MANAGEMENT

Pilot study to validate PIKE-based inferences at site level

Hugo Jachmann

Bergstaat 77, 6174RP Sweikhuizen, The Netherlands
email: hugo.jachmann@gmail.com

Abstract

The primary objective of the Monitoring of Illegal Killing of Elephants (MIKE) programme is to monitor worldwide trends in elephant poaching. MIKE has been employing in its analyses the proportion of illegally killed elephants (PIKE) as a relative indicator of poaching levels. PIKE is subject to a number of potential biases that need to be understood to assess the validity of inferences made from analyses based on it. In four well-managed sites (Queen Elizabeth and Murchison Falls in Uganda, and Mole and Kakum in Ghana), a pilot study was carried out to examine the on-site reliability of PIKE. The detection probability of elephant carcasses was examined in relation to visibility (habitat types) on patrol, and PIKE results were compared with the results of a catch per unit effort (C/E) analysis. Due to sharply increased patrol coverage in three out of four sites, by 2011, the detection probability of elephant carcasses approached 1. PIKE, based on verified field data corrected for detection probability, compared well with data from the carcass sheets in the MIKE database. C/E results provided support for the on-site use of PIKE. Because the relationship between the C/E index and law-enforcement effort varied by site, which makes pooling of data complicated, for MIKE's purposes C/E analysis was not considered a practical tool with which to monitor worldwide elephant poaching. PIKE data on the other hand can be easily pooled, and the pooling may erode away some of its imperfections. PIKE was found to be superior to C/E analysis for a system like MIKE.

Additional key words: MIKE, elephant poaching, monitoring

Résumé

L'objectif principal du programme du Suivi de l'abattage illégal des éléphants (MIKE) est de faire le suivi des tendances mondiales du braconnage des éléphants. Dans ses analyses MIKE utilise la proportion des éléphants abattus illégalement (PIKE) comme un indicateur relatif du niveau de braconnage. PIKE est sujet à un certain nombre de partis pris potentiels. On doit comprendre ces partis pris afin d'évaluer la validité des conclusions faites à partir des analyses qui se basent sur PIKE. Sur quatre sites bien gérés (Queen Elizabeth et Murchison Falls en Ouganda, Mole et Kakum au Ghana), une étude pilote a été réalisée pour examiner la fiabilité de PIKE sur le site. La probabilité de détection des carcasses d'éléphants a été examinée par rapport à la visibilité (types d'habitats) en patrouille, et on a comparé les résultats de PIKE à ceux de l'analyse de la capture par unité d'effort (C/E). En raison de la forte intensification de la couverture de patrouille dans trois des quatre sites, jusqu'en 2011, la probabilité de détection des carcasses d'éléphants avoisinait 1. PIKE basée sur des données vérifiées, corrigée pour la probabilité de détection, s'est comparée bien aux fiches de carcasse dans la base de données de MIKE. Les résultats de l'analyse C/E ont appuyé l'utilisation de PIKE sur le site. Puisque la relation entre l'indice de l'analyse de C/E et l'effort de l'application de la loi variait selon le site, ce qui complique la mise en commun des données, pour les fins de MIKE, on ne considère pas l'analyse C/E d'être un outil pratique pour surveiller le braconnage des éléphants dans le monde entier. D'autre part, on peut facilement mettre en commun les données de PIKE, et la mise en commun peut éroder certaines de ses imperfections. On a donc trouvé que PIKE était meilleure que l'analyse C/E pour un système comme MIKE.

Mots clés supplémentaires: MIKE, braconnage des éléphants, monitoring

Introduction

The Monitoring of Illegal Killing of Elephants (MIKE) programme, approved in 1997 by the Convention on International Trade in Endangered Species (CITES) and ratified at the 11th Convention of Parties in 2000, was set up to monitor trends in elephant poaching so that decisions on elephant issues taken by CITES are based on sound information. Poaching trends are monitored in a sample of about 80 sites spread across the range of African and Asian elephants. The second objective of MIKE is to build capacity in range States to manage elephant populations. The MIKE programme was designed to analyse data on elephant mortality and law-enforcement effort, obtained primarily from law-enforcement patrols local patrol staff routinely conduct at designated MIKE sites. While a reasonable amount of data on elephant mortality has been compiled since MIKE's inception in 1997, it has not been possible to obtain law-enforcement effort data from the vast majority of MIKE sites, primarily due to a number of operational difficulties.

In 2008 the MIKE programme initiated the deployment of MIST (Management Information System), a comprehensive field data management information system. It was anticipated that by better serving the protected area management needs of range states (and not just those of MIKE), MIST would help to improve the quantity and quality of data flowing to MIKE. Although the goal of obtaining comprehensive law-enforcement data maintains a high priority on the agenda for MIKE, and while MIST deployment has been progressing well, most sites are not yet ready to deliver effort data.

In view of the lack of effort data, and to meet its reporting obligations to the CITES parties, 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 a relative indicator of elephant poaching levels that does not require adjustment by level of law-enforcement effort but is subject to a number of potential biases. These biases need to be understood in order to assess the validity of inferences made from analyses based on PIKE.

This paper presents the results of a pilot study carried out from March to April 2012 to examine the reliability of the within-site sample used to compute PIKE. Mainly due to time constraints, this pilot study was not expected to result in conclusive data on PIKE's reliability, but to provide the foundation of a comprehensive study planned for phase 3 of the MIKE programme.

We began by looking at the detection probability of elephant carcasses in relation to visibility or habitat type, to compare PIKE calculated from the raw carcass data with that corrected for differential detection probabilities. We then examined the detection probability in relation to the cause of death, e.g. natural deaths, illegally killed, and those in the unknown category. Because law-enforcement effort data were available for the four sites that were selected for this study, we compared PIKE with the results of a catch per unit effort analysis (C/E), first to look at the pitfalls and merits of both methods, and second to examine whether C/E results provided support for PIKE-based inferences at the site level. We concluded by comparing PIKE with absolute elephant mortality.

Study areas

For this pilot study we focused on relatively small populations in relatively small but well-managed sites (≤ 4,500 km²), representative of the main habitat types found within the elephant range (savannah and forest), with MIST as the main tool for monitoring law enforcement. Considering these broad criteria, we selected four sites:

1. Kakum Conservation Area (CA) in Ghana comprises Kakum National Park (NP) and the adjoining Assin Attandanso Resource Reserve, both covered by moist evergreen forest of the Upper Guinea forest belt, totalling 366 km². The last count

in 2004 returned 164 elephants (Danquah 2004).
2. Mole NP in Ghana is covered by Guinea savannah woodland with gallery forests along the main rivers; it totals 4,504 km². The last count in 2006 returned 401 elephants (Bouché 2007).
3. Murchison Falls NP in Uganda comprises open savannah and woodland, with gallery forest along the main rivers, totalling 3,893 km². The last count in 2010 returned 904 elephants (Rwetsiba & Wanyama 2010).
4. Queen Elizabeth NP in Uganda has a mosaic of open savannah, wetlands and semi-deciduous forest, covering 2,294 km². The last count in 2010 returned 2,502 elephants (Plumptre et al. 2010).

Methods and materials

Detection probability

In each of the four sites, we estimated the maximum mean strip width with regard to detecting elephant carcasses. Using a vegetation map combined with maps of the road system and elephant distribution, we applied a simple general stratification process based on three factors: elephant distribution, ratio of dominant vegetation types, and presence of roads. Layout of transects followed elephant distribution and was in proportion to the distribution of dominant vegetation types, but due to time constraints accessibility (road network) remained an important factor. Each of the roads selected was sampled both left and right at exactly 1-km intervals for the three savannah sites, and at 50-m intervals at Kakum, by sending a patrol staff at a perpendicular walk away from the road until roughly 1.3 m of the person became invisible to the observers (only head and shoulders visible). However, this approach may result in a biased estimate of strip width: first, because a moving object is easier to detect than a stationary one, and second, because an object moving away from focused observers may be visible longer than stationary objects at shorter distances. These sources of bias are interrelated and may lead to an overestimate of strip width and an underestimate of carcass densities. There was simply not enough time to carry out a more complicated, bias-free design using stationary objects. Moreover, carcasses in an advanced state of decay, such as merely bones and some skin remaining, will have a lower detection rate and therefore narrower strip width, while strip width will also be narrower during the peak and late wet season.

