Estimates of Ape abundance in the Kahuzi-Biega National Park and Oku Community Reserve

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INSTITUT CONGOLAIS POUR LA CONSERVATION DE LA NATURE

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Executive Summary

An analysis of the status of Grauer's gorilla (*Gorilla beringei graueri*) in 2016 estimated a 77% decline in the population of this ape since the mid 1990s, upgrading its status on the IUCN Redlist to critically endangered (Plumptre *et al.* 2016). The analysis also identified the Kahuzi-Biega National Park (KBNP) and particularly the region to the west of the park as the last major stronghold for Grauer's gorilla. Reliable estimates of the numbers of Grauer's gorilla and chimpanzees (*Pan troglodytes schweinfurthii*) were not possible in this region at the time because of insecurity, although line transects had been undertaken in some sectors of the KBNP.

This report pulls together the results of line transect surveys totalling 691,2 km across the KBNP and proposed Oku Community Reserve (OCR), the most extensive transect survey ever made in this region. We provide estimates the abundance of Grauer's gorillas and chimpanzees, as well as summarise the relative abundance of other species of large mammal.

Using a decay rate for ape nests of 106 days (as has been used for all previous surveys of this region) we estimate about 3,474 Grauer's gorilla, of which 1,223 occur in KBNP, 1,967 occur in the area surveyed in OCR and 284 occur outside of these two protected areas but within areas we surveyed. We also estimate 4,474 chimpanzees with 2,664 in KBNP, 1,170 in the surveyed area of OCR and 640 in areas outside these protected areas.

Assessments of monkey density from KBNP indicate that they are lower than had previously been estimated in 1994. Encounter rates of ungulate sightings and dung were also very low. OCR had higher monkey densities, more similar to the 1994 KBNP densities at least for the species that could be estimated. Encounter rate for ungulate sign in the OCR was quite low and is thought to be as much related to habitat and productivity in this lower altitude region as it is to human impact.

The results show that the population estimates from these extensive transect surveys are in the same ball park as the 2016 range-wide analysis of Grauer's gorilla which used a new method to estimate their numbers using occupancy analysis. We estimate that the KBNP-OCR region contains between 84-91% of the global population of this ape. More gorillas are found in OCR as had been predicted in the global analysis and our findings confirm the importance of this region and the need to establish the proposed community reserves soon.

Table of Contents

Surveys of Great Apes in Eastern Democratic Republic of Congo

This report summarises the results of transect surveys of the Grauer's gorilla (*Gorilla beringei graueri*) and the eastern Chimpanzee (*Pan troglodytes schweinfurthii*) in the Kahuzi Biega National Park (KBNP) and proposed Oku Community Reserve (OCR) in eastern Democratic Republic of Congo (DRC). This region forms the heartland of Grauer's gorilla distribution both historically (Hall *et al*. 1998a, Omari *et al.* 1999) and currently (Plumptre *et al.* 2016a). Estimates of Grauers gorilla numbers in 2016 showed a 77-93% decline in the population from estimates made in the mid 1990s (Hall *et al.* 1998a) making Grauer's gorilla critically endangered (Plumptre *et al.* 2016c). The surveys used to estimate this decline were based on reconnaissance walks across a large part of Grauer's range and extrapolated densities from a few sites where line transect data were available to larger areas (Plumptre *et al.* 2016b). Although it stands as the best estimate that could be obtained across such a large region, given the insecurity in eastern DRC, it had always been planned to undertake a more rigorous line-transect survey. As security in the KBNP-OCR region improved WCS commenced line transect surveys with the Institut Congolais pour la Conservation de la Nature (ICCN) in 2013 with a long term plan to survey the whole area as and when security made surveys possible.

Grauer's gorilla's historic range is encompassed within an area of approximately 52,000 km^2 (Mehlman 2008), from the Albertine Rift escarpment in the east towards Kasese town in the west, and from the Lindi River in the north to the Itombwe massif in the south. Currently, four broadly-defined population centres are recognized: Maiko (including Maiko National Park and adjacent forests, Tayna-Usala (including Tayna Nature Reserve, Kisimba-Ikoba Nature Reserve and the Usala forest), Kahuzi-Kasese (including KBNP lowland sector and the adjacent forest to the west in the OCR), and the Itombwe Massif (including Itombwe Natural Reserve). Additional isolated populations are found in Masisi and the KBNP highland sector, and on Mt. Tshiaberimu in Virunga National Park (Figure 1).

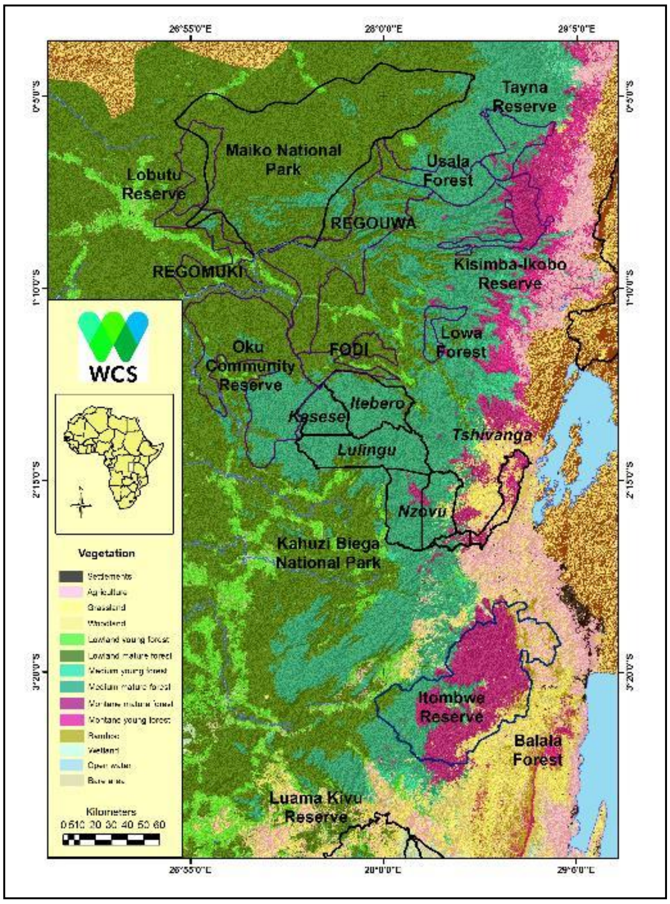

Figure 1. The protected areas and main vegetation types within the core area of distribution of Grauer's gorillas in eastern DRC.

Historic surveys of the Kahuzi Biega and Oku Community Reserve region

The first surveys of Grauer's gorilla (then grouped with the Virunga and Bwindi populations as mountain gorillas) by Emlen and Schaller in 1959 documented that gorillas west of the Albertine Rift occurred at low overall density with a highly fragmented and patchy distribution (Figure 2). High densities were found only in small, localised subpopulations, while large areas of contiguous and seemingly suitable habitats were unoccupied (Emlen & Schaller, 1960). They concluded that gorillas were rare and likely undergoing a rapid population decline due to habitat conversion in the highland regions and widespread hunting in retaliation for crop raiding and, opportunistically, for meat. Based on limited data, they broadly estimated the existence of between 5,000 and 15,000 individuals (Emlen & Schaller, 1960; Schaller, 1963).

