks were made from May 1998 to June 2000. The total linear distance covered was 2,742 km during 330 data-collection days, an average of 8.7 km day^{-1}. A total area of about 20,000 km^2 was surveyed (Fig. 1). Table 1 shows gorilla and chimpanzee signs encountered during these recce walks. Only one direct sighting of a gorilla, a lone male, was made. Chimpanzees were seen on only three occasions: a solitary male, two adults, and a group estimated at four individuals. In addition, gorillas

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Table 1 Gorilla and chimpanzee signs recorded in Minkebe Forest during 2,742 km of 'recce' walks (see text for details) made during 1998–2000.

	Gorilla	Chimpanzee
Sign	Numbers per km	Numbers per km
Nesting sites	0.013	0.019
Nests	0.027	0.039
Seen	0.0004	0.0011
Heard	0.0007	0.0022
Dung	0.095	0.001
Footprint	0.011	0.005
Food eaten	0.015	0.003

were heard twice and chimpanzees six times. Project teams also visited 136 active hunting and fishing camps in Minkebe, none of which had any signs of gorilla or chimpanzee hunting (i.e. no skulls or meat).

Discussion

Considering that about 60% of the recce transects were cut in undisturbed forest (i.e. non-hunted, with no human signs), and suitable gorilla and chimpanzee habitat is abundant, the encounter rates in Minkebe Forest are very low. Comparison with data from other sites in western Central Africa (Table 2) shows that the Minkebe Forest has a very low nest density, with 0.03 and 0.04 gorilla and chimpanzee nests per km, respectively, compared to overall averages of 1.88 and 2.76 gorilla and chimpanzee nests per km, respectively, for the other study sites. Other researchers who have been working recently in the Minkebe Forest confirm these low encounter rates. In 2000, M. Fay walked a total distance of *c*. 200 km in the Minkebe Forest and found a near total absence of gorillas and chimpanzees (Quammen, 2001). From May 1998 to May 2000, two pairs of 5 km transects were cut perpendicular to the Nouna River, in the core of the

Table 2 Population densities of gorillas and chimpanzees in various study sites in western Central Africa in comparison with data from Minkebe Forest in 1998–2000 and 1990.

	Gorillas				Chimpanzees				
Site	Nests	Linear distance (km)	Nests per km	Nest building individuals per km^2	Nests	Linear distance (km)	Nests per km	Nest building individuals per km^2	Reference
Congo									
Likouala	228	80	2.90	5.90					Blake, 1993
Odzala	630	68	9.30	5.10	918	68.1	13.5	2.70	Bermejo, 1995
Mboukou			1.40	1.20					Fay & Agnagna, 1992[1]
Motaba			0.10	0.10					Fay & Agnagna, 1992[1]
Ndoki1			0.20	0.20					Fay & Agnagna, 1992[1]
Cameroon									
Dja	147	94.7	1.60	1.70	203	94.7	2.10	0.79	Williamson & Uongo, 1995
Dja	40	50.0	0.80	1.90	140	50.0	2.80	0.70	Wal, & Nku, 1999
Boumba-Bek/Nki				0.90				0.30	Ekobo, 1998[2]
Republic of Central Africa									
Dzangha-Sangha			1.80	1.50			0.10	0.07	Carroll, 1988[1]
Dzangha-Sangha 2			2.60	1.60			0.10		Fay, 1989
Dzangha-Sangha 3			1.80	1.50			0.40		Remis & Mbassangao, 1998[1]
Ngotto			1.90	1.10			1.60	0.36	Brugiere *et al.*, 1999
Equatorial Guinea									
Monte Alen			2.40	1.90			3.90	0.65	Garcia, 1995[1]
Nationwide			0.49	0.5					Gonzalez-Kirchner, 1997[1]
Gabon									
Lopé				0.58				0.58	White, 1994[1]
Lopé, lot 32	21	84.0	0.25		83	84.0	1.00		Lahm & Benga Zobo, 1997
Petit Loango				0.5				0.78	Furuichi *et al.*, 1997[1]
Nationwide	540	782.8	0.68	0.18	1,606	782.8	2.10	0.32	Tutin & Fernandez, 1983
Average			1.88	1.55			2.76	0.73	
Minkebe 1998–2000	72	2,742	0.03		106	2,742	0.04		This study
Minkebe 1990	36	20	1.80		126	20	6.29		White, 1990

[1]Data from Brugiere *et al.* (1999).
[2]Data from van der Wal & Nku (1999).