To test for bias due to the object moving away from the observers, once the patrol staff had moved completely out of view, without informing the observers, he walked to either the left or the right for a particular distance, then back to the road. The perpendicular distance to the location where head and shoulders of the person re-appeared as first detected by the observers was measured and compared with the distance obtained when moving away from the road. Distances were measured with a Garmin GPSMap 60CSx using the 3D setting to limit the error to 1 to 2 m. Shorter distances in the Kakum forest, where satellite coverage was poor, were obtained with a tape measure.

After inspection of the underlying distribution of each data set, a Wilcoxon matched pairs test was done to test for differences between the moving-away and the moving-back data. When the difference was not significant, the two data sets were combined to estimate strip width. The resulting estimate of strip width should be considered an approximation of the maximum mean strip width for the six-month period covering the dry season. The mean for the six-month wet season was approached by comparing unburned areas with burned areas of the same vegetation type, wherever possible by comparing left and right at the same location for sites that were nearly completely burned (Murchison Falls and Mole). For Queen Elizabeth, of which approximately 35% was burned (estimate by management), we used measurements in burned areas to estimate dry-season mean strip width and those in unburned areas to estimate the mean for the wet season. We estimated the size of the area patrolled each year by multiplying the maximum mean strip width with the total distance patrolled, while correcting for the six-month period with lower visibility. The probability of detecting an elephant carcass on patrol was estimated by the proportion of the site covered by patrols for a particular year. Elephant carcasses found by patrol teams, for both natural and illegal or unknown deaths, except for those detected through the presence of vultures, were corrected for the area not covered by patrols in a particular year using the inverse of the detection probability. Carcasses corrected for detection probability were enumerated with those detected through information a priori (informers, general public, tourists and researchers) or through the presence of vultures in savannah sites (strip width between 1 and 3 km).

Using MIST data, we examined patrol distribution and the distributions of live and dead elephants for each year. Testing for randomness of patrols was not necessary, because the four sites selected are relatively small and were intensively patrolled on foot, applying a patrol strategy that aimed for total coverage per year (Murchison Falls and Mole) or per quarter (Kakum and Queen Elizabeth) whenever practically feasible. The spatial distribution of illegally killed elephants was compared with that of elephants that died of natural causes.

The corrected PIKE was then compared with the raw PIKE as estimated from the detailed carcass data from the MIKE database.

Carcass detection probability and cause of death

For relatively small sites with small elephant populations under sound management, the information provided by the protected area staff and MIKE carcass forms on the mode of detection of each carcass, combined with area coverage by patrols, gave approximations of the mean detection probability over a six-year period for each class of carcass, i.e. natural deaths, illegally killed elephants and unknown.

Comparing C/E results with PIKE

For each of the four sites, annual effort data were available in the form of distance covered on patrol (km) for the period from 2006 to 2011. The relationship between conventional patrol effort and poaching, which includes elephant poaching, follows a detection/deterrence curve, its shape determined by a number of factors such as size of the elephant population, size of the area, patrol effort and coverage, which includes the average size of patrol groups, poaching rate and visibility (Jachmann 1998, 2008). For example, in terms of visibility or habitat type, the curve peaks at much lower efforts in wide, open areas (grass-dominated savannah) compared with areas with low visibility, such as forest (Jachmann 2008). Initially, increasing patrol effort results in increased detection of poaching activities, resulting in a near linear to exponential ascending detection part of the curve that peaks at a short consolidation phase whereby effort and poaching levels are in equilibrium, followed by a descending deterrence phase, whereby the catch declines with increasing effort. As an example, the relationship between serious poaching offences encountered per effective patrol man-day per month (catch) and increasing patrol effort (effective patrol man-days per month) for three forest sites in Ghana combined from 2005 to 2007 (Kakum, Ankasa and Bia Conservation Areas) is provided (Fig. 1). This relationship was best described by a third degree polynomial: $Y = -1E - 0.7x^3 + 0.0003x^2 - 0.0841x + 63.3020$, $P < 0.001$ (Jachmann 2008). Prior to comparing C/E results with PIKE, we had to examine where the C/E data sets of the four sites were located on their respective detection/deterrence curves. We started by plotting patrol coverage and C/E elephants found killed illegally over time for each site. Then we inspected the relationships between C/E and PIKE and compared their trends. However, we should note that the C/E index is not independent from PIKE, because both have elephants killed illegally in the nominator. Therefore, results and discussion will merely focus on pitfalls and merits of both methods.

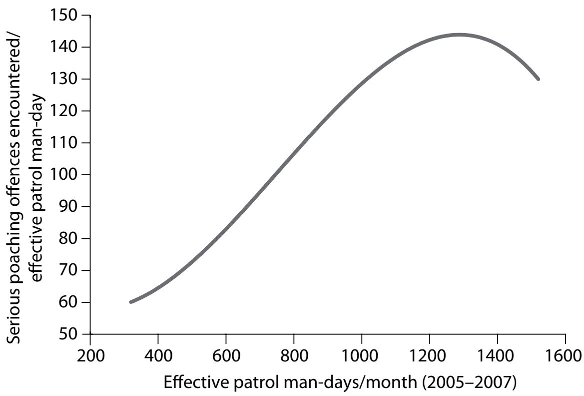

Figure 1. Relationship between serious poaching offences encountered per effective patrol man-day/month and effective patrol man-days per month for three forest sites combined for 2005 to 2007 (Jachmann 2008).

Comparing absolute mortality with PIKE

For the years 2006 to 2011, PIKE corrected for detection probability was compared with absolute elephant mortality (total mortality) for the four sites combined. Because few elephant counts had been done in Ghana, we used the results of the most recent ones (see section on Study areas above) to estimate total annual mortality for all sites combined.

Results

Estimation of mean maximum strip width

Queen Elizabeth National Park, Uganda

The away and the back data followed a log-normal distribution (Fig. 2), but with significantly different means (Wilcoxon matched pairs test (T = 367.50, Z = 6.54, P = 0.0000), with the mean strip width for the back data being 25% lower than that for the away data, and the variance 24% lower (mean away = 136.53 ± 146.65, range 11–622; mean back = 102.44 ± 111.72, range 8–525). Due to bias in the away data, the back data were used to estimate the mean maximum strip width. The sample of 88 back measurements showed that 39% of the site was burned, which was close to the estimate provided by management. For burned areas, the mean strip width was 164.85 m, and for unburned areas it was 64.07 m. The mean maximum strip width was (6 x 329.70 + 6 x 128.14)/12 = 229 m.

Murchison Falls National Park, Uganda

The away and the back data both followed the same approximate log-normal distribution (Fig. 3) with similar means (Wilcoxon matched pairs test (T = 1373.00, Z = 1.84, P = 0.0662), (mean away = 158.01 ± 85.92, range 31–403; mean back = 151.70 ± 87.36, range 18–404). The two sets of data were combined to estimate the mean maximum strip width. The sample of 176 strip width measurements showed that 93% of the site was burned. Corrected for the six-month wet season (33.4% lower visibility than dry season), mean maximum strip width was (6 x 310 + 6 x 206)/12 = 258 m.