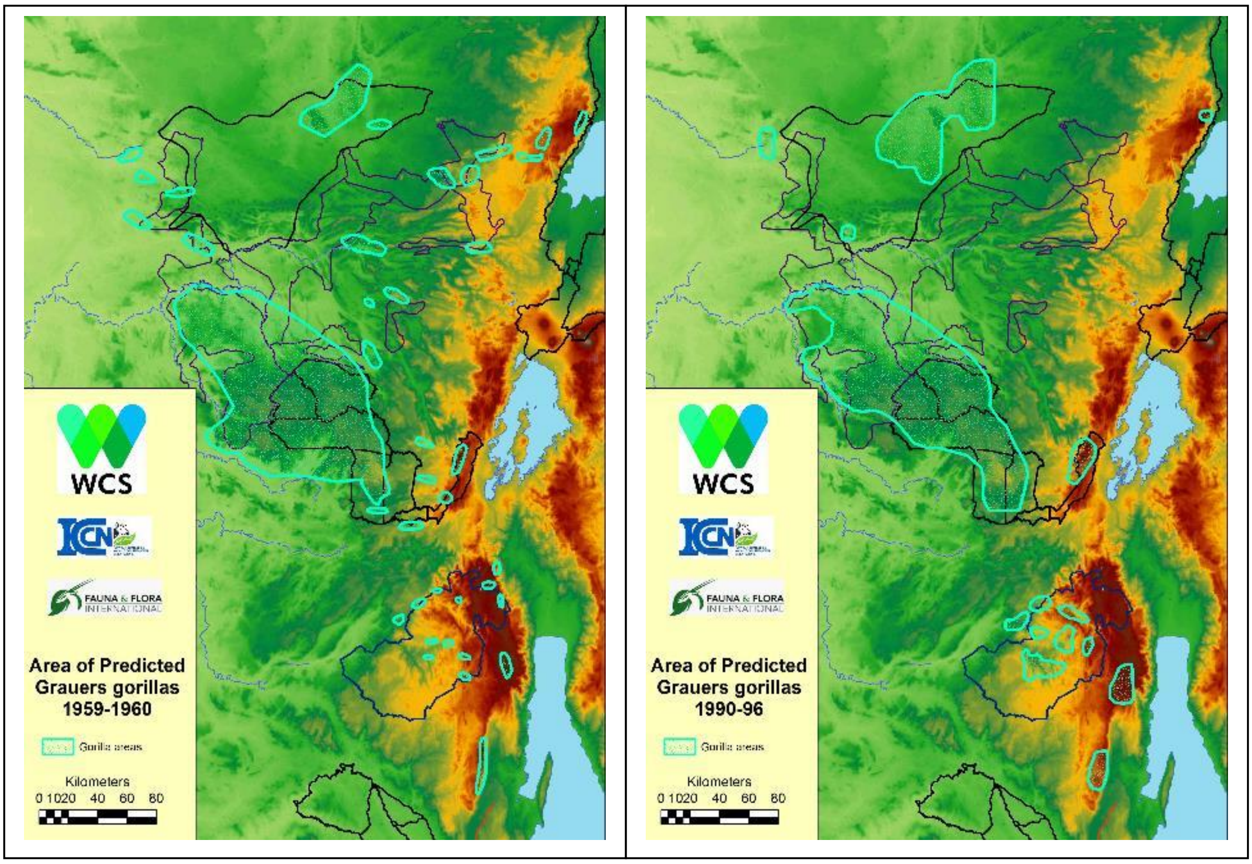

Figure 2. Distribution of Grauer's gorilla from Emlen and Schaller's surveys (left) and Hall *et al.*'s surveys (Right). Distribution layer by S. Nixon and L. Pintea (Jane Goodall Institute).

Subsequent surveys did not take place until the 1990s and focused on KBNP and adjacent Kasese forest now referred to as the OCR (Hall *et al.,* 1998b; Yamagiwa *et al*. 1993). These surveys found that gorillas remained highly threatened, primarily by hunting and expanding human settlements. Hall *et al.* (1998a) estimated a total population of 16,900 (8,660–25,500) individual gorillas. The wide estimates calculated from both studies illustrate the difficulties associated with calculating accurate abundance estimates for Grauer's gorilla from one-off surveys.

Prior to the 1990s surveys even less was known about the status of chimpanzees in the region, with the 1994-95 KBNP surveys representing the first systematic effort to census this species. These surveys estimated the numbers of chimpanzees in the KBNP and the Kasese/OCR region to the west of the park at 2,600 weaned individuals, with 2000 in the park and 600 in the Kasese/OCR region.

The civil war that started in 1996 and continued up to 2003 made it very difficult to monitor the ape populations in this region. Armed groups occupied KBNP in particular and controlled illegal mines in the park to generate revenue to purchase their arms and food (Kirkby et al. 2015; Spira et al. 2017). Hunting of large mammals for bushmeat was common and a likely reason for the decline in gorillas that has been documented in KBNP (Plumptre et al. 2016a). Some surveys were possible at this time (Amsini et al. 2008; Hart et al. 2007) but could only be conducted in a small area of the region.

Estimate of numbers between 2011-2015

Insecurity following the civil war of 1996, which was prolonged until about 2003 but left pockets of armed groups within Grauer's gorilla range in eastern DRC, made it difficult to quantify the impact of the conflict on apes despite estimates that declines were occurring (Mehlman, 2008). A Conservation Action Plan (CAP) was developed in 2010, led by the Jane Goodall Institute (JGI) and supported by the ARCUS Foundation (Maldonado et al. 2012). This plan identified the updating of the ape population estimates as a priority. Between 2011 and 2016, WCS and FFI worked together to collect and combine data collected from reconnaissance surveys across Grauer's gorilla's range to estimate the occupancy probability of both Grauer's gorillas and chimpanzees in this region (figure 3).

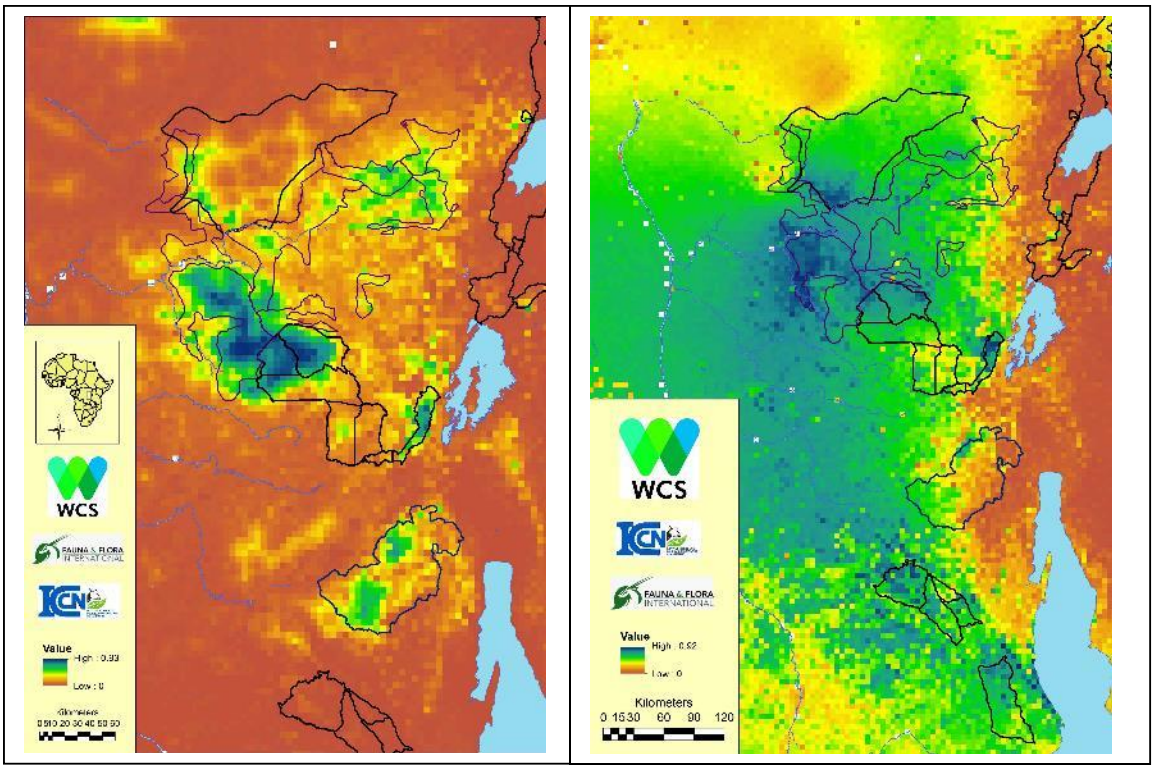

Figure 3. Occupancy probability maps for Grauer's gorilla (left) and chimpanzee (right).

An estimate of population size was derived from the occupancy probability by obtaining a threshold probability where it is likely gorillas/chimpanzees are present and multiplying this area by an average density of gorillas/chimpanzees obtained from density estimates at 10 sites. Using this method we estimated 3,800 (95% CL: 1,280–9,050) Grauer's gorillas and 37,740 (95%CL: 14,020-67,200) chimpanzees in the region (Plumptre et al. 2016b).

While the methods we used to survey these apes across their range were the best, given the insecurity in the region and inability to make detailed surveys over such a large landscape, it was recognised that better estimates of gorilla numbers needed to be obtained from rigorous line transect sampling of the apes. It is clear from the occupancy probability map that Grauer's gorilla's remaining heartland is in western KBNP and the OCR region (figure 3). Between 2013 and 2017 WCS therefore worked with ICCN and the local community in the OCR to survey the apes here using line transect methods.

Methods

A design for line transects was developed for both the KBNP and OCR. 162 three km long transects were selected for KBNP because of the steeper terrain found there while 68 five km long transects were used in lower altitude OCR (figure 4). Surveying these transects is very intensive and has taken time because of the presence of armed rebels operating in parts of the KBNP. Surveys of some sectors, for example the Kasese sector in KBNP in the far west, were made in 2013 because of good security at that time but some sectors have only been able to be visited in 2017.

