CONVENTION ON INTERNATIONAL TRADE IN ENDANGERED SPECIES
OF WILD FAUNA AND FLORA

Fifteenth meeting of the Conference of the Parties
Doha (Qatar), 13-25 March 2010

Monitoring of illegal hunting in elephant range States

TRENDS AND FACTORS ASSOCIATED WITH THE ILLEGAL KILLING OF ELEPHANTS

This document has been submitted by the MIKE Central Coordination Unit of the Secretariat.

TRENDS AND FACTORS ASSOCIATED WITH THE ILLEGAL KILLING OF ELEPHANTS

R.W. Burn, F.M Underwood and J.J. Blanc

Introduction

The system known as Monitoring the Illegal Killing of Elephants (MIKE) aims to measure and record the levels and trends of illegal killing of elephants, as well as to assess the extent to which such trends are related to changes in the listing of elephant populations in the CITES appendices or the resumption of legal international trade in ivory (COP 10.10 Rev COP 14). A preliminary baseline analysis of factors influencing levels of illegal killing of elephants was presented to the CITES Standing Committee at its 55th Meeting (SC55 Doc. 10.2 Rev 1). This document presents a more refined and updated analysis of carcass data, as well as information on trends in the proportion of illegally killed elephants in MIKE sites since 2002, when the implementation of the MIKE programme began.

Data

The data consist of 6,566 carcasses of elephants that died between 2002 and 2009 in 70 MIKE sites in 38 range States in Africa and Asia (Annex). The response variable analysed was the proportion of illegally killed elephants (PIKE), defined for every year and every site as the number of illegally killed elephants encountered divided by the total numbers of carcasses found. Year of death was assigned to every carcass using standard carcass ageing criteria, based on Douglas-Hamilton and Hillman (1981) and endorsed by the MIKE Technical Advisory Group. Site-year combinations where zero or no carcasses were reported were excluded from the analysis, as PIKE cannot be calculated in such cases.

Potential influencing factors (covariates)

In order to derive unbiased trends in levels in the illegal killing of elephants, it is necessary to correct for any influencing factors (we refer to them as “covariates”) that may bias the data and thereby the trends derived from them. The MIKE baseline analysis examined 29 potentially associated factors, and identified 5 factors that strongly correlated with levels of illegal killing. These included ecosystem type, actual levels of protection, ease of human access and the Corruption Perceptions Index (CPI) produced by Transparency International. With the exception of the CPI, all of these factors were categorical variables scored by experts. For the present analysis, more refined measures of these variables were sought, both at the country and site levels. These are described in turn below.

Country-level covariates

Previous analyses (see e.g. SC55 Doc 10.2 (Rev. 1)) suggested that the level of corruption, as measured by the Corruption Perceptions Index (CPI) of Transparency International (2009), is an important predictor of elephant poaching. It is possible, however, that it is not corruption *per se* that drives poaching, but rather that CPI is in fact a proxy variable for a broader range of phenomena related to governance. With this in mind, additional variables on various dimensions of governance were explored. These were obtained from the World Bank’s *World Governance Indicators (WGI)* project (World Bank, 2009). Definitions of the governance indicators and methodologies used in deriving them are explained in both the World Bank and Transparency International websites.

Other country characteristics, aside from governance, were also investigated. These variables were indicators of various aspects of development and economy that are compiled mainly by the United Nations Development Programme (UNDP) and most are available from the United Nations Statistics Division (UNSD). The Human Development Index (HDI) is a composite index comprising life expectancy, educational attainment and income. Finally, a measure of domestic ivory market activity obtained from the Elephant Trade Information System (ETIS) was included as a covariate (CITES, 2007). The country-level covariates that were examined in the analysis are summarised in Table 1.

Table 1. Country-level covariates explored in the analysis.

Name	Description	Source
cc	Control of corruption	World Bank
ge	Government effectiveness	World Bank
ps	Political stability and absence of violence	World Bank
rl	Rule of law	World Bank
rq	Regulatory quality	World Bank
va	Voice and accountability	World Bank
cpi	Corruption perceptions index	Transparency International
gdp	Gross domestic product per capita	UNDP
popgth	Annual population growth rate	UNSD
oda	Overseas development aid per capita	UNSD
edu	Educational attainment	UNDP
lifeexp	Human life expectancy	UNDP
hdi	Human development index	UNDP
mktscor	Index of domestic ivory markets	ETIS

Relationships among the country-level covariates for the elephant range States were explored using a principal components analysis (PCA) (Legendre and Legendre, 1998). The first two components in the PCA accounted for 70.8% of the variation among the 14 variables (50.8% for the first component and 20.0% for the second). A biplot (Legendre and Legendre, 1998) for the first two components is shown in Figure 1.

A biplot represents both the data points (countries) and the variables plotted together in the space of the first two principal components (the directions of the axes are arbitrary). The angle between two variables is related to the correlation between them, with small angles indicating high correlation. A right angle suggests no correlation and two variables pointing in opposite directions means that they are negatively correlated. The angles between a variable and one of the axes indicate the degree the contribution of the variable to that particular component. The positions of the data points help visualise the relative scores of the countries with respect to the variables. In interpreting a biplot, it is important to remember that it represents the variation explained by the first two principal components only. In this case, therefore, the biplot accounts for 70.8% of the total variation.

Clear groupings of variables are apparent from the biplot. First, the World Governance Indicators *cc, rq, ps, rl and ge,* together with Transparency International's *cpi*, form a group with *va* somewhat less strongly associated. The next obvious group is *hdi, edu, lifeexp* and *popgth* (the latter negatively associated). It is not surprising that *edu* and *lifeexp* cluster together with *hdi*, given that the latter is a composite index incorporating the others. These two groups appear to represent *governance* and *development*.

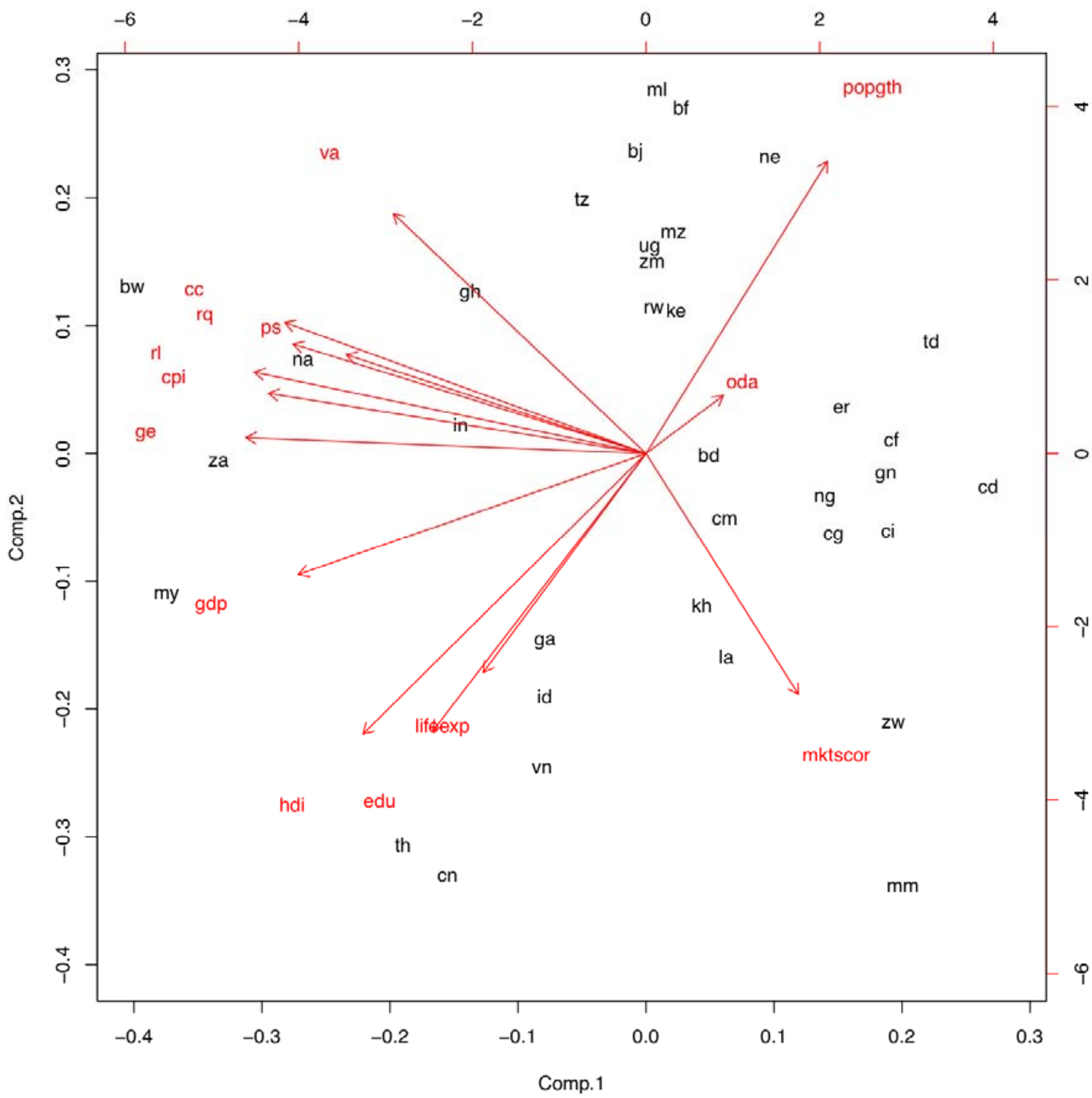

Figure 1. Biplot from the PCA of the 14 country-level variables explored. Country codes can be found in the Annex.