Mole National Park, Ghana

The away and the back data both followed an approximate log-normal distribution, but with significantly different means (Wilcoxon matched pairs test (T = 387.50, Z = 7.29, P = 0.0000), (mean away = 67.67 ± 30.55, range 22–241; mean back = 52.95 ± 27.74, range 18–216). The back data were 21.8% lower than the away data and were used to estimate the mean maximum strip width (Fig. 4). Our sample of 100 back measurements showed that 96% of the site was burned. Although based on a small sample size (n = 4), visibility in unburned areas (wet season) was roughly 40% lower than in burned areas (dry season). Corrected for the six-month wet season period with lower visibility, the mean maximum strip width was (6 x 106 + 6 x 42)/12 = 74 m.

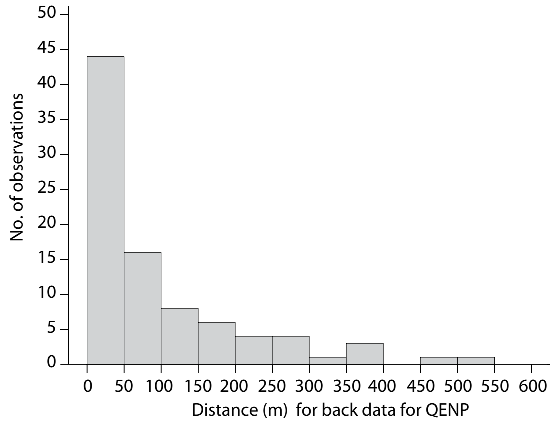

Figure 2. Frequency diagram and distribution of back data for Queen Elizabeth NP (QENP).

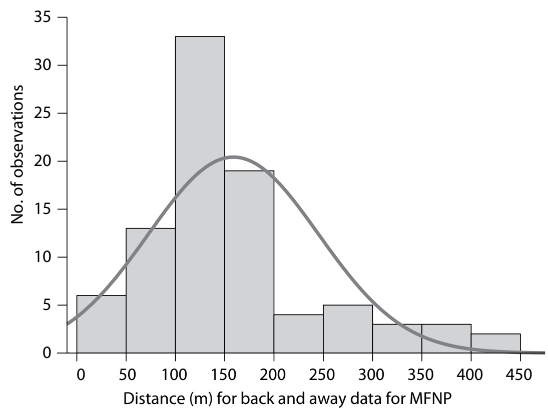

Figure 3. Frequency diagram and distribution of away data and back data combined for Murchison Falls National Park (MFNP), North Bank.

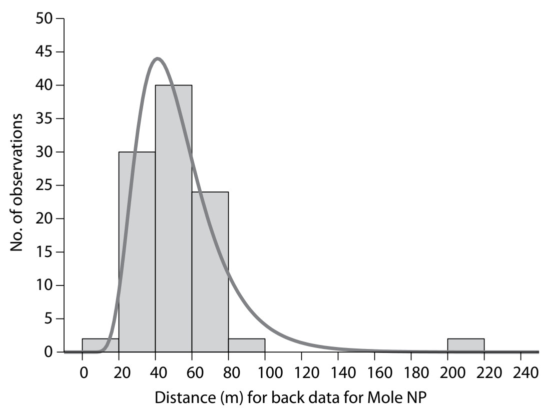

Figure 4. Frequency diagram and distribution of back data for Mole NP.

Kakum Conservation Area, Ghana

The away and the back data both followed an approximate log-normal distribution, but with significantly different means (Wilcoxon matched pairs test (T = 338.50, Z = 2.21, P = 0.0273), (mean away = 20.68 ± 8.23, range 3–37; mean back = 17.56 ± 7.96, range 3–45). The back data (Fig. 5) were 15.1% lower than the away data and were used to estimate the mean maximum strip width (2 x 17.56 m) = 35 m.

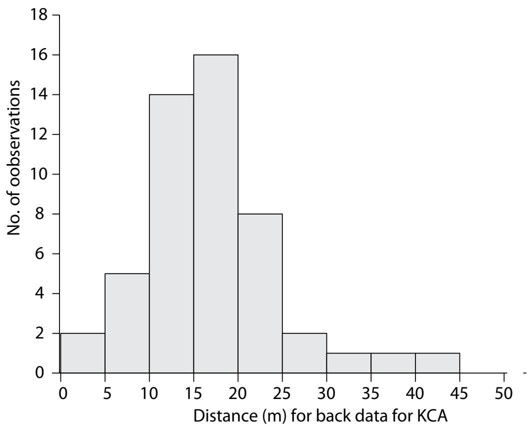

Figure 5. Frequency diagram and distribution of back data for Kakum Conservation Area (KCA).

Summary of site mean maximum strip widths

Approximate log-normal distributions of strip width for the four sites show the pronounced differences in visibility profiles, thus detection probabilities (Fig. 6). Kakum CA consists predominantly of moist secondary forest with pockets of primary forest on mildly undulating terrain; it had a mean maximum strip width of 35 m. Mole NP consists primarily of woodland savannah on mildly undulating terrain; it had a mean strip width of 74 m. Queen Elizabeth NP was covered by a mosaic of different vegetation types but was dominated by open grassland on mildly undulating terrain; mean strip width was 229 m. Murchison Falls NP consisted primarily of wide open grassland with *Borassus aethiopum* and *Acacia* woodlands on mildly undulating terrain but with sharp ridges; mean strip width was 258 m.

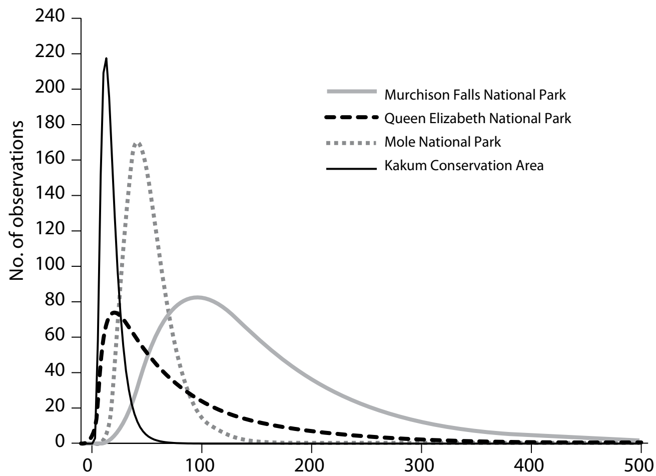

Figure 6. Log-normal distribution of strip width data for the four sites.

Patrol coverage

Park management in Queen Elizabeth NP aims to have patrols cover the entire site on a quarterly basis, without duplicating a single patrol path. Although management of Murchison Falls NP aims for patrols to cover the entire park annually but with emphasis on the North Bank, only 30–40% of all patrol data were entered into MIST. There was no information on duplicate patrol routes. Park management in Mole NP aims to have patrols cover the entire site annually, with all patrols using a GPS and all patrol data incorporated in MIST. As the site is savannah with easy access throughout, according to management, duplicate patrol routes are rare. Management of Kakum aims to have patrols cover the entire site every quarter. Although Kakum is a forest site, where patrols tend to use existing elephant trails, management enforces strict rules that elephant trails or other existing pathways are not to be used during patrols. This implies that even at this patrol density, duplicate routes may be rare. Because all four sites were completely covered at least annually, there was no need to perform tests of randomness of patrol routes.

Estimation of detection probability

Distances and areas patrolled, detection probabilities and correction factors for each of the four sites are provided in Tables 1 to 4. In Murchison Falls NP, numbers of patrols using a GPS, hence patrol data entered into the MIST system, varied between roughly

30% and 40%. Moreover, before 2011 few patrols were carried out on the South Bank of the park. Therefore, we may conclude that the North Bank, which is also the main tourist area, was always entirely covered. Thus detection probabilities for the years 2006 to 2011 (Table 2) are most likely much higher, approaching 1 in most years, which implies that the carcass data did not need to be corrected for detection probability. However, due to limited incorporation of patrol data into the MIST system, results for Murchison Falls should be interpreted with caution.