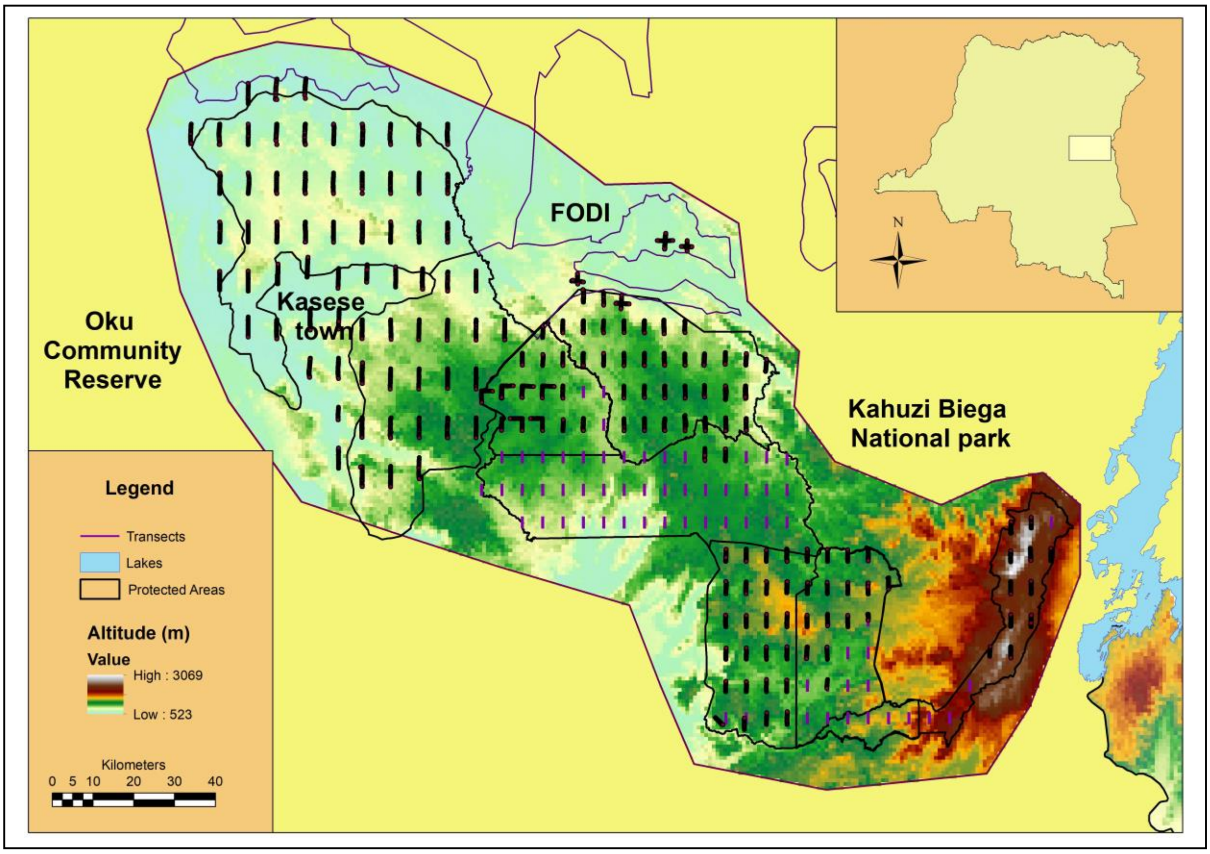

Figure 4. Location of transects in the KBNP and OCR (transects surveyed with black points). The boundary of the region with altitude data shows the 'study area' used for the density surface modelling.

Two or three observers would navigate to each transect with a team of porters/camp staff and set up camp about 500m away from the transect. The following day they walked the transect cutting as little as possible of the vegetation. Sightings of live animals, tracks, calls, dung and nests were recorded and the perpendicular distance to each sighting made. In the case of dung and nests the perpendicular distance to the centre of each dung pile or nest was measured even when in groups. In the case of groups of live animals the distance to the nearest and farthest animal was measured if all the group were to one side of the transect to estimate the perpendicular distance as: (Nearest + Farthest)/2. If the animal group straddled the transect then the distance to the farthest individual on the left and right sides of the transect were measured and the perpendicular distance calculated as: ($Farthest_{left}$ – $Farthest_{Right}$)/2. Once the transect was walked and data recorded the team would then transfer towards the next transect and camp.

Analysis methods

Line transect estimates of density

Data on nest sightings were analysed for both chimpanzees and gorillas using standard line transect sampling methods (Buckland *et al.* 1993; Thomas *et al.* 2010). This method fits a detection curve to the perpendicular distance data for each nest to estimate the decrease in the probability of detection with distance from the transect. The effective strip width surveyed is estimated from the detection curve, from which a density of nests can be calculated. In order to convert nest density to a density of apes the production rate of nests and the decay rate of nests need to be estimated.

$$Animal\ density = \frac{nest\ density}{average\ nest\ production\ rate \times average\ nest\ decay\ rate}$$

Where it has been studied, most chimpanzees build about 1.1 nests per day (Plumptre & Cox 2005; Plumptre & Reynolds 1997; Kouakou, Boesch & Kuhl 2009) and it is usually assumed most gorillas build 1 nest per day but this has not been measured with habituated groups of gorillas.

The average nest decay rate for this region was estimated at 106 days (Hall *et al.* 1998b; Plumptre *et al.* 2016a; 2016b) for both gorillas and chimpanzees using estimates from other sites in the Congo basin, but was not measured in this region. We monitored the time to decay of gorilla nests built in the highland sector of KBNP where habituated groups of gorillas are followed daily for tourism. The provisional results show a faster nest decay rate at that site (average of 61 days for 83 nests monitored in this high altitude sector) with few nests surviving for over 100 days (figure 5). Whether this rate is typical of the whole KBNP-OCR region is unknown but we believe that the decay of nests is likely to be faster in the highland areas as more nests are constructed with herbaceous rather than woody plants. We therefore used the 106 days to make estimates comparable between surveys but recommend that nest decay measures are calculated in the lowland areas where security allows to make this possible.

Spatial density estimates

A spatial density analysis was also possible because of the regular spacing of many transects across the landscape. This method uses the R package Distance (Miller 2017) and allows an interpolation of density estimates (density surface analysis) calculated for transect segments across the landscape. We used 1000m transect segments as the unit of analysis and calculated density in 1km^2 cells. The R code for the density surface analysis is given in Appendix 1 and follows the model-based approach to density estimation across a landscape proposed by Buckland *et al.* (2015). Seventeen covariables were calculated to extrapolate between sites which had been surveyed (table 1). We used a study area (figure 4) for the modelling that included some area outside the protected areas so that the effects of variables beyond the protected areas could be included.

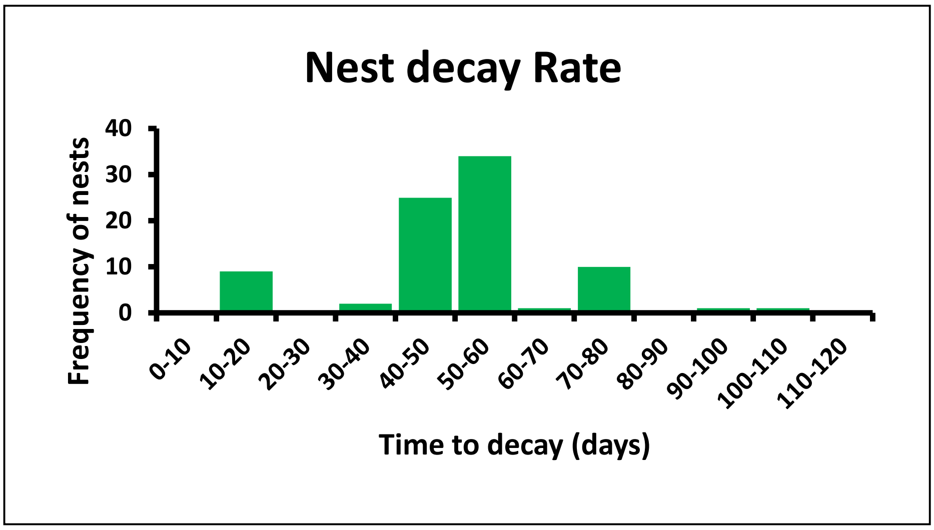

Figure 5. Rate of decay of nests monitored in the Kahuzi Biega Highland Sector.

Table 1. Covariables used for the analysis of occupancy across the landscape.