The economic indicator *gdp*, which is also a component of *hdi*, seems to be, together with *oda,* partially associated with both of these groups. The domestic ivory market score, *mktscor*, seems to be more or less unrelated to both of the main groups.

<u>Site-level covariates</u>

For most sites, size of the site (*area*) and its estimated elephant population (*est*) were obtained from the IUCN African Elephant Status Report 2007 (Blanc *et al.* 2007). More recent survey estimates and Asian estimates were directly obtained from range State Governments and MIKE-sponsored surveys.

Earlier analyses were based on a binary classification of ecosystem type as forest or savannah. In the present analysis this has been replaced by a more refined, continuous variable, *npp*, which is the net primary production at the site, defined as the net amount of solar energy converted to plant organic matter through photosynthesis (in units of elemental carbon). Higher values of *npp* indicate greater vegetation cover. Data for this variable was obtained by overlaying MIKE site boundaries with the spatial data set developed by Imhoff et al. (2004) and calculating the average *npp* values therein.

Previous analyses also found significant relationships between the level of illegal killing and categorical variables representing ease of human access and land use type. For this analysis, the Human Footprint

Version 2 dataset (WCS & CIESIN 2005) was used instead. The Human Footprint (*ftprint*) is a normalized spatial dataset created from nine global data layers covering human population pressure (population density and population settlements), human land use and infrastructure (built up areas, night-time lights, land use/land cover), and human access (coastlines, roads, railroads, navigable rivers). This variable can therefore be considered to encompass the factors associated with human presence in the MIKE baseline analysis.

A variable representing human population pressure (*people*) was obtained from the Landscan data set (ORNL 2006). The LandScan dataset comprises a worldwide population database compiled on a 30" X 30" latitude/longitude grid. Census counts (at sub-national level) are apportioned to each grid cell based on likelihood coefficients, which are based on proximity to roads, slope, land cover, night time lights, and other information.

Data for *ftprint* and *people* were obtained by overlaying the source datasets with boundaries comprising the MIKE sites and a 20 km buffer around each one of them. The values used for analysis were calculated as the average value of all the grid cells contained within these boundaries.

Another significant factor in the baseline analysis, namely the actual level of protection, was estimated by the “Probable Fraction” (*pf1*). The Probable Fraction is a measure of the quality of elephant population surveys in terms of the precision of their estimates (Blanc *et al.* 2007). The precision of an elephant population estimate depends on a number of factors, such as the available budget, the capacity, motivation and experience of survey teams, and the appropriateness of the chosen survey method in relation to prevailing habitat and elephant density. As these factors are related to the amount of effort devoted by countries to conserve their elephant populations, it was regarded as a reasonable proxy for conservation effort.

The site-level variables are summarised in Table 2.

As with country variables, PCA was used to explore relationships between site variables. The variables *area*, *est*, *dens* and *people* all had positively skew distributions and were therefore replaced by their natural logarithms for the PCA. The first two components of a PCA of the seven site variables accounted for 63.9% of the total variation (44.9% for the first component and 19.0% for the second), and the resulting biplot is shown in Figure 2. Note that *ftprint* and *people* appear to be strongly correlated and that *area* is negatively correlated with both of them. It turns out that most of the *npp* effect is taken up by the third principal component, which accounts for 18.7% of the variation, and therefore appears quite weak in the plot of the first two components. This fact could also explain why, in the biplot, *npp* appears to be highly correlated with *dens*, whereas in fact it there is no correlation.

Table 2. Site-level covariates explored in the analysis

Name	Description	Source
area	Area of site (km^2)	AED
est	Estimated size of elephant population	AED & elephant surveys
dens	Estimated elephant density	Derived
npp	Net primary production (see text)	Imhoff et al, 2004 - CIESIN
people	Human population density	ORNL, 2006
ftprint	Human footprint (see text)	WCS & CIESIN, 2002
pf1	Probable fraction (see text)	AED & elephant surveys

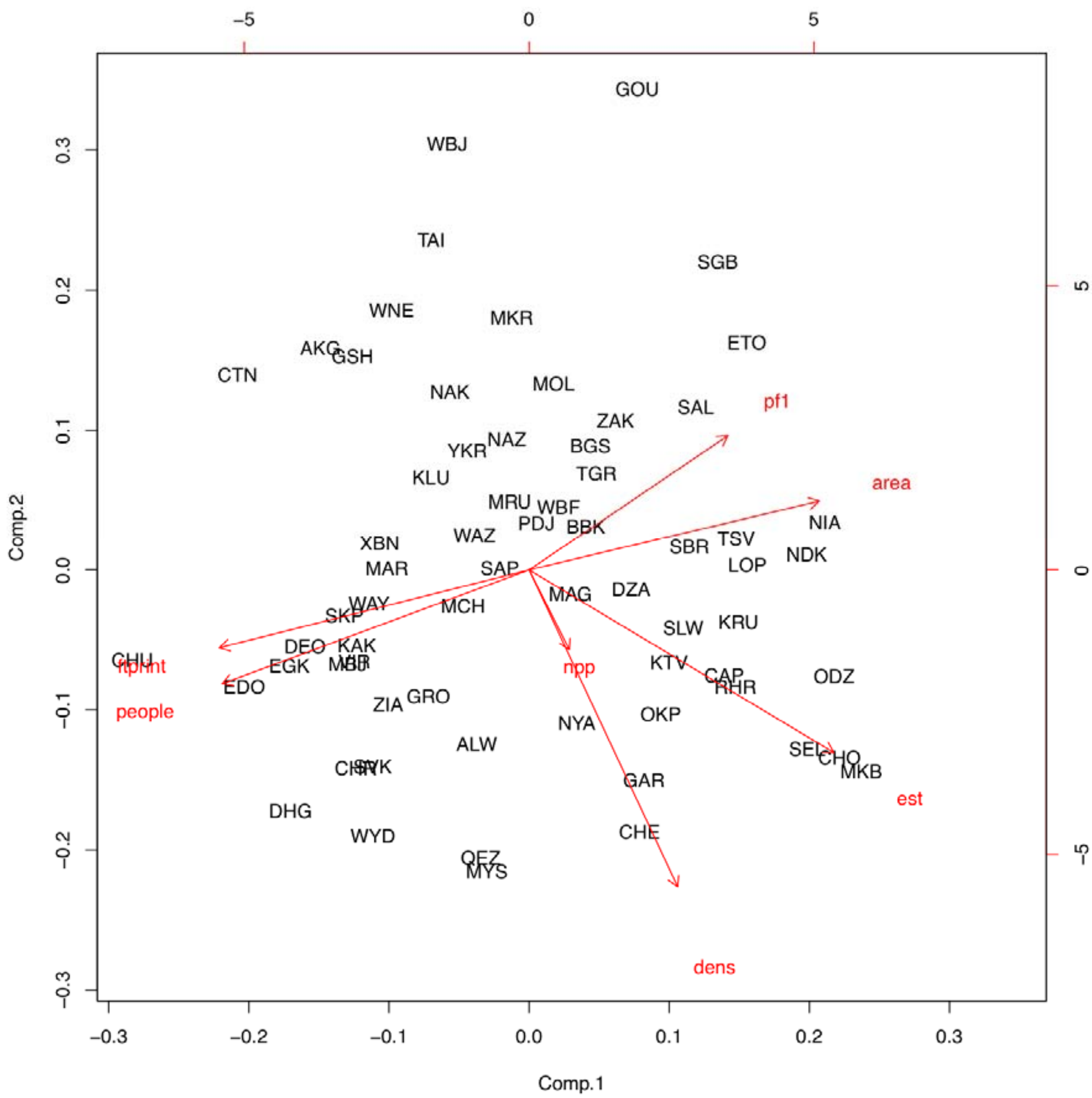

Figure 2. Biplot from the PCA of the 7 site-level variables explored. Site codes can be found in the Annex.

