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How much is enough? Estimating the minimum sampling required for effective monitoring of African reserves

JUSTIN S. BRASHARES[1,]* and MOSES K. SAM[2]
[1]*Department of Zoology, Conservation Biology Group, Cambridge University, Cambridge CB2 3EJ, UK and Department of Environmental Science, Policy and Management, University of California, Berkeley, CA 94720, USA;* [2]*Ghana Wildlife Division, P.O. Box M.239, Ministries, Accra, Ghana;* **Author for correspondence (e-mail: brashares@nature.berkeley.edu)*

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Abstract. Effective biological monitoring in developing countries requires a balance of rigour and practicality. Unfortunately, there exist few general guidelines to help practitioners design monitoring programs that reach this balance. Here, we analyse a 33-year monitoring program from Ghana, West Africa, to provide both specific and general suggestions for monitoring in developing countries. Since the late 1960s the Ghana Wildlife Division has monitored more than 40 wildlife species with monthly surveys at sites throughout Ghana's nature reserves. These data present unparalleled opportunities to illuminate the scale and pattern of changes in animal abundance over time and the forces that drive these changes. We used sub-sampling of the Ghana monitoring data for four species in two savanna reserves to identify the minimum level of monitoring necessary to reliably detect changes in wildlife populations over 5-year intervals. We used a similar approach to estimate the minimum sampling needed to infer changes in abundance of hunters in reserves. Our results highlight the relative importance of comprehensive spatial and temporal sampling and suggest a requirement of no less than one monitoring site per every 285 km^2 in large reserves and 65 km^2 in smaller reserves. We discuss briefly the cost of effective monitoring and the relevance of our results to other regions of Africa and the world.

Introduction

Monitoring has become the methodological centrepiece of strategies for the management and conservation of biodiversity (Bawa and Menon 1997; Kremen et al. 1998). In this context, monitoring is envisioned to identify priority areas for research and conservation and to quantify the response of populations to disturbance and management interventions. Most practitioners agree that in an ideal world monitoring programs would always be spatially and temporally comprehensive, rigorous in their treatment of sampling error, and sustainable over the time scales necessary to examine population and community level processes (Olsen et al. 1999; Yoccoz et al. 2001). However, the 'real' world's shortage of funding, human resources, and stability demand that managers face difficult trade-offs between precision vs. sustainability when devising monitoring strategies (Margules and Austin 1991; Danielsen et al. 2003).

The conflict between the scientific ideals and practical realities of monitoring is perhaps most evident in developing countries where limited internal resources and sporadic international funding destine many data collection efforts to failure (Danielsen et al. 2003). In these places in particular, there is great incentive to identify the best methodological 'middle ground' between the need for rigour and goals for program sustainability. Despite this, there exist few general suggestions to guide managers in finding such a balance (Danielsen et al. 2000; Steinmetz 2000). Moreover, practitioners disagree about whether such a balance exists and the issue has become a source of healthy debate (e.g., Yoccoz et al. 2001, 2003; Danielsen et al. 2003). At the centre of this debate is the fact that where suggestions or examples of 'appropriate' monitoring in developing countries exist, they generally are unproven in their ability to detect 'true' trends (Danielsen et al. 2003). For now, it is clear only that poor statistical power and bias may turn overly simplistic monitoring schemes into wastes of time and precious resources (Renner and Ricklefs 1994; Yoccoz et al. 2001). Yet equally wasteful are programs so intensive they cannot be sustained long enough to address questions fundamental to effective management (Danielsen et al. 2003).