For each of the four sites we calculated patrol density (coverage) in terms of distance covered on patrol (km) per square kilometre of site. By plotting detection probability against patrol density, we estimated the minimum patrol density for which the probability of detecting an elephant carcass approached 1.00 (Tables 1 to 4). Using grassland cover in each of the four sites

Table 1. Distance and area patrolled, and detection probability of carcasses in Queen Elizabeth NP, Uganda

Year	Distance patrolled (km)	Area patrolled (km²)	Detection probability	Correction factor
2006	7,245	1,659	0.72	1.39
2007	5,531	1,267	0.55	1.82
2008	7,243	1,659	0.72	1.39
2009	7,809	1,788	0.78	1.28
2010	10,439	2,390	1.00	1.00
2011	10,339	2,368	1.00	1.00

The area site is 2,294 km², strip width 0.229 km for all years.

Table 2. Distance and area patrolled, and detection probability of carcasses in Murchison Falls NP, Uganda

Year	Distance patrolled (km)	Area patrolled (km²)	Detection probability	Correction factor
2006	6,333	1,634	1.00	1.00
2007	4,228	1,091	0.73	1.37
2008	6,212	1,603	1.00	1.00
2009	4,744	1,224	0.82	1.22
2010	2,989	771	0.51	1.96
2011	4,706	1,214	0.81	1.24

Area site is 1.500 km², strip width 0.258 km for all years.

Table 3. Distance and area patrolled, and detection probability of carcasses in Mole NP, Ghana

Year	Distance patrolled (km)	Area patrolled (km²)	Detection probability	Correction factor
2006	58,866	4,356	0.97	1.03
2007	48,314	3,575	0.79	1.27
2008	65,832	4,872	1.00	1.00
2009	81,437	6,026	1.00	1.00
2010	107,777	7,976	1.00	1.00
2011	122,528	9,067	1.00	1.00

Area site is 4,505 km², strip width 0.074 km for all years.

Table 4. Distance and area patrolled, and detection probability of carcasses in Kakum CA, Ghana

Year	Distance patrolled (km)	Area patrolled (km²)	Detection probability	Correction factor
2006	8,693	304	0.83	1.21
2007	9,206	322	0.88	1.14
2008	12,765	447	1.00	1.00
2009	12,170	426	1.00	1.00
2010	14,696	514	1.00	1.00
2011	10,857	380	1.00	1.00

Area site is 366 km², strip width 0.035 km for all years.

as a measure of visibility, with 0 grassland cover ranked as 10 and 100% grassland cover ranked as 0, we plotted patrol density at detection probability 1.00 against visibility (Table 5, Fig. 7).

The relationship between patrol density (coverage) at which the detection probability approaches 1.00, and visibility in terms of percentage of grass cover was negative exponential ($y = 1.384 + e^{(3.166 - 0.047x)}$; $R = 0.97$, variance explained = 94.356%), most likely running asymptotic at roughly 60% grass cover (Fig. 7). Although this relationship is based on the data of four sites only, it suggests that independent of grass cover, thus visibility, a minimum patrol density of roughly 4 patrol km/km² of site is required (Fig. 7).

Table 5. Visibility (percentage of grassland cover) and minimum patrol density (patrol distance (km/km²) for a carcass detection probability of 1.00, for four sites

Site	Grassland (%)	Rank	Patrol density (km/km²)
Murchison Falls NP	60	4	4.0
Queen Elizabeth NP	40	6	4.4
Mole NP	10	9	14.5
Kakum CA	0	10	29.5

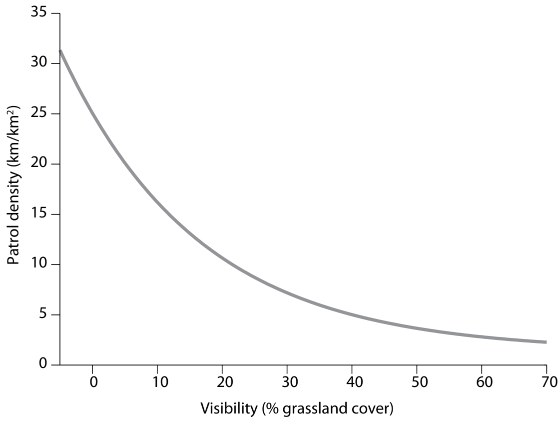

Figure 7. Patrol density at detection probability 1.00 against visibility (percentage of grass cover) for four sites.

Mode of detecting carcasses

For each carcass found in the four sites and their immediate surroundings, the mode of detection was obtained from the MIKE carcass sheets, complemented with information provided by management and patrol staff (Tables 6 to 9). For natural, illegal and unknown deaths, carcasses were divided into three categories: those found with prior information through the intelligence network, tourists, general public and researchers; those found on regular foot patrols; and those found through the presence of vultures. Because the presence of vultures increased strip width to anywhere between 1 and 3 km, these carcasses did not require correction for detection probability. With the exception of Murchison Falls, carcasses found during regular foot patrols were corrected for detection probability. Because the MIST data on patrol statistics for Murchison Falls were not reliable, carcass data could not be corrected for detection probability. However, as concluded in a previous section, detection probability of all classes of carcasses must have been close to 1.00, and for Murchison Falls we will merely compare PIKE derived from the detailed carcass data (MIKE) with the raw but verified field data.

Spatial distribution of carcasses

For Kakum CA and Mole NP in Ghana, numbers of carcasses were too low to examine spatial distribution. Elephant carcasses found in Queen Elizabeth between 2002 and 2011 were evenly distributed over the park, much in line with elephant distribution, while the cause of death was of no influence on the spatial distribution of carcasses, with natural, illegal and unknown deaths evenly spread over the site. Although inspection of field data on site showed that more or less the same applied to Murchison Falls, most carcass data were missing in the MIST database.

Corrected PIKE versus MIKE PIKE

For Queen Elizabeth, Murchison Falls and Mole NPs, PIKE obtained from verified field data and corrected for detection probability closely followed PIKE calculated from the detailed carcass sheets obtained from MIKE/CCU (Table 10, Figs. 8–10).

Due to the small numbers of carcasses and minor inaccuracies in reporting from the field for Kakum Conservation Area, PIKE obtained from verified field data and corrected for detection probability deviated from PIKE calculated from the detailed carcass sheets (Fig. 11).

Cause of death and detection probability

The samples were too small to compare detection probabilities for the three different categories of carcasses for the four different sites. However, for the four sites combined, the mean detection probability for elephants that died of natural causes (0.887 +/- 0.125

Table 6. Carcass numbers by mode of detection for Queen Elizabeth NP, with carcasses corrected for detection probability in brackets

	Carcass numbers per year					
Mode of detection	2006	2007	2008	2009	2010	2011
Legal	0	0	0	0	0	1
Natural						
Prior information	1	0	2	1	1	0
Regular patrol	2 (2.8)	0	2 (2.8)	1 (1.3)	0	0
Vultures	0	0	0	0	1	0
Illegal						
Prior information	0	0	0	1	1	7
Regular patrol	2 (2.8)	2 (3.6)	0	2 (2.6)	3	12
Vultures	0	0	0	0	0	1
Unknown						
Prior information	1	4	1	1	1	0
Regular patrol	0	2 (3.6)	1 (1.4)	2 (2.6)	4	4
Vultures	0	0	0	0	0	0
Total	6 (7.6)	8 (11.2)	6 (7.2)	8 (9.5)	11	25