Analysis Methods

Data Structure

The data available for this analysis are total yearly counts of elephant carcasses encountered by patrols or other means at MIKE sites, and the numbers of these carcasses that were judged to be illegally killed. The data have a three-level hierarchical structure with countries as level 3, sites within countries as level 2 and repeated (yearly) observations within sites at level 1. There are covariates at each level of the hierarchy. At country and site levels they are the variables described above, and at level 1 *Year* is a covariate. The hierarchical structure of the data is illustrated in Figure 3.

The response variable was the number of carcasses that were judged to have been illegally killed for each site in each year. This was modelled as having a binomial distribution $Bin(n,\theta)$, where n is the total number of carcasses encountered in that year at the site, and θ is the probability that a carcass was illegally killed, estimated by *PIKE* as the proportion of carcasses that were illegally killed.

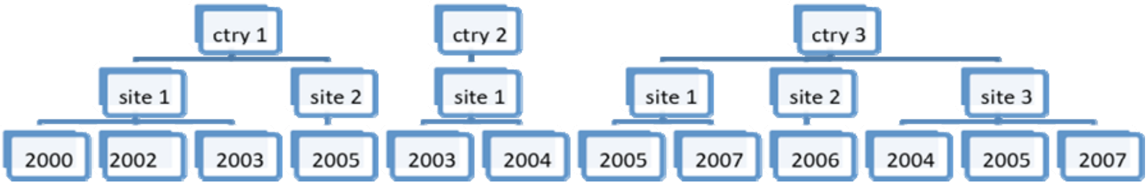

Figure 3. Structure of the data used in the present analysis.

Statistical Models

The main statistical tool for analysing *PIKE* was binomial logistic regression, a special case of generalised linear models (GLMs) (Dobson & Barnett, 2008). Given the hierarchical structure of the data, hierarchical models were used with random effects to represent countries and sites within countries. With random effects, the GLMs become generalised linear mixed models (GLMMs) (Gelman & Hill, 2007). Although adding to the complexity of the analysis, using hierarchical models is important for two reasons (Goldstein, 2003). First, ignoring the multilevel structure amounts to assuming that all observations are mutually uncorrelated with each other, both within and between sites and countries. This is a strong assumption and is unlikely to be even approximately true: observations at the same site are likely to be more similar than observations from different sites. The second reason is that in a conventional single level GLM that includes a site-level explanatory variable, it is implicitly assumed that *all* of the site variation is accounted for by that variable, thus increasing the chance of inferring a significant association when in fact there is none. In a hierarchical model, mean differences between sites (and countries) are accounted for by the random effects, and if a site-level (or country-level) explanatory variable turns out to be significant then the effect can be interpreted as additional to the overall site (or country) differences.

Random effects to represent the site/country hierarchical structure were included in all models, and site- and country-level covariates were fitted as fixed effects (see Gelman and Hill (2004) for explanations of fixed and random effects). Because of the known difficulties with significance tests for fixed effects in hierarchical models (Pinheiro & Bates, 2000), and also to take full account of all sources of uncertainty in the data (although see Discussion below), models for estimating the effects of site- and country-level covariates were fitted in a Bayesian framework (Gelman et al, 2004) with non-informative priors for all model parameters. Statistical computations were performed using the R software (R Development Core Team, 2009), while WinBUGS (Spiegelhalter et al, 2005) was used for the Bayesian computations. The general form of the fitted models is described below.

Notation:

n_{ijk} = number of carcasses found in year $i = 2002,\ldots,2009, site_j = 1,\ldots m_k$, country k.

y_{ijk} = number of illegally killed carcasses encountered, $0 \le y_{ijk} \le n_{ijk}$

θ_{ijk} probability that a carcass was illegally killed (the *PIKE* parameter)

General form of fitted model:

$$y_{ijk} \sim Binomial(\theta_{ijk}, n_{ijk})$$

$$logit(\theta_{ijk}) = \mu + poly(year_i, p) + u_{jk} + v_k + \beta_1 x_{1jk} + \beta_2 x_{2jk} + \ldots$$

where $logit(\theta_{ijk}) = \ln\left(\dfrac{\theta_{ijk}}{1-\theta_{ijk}}\right)$

$poly(year_i, p)$ is a polynomial function (of order p) of *year*;

$u_{jk} \sim N(0,\sigma_u^2)$ and $v_k \sim N(0,\sigma_v^2)$ are site- and country-level random effects;

and $x_{1jk}, x_{2jk}, \ldots$ are site- and country-level covariates (explanatory variables).

The time trend terms were first fitted and retained in the model. Using orthogonal polynomials, the best fitting order was determined. Taking this model as a baseline, a kind of iterative manual stepwise procedure was adopted, first for the site-level variables, and then for the country-level variables, and then repeating the process while retaining the variables that appear to be important. AIC (Akaike information criterion) was used to assess model adequacy (Burnham & Anderson, 2002). Because of the correlations that were found between some of the covariates, it was thought likely that potentially important causal factors could be missed by finishing up with a single set of covariates as the "best" fitting model. The conclusions of the analysis were therefore based on several models, in the spirit of the multi-model inference proposed by Burnham and Anderson (2002); their AIC weights w_i were computed as a measure of the relative importance of the fitted models. Note that $0 \le w_i \le 1$.

The fitted Bayesian models were used to predict associations of covariates with the response variable *PIKE*.

Results

Model Selection

Random effects for countries and sites within countries were fitted and retained in all subsequent models (AIC = 1199.5).

A fifth-order polynomial was found to fit the data well (the AIC dropping to 1062.2). Averaging the effects of other covariates, the time trend is as shown in Figure 4. The time trend effect was retained in all further models.

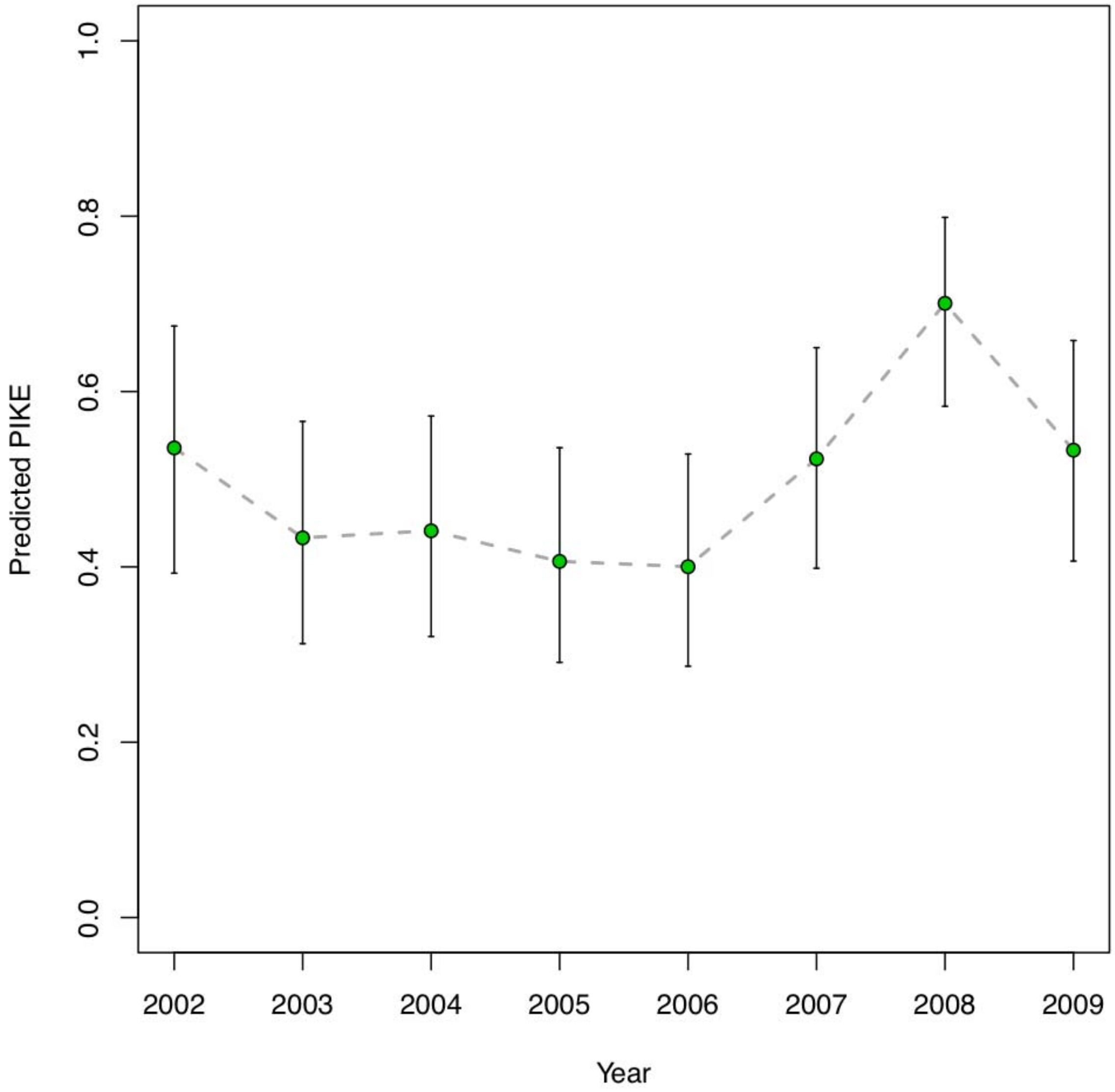

Figure 4. Trend through time (with 95% interval). All covariates other than Year set to mean value and iPop=0.

