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

Sixty-first meeting of the Standing Committee
Geneva (Switzerland), 15-19 August 2011

MONITORING THE ILLEGAL KILLING OF ELEPHANTS: TECHNICAL REPORT FOR CITES SC61

This document has been prepared by the Secretariat in relation to agenda item 44.2 on *Elephant management and conservation*.

MONITORING THE ILLEGAL KILLING OF ELEPHANTS: TECHNICAL REPORT FOR CITES SC61

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Introduction

The MIKE programme was established in 1999 by Resolution 10.10 of the Conference of the Parties (COP) to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). MIKE aims to institute a standardized monitoring system in a representative sample of sites spread across the range of African and Asian elephants. The primary objective of this monitoring system is to measure trends in the levels of illegal killing of elephants to inform decision-making.

An analysis of MIKE data was presented to the 15th Meeting of the Conference of the Parties to CITES, held in Doha, Qatar in March 2010. At that meeting, the Parties to CITES instructed the MIKE programme to produce updated analyses for the 61st and 62nd Meetings of the CITES Standing Committee [Decision 14.78 (Rev. CoP15)]. An updated analysis, including poaching data up to the end of 2010, was conducted in May 2011, and a summary of its results is presented in SC61 Doc 44.2 A1. This document presents the results of that analysis in more technical detail.

Background

The MIKE programme was designed to obtain data primarily from law enforcement patrols routinely conducted by local rangers at designated MIKE sites. When an elephant carcass is found, observers (usually rangers) at MIKE sites attempt to judge whether the elephant was illegally killed by looking for signs such as bullet holes in the carcass, spent cartridges and other evidence. They are also expected to report on the status of the ivory (whether present, removed or naturally absent), to assess the age of the carcass using standard criteria, and to make judgments on the sex and age of the animal. This information, along with the location of the carcass (based on a Global Positioning System (GPS) reading) and the date and time in which it was found, should entered in standardized MIKE carcass forms.

It is also expected of rangers to collect data on their patrol movements with the aid of GPS receivers, and to enter that information into standardized forms, so that measures of patrolling effort (such as distance, time patrolled, coverage, etc) can be derived.

It was the expectation that sites would regularly submit these data on elephant mortality and law enforcement effort, so that models of elephant poaching based on catch per unit effort could be constructed. Due to a number of operational difficulties, it has not been possible to date to obtain law enforcement effort data from the vast majority of MIKE sites in the nearly 10 years since the MIKE programme has been in place.

Even data on elephant mortality is sparse in many sites, as carcass forms are frequently not fully or correctly completed. For instance, only a quarter of the carcasses reported in Africa between 2002 and 2010 have any information on the sex of the animal. Nearly half of the entries have no information on carcass age, and more than a third of them lack information on ivory status. The legality of death (i.e. natural versus illegal) is the only variable that has been more consistently reported across sites and years, although there are data gaps there too, with an important number of carcasses in which the cause of death was categorized as “unknown” (see more on this issue below).

In view of the above difficulties, the MIKE programme has been employing in its analyses the proportion of illegally killed elephants (PIKE) as a relative indicator of poaching levels. PIKE is the number of illegally killed elephants found divided by the total number of elephant carcasses encountered by patrols or other means, aggregated by year for each site. PIKE is modeled as the probability that an elephant was illegally killed (given that its death occurred and was reported) using generalized linear models with a binomial distribution and a logit link function. This method, which is also known as binomial logistic regression, permits the inclusion of continuous, ordinal and categorical explanatory variables (covariates). Such models automatically

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weight by sample size (i.e. the denominator in the PIKE ratio), thus ensuring that sites that report little data have a proportionately small influence on the overall analysis.

Data

The basic data for analysis consist of total numbers of carcasses and numbers of illegally killed elephants encountered at MIKE sites, aggregated by site and year, as submitted by elephant range States. These data are presented in Table A1 in the Annex to this document. Data prior to 2002 were excluded from the analysis, as the MIKE programme was only operational in a small number of sites at the time. Sites with no elephants and site-year combinations in which no carcasses were reported were also removed, as it is not possible to compute PIKE when no carcasses have been reported. Some site-year combinations are missing from the data due to non-reporting by the range States. Sites with only one year of data were also removed, as they cannot contribute trend information. Finally, data for the Yankari MIKE site in 2008 and 2009 were also removed due to discrepancies in the reports submitted by Nigeria, which could not be resolved.

The final dataset used for analysis consists of 7,378 carcasses of elephants that died between 2002 and 2010 in 46 sites in 25 countries in Africa and 11 sites in 4 countries in Asia, representing a total of 348 site-years. Data availability by sub-region site and year is represented graphically in Figure 1. The figure shows that data are considerably imbalanced, with many gaps across several years, particularly in West African and Asian sites. The potential effects of data imbalance are evaluated in the Exploratory analysis section below, but while some gaps are unavoidable in a programme such as MIKE, it is clear that a number of sites do not add much value to the analysis.

It is to be expected that different sites report widely different numbers of carcasses, as encountered carcass numbers are a function of factors such as elephant population size; elephant mortality rates; the detection probabilities of elephant carcasses in different habitats; levels of illegal killing; and levels of search effort. A crude estimate of the efficiency with which sites detect and report carcasses can be obtained as the ratio of natural deaths reported to the number of natural deaths expected to occur in a given year, assuming constant population sizes, constant natural mortality rates at each site and a detection probability of 1. Figure 2 shows the distribution of this proportion for the site-years in the present data set, for a hypothetical natural mortality rate of 5%. As the figure shows, under 5% of expected carcasses are detected and reported in the majority of cases. While it would not be reasonable to expect sites to find every single dying elephant, it is clear from the figure that there is ample room for improvement in search efficiency. The generally low levels of efficiency raise issues related to the adequacy of the sample being analyzed. This is further explored in the Discussion section.

Exploratory analysis

Table 1 shows the average sub-regional and global raw PIKE values for every year in the analysis, as well as mean PIKE across all years. The table was constructed by adding the numbers of illegal carcasses at each level and dividing that by the appropriate sums of total carcasses.

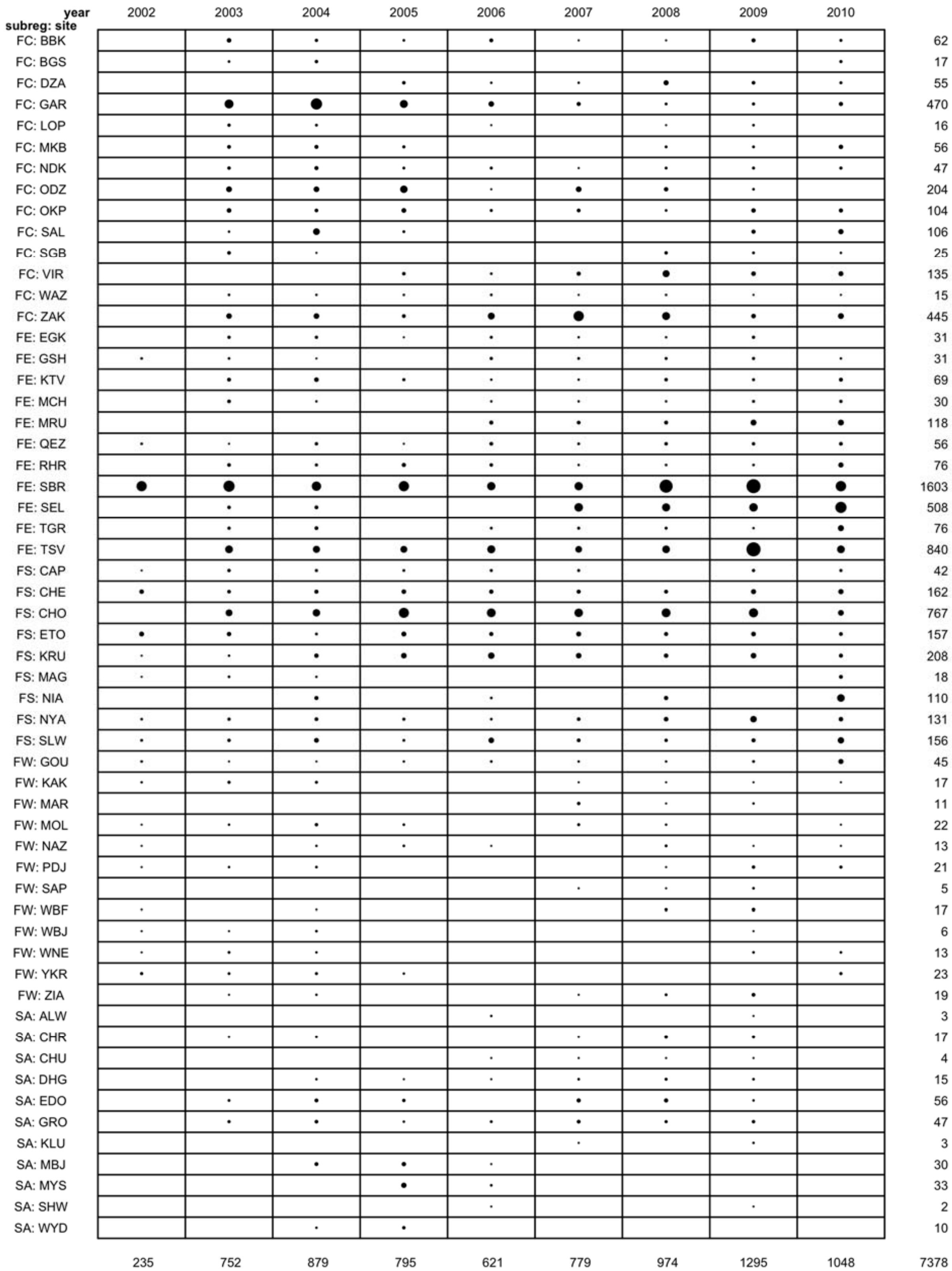

Figure 1. Summary of data availability for the present analysis. The diameters of the black circles are proportional to the total number of carcasses reported (both 'legal' and illegal). Site codes are shown in the leftmost column. For a key to site codes, see Table A1 in the Annex. The three-letter site codes are preceded by the sub-regional code, the first letter of which represents the continent (F for Africa, S for Asia) and the second letter represents the sub-region (C=Central; E=Eastern; S=Southern; W=West; A=All). The last row and column indicate total numbers of carcasses reported.