Covariable Name	Measures	Source
Climate variables		
Bio2	Mean diurnal temperature range	Worldclim database http://www.worldclim.org
Bio6	Average temperature of coldest month	Worldclim database http://www.worldclim.org
Bio7	Annual range of temperature	Worldclim database http://www.worldclim.org
Bio12	Mean annual precipitation	Worldclim database http://www.worldclim.org
Bio16	Precipitation of wettest quarter	Worldclim database http://www.worldclim.org
Bio17	Precipitation of driest quarter	Worldclim database http://www.worldclim.org
Topographic and forest variables		
dem	Elevation above sea level	SRTM data at University of Maryland http://glcf.umd.edu/data/srtm/
rugged	Ruggedness of topography	Available at http://diegopuga.org/data/rugged/#grid
slope	Slope – calculated from DEM layer	SRTM data at University of Maryland http://glcf.umd.edu/data/srtm/
stslopdis	Distance to steep slopes	From SRTM data
Treecov	Percentage tree cover	Calculated by Lilian Pintea at Jane Goodall Institute from Hansen *et al* (2103)
Human impact variables		
disforlos	Distance to forest that has been recently lost	Calculated by Lilian Pintea at Jane Goodall Institute from Hansen *et al* (2103)
minedist	Distance to artisanal mines	Data from International Peace Information Service and mine location data from SMART
Patroldays	Number of days cell patrolled between 2011-2017	SMART data for KBNP and Oku Community Reserve
rivdis	Distance to rivers	Calculated from Rivers layer for DRC

roaddis	Distance to roads	Data from UNOCHA in eastern DRC
villdis	Distance to villages	Date from UNOCHA in eastern DRC

Results

Line transect density estimates

Gorillas

A total of 194 gorilla nests were counted along 689.2 km of transects with 328.0 km walked in KBNP, 289.4 km walked in OCR and the rest outside these two sites in FODI or near Kasese town west of OCR (see transects surveyed in figure 4). The detection curve for gorilla nests was reasonable with most observations within 30 metres (figure 6). We truncated the data at 20 metres based on this figure and fitted a half normal curve with cosine adjustment terms.

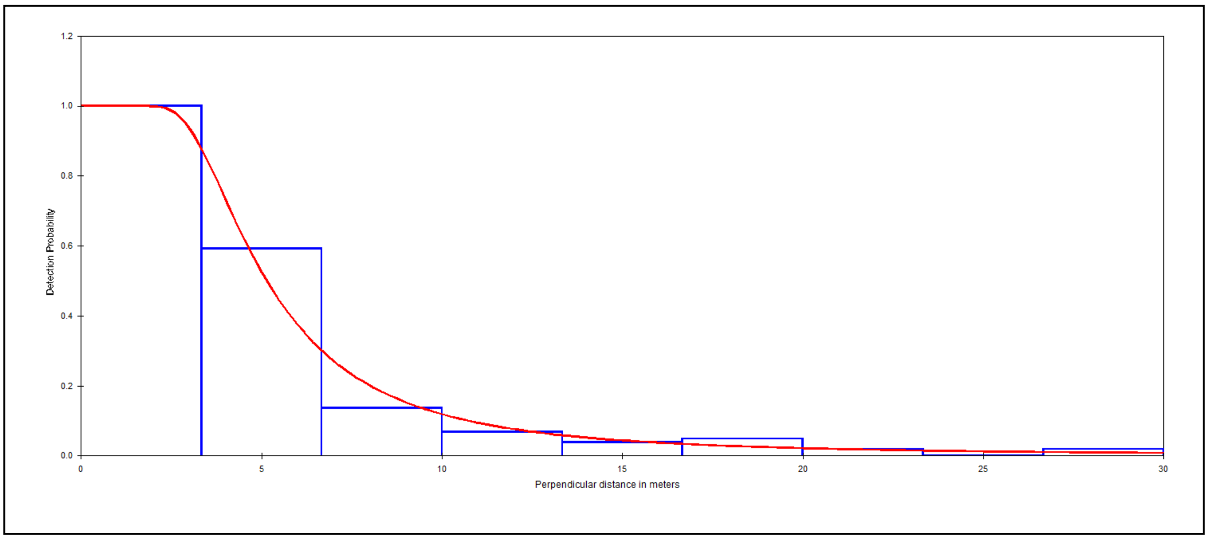

Figure 6. Detection curve for Grauer's gorilla nest detections from transects.

Density estimates were made for KBNP and OCR as a whole as well as for the management sectors in KBNP (where line transects had been surveyed) and for the eastern and northern parts of the OCR, for the FODI region (Fig. 1) to the north of KBNP and from transects walked to the south and west of the OCR in the vicinity of Kasese town (Table 2). Density for each sector was calculated assuming a similar detection curve across all sectors but with variable cluster size and detection probability. Lulingu Sector had not been surveyed in KBNP because of insecurity but when calculating the total population estimate for the park we used the total area of the park (7,257 km^2 as measured from the GIS shapefiles of the park), effectively extrapolating the average density across the other sectors to the Lulingu sector. This method estimated about 1,223 Grauer's gorilla in KBNP and 1,967 in OCR, with a total of 3,474 for the region (including FODI and Kasese town regions).

Table 2. Estimated numbers of gorillas with density (no/km^2) and 95% confidence limits for sectors of KBNP and OCR. Total numbers for KBNP is estimated for the total park area including the un-surveyed Lulingu sector, assuming an average density across the whole park.

			95% Confidence limits	
Sector	**Number of gorillas**	**Density (no/km^2)**	**Lower limit**	**Upper limit**
Outside protected areas				
FODI	50	0.058	7	343
Kasese town	234	0.261	84	652
Kahuzi Biega National Park				
Itebero	270	0.191	99	733
Kasese	125	0.174	38	405
Lulingu	To be surveyed			
Nzovu east	0	0.0	0	0
Nzovu west	117	0.110	30	450
Highland Sector	321	0.407	63	1645
KBNP (all park)	**1,223**	**0.168**	**640**	**2,338**
Oku Community Reserve				
OCR East	1,165	0.636	757	1,793
OCR North	872	0.340	366	2,075
OCR (all reserve)	**1,967**	**0.447**	**1,206**	**3,209**

Chimpanzee

A total of 319 chimpanzee nests were counted along 689.2 km of transects with 328.0 km walked in KBNP, 289.4 km walked in OCR and the rest outside these two sites in FODI or near Kasese town west of OCR (see transects surveyed in figure 4). The detection curve for chimpanzee nests was also reasonable with all observations within 30 metres (figure 7). We truncated analyses at 20 metres also.

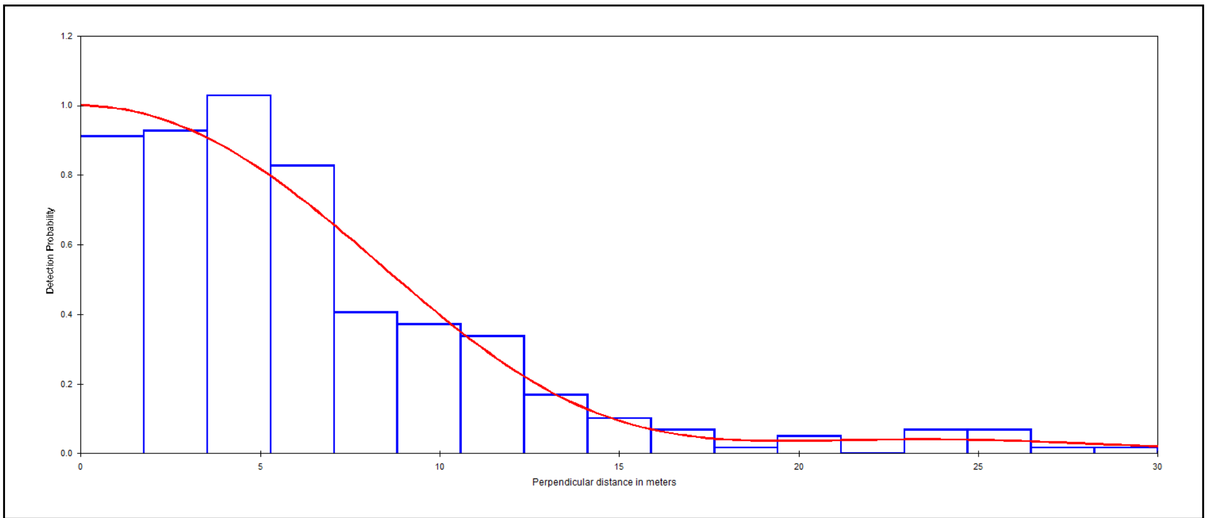

Figure 7. Detection curve for chimpanzee nest detections from transects.

Table 3. Estimated numbers of chimpanzees with density (no/km²) and 95% confidence limits for sectors of KBNP and OCR. Total numbers for KBNP is estimated for the total park area including the un-surveyed Lulingu sector, an average density across the whole park.