The human population density site-level variable *people* was problematic in that its distribution was very skew, with a small number of sites with very high density. Furthermore, these sites, although they had very low numbers of carcasses, were found to have a very high influence on the fitted models. The variable was therefore replaced by a binary categorical variable *iPop* defined as

$$iPop = \begin{cases} 1, people > 100 \\ 0, people \leq 100 \end{cases}$$

Of the 66 sites in the study, 15 were in the high population density group $(iPop = 1)$.

In addition to (a) the random effects for countries and for sites within countries, and (b) the polynomial time trend terms, the variables that were found to be important were *npp*, *iPop* and log*(area)* at site level, and *ge* and *hdi* at country level. Table 3 summarises the fit, in terms of AIC and AIC weights, of all fitted models containing these covariates. The models are listed in order of decreasing AIC, not the order of fitting.

Table 3. Fixed effects terms of fitted models. All models have random effects for countries and sites within countries. The w_i column shows the AIC weights and p(year,5) is the polynomial of order 5 for the year effect.

Model, *i*	Fixed effects	AIC_i	w_i
1	none	1199.5	0.0000
2	p(*year*,5)	1062.2	0.0000
3	p(*year*,5) + *npp*	1051.1	0.0000
4	p(*year*,5) + *npp* + *hdi*	1044.2	0.0000
5	p(year,5) + *npp* + *iPop**log(*area*)	1039.4	0.0002
6	p(*year*,5) + *npp* + *ge* + *hdi*	1033.7	0.0036
7	p(*year*,5) + *npp* + *ge* +log(*area*)	1033.5	0.0040
8	p(*year*,5) + *npp* + *ge*	1033.4	0.0042
9	p(*year*,5) + *npp* + *ge* + *iPop**log(*area*)	1024.9	0.2958
10	p(*year*,5) + *npp* + *hdi* + *iPop**log(*area*)	1023.2	0.6921

It is apparent from Table 3 that *npp* is the most important site-level covariate and that the effect of log(*area*) overall is negligible (comparing Models 7 and 8). The *area* effect becomes large, however, when considered separately for each level of *iPop* (i.e. the *iPop* x log(*area*) interaction causes a substantial drop in AIC).

The inference for country-level covariates is less clear. Both *ge* and *hdi* have quite large effects, but the inclusion of either one of them in the model makes the other redundant. The relationship between these variables was noted in the biplot (Figure 1) of the PCA for country-level variables (the correlation between them is in fact 0.64), so it is not surprising that they partially annihilate each other in fitted models. This ambivalence can be resolved by allowing multi-model inference. To quote from Burnham and Anderson (2002, p.80):

> *It is perfectly reasonable that several models would serve nearly equally well in approximating the information in a set of data. Inference must admit that there are sometimes competing models and the data do not support selecting only one.*

Although Model 10 was the best fit according to AIC, Models 9 and 10 between them have total AIC weight of 0.99. We therefore conclude that that data provide evidence that supports both *ge* and *hdi* as having an effect.

It should be noted that with mixed models, such as we have here, there are difficulties with the usual definition of AIC (Burnham & Anderson, 2002). Although the AIC values in Table 3 can probably serve as a rough guide to model selection, more reliable inferences about particular model parameters are obtained from credible intervals in the Bayesian analysis, shown in Table 4.

<u>Site- and Country-level Covariates</u>

Bayesian interval estimates of the model parameters in Models 9 and 10 are shown in Tables 4 and 5, respectively.

Table 4: Estimates of parameters in fitted Model 9 (AIC = 1024.9) – posterior means and credible intervals.

Model term		Posterior mean	Lower 2.5% limit	Upper 97.5% limit
p(*year*,5)	linear	3.94	2.72	5.17
	quadratic	2.50	1.20	3.80
	cubic	-3.22	-4.47	-1.96
	quartic	-3.33	-4.54	-2.13

	Model term	Posterior mean	Lower 2.5% limit	Upper 97.5% limit
	quintic	-2.86	-4.07	-1.65
Site-level	*npp*	0.64	0.25	1.06
	iPop	-0.75	-2.09	0.60
	log*(area) (iPop* lo*)*	-0.68	-1.14	-0.23
	log*(area) (iPop* hi*)*	0.61	-0.49	1.77
	Variance (σ_u^2)	1.17	0.54	2.19
Country-level	*ge*	-0.98	-1.52	-0.49
	Variance (σ_v^2)	0.64	0.01	1.86

Table 5. Estimates of parameters in fitted Model 10 (AIC = 1023.2) – posterior means and credible intervals.

	Model term	Posterior mean	Lower 2.5% limit	Upper 97.5% limit
p(*year*,5)	linear	3.95	2.75	5.17
	quadratic	2.47	1.20	3.75
	cubic	-3.24	-4.48	-1.99
	quartic	-3.31	-4.51	-2.12
	quintic	-2.83	-4.04	-1.61
Site-level	*npp*	0.89	0.52	1.28
	iPop	-0.98	-2.33	0.37
	log*(area) (iPop* lo*)*	-0.90	-1.37	-0.46
	log*(area) (iPop* hi*)*	0.53	-0.59	1.73
	Variance (σ_u^2)	1.27	0.62	2.28
Country-level	*hdi*	-1.10	-1.63	-0.60
	Variance (σ_v^2)	0.37	0.00	1.38

The 95% credible intervals that do not contain zero are regarded as indicating ‘significant’ effects (except for variance estimates, which always have non-negative interval end points). An interval with zero inside but very close to the end point can be regarded as marginally important.

The estimated parameter values indicate that:

1. The parameter estimates for the fifth order polynomial time trend all have credible intervals that are well clear of zero, and so can be regarded as ‘significant’.
2. Sites with higher *npp* tend to have higher *PIKE* – suggesting a greater rate of poaching in forest sites than in savannah sites. Figure 5(a) shows this effect.
3. Overall, the effect of human population density (*iPop*) seems to be small (the credible interval straddles zero), but it is important when considering the *area* effect.
4. At sites with low human population density (*iPop* = lo), there is quite strong evidence that large sites (as measured by log(*area*)) tend to have lower *PIKE* than smaller ones. The estimated relationship is shown in Figure 5(b).
5. On the other hand there is no evidence of an *area* effect at sites with high human population density (*iPop* = hi).
6. There is clear evidence that governance, as measured by the *ge* (government effectiveness) variable, has a strong negative relationship to *PIKE* – i.e. *PIKE* tends to be lower in countries with good governance. This effect is shown graphically in Figure 5(c).

7. It appears that there is more "unexplained" variability (i.e not accounted for by the covariates) between sites within countries than between countries.

Model 10 is a slightly better fit than Model 9; the difference between the two models is that *ge* is replaced by *hdi*. Conclusions that can be drawn from these estimates, additional to those above, are:

1. The parameter estimates for the polynomial time trend are virtually the same as in Model 9.
2. The model provides clear evidence of an *hdi* effect – higher levels of development tend to be associated with lower values of *PIKE*. This relationship is shown in Figure 5(d).
3. Although the estimates for the site-level parameters are numerically somewhat different from those of Model 9, the overall conclusions remain unchanged.