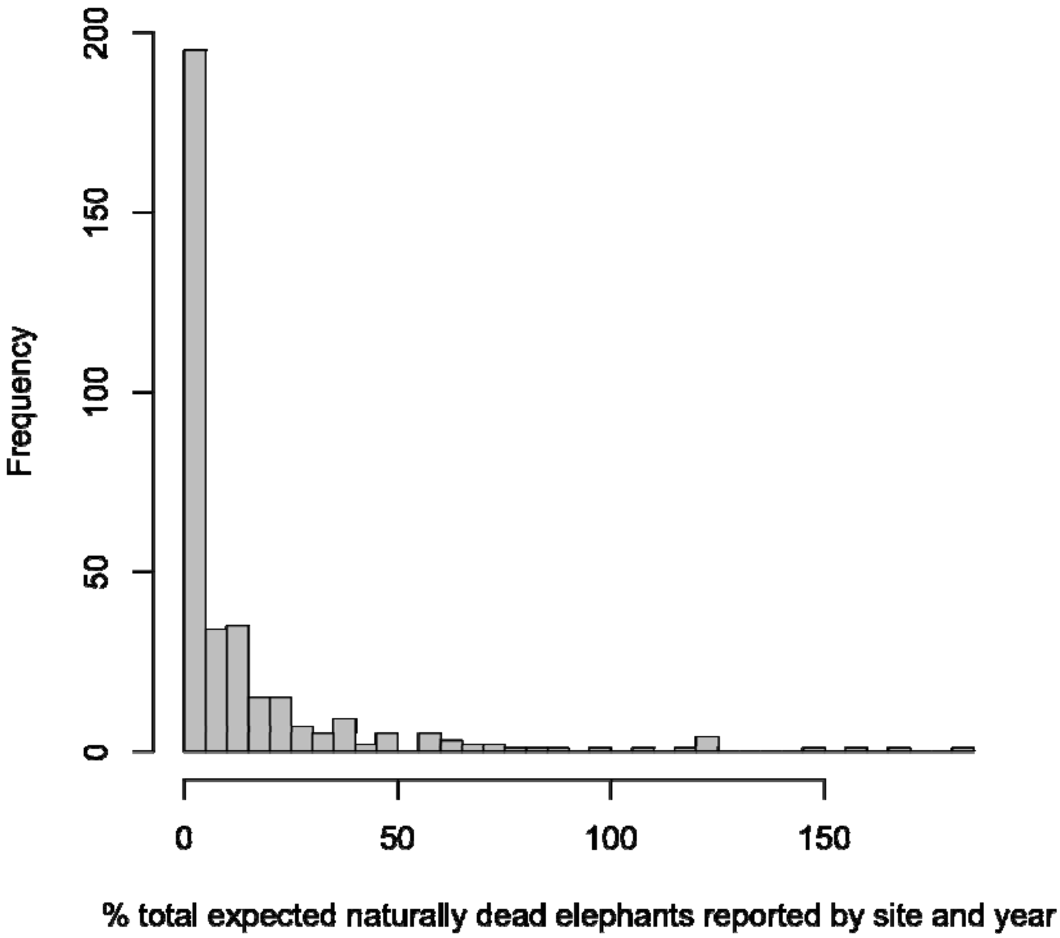

Figure 2. Distribution of carcass detection efficiency for all the site-year combinations in the present dataset. Note that while most sites report only a small proportion of expected natural deaths, a small number of them report well above what is expected to occur naturally. Mean = 14.52 ± 27.20 (s.e.); median=4.03

Table 1. Average PIKE values at the subregional and global levels recorded by the MIKE programme between 2002 and 2010.

Subregion	2002	2003	2004	2005	2006	2007	2008	2009	2010	TOTAL
Central Africa	-	0.70	0.79	0.54	0.63	0.87	0.86	0.72	0.86	**0.75**
Eastern Africa	0.36	0.25	0.33	0.23	0.22	0.32	0.50	0.26	0.55	**0.36**
Southern Africa	0.19	0.11	0.21	0.06	0.19	0.16	0.22	0.28	0.52	**0.23**
West Africa	0.12	0.24	0.31	0.30	0.00	0.78	0.86	0.81	0.16	**0.45**
Asia	-	0.00	0.05	0.12	0.23	0.03	0.09	0.22	-	**0.10**
GLOBAL	**0.31**	**0.39**	**0.49**	**0.26**	**0.29**	**0.44**	**0.51**	**0.33**	**0.58**	**0.42**

Across all years, PIKE is highest in Central Africa, followed by West and Eastern Africa. Southern Africa has the lowest PIKE in the African continent, but higher than in Asia. The overall PIKE mean across all years (2002-2010) currently stands at 0.42.

Spatial vs. temporal variation in PIKE

In order to investigate the main spatial and temporal sources of variation in PIKE, binomial models (adjusted for over-dispersion; see below) were fitted using year as a factor as well as factors for three levels of spatial structure, namely sites, countries and sub-regions. A model including all these factors accounts for 76.29% of the variation (deviance) in PIKE. An analysis of deviance of this model, shown in Table 2 below, shows that most of the variation in PIKE is explained by spatial factors (which together account for 69.10% of the variation), whereas time (year) only accounts for 7.19% of the deviance.

Table 2. Results of a simple model to investigate the main sources of variation in the data.

Factor	df	Deviance	Residual df	Residual deviance	F	Pr(>F)
null	352	3860.1				
subregionid	4	1236.05	348	2624	98.2795	<2.2e-16
ccode	27	1168.77	321	1455.2	13.7674	<2.2e-16
siteid	32	262.38	289	1192.9	2.6077	1.479e-05
year	8	277.47	281	915.4	11.0311	1.524e-13

In this model, sub-region and country explain most of the variation (each accounting for more than 30% of total deviance), while site accounts for approximately as much variation as year (about 7% each). It is perhaps not surprising that site is a relatively small source of variation, as many countries have but one site, and even sites in countries with multiple sites are likely to be affected by a number of conditions acting at the national level.

A variant of the above model, which takes the hierarchical spatial structure of the data into account (sites within countries and countries within regions plus year), explains the same amount of variation as the above model, with the temporal (year) component accounting for a similar proportion of total variation (9.14%). This reinforces the view that the most important factors that determine levels of poaching in different parts of elephant range are more associated with spatial factors (site, country and so on) than with temporal factors. In other words, in the areas and time period considered here, poaching levels vary more in space than they do in time.

The dispersion parameter from this saturated model was 3.1427, meaning that the variance in PIKE is more than 3 times larger than expected under a binomial distribution. Thus all models constructed in this analysis (including those reported above) were adjusted by a variance inflation factor. In exploratory models, over-dispersion was estimated from the model being evaluated, but for the model selection procedure described under Covariate Modelling below, the dispersion parameter from the saturated model above was used to compare models.

Trends in PIKE

Regional (i.e. continental) trends in PIKE were derived from averages of site-based annual PIKE values weighted by sample size. These trends are shown graphically Figure 3.

The African data are suggestive of a mildly increasing overall trend, punctuated by declines in 2005-2006 and 2009. However, given the widths of the error bars, the overall trend in raw PIKE is only of marginal significance – even though some inter-annual changes, such as that between 2009 and 2010 are highly significant. Similarly, the data suggest an ongoing and sustained increase in levels of illegal killing since 2006, only interrupted by a transitory decline in 2009.

Some of the temporal variation in the trend could be affected by issues associated with data quality. This is most apparent for the Asian region, where the paucity of data (220 carcasses over seven years) makes it impossible to infer any trend for that region. For Africa, on the other hand, it seems plausible that the patterns recorded may reflect real trends in illegal killing, influenced by fluctuations in factors directly related with the demand for ivory.