Table 7. Carcass numbers by mode of detection for Murchison Falls NP, 2006–2011

	Carcass numbers per year					
Mode of detection	2006	2007	2008	2009	2010	2011
Legal	0	0	0	1	0	0
Natural						
Prior information	0	0	0	0	1	0
Regular patrol	0	1	1	0	0	4
Vultures	0	0	0	0	0	0
Illegal						
Prior information	0	0	0	1	0	7
Regular patrol	1	0	2	2	3	9
Vultures	0	0	0	0	0	0
Unknown						
Prior information	0	0	0	2	1	0
Regular patrol	1	0	1	0	2	4
Vultures	0	0	0	0	0	0
Total	2	1	4	6	7	24

Table 8. Carcass numbers by mode of detection for Mole NP, with carcasses corrected for detection probability in brackets

	Carcass numbers per year					
Mode of detection	2006	2007	2008	2009	2010	2011
Legal	0	0	0	0	0	0
Natural						
Prior information	0	0	0	0	0	0
Regular patrol	0	0	0	0	0	0
Vultures	0	0	0	0	0	0
Illegal						
Prior information	0	0	0	0	0	0
Regular patrol	2 (2.1)	2 (2.5)	3	0	2	0
Vultures	0	1	0	0	0	0
Unknown						
Prior information	0	1	0	0	0	1
Regular patrol	0	1 (1.3)	1	0	0	0
Vultures	0	0	0	0	0	1
Total	2 (2.1)	5 (5.8)	4	0	2	2

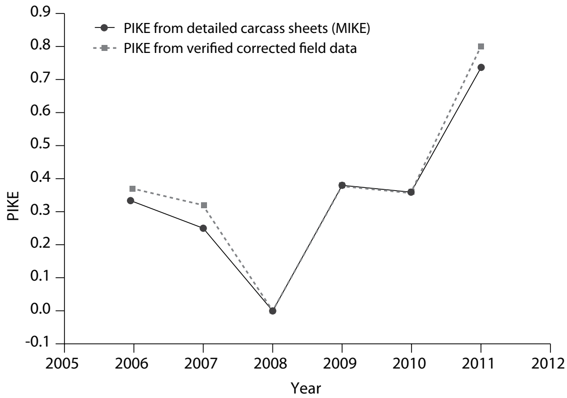

Figure 8. Comparison of proporation of illegally killed elephants (PIKE) from detailed carcass sheets (MIKE/CCU) with verified field data, corrected for detection probability, for Queen Elizabeth NP.

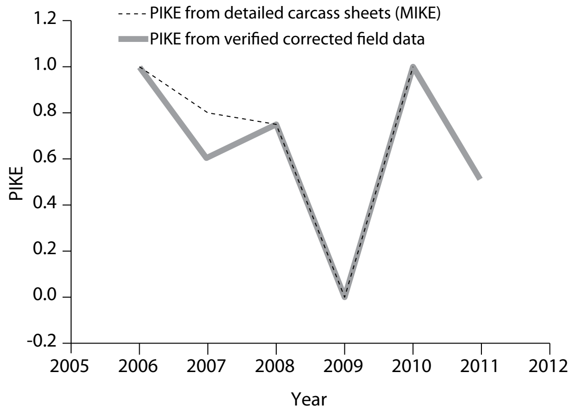

Figure 10. Comparison of proporation of illegally killed elephants (PIKE) from detailed carcass sheets (MIKE/CCU) with verified field data for Mole NP.

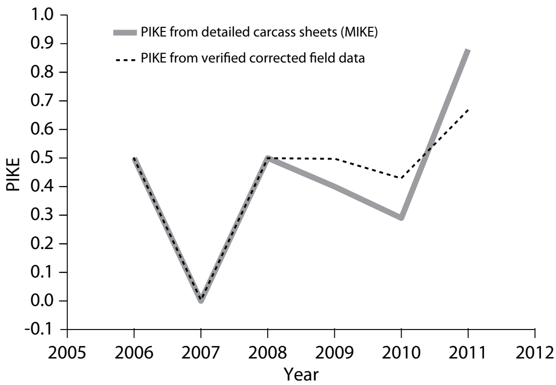

Figure 9. Comparison of proporation of illegally killed elephants (PIKE) from detailed carcass sheets (MIKE/CCU) with verified field data, for Murchison Falls NP.

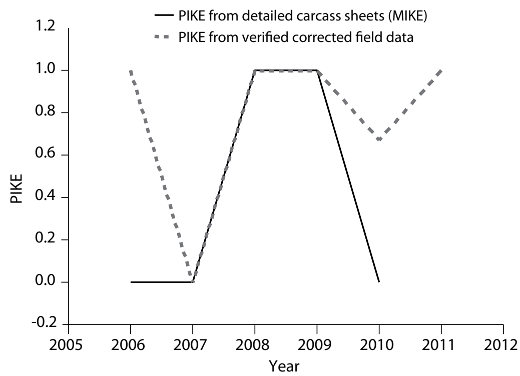

Figure 11. Comparison of proporation of illegally killed elephants (PIKE) from detailed carcass sheets (MIKE/CCU) with verified field data, corrected for detection probability, for Kakum Conservation Area.

Table 9. Carcass numbers by mode of detection for Kakum CA, with carcasses corrected for detection probability in brackets, 2006–2011

	Carcasses numbers					
Mode of detection	2006	2007	2008	2009	2010	2011
Legal	0	0	0	0	0	0
Natural						
Prior information	0	0	0	0	0	0
Regular patrol	0	0	0	0	1	0
Vultures	0	0	0	0	0	0
Illegal						
Prior information	0	0	1	0	1	0
Regular patrol	1 (1.2)	0	0	1	1	1
Vultures	0	0	0	0	0	0
Unknown						
Prior information	0	1	0	0	0	0
Regular patrol	0	0	0	0	0	0
Vultures	0	0	0	0	0	0
Total	1 (1.2)	1	1	1	3	1

Table 10. Comparing PIKE from detailed carcass sheets with verified field data corrected for detection probability

PIKE comparison	2006	2007	2008	2009	2010	2011
Queen Elizabeth NP						
Carcass sheets	0.33	0.25	0	0.38	0.36	0.74
Field data	0.37	0.32	0	0.38	0.36	0.80
Murchison Falls NP						
Carcass sheets	0.50	0	0.50	0.40	0.29	0.88
Field data	0.50	0	0.50	0.50	0.43	0.67
Mole NP						
Carcass sheets	1.00	0.80	0.75	0	1.00	–
Field data	1.00	0.60	0.75	0	1.00	0.50
Kakum CA						
Carcass sheets	0	0	1.00	1.00	0	–
Field data	1.00	0	1.00	1.00	0.67	1.00

– = no data

(SD)) was identical to that for those killed illegally (0.887 +/- 0.151) (Table 11). Detection probability for carcasses in the 'unknown' category was slightly higher (0.906 +/- 0.157) than in the other two categories (Table 11), and significantly different from those that died of natural causes (sign test, $Z = 2.846$, $P = 0.004$), but not from those killed illegally ($Z = 0.267$, $P = 0.789$). This difference stems from the fact that 37% of the carcasses in the unknown category were found through information systems (intelligence networks, tourists, researchers, or general public), which compares with 29% of those that died of natural causes. Because the majority of carcasses in the unknown category were old, the cause of death was difficult to determine, but there had been ample time for these carcasses to be detected through another information system.

Comparing elephants found killed illegally/ patrol km (C/E) with PIKE

For this entire section, elephants found killed illegally by patrols includes those found through information channels, while PIKE was calculated from the raw carcass sheets, validated in the field, and corrected for detection probability. Elephant carcasses found by patrols using prior information only involved a few years, mostly concerning 2011 for the two sites in Uganda and two carcasses in Kakum, while analyses omitting these carcasses gave identical results. For the period 2006 to 2011, the size of patrol groups was between about four and five for each of the four sites. Throughout this section, patrol density and patrol coverage are used alternately, but both apply to patrol km/km² of site. Furthermore, as discussed in a previous section, the C/E index and PIKE are not independent, because both have elephants killed illegally in the nominator. Taking into account differences in habitat types, hence visibility, we were able to compare patrol density (coverage) in terms of patrol km per km² of site (Fig. 12).