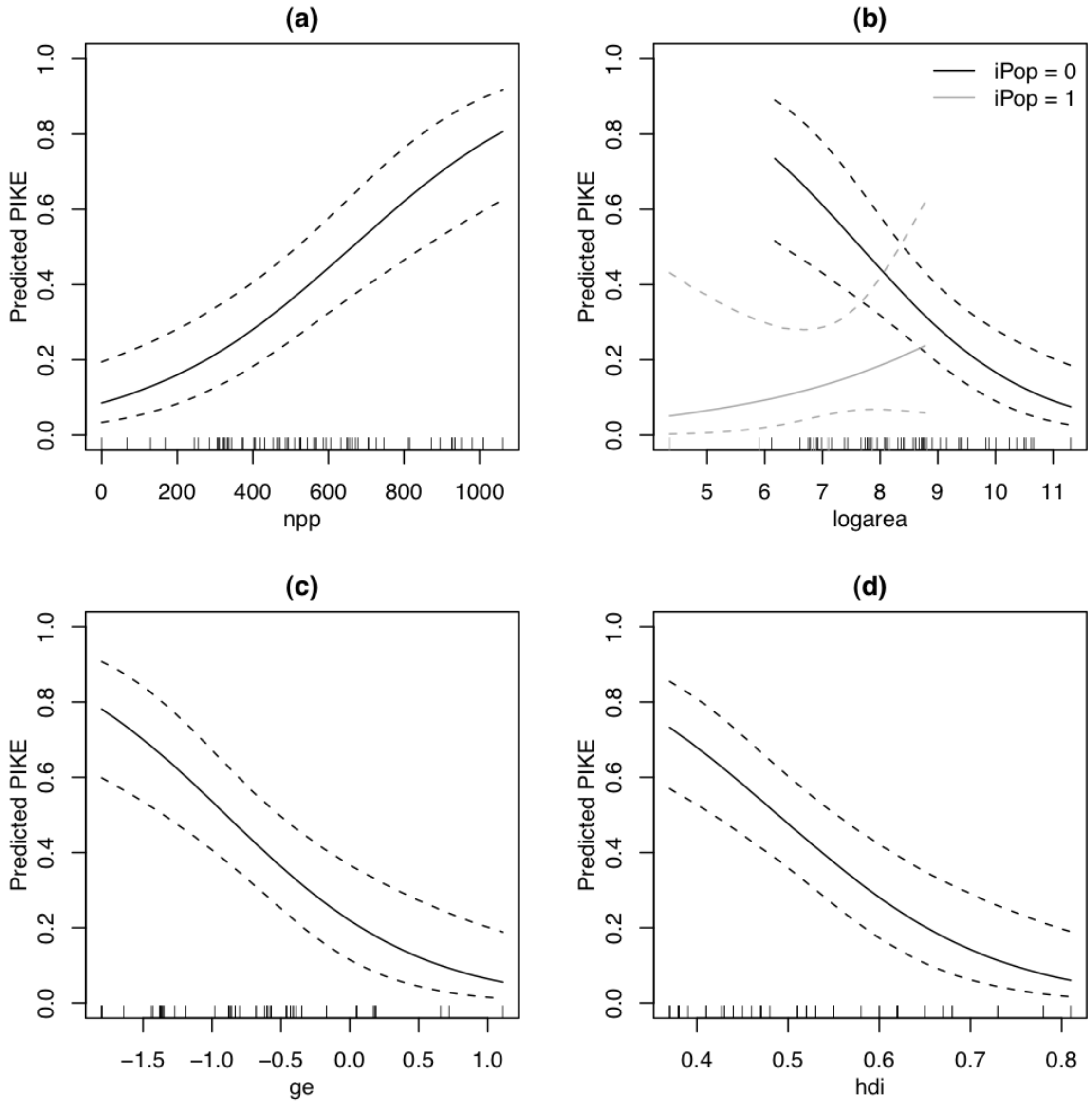

Figure 5. Predicted PIKE for varying (a) npp (b) logarea (c) ge and (d) hdi with 95% intervals. All other covariates set to mean, iPop=0 unless shown and Year = 2006. Rug plot at bottom of each graph shows data values for the relevant variable.

Individual random effects at site and country levels are shown, with 95% credible intervals, in Figures 6 and 7, respectively. These effects were computed from Model 10. Care is needed in the interpretation of these graphs. The random effect of a given site represents the residual, or the difference between measured and predicted values, *having accounted for the effects of the covariates* in the model. Put another way, the fitted model may predict a certain *PIKE*, and the random effect is the estimated residual amount by which that particular site deviates (above or below) that predicted value. Similar remarks apply to country random effects.

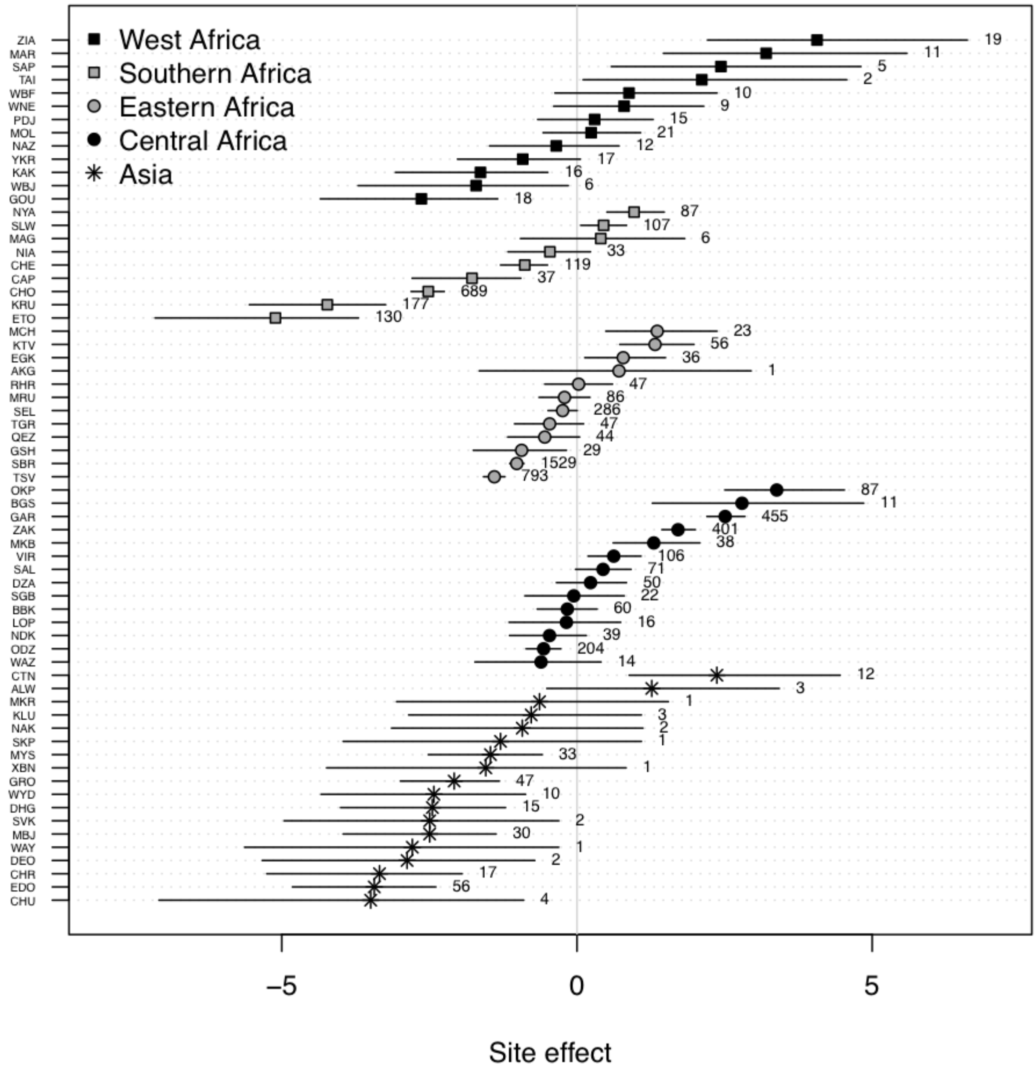

Figure 6. Site effects. Predicted median and 95% interval

The predicted *PIKE* values for 2009 are shown in Figure 8. What is meant by “predicted” here is that these values represent *PIKE* as estimated from the fitted model (Model 10). The random effects are the components of the deviation of the actual data from these estimates at site and country levels.