Given that subregion accounts for much of the variation, it is illustrative to show PIKE trends at the subregional level (Figure 4). Consistent with the results in Table 1, Figure 4 shows that Central Africa experiences the highest overall levels of poaching. Poaching levels are generally lower in eastern Africa and lowest of all in southern Africa. The picture is mixed in west Africa, with PIKE levels varying widely across years. This is probably a result of poor reporting rates and small numbers of carcasses reported by that subregion. Indeed, the low

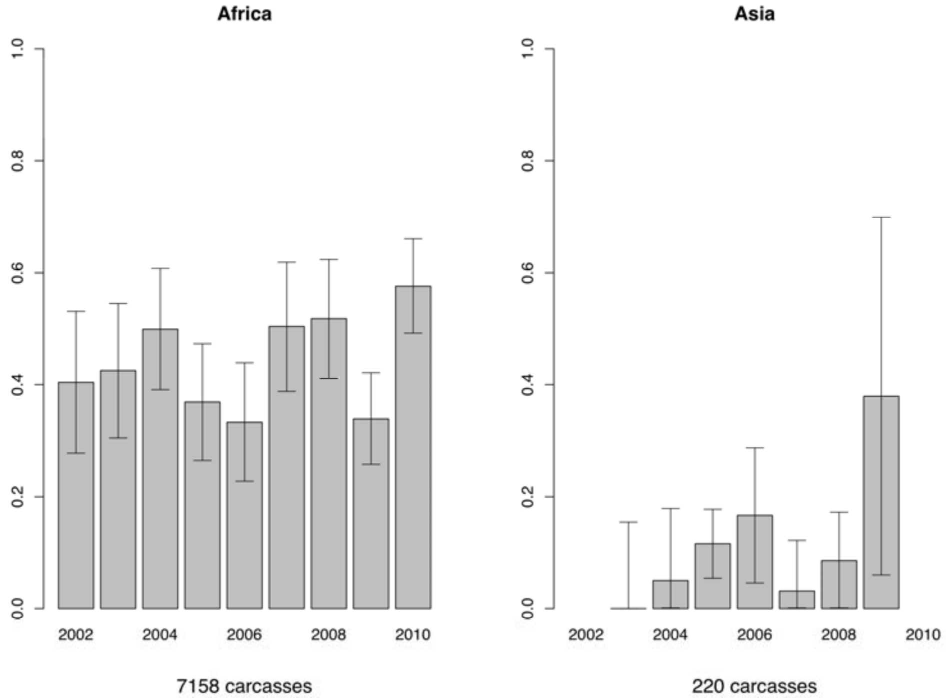

Figure 3. Regional PIKE trends with 95% confidence intervals. The numbers of carcasses on which the graphs are based are shown at the bottom of each graph.

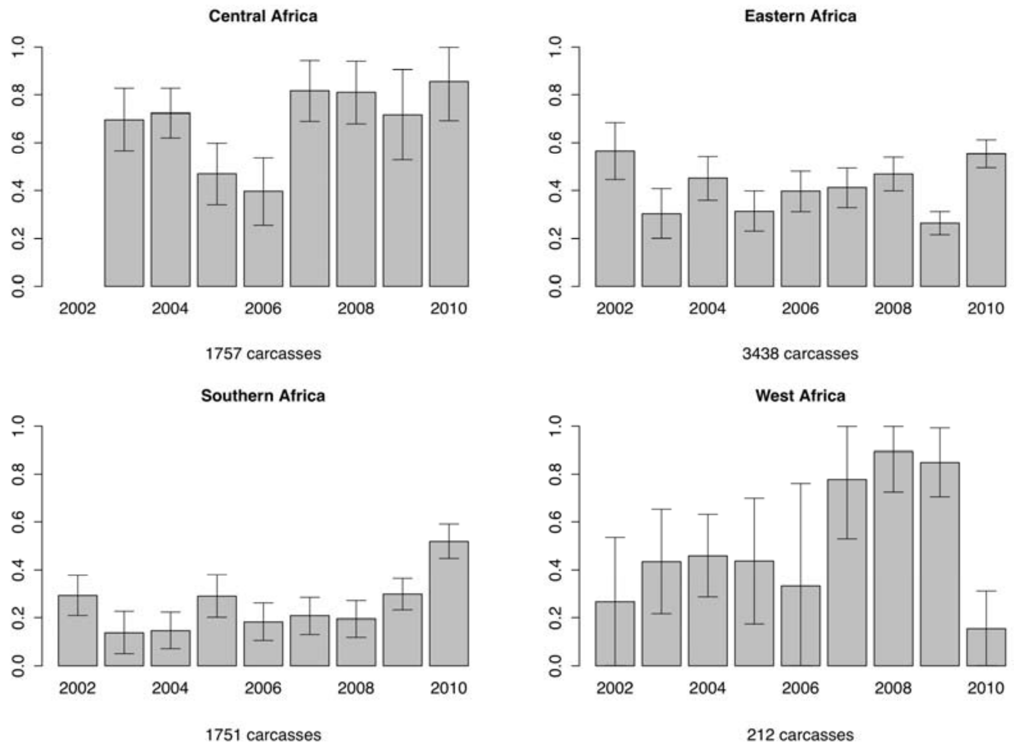

Figure 4. Subregional PIKE trends with 95% confidence intervals. The numbers of carcasses on which the graphs are based are shown at the bottom of each graph.

PIKE level for 2010 in this subregion may be a consequence of the fact that a number of the sites that have in the past reported high PIKE values did not submit any data for 2010, and that one range State (Mali) reported an unusually large number of carcasses for that year, none of which were illegally killed. Conversely, the high PIKE value for Southern Africa in 2010 may be explained by the fact that two sites (Cabora Bassa and Niassa, both in Mozambique), which had only reported irregularly in the past, did submit data for 2010. Partitioning PIKE trends at a finer spatial scale (country or site) would not be appropriate, as many countries only have one or two sites, and site-level trends are likely to be unreliable due to small sample sizes and data imbalances.

In order to investigate whether data imbalance affects trends in PIKE, the combined trend from sites which have supplied at least 8 years of data (all of which are in Africa, and which account for about half of the carcasses in the data set) was compared with the overall trend for Africa. The resulting trend (shown in

Figure 5) is remarkably similar to the trend obtained using the full African data set. In consequence, all subsequent analyses were performed on the entire data set (with the exceptions noted in the Data section above).

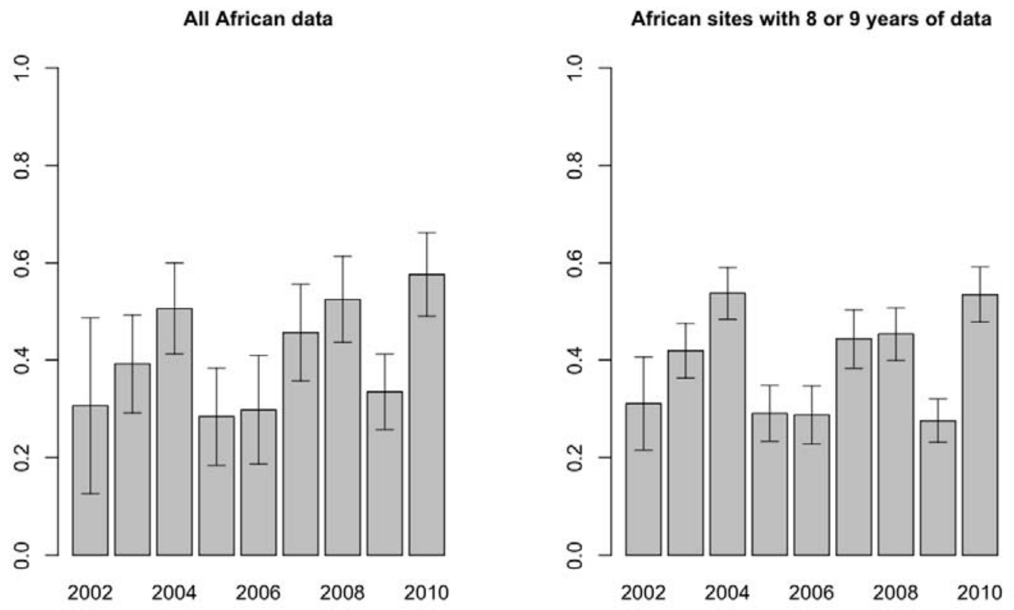

Figure 5. Comparison of PIKE trends for all African sites (left) and (African) sites for which there are 8 or 9 years of data. The only noticeable differences in the two plots are the values for 2008 and the width of the confidence intervals.

As pointed out above, sites often report elephant carcasses in which the cause of death is either recorded as "unknown" or simply not recorded. For the purposes of calculating PIKE, such carcasses have up to the present been regarded as "not illegally killed". It was noticed from previous MIKE data sets that the proportion of "unknowns" can be quite considerable, sometimes even exceeding PIKE itself (Figure 6). In order to investigate whether the 'unknowns' affect trends in PIKE, an alternative form of PIKE, which excludes the unknowns from the denominator, was calculated from the African data. These alternative PIKE values are naturally higher than the normal PIKE, but their trend is very similar to that of normal PIKE. For this reason, and as the proportion of unknowns has been consistently declining since 2005, it was decided to continue to use the normal PIKE statistic for analysis.