Patrol density required for a carcass detection probability of 1 will be lower than that required to deter poachers from entering a conservation area. Information on patrol density merely provided an indication on where approximately the C/E results were located on their respective detection/deterrence curves (see Fig. 1). With C/E results located around the peak and descending part of the curve, comparing with PIKE may give unreliable results. Moreover, PIKE, given stable natural and legal mortality, follows

Table 11. Detection probability by cause of death for four sites

Site	Cause of death and detection probability		
	Natural	Illegal	Unknown
Queen Elizabeth National Park	0.88	0.94	0.92
Murchison Falls National Park	0.85	0.86	0.84
Mole National Park	–	0.99	0.98
Kakum Conservation Area	1.00	0.97	1.00
Combined +/– SD	0.887 +/– 0.125	0.887 +/– 0.151	0.906 +/– 0.157

– = no data

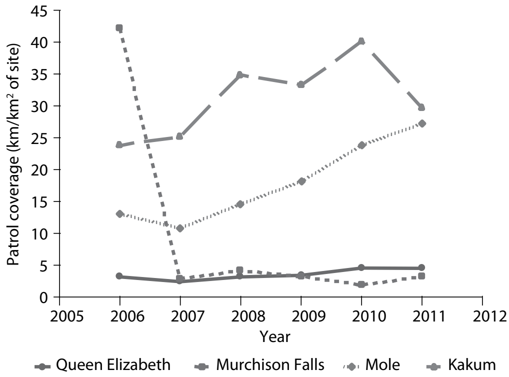

Figure 12. Patrol density (coverage) in patrol km/km² of site for Queen Elizabeth and Murchison Falls NPs in Uganda, and Kakum Conservation Area and Mole NP in Ghana, 2006–2011.

an asymptotic function, gradually slowing down at higher levels of poaching, and levelling off when it approaches 1 (Jachmann 2012). Therefore, even when C/E results are located on the mostly linear ascending part of the curve, when comparing these results with PIKE values > 0.7 (Jachmann 2012), they may not be reliable. During the study period, patrol density (coverage) in Queen Elizabeth slowly increased but remained under 5 km/km² of site, whereas coverage in Murchison Falls sharply dropped from more than 40 km/km² in 2006 to less than 5 km/km² in 2007, and remained well below 5 km/km² up to 2011 (Fig. 12). Due to anomalies in data collection and incorporation into the MIST system, as outlined above, the results for Murchison Falls National Park should be interpreted with caution. In Mole, patrol density steeply increased from slightly below 15 km/km² in 2006 to about 27 km/km² of site in 2011, while Kakum showed a similar steep increase from about 14 km/km² in 2006 to about 40 km/km² of site in 2010, and then sharply dropped to about 29 km/km² in 2011 (Fig. 12).

With mean maximum strip width used as a measure of visibility, Mole, being dominated by woodland savannah, had more than twice the visibility of the Kakum forest environment (0.074/0.035 = 2.11), and therefore theoretically Kakum required more than twice the patrol coverage of Mole for a similar deterrence effect. Murchison Falls and Queen Elizabeth, dominated by grassland savannah, had respectively 3.49 and 3.10 times better visibility than Mole and therefore theoretically required only one-third the patrol coverage of Mole for a similar deterrence effect. However, in 2011, Mole had more than five times the patrol density of Queen Elizabeth and hardly any elephant poaching, with C/E most likely in the deterrence part of the curve. On the other hand, effort in Kakum, being a forest area with low visibility but high patrol density, may have been along the top of the curve, with parts in the ascending detection phase. In Queen Elizabeth and Murchison Falls, effort was most likely still in the mostly linear ascending part of the curve. With only 30–40% of patrol data entered in MIST, comparing C/E results with PIKE for Murchison Falls may give unreliable results, but those for Queen Elizabeth may compare well.

For Queen Elizabeth NP, the C/E trend in terms of elephants found killed illegally/patrol km roughly follows that of PIKE (Fig. 13). Because the data sets were small, the underlying distributions of C/E and PIKE were not significantly different from normal (Kolmogorov-Smirnov test; C/E, $d = 0.432$, $P < 0.2$; PIKE, $d = 0.272$, $P > 0.2$), and the linear relationship was significant at $P = 0.012$ (Fig. 14). As an additional test, the Spearman rank correlation was also significant at $P < 0.05$ ($r = 0.943$). For Queen Elizabeth, C/E analyses provided support for the use of PIKE to monitor elephants killed illegally, albeit at relatively low levels of patrol density and at relatively low levels of elephant poaching.

For Murchison Falls NP, albeit with strong divergence of individual data points, both the C/E index and PIKE showed an upward trend in elephant poaching from 2007 onwards (Fig. 15). Due to this divergence in data points, the relationship between the C/E index and PIKE was not significant.

For Mole NP, with the exception of 2006 and 2007, the trend of the C/E index roughly followed that of

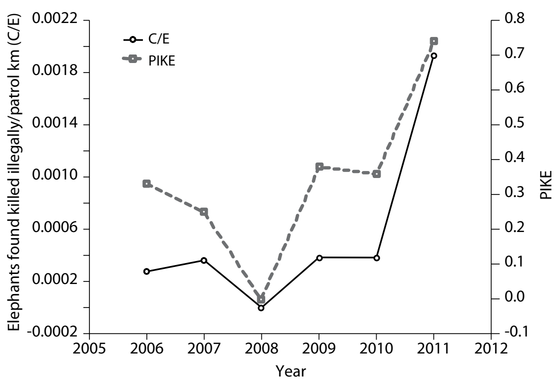

Figure 13. Comparison of the trend in C/E with that of proportion of illegally killed elephants (PIKE) for Queen Elizabeth NP, 2006–2011.

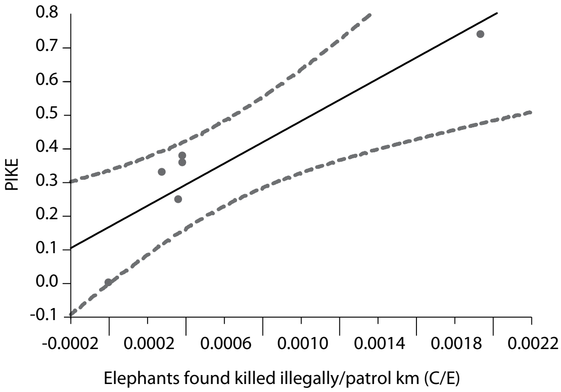

Figure 14. The relationship between proportion of illegally killed elephants (PIKE) and C/E for Queen Elizabeth NP, 2006–2011 (broken lines represent the 95% confidence limits).

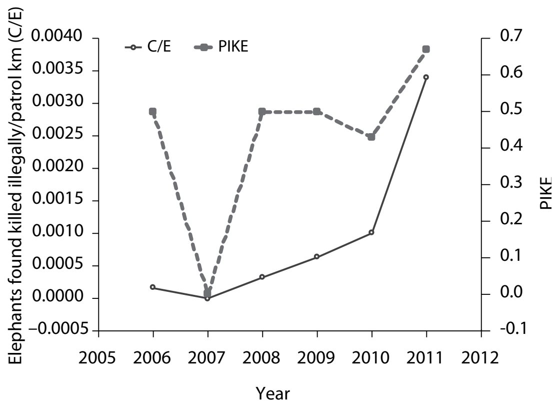

Figure 15. Comparison of the trend in C/E with that of proportion of illegaly killed elephants (PIKE) for Murchison Falls NP, 2006–2011.