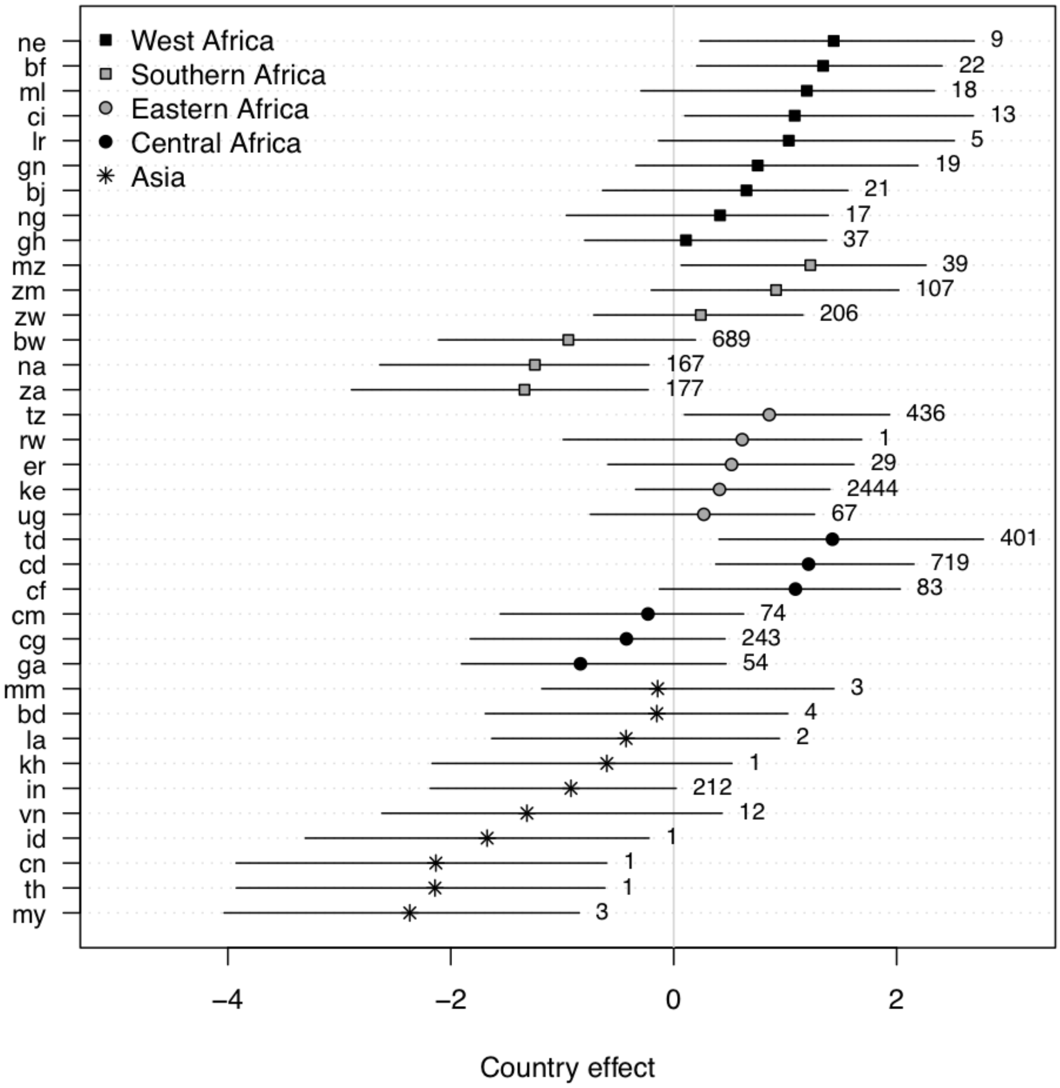

Figure 7. Country effects. Predicted median and 95% interval

It may seem strange to see estimates based on just one carcass at some sites. However, it should be borne in mind that a result of fitting hierarchical models is that there is a certain amount of sharing, or pooling of information across sites (and countries). The effect of this is that a mean at a site with few observations is a weighted mean of observations at that site together with observations from other sites. In any case, the wide credible intervals for these estimates reflect the uncertainty arising from small samples.

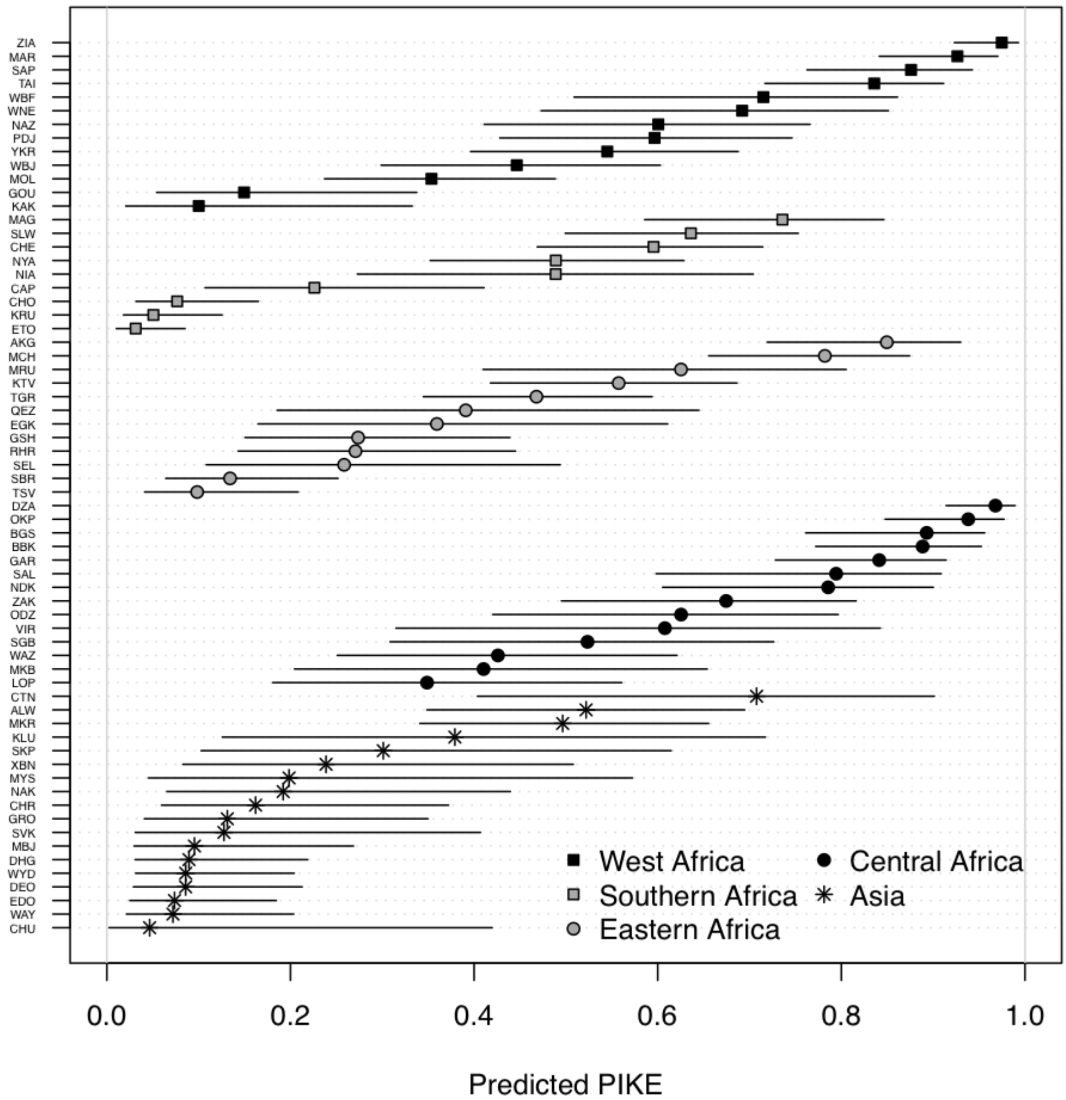

Figure 8. Predicted PIKE for 2009. Predicted mean and 95% interval.

Discussion

There are a number of potential weaknesses with the analysis presented here.

1. The rationale for the use of *PIKE* as a response variable is as follows. Analysis of carcass count data collected by patrols would normally need to account for patrol effort, measured by, for instance, distance or length of time covered by patrols, or some other indicator. In other words, some sort of catch-effort modelling would be appropriate. Using the *PIKE* response circumvents this problem by assuming that the effort measure would occur in both numerator and denominator of the ratio defining PIKE and would thus cancel out. An implicit assumption is that, for a particular patrol, the detection probability of all carcasses is the same. This is unlikely to be true. Patrol routes may not cover the area randomly, in particular when the patrols use informants to provide intelligence that can guide them to carcasses of illegally killed elephants. A particular reason why *PIKE* may be a biased indicator of poaching occurs at sites where the current elephant population is recovering from some previous very high poaching pressure. An example of this is the Queen Elizabeth site in Uganda (Andy Plumptre, *pers. comm.*). It is then likely that the age

structure of the population is skewed so that there are unusually few older animals, so that natural mortality is lower than normal. This would nevertheless tend to bias PIKE towards overestimating levels of poaching, i.e. in a conservative direction.