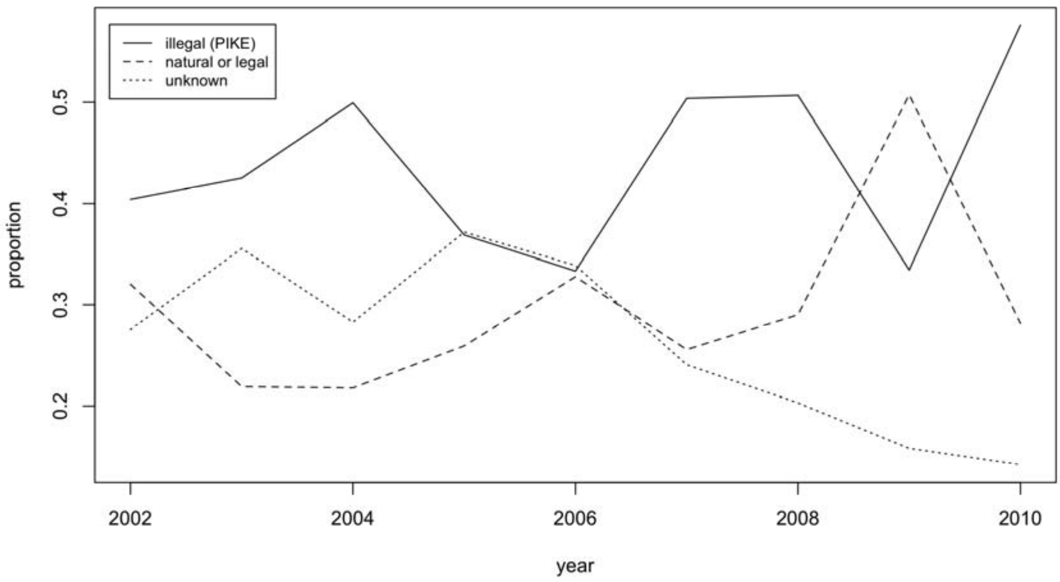

Figure 6. Trends in the proportions of three causes of death: illegal (PIKE), natural or legal and unknown.

Covariate modeling

In order to explore the effects of various factors on levels of poaching, a comprehensive set of covariates at the site, national and global levels was assembled. Details of covariates explored in this study are presented in Table A2 in the Annex.

Most of the site-level variables were derived from global spatial datasets at various resolutions. Data for the analysis were obtained by overlaying the spatial data sets with a layer of MIKE site boundaries plus 20 km buffers (except where noted in Table A2), and means or other relevant statistics were calculated from the grid cells covered by those boundaries. Site-level variables can be broadly categorized into 6 groups:

1. Physical/political – relating to the geography of the site (area, distance to international border)
2. Elephants – elephant population estimates, precision, elephant density.
3. Bioclimatic – Rainfall, seasonality, net primary productivity
4. Human population – number of people, human impact.
5. Land cover / land use - Land cover heterogeneity, major land use type, prevalence of crops, livestock production systems, livestock density, etc.
6. Socio-economic – site-level measures of poverty. Specifically, infant mortality, prevalence of stunting in children under 5 and proportion of underweight children were used as proxies for malnutrition and poverty.

As noted in Table A2, many of the national-level covariates explored are time series. For those national covariates for which a time series was not available, the single values for each country were used across all years. The national-level covariates fall broadly into three groups:

1. Governance – World Governance Indicators, Corruption Perceptions Index, small arms per 100 people.

1. Socio-economic – Human Development index and its components (GDP per capita, educational attainment and life expectancy)[3]; economic indicators such as inflation, GPD growth, strength of the local currency, overseas development aid received; and a number of indices of economic competitiveness and economic freedom.

2. Trade-related – value of exports and national-level ETIS scores related to the ivory trade (law enforcement ratio and domestic ivory market score).

The global-level variables used in this study attempt to measure demand for ivory, which is widely believed to be a key driving factor behind the illegal killing of elephants. As ivory is largely an illegal commodity, it is not possible to measure demand for it based on trade data, and suitable proxies were sought instead. It was speculated that a measure of general demand for goods and services in ivory-consuming nations could serve as a good proxy for ivory demand. According to ETIS and other sources, China and Japan are currently the world's largest consumers of ivory. In addition, ETIS data implicate countries such Malaysia, The Philippines, Thailand and Vietnam in the importer side of the ivory supply chain. The annual percent change in household, or private, consumption expenditure (i.e. consumer spending) was used as a measure of consumer demand in these countries.

<u>Relationships between PIKE and covariates</u>

In order to explore relationships between national covariates and PIKE, national covariates were averaged over years, while PIKE was aggregated at the national level and similarly averaged over time. The resulting data were analyzed by means of focused principal components analysis (fPCA), a statistical method that allows faithful representation of correlations between the dependent variables and the predictors, and which provides a convenient way of identifying candidate variables for use in modeling. The results of this analysis are shown in Figure 7.

National covariates significantly correlated with PIKE (i.e. those inside the red circle in Figure 7) tend to cluster together, and include all six of the World Bank's Worldwide Governance Indicators; the corruption perceptions index; economic competitiveness; protection of property rights; tourism competitiveness; and GDP per capita. Unfortunately, most of these variables had a considerable number of missing values. For instance, the World Governance Indicators were missing data for 2010. At the time of writing these had yet to be published. Similarly, the economic and tourism competiveness variables do not include data for six MIKE countries, and were therefore not used in further analyses. Only the Corruption Perceptions Index (cpi) and the Human Development Index (hdi) had sufficient data for use in the analysis.

[3] *The composition of the human development index (HDI) has been recently modified by the organization that produces the index, namely the United Nations Development Programme. Not only is the new HDI calculated differently (using a geometric mean), but it is also composed of different factors, some of which are not available in historical datasets. For trend-related analyses, UNDP recommends using a "hybrid HDI", which uses the old components but the new method of calculation. It is this hybrid HDI that has been used in this study, but it is referred to throughout simply as HDI.*

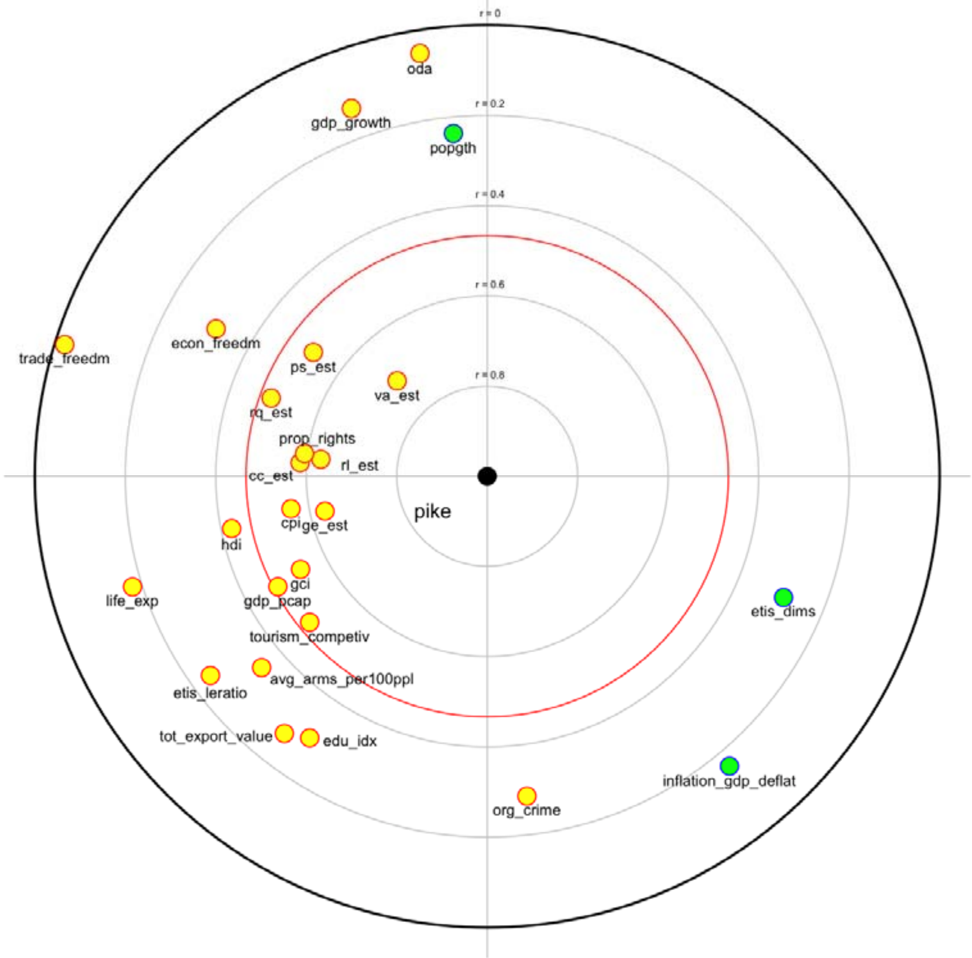

Figure 7. Focused PCA of national covariates and their relationship with PIKE. The relationships between non dependent variables are interpreted like in a PCA biplot: correlated variables are close or diametrically opposite (for negative correlations), while independent variables make a right angle with the origin. Yellow dots represent negative correlations with PIKE, while green dots represent positive correlations. Dots falling inside the red circle are significantly correlated with PIKE. The closer they are to the centre of the circle, the more strongly correlated with PIKE they are.

To explore relationships between PIKE and site level covariates, PIKE was averaged over time at the site level, and the fPCA procedure was conducted with all site-level covariates, none of which were time-varying. The results of this analysis are shown in Figure 8.

