Effects of anti-poaching patrols on the distribution of large mammals in Taï National Park, Côte d'Ivoire

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SUPPLEMENTARY MATERIAL 1 Additional information on data collection

Data were recorded in the research area during January 2010–March 2015 by a team from the Wild Chimpanzee Foundation in collaboration with the Taï Chimpanzee Project and l'Office Ivoirien des Parcs et Reserves, the park authority. This area covers 210 km² (c. 4% of the total area of the park; Fig. 1). We used 75 line transects, each 1 km in length, designed using *Distance 5.0* (Thomas et al., 2009), to survey mammals and illegal activities. These transects (the same as those used by Campbell et al. (2011) during September 2008–July 2009) covered the research area systematically and were walked once per year. Given the difficulty in observing duikers, pygmy hippopotamuses, elephants and chimpanzees directly along transects, we focused on signs of their presence (dung, footprints, nests). Data were recorded following standard procedures (Buckland et al., 2001) and IUCN survey guidelines (Kühl et al., 2008). A particular effort was made to detect all signs on transects. All dung piles of duikers, elephants and pygmy hippopotamuses were recorded. Dung piles of duikers were pooled because of the difficulty in identifying them by species. Footprints of elephants and pygmy hippopotamuses (distinguishable by their size and shape) were also recorded. For chimpanzees, signs of presence such as nests, nut cracking sites, footprints, vocalizations and drumming were recorded. As the mean lifetime of a chimpanzee nest in Taï National Park is 91.22 days (Kouakou et al., 2009), the probability of a nest being recorded again the following year was practically null. All signs visible along and adjacent to the line transect had to be sufficiently identifiable to be recorded. Direct and indirect observations of monkeys were also recorded. When an individual was seen or heard, we assumed the presence of a group of the species to which the individual belonged. All signs of human activities (e.g. poaching tracks, gunshots, smoking sites, poaching camps, traps, cartridges) were also recorded to take account of anthropogenic factors.

Data from the rest of the park were provided by the Wild Chimpanzee Foundation and l'Office Ivoirien des Parcs et Reserves, and were from ecological monitoring conducted in the park during 2006–2015 (N'Goran et al., 2012, 2013; N'Goran, 2015). These data were collected along 176 linear transects (of a total of 184) that systematically covered the whole park (we excluded eight transects that fell within the research area because of existing transects already used in the analysis). These data were collected following the same methods as used in the research area during the same time period (i.e. 2008–2015). Thus, a total of 3,011 km of transects were walked in the park: 582 km in the research area and 2,429 km in the rest of the park.

Supplementary Material 2 Law enforcement data and estimating patrolling effort

Anti-poaching patrols in Taï National Park are conducted mainly by the Brigade Mobile of l'Office Ivoirien des Parcs et Reserves, a special unit composed of c. 60 rangers who have received anti-poaching training. Since 2005, each team of the Brigade Mobile conducted patrols on 10–15 days per month. The results of the annual ecological monitoring in the park showing areas with high human pressure were used by the park authorities to target anti-poaching patrols more effectively (N'Goran et al., 2012; N'Goran, 2015). The Brigade Mobile also utilizes a network of local informants (living in surrounding villages) who sometimes provide information on intrusions by local residents in the park. For this study we collected monthly reports of patrol missions conducted both in the research area and in the rest of the park from the Brigade Mobile authorities. These reports provided detailed information about the number of patrols, the number of patrol days, the number of rangers involved in each patrol, and the area patrolled (research area or rest of park). Given the mishandling of global positioning systems by some rangers in recording track-logs during patrols, these reports constitute the best information that we could obtain to quantify the patrolling effort in the park.

To test the effect of anti-poaching patrols on the relative abundance of large mammals, we determined patrolling effort by extracting data from patrol reports during 2006–2015. We counted the number of patrol days per month for both the research area and the rest of the park. We divided this number by the area of each, to obtain the number of patrol days per km^2 per month (i.e. the patrolling effort per month). Then, according to the date of data collection on each transect, we summed this number over the 2 years preceding that date to determine the total patrolling effort that was likely to affect the transect, using the formula

$$PE = \sum_{i=1}^{24} (Nd_i / A)$$

where PE is the patrolling effort (number of patrolling day per km^2 over 2 years); Nd_i is the number of patrolling days during the month i; and A is the area (km^2) of the research area or the rest of the park.

The time period of 2 years was based on life history patterns described by Estes (1991), Ross (1991), Rowe (1996) and Huffman (2016), with even fast reproducing duiker and monkey species requiring at least this duration for a population increase.

Supplementary Material 3 Determining the other covariates

Other variables were used in our analysis to control for their effects on the relative abundance of mammals. We expected anthropogenic factors to have a negative effect on relative abundance, so for each transect we calculated the encounter rate of illegal activities by dividing the number of signs by the total length of the transect. Factors such as vegetation and rainfall are known to influence the distribution signs of wildlife in general and large mammals in particular (White, 1994; Blom et al., 2005; Scholte et al., 2007). Thus, we estimated the percentage of primary forest (compared to secondary forest and degraded forest) on each transect by calculating the proportion of the distance walked in primary forest over the total length of the transect. Rainfall data were collected at the park's meteorological station during January 2008–December 2015. We attributed the quantity of rainfall during the month of data collection to each transect. Distances from the transects to edge of the park and to the closest research or ecotourism camp were estimated using the tool Near in *ArcGIS 10.1* (ESRI, Redlands, USA). They were included in the analysis because of their importance in the distribution of large mammals (Köndgen et al., 2008; Hoppe-Dominik et al., 2011; Campbell et al., 2011; N'Goran et al., 2012).