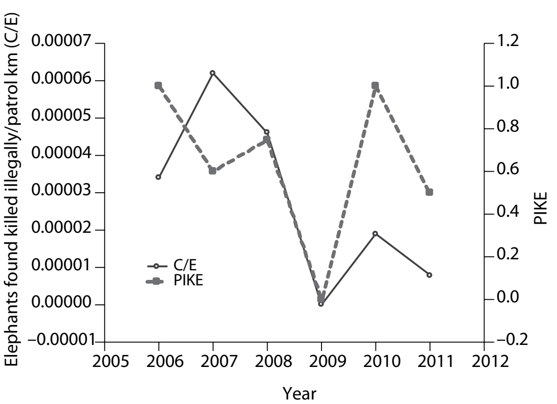

Figure 16. Comparison of the trend in C/E with that of proportion of illegaly killed elephants (PIKE) for Mole NP, 2006–2011.

PIKE (Fig. 16). Consistently high and increasing patrol coverage deterred most elephant poaching, resulting in small numbers of carcasses with C/E data mainly distributed over the peak and descending deterrence parts of the curve, causing high variability (Fig. 16). The relationship between the C/E index (elephants found killed illegally/patrol km) and PIKE was not significant but otherwise provided a textbook example of a detection/deterrence curve (Fig. 17).

For the Kakum Conservation Area, with the exception of 2010, the trend in PIKE closely followed that of the C/E index (Fig. 18). However, the relationship between the C/E index and PIKE was not significant. Throughout the study period, patrol coverage in Kakum was sufficiently high to deter most elephant poaching, which resulted in few elephants killed illegally, a PIKE data set containing mostly ones and zeros, and C/E data distributed over the peak and ascending detection parts of the detection/deterrence curve. In general terms, the trend in C/E for Kakum supports the use of PIKE for monitoring elephant poaching.

For Queen Elizabeth, Mole and Kakum combined, with the exception of 2007 the trend in PIKE was similar to that of the C/E index (Fig. 19). The underlying distributions of C/E and PIKE were not significantly different from normal (Kolmogorov-Smirnov test: C/E, d = 0.223, $P > 0.2$; PIKE, d = 0.164, $P > 0.2$), but due to the divergence in data points for 2007, the linear relationship was barely significant at the 10% level (Fig. 20; $P = 0.100$). If 2007 is omitted, a highly significant linear relationship emerges ($P = 0.0137$).

In summary, because the shape of the detection/deterrence curve depends on a number of factors that may vary by site, C/E analysis remains a complicated method to monitor elephant poaching using aggregated data from a large number of sites, frequently with pronounced differences in habitat type, poaching, law enforcement and other relevant factors. When C/E is compared with PIKE, the latter has its limitations due to its asymptotic function, but in spite of a number of potential biases in the method, it remains superior to C/E analysis to monitor poaching trends using aggregated data from sites that vary in at least a few but often most of the factors discussed above.

Comparing absolute mortality with PIKE

With the exception of 2006, in general terms, the trend

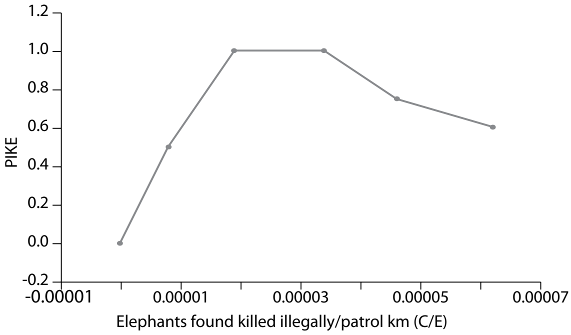

Figure 17. The relationship between proportion of illegally killed elephants (PIKE) and C/E (elephants found killed illegally/patrol km) for Mole NP, 2006–2011.

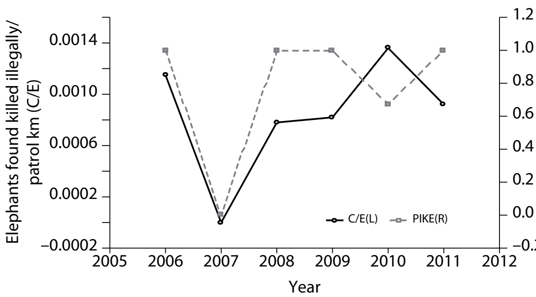

Figure 18. Comparison of the trend in C/E with that of proportion of illegally killed elephants (PIKE) for Kakum Conservation Area, 2006–2011.

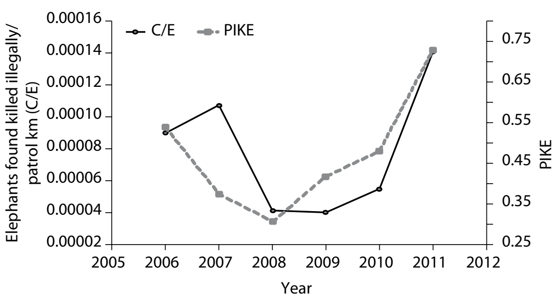

Figure 19. Comparison of the trend in C/E with that of proportion of illegally killed elephants (PIKE) for Queen Elizabeth and Mole NPs, and Kakum Conservation Area combined, 2006–2011.

in PIKE follows that of absolute mortality in the four sites combined (Fig. 21). With more up-to-date and a longer series of survey results, the trend in absolute mortality could be refined and may follow that of PIKE more closely. Thus, PIKE may also be used to monitor absolute mortality.

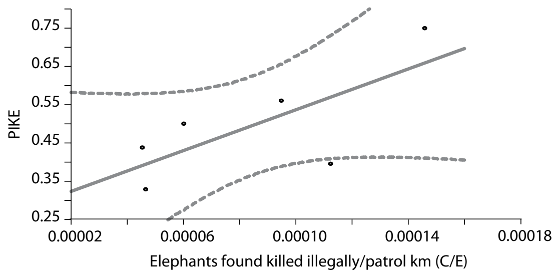

Figure 20. The relationship between proportion of illegally killed elephants (PIKE) and C/E for Queen Elizabeth and Mole NPs and Kakum CA combined; 2006–2011 (broken lines represent the 95% confidence limits).

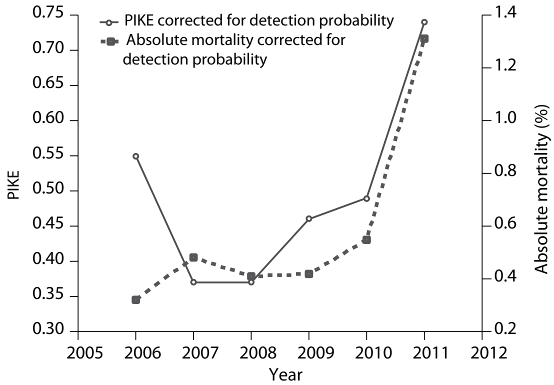

Figure 21. Comparison of the trend in PIKE, corrected for detection probability, with that in absolute mortality for the four sites combined, 2006–2011.

Discussion

Throughout the report, the mean strip width was dubbed the mean *maximum* strip width for a good reason. The strip width measured applied to the detection of relatively fresh carcasses with a height of roughly 1.3 m, but not to old carcasses in various stages of decay. For older carcasses, the strip width will be narrower. We considered incorporating a correction factor for older carcasses in the estimation of strip width but refrained from doing so simply because without sufficient research combined with a small data set, we would merely further weaken the results. Moreover, although management at three out of four sites insisted that patrols never used duplicate routes, upon inspecting patrol coverage we were inclined to doubt these statements. The higher the frequency of duplicate patrol routes, the lower the probability of detecting a carcass. In other words, our estimates of strip width may be positively biased—that is, they may be too wide—and so may be our estimates for patrol density (coverage).