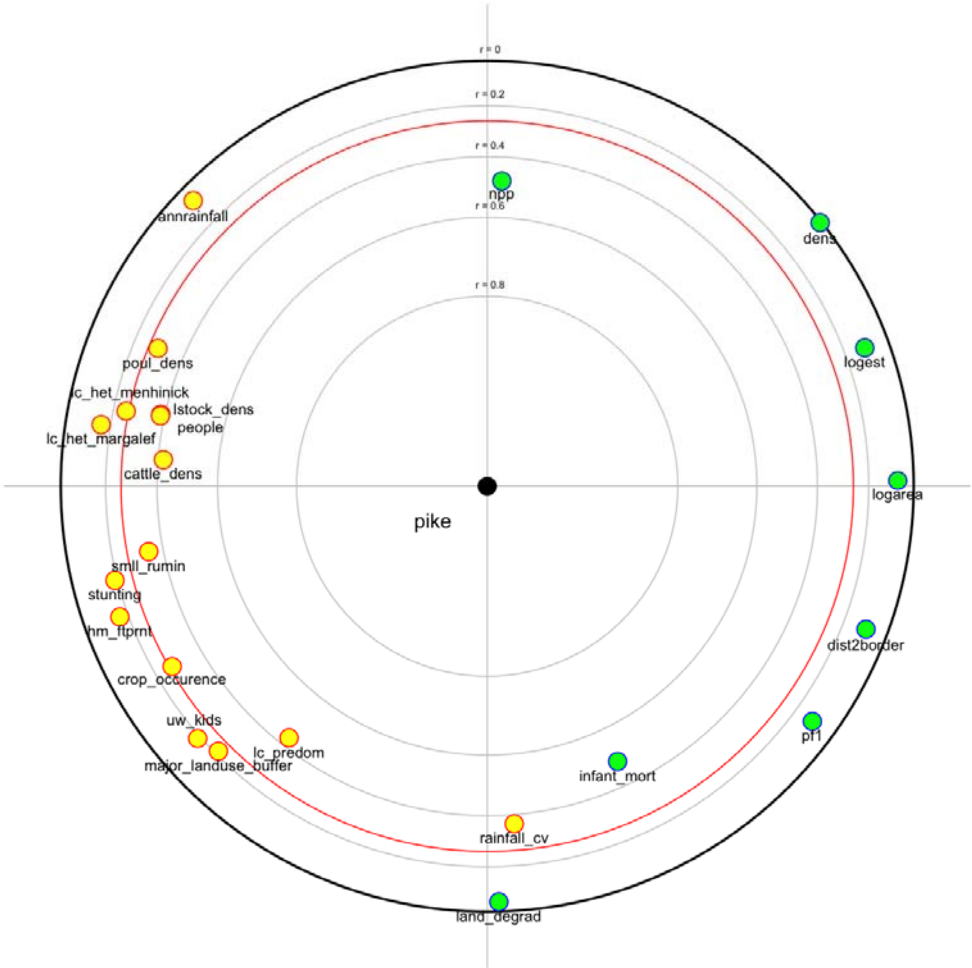

Figure 8. Site-level focused PCA. For details on interpretation, see the caption to Figure 6.

The strongest relationships at the site level were between PIKE and net primary productivity, infant mortality (both positively related), predominant land cover type and cattle density (both negatively related to PIKE). The other livestock variables (small ruminants, poultry and the average of all three livestock densities) as well as some of the human impact variables (people, crop occurrence, habitat heterogeneity) were also significantly, and negatively, correlated with PIKE.

At the global level, the relationship between PIKE and growth in consumer spending in major ivory-importing nations was evaluated. These time series are plotted in Figure 9 along with the time series of global PIKE means. The nature and strength of these relationships were evaluated in the covariate modelling procedure.

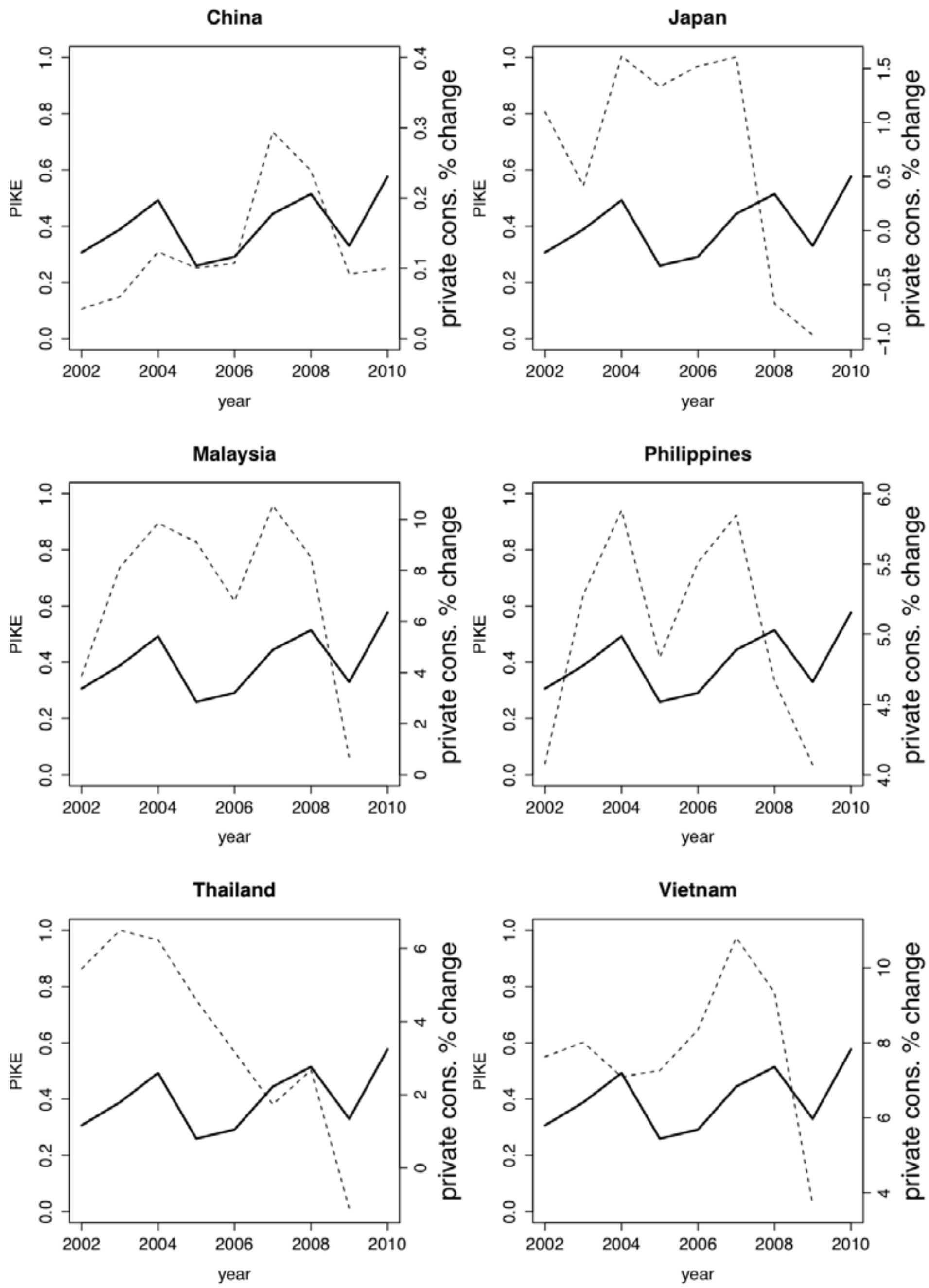

Figure 9. Comparison of PIKE trends (solid lines) with annual growth in private consumption expenditure in countries associated with the demand side of the ivory supply chain. Data for 2010 was only obtainable for China.

Modelling strategy and results

The results from the site- and country-level fPCA analyses were used to assist in the selection of covariates for building models, but all covariates were tested in logistic models using the QAICc (a variant of the Akaike Information Criterion adjusted for over-dispersion and small sample size). Site-level variables were added first one at a time, trying different combinations until a satisfactory site-level model was obtained. Only then were national covariates added to the model, following a similar method. Global covariates and time (using powers of year) were then added in the same manner. When a final model was selected, all possible nested models were evaluated in order to select the most parsimonious model using QAICc, model weights and variable importance weights, using the dispersion parameter from the saturated model described in the Exploratory analysis section above. Finally, the spatial factors (site, country, subregion and interactions thereof) were added in turn to the final model to evaluate what additional unexplained variation remained at each of those levels.

The final model, which accounts for 60.57% of the total variation with just 10 parameters, is summarized in Table 3 below. The model weight is 0.997, and hence all the covariates included in it have variance importance weights of at least that magnitude. The QAICc for this model was 504.60, which compares very favourably with that of a saturated model (using site, country, subregion plus year as a factor), which had a QAICc of 451.13 with 97 parameters.

Table 3. Summary of final model with parameter estimates and standard errors.

	Estimate	Std error	t	Pr(>|t|)
(Intercept)	2.645e+05	6.291e+04	4.205	3.35e-05
infant_mort	2.560e-03	2.793e-04	9.165	<2e-16
npp	1.268e-03	3.583e-04	3.539	0.000458
logarea	-3.048e-01	5.483e-02	-5.559	5.51e-08
cattle_dens	-2.214e-02	5.327e-03	-4.156	4.11e-05
lc_het_margalef	1.725e+00	5.484e-01	3.145	0.001805
cpi	-6.105e-01	9.045e-02	-6.75	6.45e-11
cn_hhcons	5.139e+00	1.068e+00	4.81	2.27e-06
year	-2.638e+02	6.271e+01	-4.206	3.33e-05
$year^2$	6.575e-02	1.563e-02	4.207	3.31e-05

An analysis of deviance table from the final model is shown in Table 4 below to illustrate effect sizes.