SUPPLEMENTARY MATERIAL 4 Statistical analyses

Autocorrelation, model stability and collinearity issues

The encounter rate was likely to be spatially autocorrelated beyond what is explained by the predictors in the model. Such autocorrelation would lead to non-independent residuals, violating one of the assumptions of the model. Hence we aimed to account explicitly for spatial autocorrelation in the model. We did this by firstly fitting the model as described above and retrieving the residuals from it. Then, separately for each data point, we averaged the residuals of all other data points for the same species, weighting their contribution by the inverse of their spatial distance to the data point. The weighting function had the shape of a Gaussian distribution with a mean of zero (i.e. maximum weight at a distance being zero). The standard deviation of the function was determined such that the likelihood of the model with the derived autocorrelation term included was maximized. However, we found the estimated coefficient for the autocorrelation term appeared to be negative (presumably because of the rarity of two of the taxa investigated), so we removed it from the final model (see below the complete full model formula).

To assess model stability we excluded transects, one at a time, fitted the same full model as to the entire data set and compared the estimates derived with those obtained from the full data set. We found the model to be stable for most estimates.

To evaluate whether the results could be influenced by collinearity among the predictors, we firstly inspected the squares of the kth root of generalized variance inflation factors, where k was twice the degrees of freedom associated with the relelvant term (Fox & Monette, 1992; Fox & Weisberg, 2011), which we derived using the function *vif* in the *R* package *car* (Fox & Weisberg, 2011) applied to a standard linear model lacking the random effects and interactions. The generalized variance inflation factors were larger for distance to camp (3.720), number of patrol days (8.501), and area (11.181). Hence we inspected plots of either combination of the three predictors. For each of the three predictors there was sufficient variation over the entire range of each of the other two (Fig. S1; Mundry, 2014). Hence we are confident that the model can reliably disentangle their effects.

Formulae of the models fitted

The formula for the full model is

> encount_rate ~ species*patrolling.effort*julian.date + Area + human.activity + dist.border + dist.camp + veg.type + rainfall + offset(log(transect.length)) + (1 +

species.duiker + species.eleph + species.hippo + species.monkeys + julian.date + human.activity + patrolling.effort + species.duiker:patrolling.effort + species.eleph:patrolling.effort + species.hippo:patrolling.effort + species.monkeys:patrolling.effort + species.duiker:julian.date + species.eleph.:julian.date + species.hippo:julian.date + species.monkeys:julian.date + patrolling.effort:julian.date + species.duiker:patrolling.effort:julian.date + species.eleph:patrolling.effort:julian.date + species.hippo:patrolling.effort:julian.date + species.monkeys:patrolling.effort:julian.date||ID_transect)

In the model formulae, patrolling.effort, julian.date, human.activity, dist.border, dist.camp, veg.type, and rainfall refer to the variables being z-transformed to a mean of 0 and a standard deviation of 1. The predictor 'species' was a factor with five levels (chimpanzee, duikers, elephant, hippopotamus and monkeys); in the random effects part it was represented by four dummy variables, each centred to a mean of zero. The predictor 'area' is a factor with two levels (research area and rest of park). Two or more terms combined by asterisk(s) indicate the main effects and also all interactions up to the highest possible order (three in the full model, two in the model for the bootstrap). Two or more terms combined by colon(s) refers to only the interaction term (used in the random effects parts for technical reasons). An expression such as (1 + x + y||ID_transect) means a random intercept for transect ID and random slopes of x and y within transect ID but no correlations among any of these.

The formula for the null model is

encount_rate ~ species*julian.date + Area + human.activity + dist.border + dist.camp + veg.type + rainfall + offset(log(transect.length)) + same random effects structure as full model

The bootstrapping method

To determine the minimum patrolling effort we used parametric bootstrapping of the response based on the model results. More specifically, we took the following approach: we began by defining a set of particular values of patrolling effort for which to evaluate the effect of date on encounter rates of signs per taxon. The values we chose for patrolling effort ranged from its minimum to its maximum (increment: 0.14). We then used all estimates of the full model (estimated coefficients for the fixed main effects and interactions as well as the variance components for random intercepts and slopes) to determine the predicted encounter rate given the model, all predictors and also the offset term of transect length. The data for the predictors used to determine the predicted values per species, transect and date were identical to those used to fit the model, with the exception that we set patrolling effort to a fixed value (each of the set of values described above, one at a time). For an individual bootstrap we then randomly sampled new values for the response (encounter rate) from a Poisson distribution, with the mean per transect, date and species being equal to the predicted values just described. Subsequently we fitted a model with the bootstrapped rather than the original response. The model was identical to the full model, with the exception that we excluded all terms (fixed and random effects) including patrolling effort, as this was constant per bootstrapped data set (see below the model fitted). From the model we extracted the estimates for the effects of date, taxon and their interaction. Conducting 1,000 such bootstraps, we were able to determine confidence intervals for the effect of date on encounter rate, separately for each taxon and varying levels of patrolling effort. We determined 95% confidence intervals for the effect of date on encounter rate for a given species/taxon and value of patrolling effort using the percentile method (Manly, 1997).