			95% Confidence limits	
Sector	**Number of chimpanzee**	**Density (no/km²)**	**Lower limit**	**Upper limit**
Outside protected areas				
FODI	408	0.474	182	914
Kasese town	232	0.259	84	640
Kahuzi Biega National Park				
Itebero	518	0.367	328	817
Kasese	56	0.078	17	181
Lulingu	To be surveyed			
Nzovu east	261	0.302	60	1,128
Nzovu west	653	0.616	364	1,173
Highland Sector	449	0.570	167	1,205
KBNP (all park)	**2,664**	**0.367**	**1,862**	**3,810**
Oku Community Reserve				
OCR East	489	0.267	263	911
OCR North	681	0.265	321	1,445
OCR (all reserve)	**1,170**	**0.266**	**686**	**1,995**

A total of 4,474 chimpanzees were estimated for the KBNP, OCR, FODI and near Kasese town.

Monkeys

Sightings of monkeys were few given the distance walked with 150 sightings of monkey groups from six species: Redtail monkey (*Cercopithecus ascanius*), Owl-faced monkey (*C. hamlyni*), L'hoest's monkey (*C. lhoesti*), blue monkey (*C.mitis*), Mona monkey (*C.mona*), and grey-cheeked mangabey (*Lophocebus albigena*). Red colobus monkeys (*Procolobus rufomitratus lulindicus*) were heard in OCR once and not detected anywhere else. Red colobus are a species often hunted out first because they occur in large groups and tend to stand their ground and try to hide rather than flee.

As sightings of individual species were few we calculated the density of four species assuming the same detection curve across sites as it was possible to combine enough sightings to obtain a reasonable detection curve (Table 4). We also calculated an estimate of monkey density at each site assuming the same sighting distances for all monkey species. Monkey densities are highest in OCR with about 36 individuals per square kilometre while in KBNP, FODI and outside the OCR (south west of OCR) densities are between 7-15 individuals/km². These densities are low in comparison with monkey densities in western Uganda or Rwanda indicating that hunting is having a major impact on these species. Apart from OCR they tend to be lower than densities estimated for the Itebero sector by Hall et al. (2003) who found monkey densities between 10-36 individuals/km² for all primate species estimated here apart from owl-faced monkey which were around 5-7 individuals/km².

Table 4. Monkey densities, standard errors (SE) and 95% confidence limits for density estimates.

			95% Confidence limits	
Sector	**Density (No. individuals/km²)**	**SE Density (No. individuals/km²)**	**Lower limit (No. individuals/km²)**	**Upper limit (No. individuals/km²)**
Kahuzi Biega National Park				
Cercopithecus ascanius	5.7	1.8	3.1	10.6
Cercopithecus hamlyni	0.2	0.3	0.0	1.3
Cercopithecus mitis	5.8	1.7	3.2	10.4
Cercopithecus mona	4.2	2.3	1.5	11.5
Monkeys	**15.6**	**3.0**	**10.6**	**22.8**
Oku Community Reserve				
Cercopithecus ascanius	9.1	2.8	5.1	16.5
Cercopithecus hamlyni	2.2	1.2	0.8	6.1
Cercopithecus mitis	12.5	3.5	7.3	21.5
Cercopithecus mona	13.5	6.1	5.7	31.9
Monkeys	**36.1**	**6.2**	**25.6**	**50.7**
Monkeys Outside KBNP-OCR				
Kasese town	14.9	8.0	4.9	46.0
FODI	7.2	7.0	1.2	43.8

Ungulates

Sightings of ungulates were fewer still, but sighting of dung from some ungulates was more frequent. Densities (Table 5) were calculated for blue duiker and buffalo dung as well as all small antelopes (blue, black-fronted, yellow-backed and bay duikers as well as water chevrotain). These numbers need to be corrected by the defaecation rate and the decomposition rate of dung but as we do not have these values for this region we did not attempt to calculated actual densities of the species.

Table 5. Ungulate dung densities, standard errors (SE) and 95% confidence limits for density estimates.

			95% Confidence limits	
Sector	**Density (No. individuals/km²)**	**SE Density (No. individuals/km²)**	**Lower limit (No. individuals/km²)**	**Upper limit (No. individuals/km²)**
Kahuzi Biega National Park				
Philantomba monticola dung	42.1	15.1	21.1	83.8
Syncerus caffer dung	4.3	2.4	1.6	12.1
Duiker dung	**64.4**	**14.4**	**41.5**	**99.7**
Oku Community Reserve				
Philantomba monticola dung	11.8	4.4	5.7	24.3
Syncerus caffer dung	22.1	8.2	10.8	45.3
Duiker dung	**30.1**	**6.5**	**19.7**	**45.9**
Duikers outside KBNP-OCR				
FODI	0.0	0.0	0.0	0.0
Kasese Town	16.0	10.6	4.1	62.5

We also present only encounter rates per kilometre walked for sightings and dung of species (Table 6). These values are very low compared with prior surveys (Amsini et al. 2008). The only place where signs of elephants were seen was in the Kasese sector of KBNP and the far eastern section of OCR where it borders the Kasese sector. Duiker sightings and dung were most common in Itebero, Nzovu west and highland sectors of KBNP. At the lower altitudes in OCR and Kasese duikers were not as abundant possibly because forest productivity may not be as high. Water chevrotain sign were very rare and only observed in OCR north. Red river hogs were encountered most frequently in the highland sector of KBNP which is the most protected sector. Care must be taken when comparing these encounter rate values however, because most of the sightings were of dung and decay rates of dung may vary widely across this landscape.

Table 6. Encounter rates of ungulate sightings and dung per km walked on transects.

Sector	Elephant	Buffalo	Bongo	Duikers	Chevrotain	Red River Hog
Kahuzi Biega National Park						
Itebero	0.000	0.024	0.024	0.341	0.000	0.057
Kasese	0.046	0.031	0.000	0.046	0.000	0.000
Nzovu East	0.000	0.000	0.070	0.093	0.000	0.000
Nzovu West	0.000	0.000	0.000	0.123	0.000	0.015
Highland	0.000	0.000	0.213	0.640	0.000	0.122
Oku Community Reserve						
OCR North	0.000	0.092	0.033	0.163	0.011	0.011
OCR East	0.010	0.057	0.000	0.095	0.000	0.010
Kasese town	0.000	0.000	0.000	0.042	0.000	0.000
FODI	0.000	0.000	0.000	0.152	0.000	0.000

Summary of abundance estimates

From these results it is clear that KBNP and OCR are both important sites and contribute to the conservation of large mammal fauna. OCR is particularly important for Grauer's gorillas as well as for many of the monkey species, while KBNP is more important for chimpanzee conservation than OCR. Many of the ungulates also seem to be more abundant still in KBNP than OCR and the Kasese sector together with the adjacent part of OCR is the last place elephant can be found in the region.

Density surface models of the region

Gorillas

The results of the density surface modelling, extrapolating density from 1km transect segments with average environmental variables for that segment across the study area, show that the higher densities of Grauer's gorillas are predicted to occur in OCR (figure 8). After testing the full model and then removing variables that had little influence on the final model the following model was used: the model incorporated distance to steep slopes, annual rainfall, tree cover and rainfall in the driest quarter. The variables explained only 15.0% of the variance in the model with annual rainfall being the most significant variable. Gorilla density was positively correlated with distance to rainfall and tree cover but negatively with distance to steep slopes (figure 9).

The highest densities of gorillas are predicted to occur in the northern part of OCR in particular, as well as in the south western portion of the eastern block of OCR (figure 8). Using this model, it is possible to predict gorilla density across the study area and estimate a total population for the region in figure 8. This estimates 3,787 gorillas to occur within this region, slightly higher than the 3,474 estimated from the density from transects (above). This is likely because of the additional area that was unsurveyed around the study areas in the region depicted in figure 8.