Table 4. Results of an analysis of deviance on the final model.

Covariate	df	Deviance	Residual df	Residual deviance	F	Pr(>F)
null	347	3839.8				
infant_mort	1	1027.83	346	2812	235.3452	<2.2e-16
npp	1	203.19	345	2608.8	46.524	4.186e-11
logarea	1	78.22	344	2530.6	17.9109	2.986e-05
cattle_dens	1	18.4	343	2512.2	4.2128	0.0408898
lc_het_margalef	1	539.67	342	1972.5	123.5702	<2.2e-16
cpi	1	266.84	341	1705.7	61.0994	6.952e-14
cn_hhcons	1	53.84	340	1651.8	12.3278	0.0005068
year	1	60.46	339	1591.4	13.8445	0.0002325
$year^2$	1	77.52	338	1513.9	17.7495	3.236e-05

The relationships between site-, national-, and global-level covariates and predicted PIKE, with all other covariates held constant at their means and year set to 2010, are shown in

Figure 10, and are discussed in turn below.

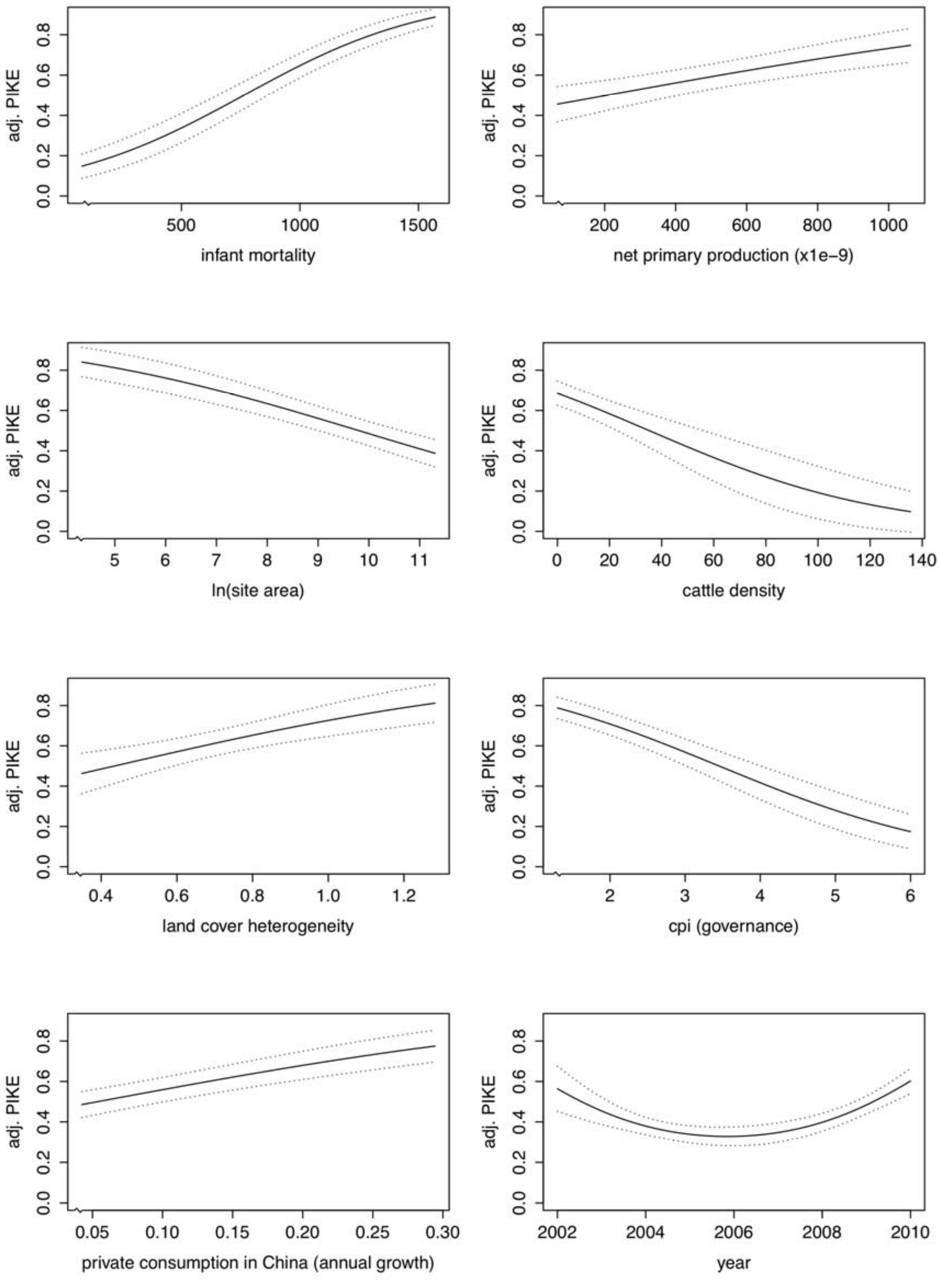

Figure 10. Relationships between predicted PIKE and individual covariates with 95% confidence intervals (dotted lines). All other covariates held constant at their means and year set at 2010.

Discussion

<u>Site-level covariates</u>

The strong relationship between site-level infant mortality and PIKE suggests a link between poaching and poverty levels, with sites suffering from higher levels of poverty experiencing higher levels of poaching. The relationship between cattle density and PIKE may also be related to human nutrition, as going out to hunt is less of an imperative in places where there is a readily available supply of animal protein in the form of livestock. It is important to note, however, that livestock density is correlated with human density, and particularly so on the upper ranges of both variables. It is possible therefore that the effect of cattle density on PIKE may be somewhat confounded by the effect of human population density. However, the relationship between human population and PIKE was not sufficiently strong for it to remain in the model. On the other hand, the richness of land use/land cover types (lc_het_margalef), which is positively related to PIKE, may be an indicator of human impact, as areas that are heavily influenced by people tend to be a mosaic of different land cover types, including agriculture, natural vegetation, livestock grazing, dwellings, etc. Thus it appears that human influence at the site level may exert both positive and negative effects on levels of elephant poaching.

The direct relationship between PIKE and net primary productivity (a proxy for vegetation cover) may be due to the fact that denser vegetation (i.e. higher npp) reduces visibility and hence decreases the detectability of poachers, making it easier and less risky for them to operate. The negative relationship between site area and PIKE may also be associated with decreased poacher detectability, or with the logistics of poaching, as it is easier to quickly get in and out of a small site and less preparation is required in terms of rations, porters, and so on.

<u>Country-level covariates</u>

At the national level, and as in previous MIKE analyses, governance emerges as the most important predictor of poaching. The consequences of bad governance are likely to manifest themselves throughout the ivory value chain, facilitating the movement of illegal ivory from the site all the way to the point of export. Human development, although not featured in the final model, was also a strong covariate which seems inextricably related to governance and poaching, in a vicious circle. Bad governance prevents the improvement of the human condition, driving the rural poor to poach for sustenance, which in turn provides incentives to corrupt officials who benefit from the illegal movement of ivory.

<u>Global-level covariates</u>

At the global level, changes in consumer spending in China were found to be strongly and positively related to PIKE, whereas the relationship between PIKE and consumer spending in Japan was negative but statistically marginal and unlikely to hold true (Figure 9). The relationships between PIKE and Malaysia, the Philippines, Thailand and Viet Nam were found to be insignificant or marginal at best.

These findings support the evidence from ETIS that China has overtaken Japan as the world’s largest consumer market for illegal ivory products, and that countries such as Malaysia, the Philippines and Viet Nam are entrepôts in the trade route to China. It is worth noting that levels of private consumption expenditure in China are continuing to increase in 2011. Thus, if demand in China is indeed a reliable predictor of levels of elephant poaching, PIKE could be expected to increase accordingly in the course of the current year (2011). Preliminary evidence from the Samburu-Laikipia MIKE site, where record levels of poaching for ivory are being measured this year, seems to support this hypothesis (Wittemyer and Douglas-Hamilton, pers. comm.).

The close relationship between trends in private consumption and levels of illegal killing suggests that illegal ivory is a luxury (or superior) good in China, and that demand for it is income-dependent (i.e. there is positive income elasticity of demand). On the other hand, if the negative relationship between PIKE and private consumption in Japan holds, it would suggest that illegal ivory in Japan has become, to use the technical term from economics, an “inferior good”, whereby increases in income would lead to declines in demand for illegal ivory (i.e. there would be negative income elasticity of demand). This could be a consequence of increased environmental awareness associated with higher levels of per capita income.

There appears to be no time lag (within the annual time-frame in which both MIKE and ETIS operate) between demand and poaching trends. This suggests that poaching levels may quickly respond to perceived levels of current demand. Longer lags may be expected between the poaching and the arrival of ivory at the consumer market, but given the breadth of the global transport network, such lags could well be much shorter than a year. Furthermore, it might be expected that dealers in illegal goods, such as ivory, would tend to prefer to move the merchandise along the trade chain as quickly as possible to minimize chances of detection by law enforcement agencies, to avoid sitting on idle inventory, and to get the product to market while demand is still high. Further research on the dynamics of the illegal ivory supply chain is required for a better understanding of these processes.