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Minkebe Forest known to be little disturbed by humans, and apes were found to be rare in all sites (Lahm, 2000). Bushmeat studies in a logging concession on the western periphery of the study area, in Konossoville, a long-established commercial hunting village, and on two tributaries of the Ivindo River (Oua and Nouna), found no dead gorillas and only one dead chimpanzee (at Konossoville) (Huijbregts & Ndong Obiang, 1999; Owono, 1999, 2000; Nzame, 2000).

The average number of gorilla nests per nesting site (for sites with >1 nest) in Minkebe (3.4) is smaller than the overall average for other study areas in western Central Africa (5.5) (Table 3). The Minkebe population has the highest proportion of solitary nest builders (60% versus an overall average of 30% for the other sites). The average number of nests per chimpanzee nest site in Minkebe (3.5) is similar to the overall average for the other study areas (3.4) but, as with gorillas, the percentage of solitary nesting sites in Minkebe is higher than the regional average (57 versus 44%).

In the area south of Minkebe Forest M. Fay (pers. comm.) observed in 2000 that gorillas seemed relatively uncommon but were present between the Ivindo River and the Ovan-Makokou road and were fairly common south of the Ivindo (Kongoue waterfalls). In 2000, mammal surveys on eight 5 km transects were conducted in the Ipassa Biosphere Reserve, Makokou (Okouyi Okouyi, *et al.*, 2001). This protected area of 100 km^2, 13 km from the provincial capital Makokou, is 6 km south of the Minkebe Forest and separated from it by the Ovan-Makokou road. Poaching is heavy on the northern outskirts of Makokou, an area surrounded by villages and accessible by canoe along the Ivindo. However, after two surveys along this 40 km of transect N. W. Okouyi Okoyi (pers. comm.) encountered two gorilla nests and saw one solitary male and counted 31 chimpanzee nests and saw 13 chimpanzees. To the north the Ayina River is probably a barrier for apes. A project team encountered three chimpanzee nests on a frequently travelled footpath from Lélé village in Cameroon to the Ayina River, a distance of *c.* 15 km. People in Lélé village, and in hunting and fishing camps along the Ayina River, told us that apes are particularly rare on the Gabon side of the river. Although data are lacking from areas east of the Ivindo River in Congo, the natural border of the Minkebe Forest block, as well as for areas on the western side of the Lalara-Minvoul road, local people reported a similar situation. This leads us to believe that the observed decline in ape numbers is limited to the Minkebe Forest block.

C. Wilks, P. Christy, R. Barnes and L. White (pers. comms), who carried out botanical, large mammal and

Table 3 Nest group size in various study sites in western Central Africa in comparison with data from Minkebe Forest in 1998–2000 and 1990.

	Gorilla				Chimpanzee				
Site	No sites	Mean nests per site	Mean nests per site (>1 nest)	Sites with one nest (%)	No. sites	Mean nests per site	Mean nests per site (>1 nest)	Sites with one nest (%)	References
Congo									
Odzala	87	7.2		<20	459	2.1	3.1	*c.* 46	Bermejo, 1995
Mboukou	24	3.4	5.3	46					Fay & Agnagna, 1992*
Cameroon									
Dja	33	3.6			62	2.1			Williamson & Usongo., 1995
Republic of Central Africa									
Dzangha-Sangha	261	5.1	6.6	28					Carroll, 1988*
Dzangha-Sangha 2	135	4.1	5.2	27	7	2.9			Fay, 1989
Dzangha-Sangha 3	147	7.6							Remis & Mbassangao, 1998*
Ngotto	28	5.5	5.8	7	45	2.7	3.7	38	Brugiere *et.al.*, 1999
Equatorial Guinea									
Monte Alen	48	4.3	5.7	*c.* 29	130	2.5	3.6	*c.* 41	Garcia, 1995*
Nationwide	39	4.8	5.3	10					Gonzalez-Kirchner, 1997*
Gabon									
Lopé, lot 32	7	3.0	5.6	57	32	2.6	3.2	28	Lahm & Zobo, 1997
Petit Loango	37	3.0	5.1	*c.* 52	154	2.1	3.9	*c.* 63	Furiuchi *et al.*, 1997*
Nationwide	136	4.0	4.7	*c.* 20	896	1.8	2.6	*c.* 52	Tutin & Fernandez, 1984*
Average		4.6	5.5	30		2.4	3.4	45	
Minkebe 1998–2000	36	2.0	3.4	60	51	2.1	3.5	57	This study
Minkebe 1990	5	6.0	7.3	20	70	1.7	3.0	66	White, 1990