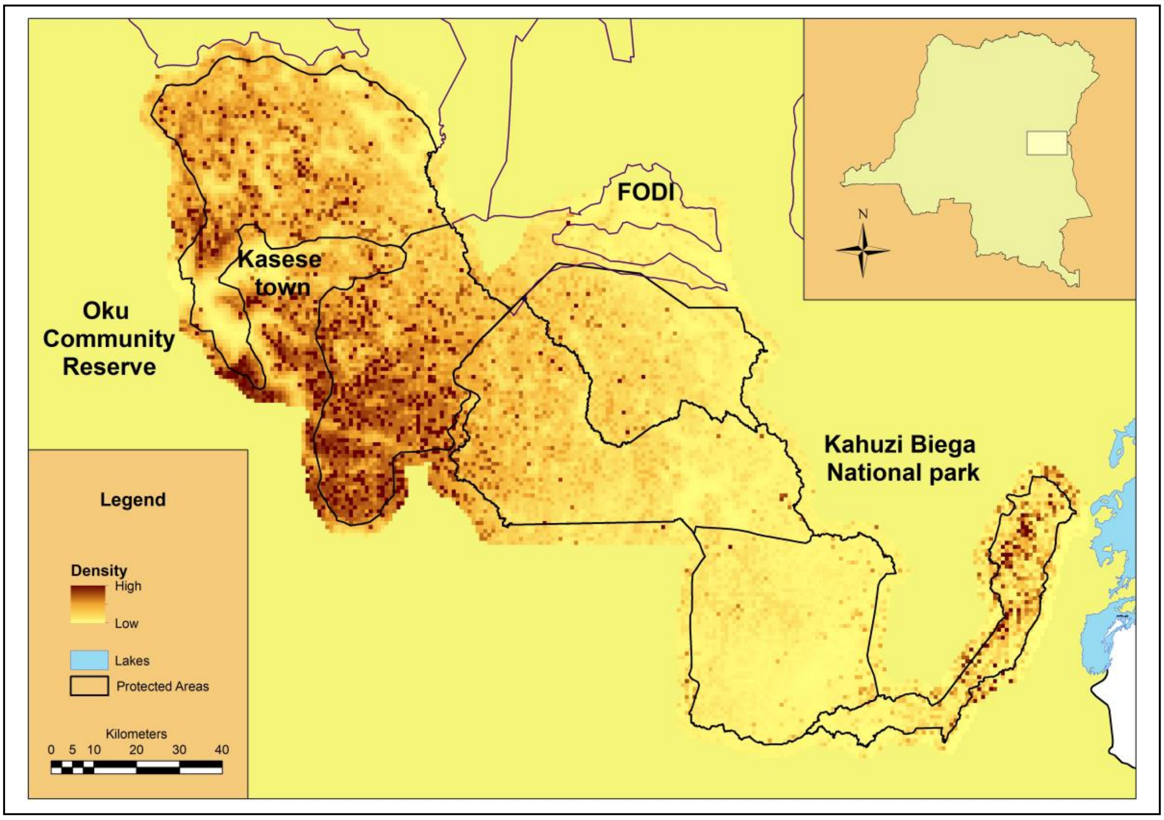

Figure 8. Predicted density of Grauer's gorilla from spatial modelling of the densities from 1 km segments along each transect.

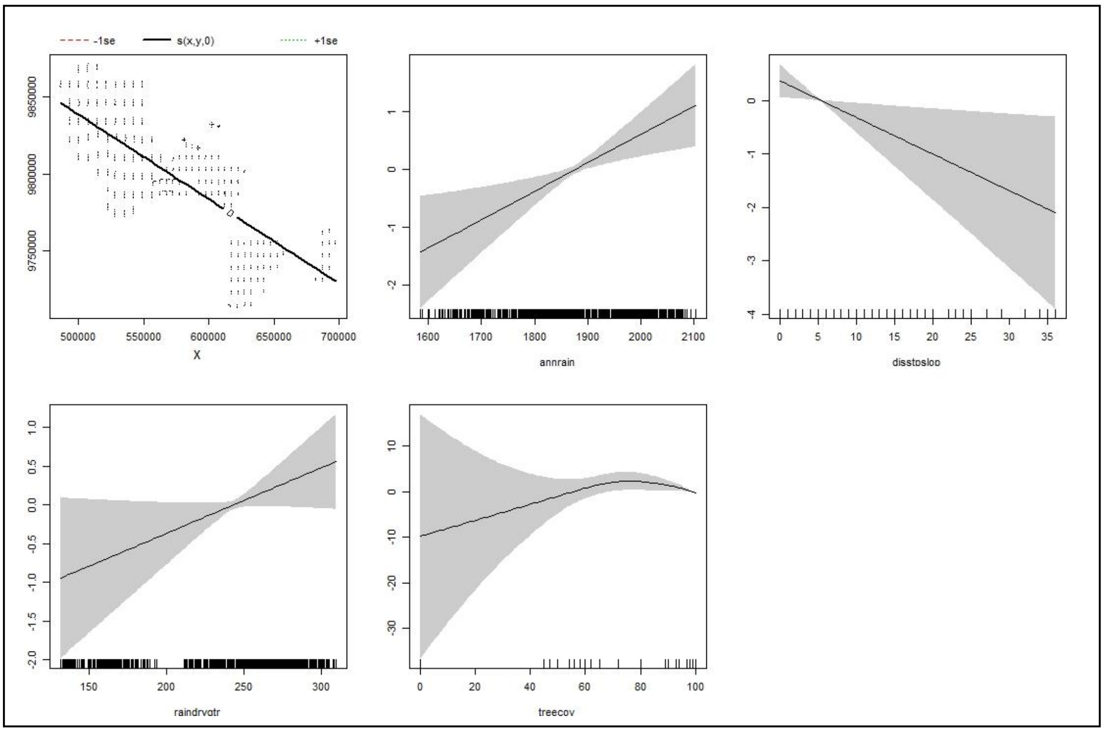

Figure 9. Relationship between explanatory variable (x-axis) and gorilla density (y-axis). Annual rainfall (top centre); Distance to steep slopes (top right); rain in driest quarter (bottom left); tree cover (bottom centre).

Chimpanzees

The results of the density surface modelling show that the higher densities of chimpanzees are predicted to occur in the Itebero and Nzovu-west sectors of KBNP as well as to the north of KBNP (figure 10). After testing the full model and then removing variables that had little influence on the final model the following model was used: the model incorporated distance to villages, ruggedness, and annual rainfall. The variables explained only 13.1% of the variance in the model with distance to village and annual rainfall being the most significant variables (Increasing gorilla numbers with ruggedness but decreasing with rainfall and a humped shape with distance to villages – figure 11).

The highest densities of chimpanzees are predicted to occur in the eastern lowland sector of KBNP (figure 10). Using this model, it is possible to predict chimpanzee density across the study area and estimate a total population for the region in figure 10. This estimates 4,709 chimpanzees to occur within this region, slightly lower than the 4,474 estimated from the density from transects (above).

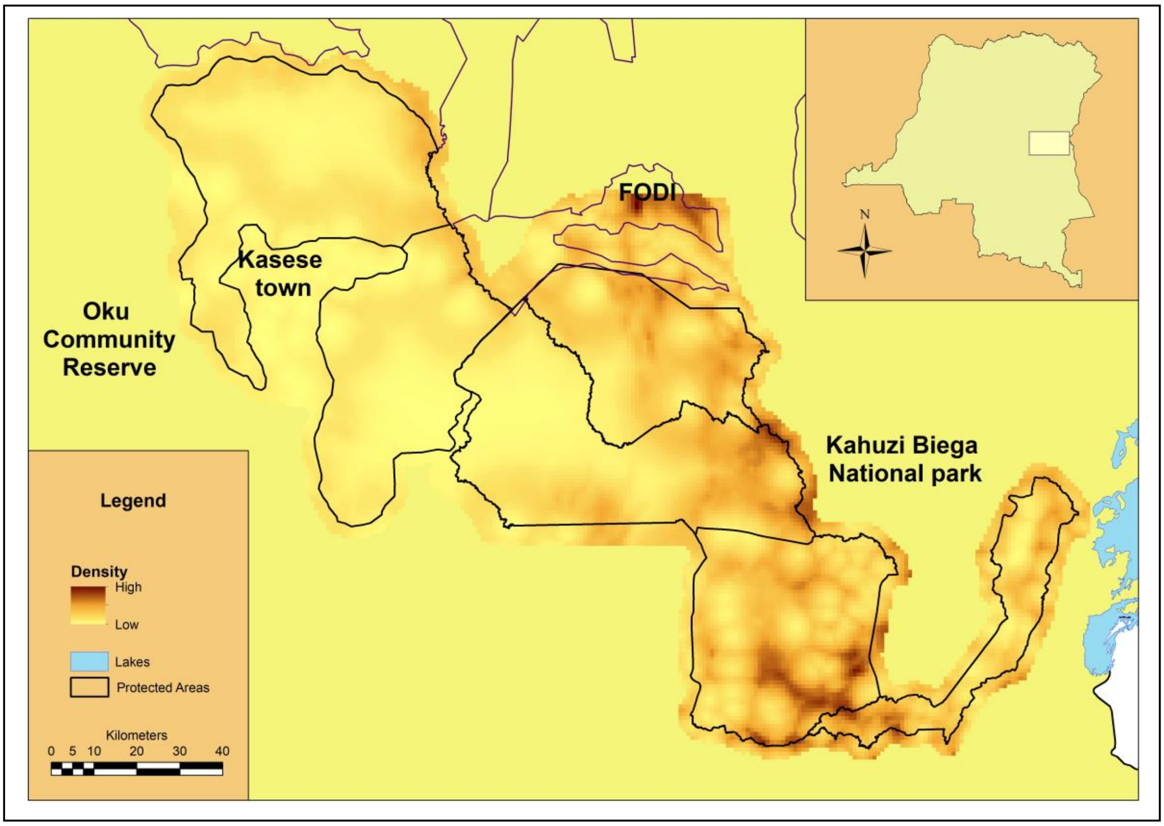

Figure 10. Predicted density of chimpanzees from spatial modelling of the densities from 1 km segments along each transect.