After accounting for the effects of the above covariates in the model, there remains a significant time trend with linear and quadratic components. The latter has a positive coefficient, suggesting a decline in poaching levels followed by an increase over the period under study (see

Figure 10).

The final model does not accept the addition of year (as a factor) nor subregion, indicating that all the temporal and subregional variation is absorbed by the covariates in the model. The model does accept, however, the inclusion of country or site (but not both) as an indicator variable, thereby increasing the amount of variation explained from 60.5% to 68.4% and a QAICc of 476.66, albeit at the expense of fitting an additional 28 parameters. There remains, therefore, potential for another site- or country-level variable to improve the inferential power of the model.

Caveats

A number of variations on the above methods gave very similar results. General linear models of PIKE weighted by sample size (as opposed to over-dispersed logistic regression) gave nearly identical results, as did the use of complementary log-log link function instead of a logit link. A generalized linear mixed model, or hierarchical model such as those used in previous MIKE analyses, also gave results consistent with those reported here, with the only difference that the landscape heterogeneity and livestock density variables decline in importance.

While the above suggests that results presented here appear to be robust to the statistical method used, the results could be affected by biases inherent in PIKE, as well as by issues of data quality. The data used to construct PIKE are largely collected by law enforcement patrols, which are non-random and purposive. It is therefore possible that the probability of detecting carcasses may not be random with respect to the cause of death of the animal. If, for instance, illegally killed carcasses are more readily detected because rangers follow poacher spoor or intelligence leads, as tends to be the case particularly in forested sites, PIKE will tend to be biased towards overestimating levels of poaching. Similarly, distortion in population age and/or sex structures could lead to biased PIKE values. The nature of the different factors causing biases in PIKE needs to be studied and understood more fully.

Perhaps a more worrying issue is the question of whether the data submitted to MIKE are accurate and are reliable, and whether they represent an adequate sample of elephant mortality at each site. The paucity of data coming from many sites, as illustrated in Figure 2 needs to be addressed, and the quality and reliability of data needs to be independently audited on a regular basis, perhaps through random audits conducted at MIKE sites.

While these issues require elucidation, the results presented here provide important insights, based on the best available evidence, into the patterns of spatial and temporal variation in levels of illegal killing of elephants, as well as into the local, regional and global factors that may affect levels of elephant poaching. The validity of the results reported here is reinforced by the fact that the broad trend in poaching levels, including the increase detected between 2006 and 2010, is fully consistent with the trends reported by ETIS.

Table A1. Data received for the 2011 MIKE analysis. PIKE is shown followed by the number carcasses from which it was calculated (in brackets).

Subregion	Country	Site	2002	2003	2004	2005	2006	2007	2008	2009	2010
Central Africa	Cameroon	Boumba-Bek (BBK)		0.68 (19)	0.71 (7)	1 (3)	0 (12)	0 (1)	0 (1)	0.36 (14)	0.6 (5)
		Waza (WAZ)		0.33 (3)	0.5 (2)	0.5 (2)	0.33 (3)	0 (1)	0 (2)	1 (1)	0 (1)
	Central African Republic	Bangassou (BGS)		1 (3)	1 (8)						1 (6)
		Dzanga-Sangha (DZA)				0.89 (9)	0.5 (2)	0.5 (2)	0.63 (27)	0.3 (10)	0 (5)
		Sangba (SGB)		0.1 (10)	0 (1)				1 (8)	1 (4)	1 (2)
	Chad	Zakouma (ZAK)		0.65 (34)	0.86 (35)	0.27 (11)	0.67 (60)	0.97 (160)	0.94 (86)	0.6 (20)	0.92 (39)
	Congo	Nouabale-Ndoki (NDK)		0.63 (8)	0.29 (14)	0.75 (4)	0 (5)	0 (1)	0.25 (4)	0.4 (5)	0.33 (6)
		Odzala (ODZ)		0.05 (38)	0.53 (36)	0 (73)	0 (1)	0.97 (36)	0.53 (17)	1 (3)	
	Democratic Republic of the Congo	Garamba (GAR)		0.96 (114)	0.89 (197)	0.9 (86)	0.94 (34)	0.5 (14)	1 (4)	1 (6)	0.67 (15)
		Kahuzi-Biega (KHB)		- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	
		Okapi (OKP)		1 (20)	0.9 (10)	0.95 (22)	1 (5)	1 (11)	0.67 (3)	1 (18)	0.87 (15)
		Salonga (SAL)		0 (2)	0.64 (56)	0.25 (4)	- (0)	- (0)	- (0)	0.93 (15)	0.97 (29)
		Virunga (VIR)				0.44 (9)	0.33 (3)	0 (15)	1 (63)	0.8 (20)	1 (25)
	Gabon	Lopé (LOP)		0.57 (7)	0.25 (4)	- (0)	0 (1)	- (0)	0 (1)	0.67 (3)	
		Minkébé (MKB)		0.73 (11)	0.92 (13)	0.5 (6)	- (0)	- (0)	1 (4)	0.75 (4)	0.94 (18)
Eastern Africa	Eritrea	Gash-Setit (GSH)	0 (3)	0.33 (3)	0 (1)		0.14 (7)	0.5 (4)	0.4 (5)	0.17 (6)	0 (2)
	Kenya	Meru (MRU)					0.5 (14)	0.27 (11)	0.38 (13)	0.48 (40)	0.7 (40)
		Mount Elgon (EGK)		0.86 (7)	0.71 (7)	0 (1)	0.4 (5)	0.5 (2)	0.5 (2)	0.71 (7)	
		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 (326)	0.47 (164)
		Tsavo (TSV)		0.22 (82)	0.29 (65)	0.28 (60)	0.17 (88)	0.2 (56)	0.33 (79)	0.16 (329)	0.68 (81)
	Rwanda	Akagera (AKG)			- (0)	- (0)	0 (1)				
	Uganda	Murchison Falls (MCH)	- (0)	1 (10)	0.5 (2)		1 (2)	0.5 (2)	0.5 (2)	0.4 (5)	0.29 (7)
		Queen Elizabeth (QEZ)	0 (3)	1 (1)	0.38 (8)	0 (1)	0.18 (11)	1 (4)	0.44 (9)	0.38 (8)	0.36 (11)
	Tanzania (United Republic of)	Katavi Rukwa (KTV)		0.75 (12)	0.75 (20)	0.5 (6)	1 (2)	1 (2)	1 (9)	0.8 (5)	0.92 (13)
		Ruaha Rungwa (RHR)		0.1 (10)	0.17 (6)	0.67 (15)	0.89 (9)	0 (2)	0.67 (3)	0.33 (3)	0.57 (28)
		Selous Mikumi (SEL)		0.22 (9)	0.18 (11)			0.42 (103)	0.59 (90)	0.48 (100)	0.55 (195)
		Tarangire (TGR)		0.14 (7)	0 (11)		0.25 (4)	0.2 (5)	0.4 (5)	0 (2)	0.5 (42)

Subregion	Country	Site	2002	2003	2004	2005	2006	2007	2008	2009	2010
Southern Africa	Botswana	Chobe (CHO)	- (0)	0 (59)	0.07 (73)	0.05 (153)	0.1 (111)	0.14 (101)	0.04 (113)	0.13 (120)	0.24 (37)
	Mozambique	Cabora Bassa (MAG)	0 (1)	0.33 (3)	1 (2)						0.58 (12)
		Niassa (NIA)			0 (14)		0.33 (3)		0.88 (16)		0.84 (77)
	Namibia	Caprivi (CAP)	0 (1)	0.25 (8)	0 (6)	0.25 (4)	0.4 (5)	0 (5)	- (0)	0 (7)	0.33 (6)
		Etosha (ETO)	0 (24)	0 (18)	0 (4)	0 (25)	0 (15)	0 (25)	0 (14)	0 (21)	0 (11)
	South Africa	Kruger (KRU)	0 (1)	0 (2)	0 (18)	0 (35)	0 (51)	0.03 (34)	0 (18)	0.03 (35)	0 (14)
	Zambia	South Luangwa (SLW)	0.25 (4)	0.63 (8)	0.65 (23)	0.25 (4)	0.77 (35)	0 (11)	0.88 (8)	0.43 (14)	0.53 (49)
	Zimbabwe	Chewore (CHW)	0.37 (19)	0.3 (10)	0.21 (14)	0 (20)	0.12 (17)	0.79 (14)	0.08 (13)	0.38 (26)	0.14 (29)
		Nyami Nyami (NYA)	0.67 (3)	0.29 (7)	0.82 (11)	0.83 (6)	0.67 (3)	0.5 (10)	0.9 (20)	0.87 (52)	1 (19)
West Africa	Benin	Pendjari (PDJ)	0 (1)	0.5 (2)	0.33 (3)				0 (1)	0.88 (8)	0 (6)
		W du Bénin (WBJ)	0 (1)	0 (1)	0 (3)					0 (1)	
	Burkina Faso	Nazinga (NAZ)	0 (1)		0 (2)	0 (3)	0 (1)		1 (4)	1 (1)	1 (1)
		W du Burkina (WBF)	0 (1)		0 (1)				1 (6)	0.89 (9)	
	Côte d'Ivoire	Marahoué (MAR)						1 (8)	1 (1)	1 (2)	
		Taï (TAI)			1 (2)						
	Ghana	Kakum (KAK)	0.5 (2)	0 (6)	0 (5)			0 (1)	1 (1)	1 (1)	0 (1)
		Mole (MOL)	0 (1)	0.5 (2)	0.25 (8)	1 (3)		0.8 (5)	1 (2)		1 (1)
	Guinea	Ziama (ZIA)		1 (1)	1 (2)			1 (1)	1 (4)	1 (11)	
	Liberia	Sapo (SAP)						1 (1)	1 (1)	1 (3)	
	Mali	Gourma (GOU)	0 (3)	0 (1)	0 (1)	0 (2)	0 (3)	0 (2)	0 (2)	0.25 (4)	0 (27)
	Niger	W du Niger (WNE)	1 (1)	0.25 (4)	1 (2)					0.33 (3)	0.33 (3)
	Nigeria	Sambisa (SBS)		0.33 (3)	0.5 (2)						
		Yankari (YKR)	0 (6)	0.25 (4)	0.6 (5)	0 (2)			0 (20)	0 (5)	0.67 (6)
	Senegal	Niokolo-Koba (NKK)		0 (1)							