2. The models fitted in the analysis were binomial logistic regression models. For the binomial distribution to be valid, the *n* parameter should be a fixed (i.e. known) number. In practice this is never true. The number of carcasses encountered by a patrol is a random variable and is not fixed. It should have its own probability distribution but this is ignored in the above analysis. It is possible to fit statistical models that account for the random variability in *n*, but this would require a measure of patrol effort, the lack of which motivated the choice of *PIKE* in the first place. The present analysis probably underestimates the uncertainty in the data by an unknown amount. With this in mind, PIKE is not strictly an estimate of the rate of poaching, but simply the proportion of encountered carcasses that happen to have been killed illegally. In the absence of further information, however, we take it to be a proxy relative indicator for poaching rates and assume that it is reasonable to use it for the purpose of making comparisons.

3. A further limitation is that the analysis is based on site *x* year totals, and not on data from individual patrols. This is problematic for two reasons:

    i) Patrol-level data would be necessary for the type of analysis outlined in 2 above;

    ii) It is well-known that erroneous conclusions can be drawn by attempting to deduce facts about the behaviour of individual units (patrols in this case) from data on groups of units only. This is a case of “Simpson’s paradox” (Blyth, 1972), or the similar problem known as “the ecological fallacy” (Robinson, 1950).

In spite of these caveats, and given the limitations of the available data, the analysis presented here should provide a reasonably good picture of trends in illegal killing of elephants, and the factors associated with it.

Care is needed in interpreting the findings of this analysis. To infer from the data that there is an *association* between, say, governance and elephant poaching is not to claim a *causal* relationship. While there may well be reasons for believing that a causal relationship exists, analysis of the data available for this study tells us nothing about the underlying causal processes and mechanisms that drive effective law enforcement and compliance (Keane et al, 2008). Put another way, although we can say that governance and human development are *correlates* of illegal activity, without knowledge of the underlying processes, it is difficult to claim that they are *drivers* of that activity. While awaiting more detailed evidence of these processes to be assembled, however, we do have enough belief in our models to claim that if human intervention can bring about improvements in governance and development, then we would expect a corresponding reduction in the rate of elephant poaching.

References

Blanc, J.J., R.F.W. Barnes, C.G. Craig, H.T. Dublin, C.R. Thouless, I. Douglas-Hamilton and J.A. Hart. 2007. *African elephant status report 2007: an update from the African Elephant Database*. Gland: IUCN.

Blyth C.R. (1972). On Simpson’s paradox and the sure-thing principle. *Journal of the American Statistical Association* **67** (338): 364-366.

Burnham K.P. and Anderson D.R. (2002). *Model Selection and Multimodel Inference (Second Edition).* New York: Springer-Verlag.

Dobson, A.J. and Barnett, A.G. (2008). *An Introduction to Generalized Linear Models, Third edition.* Chapman & Hall/CRC.

Gelman A., Carlin J.B., Stern H.B., Rubin D.B. (2004). *Bayesian Data Analysis, Second Edition*. Chapman & Hall/CRC.

Gelman A. and Hill J. (2007). *Data Analysis Using Regression and Multilevel/Hierarchical Models*. Cambridge.

Goldstein H. (2003). *Multilevel Statistical Models, Second Edition.* Arnold.

Imhoff, M. L., L. Bounoua, T. Ricketts, C. Loucks, R. Harriss, and W.T. Lawrence. (2004). *Global Patterns in Net Primary Productivity (NPP). Data distributed by the Socioeconomic Data and Applications Center (SEDAC)*: http://sedac.ciesin.columbia.edu/es/hanpp.html. Downloaded July 2009.

Keane A., Jones J.P.G., Edwards-Jones G., Milner-Gulland E.J. (2008). The sleeping policeman: understanding issues of enforcement and compliance in conservation. *Animal Conservation* 11: 75-82.

Legendre P. and Legendre L. (1998). *Numerical Ecology (Second English Edition)*. Elsevier.

Milliken T., Burn R.W., Sangalakula L. (2007*). The Elephant Trade Information System (ETIS) and the Illicit Trade in Ivory: a Report for the 14th Meeting of the Conference of the Parties to CITES.* URL: http://www.cites.org/eng/cop/14/doc/E14-53-2.pdf

Pinheiro J.C. and Bates D.M. (2000). *Mixed-Effects Models in S and S-PLUS.* Springer-Verlag, New York.

R Development Core Team (2009). *R: A language and environment for statistical computing.* R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org.

Robinson W.S. (1950). Ecological correlations and the behaviour of individuals. *American Sociological Review* **15** (3): 351-357.

Spiegelhalter D.J., Thomas A., Best N., Lunn D. (2005). *WinBUGS User Manual, Version 2.10*. Cambridge: MRC Biostatistics Unit.

Transparency International (2009). *Corruption Perceptions Index 2009*. URL: http://www.transparency.org/policy_research/surveys_indices/cpi/2009

Wildlife Conservation Society (WCS) and Center for International Earth Science Information Network (CIESIN) (2005). *Last of the Wild Data, Version 2: Global Human Footprint data set (HF)*. http://sedac.ciesin.columbia.edu/wildareas/.

World Bank (2009). *Governance Matters 2009*. http://info.worldbank.org/governance/wgi/

Proportion of illegally killed elephants (PIKE) and total numbers of carcasses encountered (in brackets) for each site-year combination. Blanks reflect site-year combinations for which no carcass reports were received. Where zero carcasses were reported, "- (0)" is shown.

Sub-Region	Country	Site	2002	2003	2004	2005	2006	2007	2008	2009
Central Africa	Cameroon (cm)	Boumba-Bek (BBK)	0.00 (5)	0.68 (19)	0.71 (7)	1.00 (3)	0.00 (12)	0.00 (1)	0.00 (1)	0.25 (12)
		Waza (WAZ)		0.33 (3)	0.50 (2)	0.50 (2)	0.33 (3)	0.00 (1)	0.00 (2)	1.00 (1)
	Central African Republic (cf)	Bangassou (BGS)		1.00 (3)	1.00 (8)					
		Dzanga-Sangha (DZA)		- (0)	- (0)	0.89 (9)	0.50 (2)	0.50 (2)	0.63 (27)	0.30 (10)
		Sangba (SGB)	- (0)	0.10 (10)	0.00 (1)	- (0)	- (0)	- (0)	1.00 (8)	1.00 (3)
	Chad (td)	Zakouma (ZAK)		0.65 (34)	0.86 (35)	0.27 (11)	0.67 (60)	0.97 (160)	0.94 (86)	0.80 (15)
	Congo (cg)	Nouabale-Ndoki (NDK)		0.63 (8)	0.29 (14)	0.75 (4)	0.00 (5)	0.00 (1)	0.25 (4)	0.00 (3)
		Odzala (ODZ)		0.05 (38)	0.53 (36)	0.00 (73)	0.00 (1)	0.97 (36)	0.53 (17)	1.00 (3)
	Democratic Republic of Congo (cd)	Garamba (GAR)		0.96 (114)	0.89 (197)	0.90 (86)	0.94 (34)	0.50 (14)	1.00 (4)	1.00 (6)
		Kahuzi-Biega (KHB)		- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
		Okapi (OKP)		1.00 (20)	0.90 (10)	0.95 (22)	1.00 (5)	1.00 (11)	0.67 (3)	1.00 (16)
		Salonga (SAL)		0.00 (2)	0.64 (56)	0.25 (4)	- (0)	- (0)	- (0)	0.22 (9)
		Virunga (VIR)		- (0)	- (0)	0.44 (9)	0.33 (3)	0.00 (15)	1.00 (63)	0.69 (16)
	Gabon (ga)	Lopé (LOP)		0.57 (7)	0.25 (4)	- (0)	0.00 (1)	- (0)	0.00 (1)	0.67 (3)
		Minkébé (MKB)		0.73 (11)	0.92 (13)	0.50 (6)	- (0)	- (0)	1.00 (4)	0.75 (4)
Eastern Africa	Eritrea (er)	Gash-Setit (GSH)	0.00 (3)	0.33 (3)	0.00 (1)	- (0)	0.14 (7)	0.50 (4)	0.40 (5)	0.50 (6)
	Kenya (ke)	Meru (MRU)					0.50 (14)	0.27 (11)	0.38 (13)	0.54 (48)
		Mount Elgon (EGK)		0.86 (7)	0.71 (7)	0.00 (1)	0.40 (5)	0.50 (2)	0.50 (2)	0.83 (12)
		Samburu Laikipia (SBR)	0.38 (159)	0.18 (195)	0.31 (128)	0.17 (160)	0.14 (96)	0.24 (97)	0.51 (278)	0.26 (416)
		Tsavo (TSV)		0.22 (82)	0.29 (65)	0.28 (60)	0.17 (88)	0.20 (56)	0.33 (79)	0.17 (363)
	Rwanda (rw)	Akagera (AKG)			- (0)	- (0)	0.00 (1)	- (0)	- (0)	- (0)
	Uganda (ug)	Murchison Falls (MCH)	- (0)	1.00 (10)	0.50 (2)		1.00 (2)	0.50 (2)	0.50 (2)	0.60 (5)
		Queen Elizabeth (QEZ)	0.00 (3)	1.00 (1)	0.38 (8)	0.00 (1)	0.18 (11)	1.00 (4)	0.44 (9)	0.43 (7)
	Tanzania (tz)	Katavi (KTV)		0.75 (12)	0.75 (20)	0.50 (6)	1.00 (2)	1.00 (2)	1.00 (9)	0.80 (5)
		Ruaha Rungwa (RHR)		0.10 (10)	0.17 (6)	0.67 (15)	0.89 (9)	0.00 (2)	0.67 (3)	0.00 (2)
		Selous Mikumi (SEL)		0.22 (9)	0.18 (11)			0.42 (103)	0.59 (90)	0.67 (73)
		Tarangire (TGR)		0.14 (7)	0.00 (11)		0.25 (4)	0.20 (5)	0.40 (5)	0.87 (15)