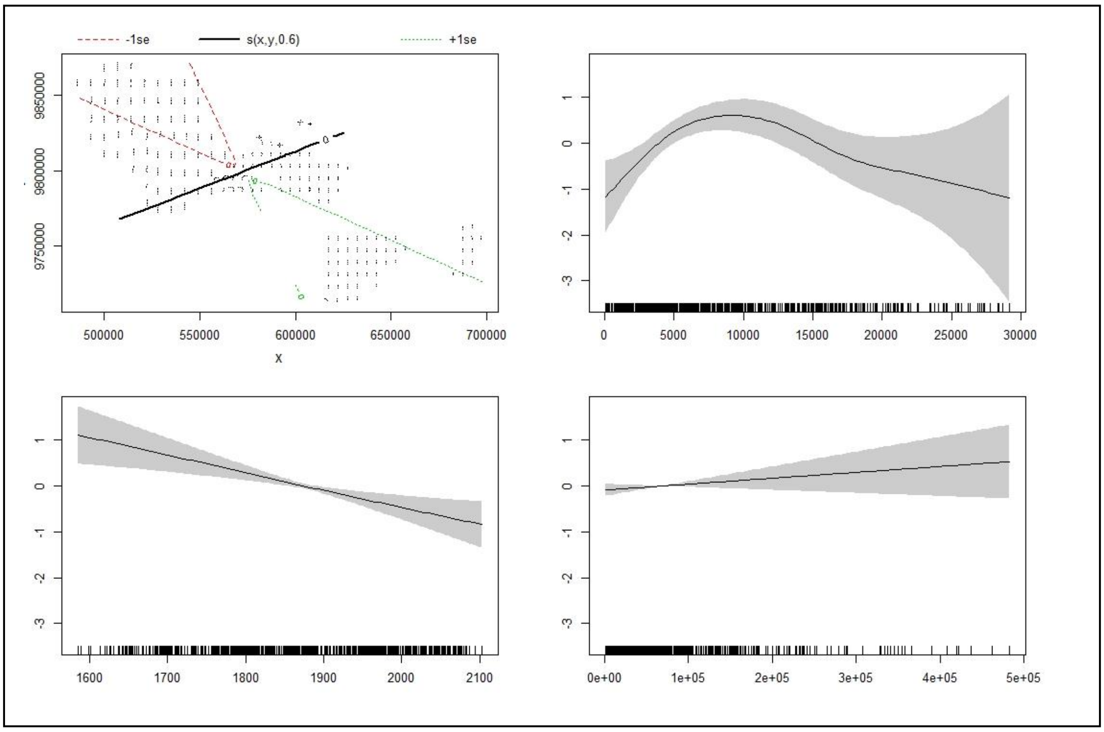

Figure 11. Relationship between explanatory variable (x-axis) and chimpanzee density (y-axis). Distance to village (top right), annual rainfall (bottom left), ruggedness (bottom right).

In conclusion, while the model results give some indication of the spatial patterns in gorilla and chimpanzee abundance, they do not explain more than about 13-15% of the variation in their distribution. As such they suffer from poor predictability. However, the numbers of individuals estimated from the models for the study region are not differing greatly from those estimated from the transect analysis, certainly within the 95% confidence limits of the estimates.

Discussion

Population changes

Estimates were made of the populations of chimpanzees and gorillas by Hall et al. (1998b) using line transects in the Itebero and Nzovu sectors of KBNP and in OCR north between 1994-1996. Plumptre et al. (2016b) estimated numbers of both apes from extrapolations based on both some transect survey data from Kasese, Itebero and Nzovu sectors in KBNP and encounter rate data in OCR using a regression equation relating encounter rate to density. These estimates were for the period 2011-2015. We compare our results from the much more extensive 2013-2017 line transect surveys with these estimates in table 7.

Table 7. Ape population estimates at different times for the region

	Gorilla		Chimpanzee	
	No individuals/km^2	**95% CL**	**No. individuals/km^2**	**95% CL**
Kahuzi Biega National Park				
1994-1996	7,670	4,180-10,830	2,000	1,290-3,290
2011-2015	1,096	352-3,481	1,784	756-4,250
2013-2019	1,223	640-2,338	2,664	1,862-3,810
Oku Primate Reserve				
1994-1996	3,350	1,420-5,950	600	330-1,210
2011-2015	254	Not reported	1,207	Not reported
2013-2019	1,967	1,206-3,209	1,170	686-1,995

The more extensive line transect survey data gives fairly similar density estimates to the survey data we had from many fewer and more randomly placed transects between 2011-2015 for both gorillas and chimpanzees given the 95% confidence limits. In all three surveys chimpanzee numbers have not changed greatly in KBNP but Grauer's gorilla numbers have declined drastically. The 2013-2017 estimate is only 16% of the 1994-1996 estimate. The line transect surveys of OCR give a larger estimate for gorillas than the extrapolation from encounter rate data (2011-2015), although most of the encounter rate data from this region was from recce walks along footpaths so this is not too surprising. Similar results were obtained from the encounter rate estimates from 2011-2015 for chimpanzees in OCR and the estimates obtained from the transect data.

Monkeys also appear to have declined significantly between 1994-96 and 2013-3017 (table 7). Very few calls were heard of the red colobus in KBNP and no sightings made, when in 1994 it was fairly abundant. Grey-cheeked mangabey (*L. albigena*) and L'hoest's monkey (*C. lhoesti*) were also rare in these surveys, although the latter had been rare in 1994 also because it tends to be found in montane forest in highland areas. These declines of both the apes and monkeys are likely to be due to bushmeat hunting, particularly around mining camps that create a high demand for inexpensive protein (Spira et al, 2017).

Table 8. Monkey density estimates for KBNP in 1994 (Itebero sector) and between 2013-2017 (Itebero, Nzovu and Kasese sectors).

Species	1994	2013-2017
Cercopithecus ascanius	30.4	5.7
Cercopithecus hamlyni	5.3	1.3
Cercopithecus mitis	36.0	10.4
Cercopithecus mona	17.3	11.5
Cercopithecus lhoesti	Too few to estimate	Too few to estimate
Lophocebus albigena	15.9	Too few to estimate
Procolobus rufomitratus	20.6	Too few to estimate

Conservation of KBNP and OCR

The gorilla estimates for the KBNP-OCR region total 3,190 individuals, which is about 84% of the global population estimate made of 3,800 (Plumptre et al. 2016a) and our total estimates including FODI and Kasese town region number 3,474 (91% of the estimated global population). The global population assessment used a new and untested method to estimate gorilla numbers using occupancy analysis. The results of the occupancy analysis predicted a threshold distribution map for gorillas (figure 3), which was then converted to estimates of gorilla numbers using an average density value calculated across several sites. The global assessment showed that the last stronghold for Grauer's gorillas was in the KBNP-OCR region. Estimating about 84-91% of the global estimate occurs in this region from the extensive transect surveys indicates that perhaps the global estimate made from the occupancy analysis is lower than the real global numbers because it is likely there are more then 300-400 gorillas in the Itombwe Reserve, Tayna Reserve and in the other community reserves between our study region and Maiko National Park. We therefore believe that surveys of these other areas are needed to better estimate the global numbers of Grauer's gorillas.

It is clear that the Oku Community Reserve is of importance for gorilla conservation as well as for the conservation of some monkeys and ungulates. It has an estimated 1,967 Grauer's gorillas and higher monkey densities than KBNP. The Wildlife Conservation Society and the ICCN have been working with communities there to create several community reserves to conserve the gorillas and the other diversity of fauna and flora from this area. It is hoped that these reserves will be established in the near future and that funding will be made available to conserve them once established.

These results also show that KBNP is not in as bad a situation as had been predicted from the 2011-2015 data. It still conserves a sizeable chimpanzee population and more than 1000 gorillas. It also appears to support larger populations of the large ungulate species than the adjacent OCR, even though the OCR is thought to have been impacted less by the civil war in the DRC. Continued support is needed to help ICCN patrol this park and political lobbying for the government to remove armed groups from the park and to stop the expansion of settlements in the lowland sector.