Subregion	Country	Site	2002	2003	2004	2005	2006	2007	2008	2009	2010
South Asia	Bangladesh	Chunati (CHU)				- (0)	0 (1)	0 (1)	0 (1)	0 (1)	
	Bhutan	Samtse (SCH)				- (0)	- (0)	- (0)	- (0)		
	India	Chirang-Ripu (CHR)		0 (1)	0 (2)			0 (1)	0 (8)	0 (5)	
		Deomali (DEO)				- (0)	0 (2)				
		Dihing Patkai (DHG)			0.5 (2)	0 (1)	0 (1)	0 (3)	0.2 (5)	0 (3)	
		Eastern Dooars (EDO)		0 (4)	0 (12)	0.13 (8)	- (0)	0 (15)	0.07 (15)	0 (2)	
		Garo Hills (GRO)		0 (6)	0.1 (10)	0 (2)	0 (4)	0.09 (11)	0.17 (6)	0.38 (8)	
		Mayurbhanj (MBJ)			0 (12)	0.12 (17)	0 (1)				
		Mysore (MYS)				0.13 (30)	0.33 (3)				
		Shivalik (SVK)				0 (2)					
		Wayanad (WYD)			0 (2)	0.13 (8)	- (0)				
	Nepal	Royal Suklaphanta (SUK)			- (0)	- (0)	- (0)	- (0)	- (0)	- (0)	
South East Asia	Cambodia	Mondulkiri (MKR)					0 (1)				
	China	Xishuangbanna (XBN)				- (0)	0 (1)				
	Indonesia	Bukit Barisan Selatan (BBS)					- (0)				
		Way Kambas (WAY)					0 (1)				
	Lao People's Democratic Republic	Nakai Nam Theun (NAK)		1 (1)				0 (1)			
	Malaysia	Gua Musang (GMS)				- (0)	- (0)	- (0)	- (0)	- (0)	
		Kluang (KLU)						0 (1)		0.5 (2)	
	Myanmar	Alaungdaw Kathapa (ALW)					1 (2)			1 (1)	
		Shwe U Daung (SHW)					0 (1)			0 (1)	
	Thailand	Kuibiri (KUI)				- (0)	- (0)				
		Salakphra (SKP)				0 (1)	- (0)				
	Viet Nam	Cat Tien (CAT)					- (0)			1 (6)	

Table A2. List of covariates explored in this study

Coverage	Group	Name	Description	Time range	Source
Site	Physical/political	logarea	Log of site area	N/A	MIKE
Site	Physical/political	dist2border	Distance from site centroid to nearest intl. border	N/A	MIKE
Site	Elephants	est	Elephant population estimate	Latest avail.	IUCN/SSC AAED
Site	Elephants	pf	Probable fraction – precision of elephant population estimate	Latest avail.	IUCN/SSC AAED
Site	Elephants	dens	Elephant population density	Latest avail.	IUCN/SSC AAED (derived)
Site	Bioclimatic	npp	Net primary productivity	N/A	UMD CIESIN
Site	Bioclimatic	annrainfall	Mean annual rainfall	N/A	WorldClim
Site	Bioclimatic	rainfall_cv	Rainfall seasonality (coefficient of variation of monthly rainfall)	N/A	WorldClim
Site+buffer	Human	people	Human population numbers	2006	Landscan (ORNL)
Site+buffer	Human	hm_ftprnt	The Human Footprint (version 2)	N/A	WCS/CIESIN
Site+buffer	Land cover/use	lc_het_margalef	Margalef index of land use/ land cover type richness	N/A	GLCC (derived)
Site+buffer	Land cover/use	lc_het_menhinick	Menhinick index of land use/ land cover type richness	N/A	GLCC (derived)
Site+buffer	Land cover/use	lc_predom	Predominant land cover type (factor)	N/A	GLCC (derived)
Site+buffer	Land cover/use	crop_occurrence	Proportion of land covered by crops	N/A	FAO (derived)
Buffer	Land cover/use	major_landuse	Major land use in the buffer zone	N/A	FAO (derived)
Site+buffer	Land cover/use	land_degrad	Land degradation (based on %change in NDVI over 1981-2003)	2003	FAO
Site+buffer	Land cover/use	lstocksys_predom	Predominant livestock production system (factor)	N/A	FAO
Site+buffer	Land cover/use	cattle_dens	Cattle density	N/A	FAO
Site+buffer	Land cover/use	smll_rumin	Small ruminant (sheep and goat) density	N/A	FAO
Site+buffer	Land cover/use	poul_dens	Poultry density	N/A	FAO
Site+buffer	Land cover/use	lstock_dens	Livestock density (mean of cattle_dens, smll_rumin, poul_dens)	N/A	FAO (derived)
Site+buffer	Socio-economic	Infant_mort	Infant mortality	N/A	FAO
Site+buffer	Socio-economic	stunting	Prevalence of stunting (malnutrition) in children under 5	N/A	FAO
Site+buffer	Socio-economic	uw_kids	Proportion of underweight children	N/A	CIESIN
Country	Governance	va_est	Voice and accountability	2002-2009	World Bank - WGI
Country	Governance	ge_est	Government effectiveness	2002-2009	World Bank - WGI
Country	Governance	ps_est	Political stability and absence of violence	2002-2009	World Bank - WGI
Country	Governance	rl_est	Rule of law	2002-2009	World Bank - WGI
Country	Governance	rq_est	Regulatory quality	2002-2009	World Bank - WGI
Country	Governance	cc_est	Control of corruption	2002-2009	World Bank - WGI
Country	Governance	cpi	Corruption perceptions index	2002-2010	Transparency International

Coverage	Group	Name	Description	Time range	Source
Country	Socio-economic	avg_arms_per100	Small arms per 100 people	2005	Small arms survey
Country	Socio-economic	hdi	Hybrid human development index	2002-2010	UNDP
Country	Socio-economic	life_exp	Life expectancy	2002-2010	UNDP
Country	Socio-economic	gdp_pcap	GDP per capita	2002-2010	UNDP
Country	Socio-economic	edu_idx	Educational attainment index (literacy & school completion)	2002-2010	UNDP
Country	Socio-economic	inflation_gdp_defl	Inflation as measured by annual change in GDP deflator	2002-2009	World Bank
Country	Socio-economic	gdp_growth	Annual % growth in GDP	2002-2009	World Bank
Country	Socio-economic	popgth	Annual % human population growth	2002-2009	World Bank
Country	Socio-economic	pppxchg	Annual change in PPP (currency units per USD)	2002-2009	World Bank
Country	Socio-economic	oda	Overseas development aid received (annual % change)	2002-2008	World Bank
Country	Socio-economic	gci	Global Competitiveness Index	N/A	World Economic Forum
Country	Governance	org_crime	Level of organized crime	N/A	World Economic Forum
Country	Socio-economic	prop_rights	Protection of physical property rights	N/A	World Economic Forum
Country	Socio-economic	tourism_competiv	Tourism competitiveness	N/A	World Economic Forum
Country	Socio-economic	econ_freedom	Economic freedom	N/A	The Heritage Foundation
Country	Socio-economic	trade_freedom	Trade freedom	N/A	The Heritage Foundation
Country	Trade	tot_export_value	Total value of exports	2002-2009	World Bank
Country	Ivory trade	etis_leratio	ETIS Law enforcement ratio	2002-2009	ETIS
Global	Socio-economic	cn_gdpdefl	Inflation in China as measured by % change in GDP deflator	2002-2010	World Bank / IMF
Global	Socio-economic	cn_gdpgth	Annual % growth in China's GDP	2002-2010	World Bank / IMF
Global	Socio-economic	cn_hhcons	Annual % growth in private consumption (China)	2002-2010	World Bank/ Asian Dev. Bank
Global	Socio-economic	jp_hhcons	Annual % growth in private consumption (Japan)	2002-2010	World Bank
Global	Socio-economic	my_hhcons	Annual % growth in private consumption (Malaysia)	2002-2010	World Bank
Global	Socio-economic	ph_hhcons	Annual % growth in private consumption (Philippines)	2002-2010	World Bank
Global	Socio-economic	th_hhcons	Annual % growth in private consumption (Thailand)	2002-2010	World Bank
Global	Socio-economic	vn_hhcons	Annual % growth in private consumption (Vietnam)	2002-2010	World Bank