Sub-Region	Country	Site	2002	2003	2004	2005	2006	2007	2008	2009
Southern Africa	Botswana (bw)	Chobe (CHO)	- (0)	0.00 (59)	0.07 (73)	0.05 (153)	0.10 (111)	0.14 (101)	0.04 (113)	0.18 (79)
	Mozambique (mz)	Cabora Bassa (MAG)	0.00 (1)	0.33 (3)	1.00 (2)					
		Niassa (NIA)			0.00 (14)		0.33 (3)		0.88 (16)	
	Namibia (na)	Caprivi (CAP)	0.00 (1)	0.25 (8)	0.00 (6)	0.25 (4)	0.40 (5)	0.00 (5)	- (0)	0.00 (8)
		Etosha (ETO)	0.00 (24)	0.00 (18)	0.00 (4)	0.00 (25)	0.00 (15)	0.00 (25)	0.00 (14)	0.00 (5)
	South Africa (za)	Kruger (KRU)	0.00 (1)	0.00 (2)	0.00 (18)	0.00 (35)	0.00 (51)	0.03 (34)	0.00 (18)	0.06 (18)
	Zambia (zm)	South Luangwa (SLW)	0.25 (4)	0.63 (8)	0.65 (23)	0.25 (4)	0.77 (35)	0.00 (11)	0.88 (8)	0.43 (14)
	Zimbabwe (zw)	Chewore (CHE)	0.37 (19)	0.30 (10)	0.21 (14)	0.00 (20)	0.12 (17)	0.79 (14)	0.08 (13)	0.58 (12)
		Nyami Nyami (NYA)	0.67 (3)	0.29 (7)	0.82 (11)	0.83 (6)	0.67 (3)	0.50 (10)	0.90 (20)	0.85 (27)
West Africa	Benin (bj)	Pendjari (PDJ)	0.00 (1)	0.50 (2)	0.33 (3)				0.00 (1)	0.88 (8)
		W du Bénin (WBJ)	0.00 (1)	0.00 (1)	0.00 (3)					0.00 (1)
	Burkina Faso (bf)	Nazinga (NAZ)	0.00 (1)	- (0)	0.00 (2)	0.00 (3)	0.00 (1)	- (0)	1.00 (4)	1.00 (1)
		W du Burkina (WBF)	0.00 (1)		0.00 (1)				1.00 (6)	1.00 (2)
	Côte D'Ivoire (ci)	Marahoué (MAR)						1.00 (8)	1.00 (1)	1.00 (2)
		Taï (TAI)			1.00 (2)					
	Ghana (gh)	Kakum (KAK)	0.50 (2)	0.00 (6)	0.00 (5)			0.00 (1)	1.00 (1)	1.00 (1)
		Mole (MOL)	0.00 (1)	0.50 (2)	0.25 (8)	1.00 (3)	- (0)	0.80 (5)	1.00 (2)	- (0)
	Guinea (gn)	Ziama (ZIA)	- (0)	1.00 (1)	1.00 (2)	- (0)	- (0)	1.00 (1)	1.00 (4)	1.00 (11)
	Liberia (lr)	Sapo (SAP)						1.00 (1)	1.00 (1)	1.00 (3)
	Mali (ml)	Gourma (GOU)	0.00 (3)	0.00 (1)	0.00 (1)	0.00 (2)	0.00 (3)	0.00 (2)	0.00 (2)	0.25 (4)
	Niger (ne)	W du Niger (WNE)	1.00 (1)	0.25 (4)	1.00 (2)	- (0)	- (0)	- (0)	- (0)	1.00 (2)
	Nigeria (ng)	Sambisa (SBS)		0.33 (3)	0.50 (2)					
		Yankari (YKR)	0.00 (6)	0.25 (4)	0.60 (5)	0.00 (2)			*	*
	Senegal (sn)	Niokolo-Koba (NKK)	- (0)	0.00 (1)						

Sub-Region	Country	Site	2002	2003	2004	2005	2006	2007	2008	2009
South Asia	Bangladesh (bd)	Chunati (CHU)					0.00 (1)	0.00 (1)	0.00 (1)	0.00 (1)
	Bhutan (bt)	Samtse (SCH)			- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
	India (in)	Chirang-Ripu (CHR)		0.00 (1)	0.00 (2)	- (0)	- (0)	0.00 (1)	0.00 (8)	0.00 (5)
		Deomali (DEO)				- (0)	0.00 (2)	- (0)	- (0)	- (0)

* *Data for Yankari in 2008 and 2009 were excluded due to unresolved discrepancies in the data reported.*

Sub-Region	Country	Site	2002	2003	2004	2005	2006	2007	2008	2009
		Dihing Patkai (DHG)		- (0)	0.50 (2)	0.00 (1)	0.00 (1)	0.00 (3)	0.20 (5)	0.00 (3)
		Eastern Dooars (EDO)		0.00 (4)	0.00 (12)	0.13 (8)	- (0)	0.00 (15)	0.07 (15)	0.00 (2)
		Garo Hills (GRO)		0.00 (6)	0.10 (10)	0.00 (2)	0.00 (4)	0.09 (11)	0.17 (6)	0.38 (8)
		Mayurbhanj (MBJ)		- (0)	0.00 (12)	0.12 (17)	0.00 (1)	- (0)	- (0)	- (0)
		Mysore (MYS)		- (0)	- (0)	0.13 (30)	0.33 (3)			
		Shivalik (SVK)		- (0)	- (0)	0.00 (2)	- (0)			
		Wayanad (WYD)		- (0)	0.00 (2)	0.13 (8)	- (0)			
	Nepal (np)	Royal Suklaphanta (SUK)			- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
South East Asia	Cambodia (kh)	Mondulkiri (MKR)		- (0)	- (0)	- (0)	0.00 (1)	- (0)	- (0)	- (0)
	China (cn)	Xishuangbanna (XBN)				- (0)	0.00 (1)			
	Indonesia (id)	Bukit Barisan Selatan (BBS)			- (0)	- (0)	- (0)	- (0)	- (0)	- (0)
		Way Kambas (WAY)			- (0)	- (0)	0.00 (1)	- (0)	- (0)	- (0)
	Laos (la)	Nakai Nam Theun (NAK)		1.00 (1)	- (0)	- (0)	- (0)	0.00 (1)	- (0)	- (0)
	Malaysia (my)	Gua Musang (GMS)				- (0)	- (0)	- (0)	- (0)	- (0)
		Kluang (KLU)				- (0)	- (0)	0.00 (1)	- (0)	0.50 (2)
	Myanmar (mm)	Alaungdaw Kathapa (ALW)		- (0)	- (0)	- (0)	1.00 (2)	- (0)	- (0)	1.00 (1)
		Shwe U Daung (SHW)		- (0)	- (0)	- (0)	0.00 (1)	- (0)	- (0)	0.00 (1)
	Thailand (th)	Kuibiri (KUI)				- (0)	- (0)	- (0)	- (0)	- (0)
		Salakphra (SKP)				0.00 (1)	- (0)	- (0)	- (0)	- (0)
	Viet Nam (vn)	Cat Tien (CTN)				- (0)	- (0)	- (0)	- (0)	1.00 (6)