*Data from Brugiere *et al.* (1999).

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bird surveys in the Minkebe Forest during the mid to late 1980s all had regular encounters with gorillas and chimpanzees. In 1990, four years before the Ebola outbreak, Lahm (1993) cut two transects with a total length of 30 km in the same areas as those visited during our Minkebe project surveys. Whereas Lahm (1993) observed 3.6 and 3.5 gorillas and chimpanzees per km, respectively, our teams encountered no gorillas or chimpanzees. White (1990), during a survey on a 20 km transect in the then proposed Minkebe protected area, found high densities of gorilla and chimpanzee nests (Tables 2 and 3). Average gorilla nest group size was 7.2 which is considerably higher than the 2.0 nests per nesting site found by us. He also observed ''a great number of gorillas'' (nine lone animals and eight groups) during animal censuses on four surveys of a 50 km transect in Minkebe. Combining his results from dung counts, nests and sightings, suggested an average density of gorillas along his transect of *c.* 1.0 km^{-2}, and based on nest counts he estimated *c.* 1.1 chimpanzees km^{-2}. Tutin & Fernandez (1983) estimated that gorillas occurred in Minkebe at a mean density in potential habitat of 0.20 km^{-2} and chimpanzees at 0.43 km^{-2}. They derived their estimates from a detailed study of densities in relation to habitat type in the adjacent Belinga Mountains, an estimation of hunting pressure, and 29.3 km of control transects in the Minkebe area. Their ''Minkebe polygon'' covered 22,088 km^2 and overlaps with most of our study zone. They used two methods for estimating populations: firstly, using the Belinga data and extrapolating this for Minkebe, and secondly using control transects. This gave population estimates of 4,171–4,411 for gorillas and 8,825–10,812 for chimpanzees.

All these pre-1994 data in selected areas of Minkebe Forest indicate that apes were abundant, whereas our data indicate extremely low densities in 1998–2000. To estimate the extent of the decline, we can compare nest abundance along recce paths in Minkebe with the average nest encounter rate in other study sites in Central Africa (Table 2). These numbers indicate 98% and 99% declines in gorilla and chimpanzee populations, respectively. Although these figures should be viewed as indicative, they are strongly supported by preliminary analyses of Lahm's transect data from the Minkebe Forest prior to and after the 1994 and 1996 Ebola virus epidemics. These indicate ''a decrease of 90% for gorillas and 98% for chimpanzees'' (Lahm, 2000), and contrast markedly with her observations in the same area before 1994. She concludes that ''since the 1994 and 1996 Ebola virus epidemics, ape numbers have decreased greatly'' in the Minkebe Forest (Lahm, 2000).

Habitat change or starvation are unlikely explanations for this die-off as the study area contains extensive areas of suitable and stable habitat. Human pressure, and especially hunting, are also not causal factors. Surveys took place in the most remote core areas of the forest block, mostly more than 30 km from nearest road or village. Only about 25% of our survey area is affected by occasional commercial hunting, mainly elephant *Loxodonta africana* poaching. About 14,000 km^2 of the forest block is never visited by humans, and ape densities here are as low, if not lower, than in zones affected by hunting. The highest densities of gorillas and chimpanzees were found in the extreme north-eastern parts of the forest block, an area near the Cameroon border that is visited by Fang and Baka hunters. This leaves disease, and particularly Ebola, as the likely cause of the die-off. The die-off appears to be similar to one recorded in 1995 in a chimpanzee population studied by C. Boesch (Morell, 1995; Le Guenno *et al.*, 1995, in Wolfe *et al.*, 1998) in the Taï Forest, Ivory Coast. New evidence from an ongoing Ebola outbreak in north-eastern Gabon, where health workers traced the outbreak to a gorilla whose remains tested positive for the virus (WHO, 2002), reinforces our hypothesis.