Both of these biases may have resulted in overestimation of detection probability and underestimation of carcass densities. However, over the past six years, in three of the sites visited, law-enforcement effort in terms of patrol distance covered per square kilometre of site increased by 69% in Kakum (2006 to 2010), 108% in Mole, and 30% in Queen Elizabeth. Therefore, it is highly likely that even with a narrower strip and correction for duplicate patrol routes, during the end of the study period, the probability of detecting an elephant carcass may have approached 1 in each of these sites. The same may have applied to Murchison Falls, with only 30–40% of all patrols entered into the MIST system. This, however, does not account for under-sampling of juvenile deaths, especially the youngest ones (< 1 year). All of the above biases may have led to underestimates of carcass densities.

PIKE may also be biased because of differential detection probabilities for different causes of mortality and because of background variation in elephant mortality (Burn et al. 2011). Although our study did not find any evidence with regard to differential detection probabilities for different causes of mortality, the sample was small and pertained to four sites that were well managed and intensively covered by patrols. Within the MIKE sample of 80 sites there are undoubtedly many sites that are not well managed or properly patrolled, where detection probabilities may vary by cause of death. Background variation in elephant mortality may be caused by adverse environmental conditions, such as prolonged drought (Burn et al. 2011). For the period and sites covered in this pilot, we did not find any adverse environmental conditions. Another source of bias may be hidden in the spatial distribution of elephant carcasses, especially where the distribution of elephants that died of natural causes differs from those killed illegally. If a statistically significant difference exists between the spatial distribution of elephants killed illegally and those that died of natural causes, detection probabilities may differ, depending on patrol density. Albeit based on limited data, this pilot study did not find any evidence for differential spatial distribution of carcasses by cause of death. Moreover, for the four sites combined, detection probabilities for elephants that died of natural causes and those killed illegally were exactly the same (Table 11). These biases, however, may balance when sample size is large enough.

An interesting observation on detection probability of carcasses in the savannah is that out of a total of 123 carcasses, only 4 were detected through the presence of vultures and none through the presence of other scavengers. This information was derived not only from carcass sheets and patrol forms but mostly through interviews with patrol staff who were present when a carcass was found. Moreover, in the forest environment of Kakum, 3 out of 8 carcasses were found through information channels (37.5%), while in the three savannah sites, 36 carcasses were found through prior information (29.3%). Although the sample is relatively small, it just may shed some doubt on the generally accepted idea that in the savannah most elephant carcasses are detected through the presence of vultures or other scavengers, and that in the forest most carcasses are found through information channels (intelligence, tourists, researchers and information provided by the general public).

It may be a few more years before sound effort data come available for more than the above four sites. However, data gaps in MIST need to be filled, sites should aim to incorporate all patrol data into MIST, all patrols need to carry a GPS, data should frequently be backed up, and problems with individual systems need to be resolved. To accomplish this, however, requires resources well beyond the current capacity of MIKE, implying that the responsible authorities in the countries involved will have to cover at least part of these shortfalls. In Ghana, data gaps and shortcomings in MIST were complemented with information from the manual system that was set up in 2004 (Jachmann 2004). Without the manual system in place, incomplete MIST data would have been insufficient to perform the analyses detailed above. It would be prudent to set up a similar system for all MIKE sites. Although C/E analysis provided support for the use of PIKE at the site level, it also showed that using patrol effort in C/E analysis has its intrinsic problems, primarily related to the polynomial function of the detection/deterrence curve. The curve shape depends on a number of factors that may vary by site.

Thus, when using effort in C/E instead of PIKE to monitor elephant poaching throughout their range in a wide variety of habitat types and other variables, the key is to find a generalized model that fits all different shapes of the curve. Elsewhere it has been suggested that to account for detection versus deterrence, a dynamic model is required that uses data of individual patrols rather than the site aggregates by year (Burn et al. 2011). Although this is undoubtedly true, practice shows it has been a major feat to obtain sound by-year aggregates from only a handful of sites. In practice, obtaining detailed data by patrol for 80 different sites will prove to be next to impossible. We may as well conclude that for MIKE's purposes—that is, to monitor elephant poaching at sub-regional, regional and continental levels, due to the highly variable nature of the detection/deterrence curve, C/E analysis is too complicated and therefore not a practical approach to achieving this objective. PIKE data, on the other hand, can be easily pooled, and the pooling is likely to erode some of its imperfections—in other words, balance out some of its biases. As concluded earlier, PIKE is superior to C/E analysis for a system like MIKE. Moreover, a three-year study in the Laikipia–Samburu area of Kenya showed that PIKE offered a useful metric for comparing levels of illegal offtake temporarily and spatially, while its trends were relatively robust to systematic differences in methodology and spatial differences in data collection (Kahindi et al. 2009). In addition, PIKE may even prove to be a useful measure to monitor absolute elephant mortality.

In the meantime, based on the information collected in four relatively small and well-managed sites, PIKE, we may conclude, may prove to be a promising measure for monitoring elephant poaching at different spatial and temporal levels. However, the exercise described in this paper should be repeated for a sample of sites at the other end of the quality range—that is, some poorly managed sites with high illegal offtake, a clumped elephant distribution, and a patrolling density that is spatially irregular and low. These sites, however, should not be so poorly managed that information cannot be retrieved.

Acknowledgements

First, I would like to express my gratitude to the sub-regional support officer for eastern Africa, Edison Nuwamanya, and the regional director of the Wildlife Division in Ghana, Moses Kofi Sam, for organizing logistics and field visits, and for being of great assistance in every possible way. Many thanks to management and field staff in each of the sites, who offered both their precious time and their assistance to facilitate data collection. Special thanks to staff of the Uganda Wildlife Authority and the Ghana Wildlife Division for granting permission to visit the sites. We are most grateful to Ken Burnham and one unknown reviewer for providing valuable comments on an earlier draft.

References

Bouché, P. 2007. Northern Ghana elephant survey. *Pachyderm* 42:58–69.

Burn, R.W., Underwood, F.M. and Blanc J. 2011. Global trends and factors associated with the illegal killing of elephants: A hierarchical Bayesian analysis of carcass encounter data. *PLoS ONE* 69: e24165.

Danquah, E.K.A. 2004. *CITES–MIKE–Kakum National Park retrospective elephant survey 2004.* A Rocha Ghana, Accra. Available at: http://www.cites.org/common/prog/mike/sub_regNN_Africa/ghana_2004_survey.pdf.

Jachmann, H. 1998. *Monitoring illegal wildlife use and law enforcement in African savannah rangelands.* Lusaka: Environmental Council of Zambia.

Jachmann, H. 2004. *Monitoring law enforcement for adaptive management: A manual.* Wildlife Division, Accra. 124 p.

Jachmann, H. 2008. Illegal wildlife use and protected area management in Ghana. *Biological Conservation* 141:1906–1918.

Jachmann, H. 2012. Pilot study to validate PIKE-based inferences at the site level. CITES/MIKE technical report. 56 p.

Kahindi, O., Wittemeyer, G., King, J., Ihwagi, F., Omondi, P. and Douglas-Hamilton, I. 2009. Illegal killing of elephants across diverse land uses in Laikipia–Samburu, Kenya. *African Journal of Ecology* 48:972–983.

Plumptre, A., Kujirakwinja, D., Moyer, D., Driciru, M. and Rwetsiba, A. 2010. *Greater Virunga landscape: large mammal surveys, 2010.* Kampala, Uganda: Wildlife Conservation Society. Available at: http://www.elephantdatabase.org/population_submission/64.

Rwetsiba, A. and Wanyama, F. 2010. *Aerial surveys of medium large mammals in Kidepo Valley and Murchison Falls Conservation Areas.* Monitoring and Research Unit, Uganda Wildlife Authority, Kampala. Available at: http://www.elephantdatabase.org/population_submissions/63.