The formula for the bootstrapped data is encount_rate ~ species*julian.date + Area + human.activity + dist.border + dist.camp + veg.type + rainfall + offset(log(transect.length)) + (1 + species.duiker + species.eleph + species.hippo + species.monkeys + julian.date + human.activity + species.duiker:julian.date + species.eleph:julian.date + species.hippo:julian.date + species.monkeys:julian.date||ID_transect)

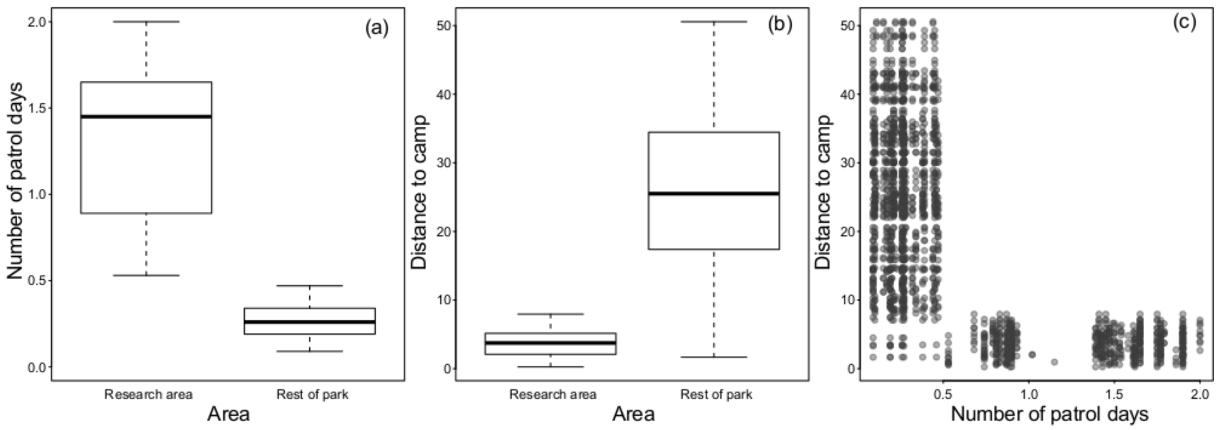

FIG. S3 Correlations between distance to camp, number of patrol days and area. There is considerable variation in of each of the three variables over the entire range of the other two.

TABLE S1 Mammal species recorded in Taï National Park, Côte d'Ivoire.

Common name	Scientific name	IUCN Red List status (2016)
Maxwell's duiker	*Philantomba maxwellii*	Least Concern
Black duiker	*Cephalophus niger*	Least Concern
Zebra duiker	*Cephalophus zebra*	Vulnerable
Bay duiker	*Cephalophus dorsalis*	Near Threatened
Ogilby's duiker	*Cephalophus ogilbyi*	Least Concern
Jentink's duiker	*Cephalophus jentinki*	Endangered
Yellow-backed duiker	*Cephalophus silvicultor*	Near Threatened
Campbell's monkey	*Cercopithecus campbelli campbelli*	Least Concern
Diana monkey	*Cercopithecus diana diana*	Vulnerable
Spot-nosed monkey	*Cercopithecus petaurista buettikoferi*	Least Concern
Putty-nosed monkey	*Cercopithecus nictitans* stampflii	Least Concern
Sooty mangabey	*Cercocebus atys atys*	Near Threatened
Olive colobus	*Procolobus verus*	Near Threatened
King colobus	*Colobus polykomos polykomos*	Vulnerable
Upper Guinea red colobus	*Piliocolobus badius badius*	Endangered
Pygmy hippotamus	*Choeropsis liberiensis*	Endangered
Chimpanzee	*Pan troglodytes verus*	Critically Endangered
Elephant	*Loxodonta cyclotis*	Vulnerable

TABLE S2 Predictor variables used in the generalized linear mixed model. The covariate ‘Patrolling effort’ was the key test predictor in our model. The others were included to control for their effects.

Predictor	Definition
Illegal activities	Encounter rate of all signs of illegal activities for each transect
Patrolling effort	Total number of patrol days per km^2 in the 2 years prior to the date of data collection on a transect
Species	Chimpanzee, duiker, pygmy hippopotamus, elephant or monkey
Area	Area where the transect was located (research area or rest of park)
Distance to camp	Distance between the centre of the transect and the closest research camp
Distance to the border	Minimum distance between the centre of the transect and the edge of the park
Julian date	Number of days elapsed since 1 January 1970
Percentage of primary forest	Proportion of primary forest that covered a transect, based on the distance walked in primary forest and total transect length
Rainfall	Quantity of rain (mm) during the month of data collection on each transect