Since 1976 there have been several Ebola epidemics in Central Africa, particularly in Sudan (1976), The Democratic Republic of Congo (1976, 1995) and Gabon (1994, 1996) (Morvan *et al.*, 1999). Apart from the latest outbreak, which is still ongoing at the time of writing, since late 1994 three apparently independent outbreaks of Ebola have occurred amongst humans in north-eastern Gabon (Georges-Courbot *et al.*, 1997), two of which originated in the Minkebe Forest. Ebola is fatal for gorillas and chimpanzees (Tutin, 2001). Deaths of apes were associated with all three previous outbreaks in Gabon as well as with the ongoing epidemic. Our assumption of a link between ape decline and Ebola was triggered by persistent reports of finding groups of dead chimpanzees and gorillas in the forest during two Ebola outbreaks. These reports came from Kwele, Kota and Fang hunters and fishermen along the Ivindo River and its tributaries, Baka pygmies from Minvoul in the north-west, and from Fang and Baka hunters along the Ayina River to the north. Also, Georges-Courbot *et al.* (1997) state that all along the upper Ivindo River and its tributaries inhabitants reported finding dead chimpanzees and gorillas in the forest during the autumn of 1994, and all the primary human patients in the outbreak of spring 1996 were infected from butchering dead chimpanzees. The 1996 outbreak was linked to the handling, especially preparation and transport, of a dead chimpanzee. Twenty seven of 37 identified cases involved exposure to the dead chimpanzee (Wolfe *et al.*, 1998). Both Lahm (2000) and our teams have obtained verbal testimony that dead gorillas and chimpanzees were found in the forest by residents of a gold-diggers camp prior to any recorded human infection. Lahm (2000)

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believes that the paucity of data collected for gorillas and chimpanzees may be a consequence of the Ebola epidemics. During our surveys, which began in mid-1998, we found no signs of dead or sick primates. This might indicate that the ape die-off finished within 18 months of the 1996 outbreak.

Die-off due to epidemic disease, in addition to hunting and habitat alteration, is an important factor influencing the long term survival of apes. It has been suggested that populations subject to catastrophic disease epidemics could be protected by subdivision, whereas they may be threatened by corridors between conservation areas (Young, 1994). However, ape populations in Central Africa are already fragmented because of natural river barriers as well as human-made barriers such as roads, along which hunting is heavy. Our data show that the epidemic probably did not cross the roads west and south of the Minkebe Forest. As such, the lesson is that if the chances of survival for the apes are to be maximized, their conservation should be addressed in all forest blocks, i.e. contiguous areas of forest without natural or human-made barriers for apes, where there is a low human population density and a large ape population. This can be done through controlling and limiting hunting in logging concessions and through establishment of a protected area in each forest block, serving as an effective catalyst for conservation action at the level of the whole block. Today, a protected area exists or is proposed for all major forest blocks in Central Africa. Finalising this network and assuring adequate management funds will be the best assurance that apes and all of the region's rich biodiversity can be maintained in the long-term.

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Biographical sketches

Bas Huijbregts has been active in nature conservation in Gabon since 1997, mostly Minkebe. Since July 2002 he has led the Gamba Conservation Project in Gabon for WWF. Pauwel De Wachter has been working on nature conservation in Central Africa since 1994. He has led the Minkebe Project for WWF since 1997. Louis Sosthène Ndong Obiang has been carrying out surveys and patrolling in Minkebe since 1996. He is presently leading the Minkebe Project's provincial base in Makokou. Marc Ella Akou has been survey team leader since 1997. In Minkebe he is responsible for implementation of MIKE (Monitoring of Illegal Killing of Elephants).

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