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Appendix 1

R-code to make the analysis of average gorilla density in the landscape and then the density surface model for the landscape.

```
setwd("C:/DRCongo/PNKB/Transect data PNKB&RGPU/Analyses/")

#Analysis of Transect data (3km in PNKB and 5km in RCO)
library(Distance)
library(rgdal)
library(ggplot2)
library(knitr)
library(dsm)

#Read in data from Gor_trans.csv created in excel
distdata <- read.csv("Gor_trans.csv", header=TRUE)
head(distdata)
distdata$distance <- distdata$Perp
distdata$size <- distdata$Number
distdata$Region.Label <-as.factor(distdata$Region)

#Map distribution of perpendicular distance data
hist(distdata$distance, xlab="Distance (m)",
    main="Gorilla Nest Observations")

#Calculate density using half-normal curve
df_hn <- ds(data=distdata, truncation=30, key="hn", adjustment=NULL)
summary(df_hn)
ddf.gof(df_hn$ddf)
plot(df_hn, showpoints=FALSE)
plot(df_hn)

#Calculate density using hazard rate curve
df_hr <- ds(data=distdata, truncation=30, key="hr", adjustment=NULL)
summary(df_hr)
ddf.gof(df_hr$ddf)
plot(df_hr, showpoints=FALSE)
plot(df_hr)

#Analysis of segment data (1km segments) –Gor_segs.csv prepared in excel file
distdata <- read.csv("Gor_segs.csv", header=TRUE)
head(distdata)
distdata$size <- distdata$Number

hist(distdata$distance, xlab="Distance (m)",
    main="Gorilla Nest Observations")

#Calculate density using half-normal curve
df_hn <- ds(data=distdata, truncation=30, key="hn", adjustment=NULL)
summary(df_hn)
```

```
ddf.gof(df_hn$ddf)
plot(df_hn, showpoints=FALSE)
plot(df_hn)

#Hazard rate model - if you want region it needs to be in a separate table
#- easier to analyse in Distance for Windows
df_hr <- ds(data=distdata, truncation=30, key="hr",adjustment=NULL)
summary(df_hr)
ddf.gof(df_hr$ddf)
plot(df_hr, showpoints=FALSE)
plot(df_hr)

#Import raster layers for covariables
##= Importing rasters of explicative variables (creating a raster stack)
library("sp")
library("raster")

G.stk <- stack("./Altitude.tif","./Ann_rain.tif","./Dist_For_loss.tif","./Dist_mines.tif",
           "./Dist_river.tif","./Dist_roads.tif","./Dist_steep_slope.tif", "./Dist_village.tif",
           "./Patrol_days.tif","./Rain_dry_Qtr.tif","./Rain_wet_qtr.tif",
           "./Ruggedness.tif","./Temp_Ann_Range.tif","./Temp_cold_Month.tif",
           "./Temp_day_range.tif","./Tree_cover.tif","./Tree_height.tif")

## Rename layers - names must be same as in segdata file
names(G.stk) <- c("alt","annrain","disforloss","dismine","disriv","disrd","disstpslop",
             "disvill","patrolday","raindryqtr","rainwetqtr","rugged","tempannrng",
             "tempcldmth","tempdayrng","treecov","treeht")

## Number of grid cells in the landscape
ncells <- ncell(G.stk) #49104
ncells
plot(G.stk$alt)

#Get x,y coordinates of raster removing cells with no data (if not in a rectangle shape)
predgrid <- as.data.frame(G.stk, xy=TRUE, na.rm=TRUE)
#set extent of grid cell size - here 10 km x 1000m squared
predgrid$off.set <- (924.6)^2

segdata <- read.csv("Segdata.csv", header=TRUE)
distdata <- read.csv("Gor_segs.csv", header=TRUE)
#region <- read.csv("region.table.csv", header=TRUE)


plotdata <- dsm(count~s(x,y), ddf.obj = df_hr, segment.data =segdata, obs=distdata)
plotdata <- plotdata$data

#Plot covariable values across their full range
par(mfrow=c(1,1))
for(cov_name in names(G.stk)){
 hist(plotdata[[cov_name]], main=cov_name, col='grey')
}
```

```
#Plot covariable values where nests were seen
for(cov_name in names(G.stk)){
 hist(plotdata[[cov_name]][plotdata$count>0], main=cov_name, col='grey')
}

par(mfrow=c(1,1))

#Start to fit DSM models
library(Distance)
library(dsm)
library(ggplot2)
library(knitr)

df_hr <- ds(data=distdata, truncation=20, key="hr",
         adjustment="cos")
summary(df_hr)
ddf.gof(df_hr$ddf)
plot(df_hr, showpoints=FALSE)
plot(df_hr)

#Density Surface model from hazard rate analysis using just x and y
dsm_hr_xy <- dsm(count~s(x,y),
             ddf.obj=df_hr, segment.data = segdata, observation.data=distdata,
             family=nb())
summary(dsm_hr_xy)
vis.gam(dsm_hr_xy, view=c("x","y"), plot.type="contour",
       too.far=0.1, main="s(x,y) (link scale)", asp=1)
vis.gam(dsm_hr_xy, view=c("x","y"), plot.type="persp",
       too.far=0.1, main="s(x,y) (link scale)", asp=1)

pp <- predict(dsm_hr_xy, predgrid)
sum(pp, na.rm=TRUE)

library(knitr)
library(dsm)
library(ggplot2)
# colourblind-friendly colourschemes
library(viridis)
#Plot result
# assign the predictions to the prediction grid data.frame
predgrid$Nhat_hr_xy <- pp
# remove the NA entries (because of the grid structure of the raster)
predgrid_plot <- predgrid[!is.na(predgrid$Nhat_hr_xy),]
# plot!
phr <- ggplot(predgrid_plot) +
  geom_tile(aes(x=x, y=y, fill=Nhat_hr_xy, width=924.6, height=924.6)) +
  coord_equal() +
  scale_fill_viridis()
print(phr)
```

```
#Density surface model using covariates and hazard rate analysis
dsm_hr_xy_ms <- dsm(count~s(x,y, bs="ts") +
                 s(disvill, bs="ts") +
                 s(rugged, bs="ts") +
                 #s(patrolday, bs="ts") +
                 s(disrd, bs="ts") +
                 s(raindryqtr, bs="ts")+
                 s(dismine, bs="ts"),
               df_hr, segdata, distdata,
               family=nb())
summary(dsm_hr_xy_ms)
par(mfrow=c(1,1))
gam.check(dsm_hr_xy_ms)
rqgam.check(dsm_hr_xy_ms)

vis.gam(dsm_hr_xy_ms, view=c("x","y"), plot.type="contour",
      too.far=0.1, main="s(x,y) (link scale)", asp=1)
vis.gam(dsm_hr_xy_ms, view=c("x","y"), plot.type="persp",
      too.far=0.1, main="s(x,y) (link scale)", asp=1)
plot(dsm_hr_xy_ms, pages=1, scale=0, shade=TRUE)
#Scale to same y-axis
plot(dsm_hr_xy_ms, pages=1, scale=-1, shade=TRUE)

#Check relationship between covariables - checks for curvilinear relationships
concurvity(dsm_hr_xy_ms) # can add full=FALSE to get full output that is plotted below
#Visually plot concurvity - high values = relationship
vis.concurvity(dsm_hr_xy_ms)

#Predict to study area
pp.cov <- predict(dsm_hr_xy_ms, predgrid)
sum(pp.cov, na.rm=TRUE)
predgrid$Nhat_hr_xy_ms <- pp.cov
# remove the NA entries (because of the grid structure of the raster)
predgrid_plot <- predgrid[!is.na(predgrid$Nhat_hr_xy_ms),]
# plot!
phr.cov <- ggplot(predgrid_plot) +
  geom_tile(aes(x=x, y=y, fill=Nhat_hr_xy_ms, width=924.6, height=924.6)) +
  coord_equal() +
  scale_fill_viridis()
print(phr.cov)

library(rgdal)
library(raster)

#Save result to raster
# setup the storage for the predictions

# make new predictions with NAs
napredgrid <- as.data.frame(G.stk, xy=TRUE)
pp <- predict(dsm_hr_xy_ms, napredgrid, off.set=(924.6)^2)
```

```
pp_raster <- raster(G.stk)
# put the values in, making sure they are numeric first
pp_raster <- setValues(pp_raster, as.numeric(pp))

# name the new, last, layer in the stack
names(pp_raster) <- "Nhat_hr_xy_ms"
writeRaster(pp_raster, "Gorilla_abund_raster.tif", datatype="FLT8S", overwrite=TRUE)
```

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