One example of a simple yet successful and enduring monitoring effort in a developing region is the Ghana Wildlife Division's vertebrate monitoring program (Brashares et al. 2001). Ghana's biological monitoring activities began in the late 1960's with the objective of tracking populations of 42 species of large vertebrates in six nature reserves. Monitoring data were collected during patrols conducted approximately monthly around posts positioned at relatively high densities throughout reserves (e.g., Figure 1). The individuals collecting these data were employees of the Wildlife Division; yet, they often came from local communities and received limited training in animal identification or sampling methods. The program was inexpensive enough that it could be sustained through long periods when no external funding was proffered. Perhaps the best evidence for the success of Ghana's monitoring effort is the value and reliability of the data that were collected (e.g., Brashares et al. 2001; Brashares 2003). Ghana's monitoring data are spatially and temporally comprehensive to the degree that they allow reliable detection of changes in animal abundance and distribution over periods as short as months (e.g., seasonal movements of elephants, *Loxodonta africana*, or buffalo, *Syncerus caffer*). These data are not only internally consistent, but the trends they identify (e.g., declines and local extinctions of larger carnivores, changes in animal distributions) are corroborated by independent, shorter-term monitoring efforts of internationally-funded scientists in the same reserves (Wilson 1994 and 25 references in Brashares et al. 2001).

Here, we analysed 20 years of monitoring data from Ghana with the goal of identifying a set of minimum requirements for effective monitoring of

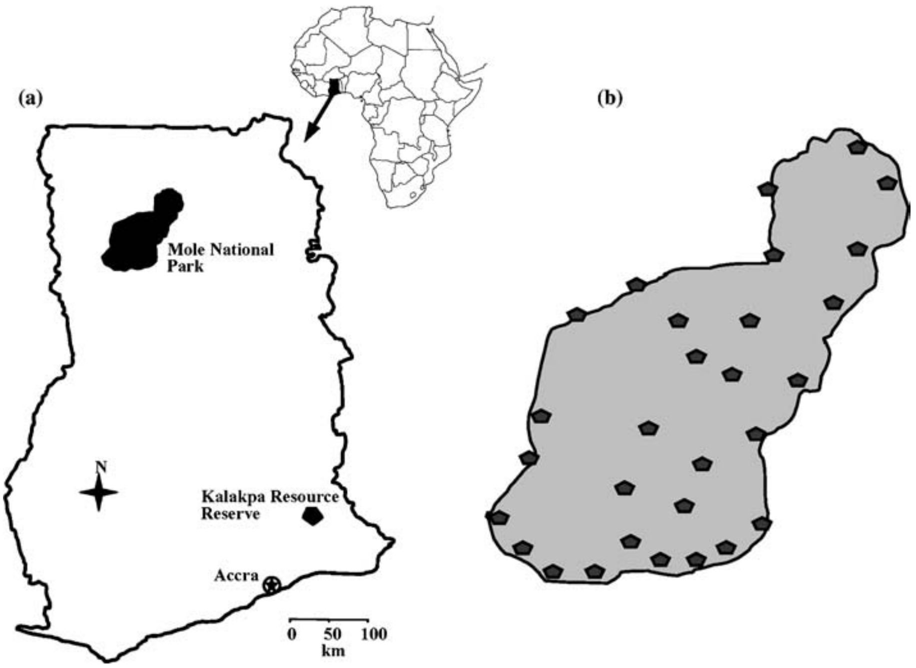


Figure 1. (a) Location of Ghanaian reserves considered in this study; (b) close-up of Mole National Park showing the approximate location of monitoring sites (ranger posts) within the reserve.

vertebrate populations. More specifically, we used sub-sampling from the complete Ghana data set to ask: (1) What is the minimum sampling effort necessary to infer significant changes in wildlife populations, and (2) To what degree is the spatial intensity of a monitoring scheme (i.e., number of monitoring sites per unit area) more or less important to effective monitoring than temporal considerations (i.e., frequency at which surveys are conducted at each site)? For the purposes of this study, we defined as 'effective' any monitoring that allowed reliable detection (i.e., ≥95% certainty) of 'true' increases or decreases of focal populations over a period of 5 years.

To address our research questions we first used the complete Ghana data set to identify population trends of four species that vary greatly in their natural abundance, habitat selection, dispersion, and detectability (see Methods below). We focused our analyses on populations of these four species in two reserves that differ greatly in total area. We assumed that population trends revealed using the complete data set for these reserves reflected true changes in animal abundance. By sub-sampling pre-designated portions of the complete data set for these same animal populations we estimated how our ability to detect the 'true' trend for each population over periods of 5 years was affected by (a) reducing the sampling interval from 12 surveys per monitoring site per year through to one or two per year, and (b) reducing the number of monitoring sites from 100% to ~10% (i.e., from 29 to two sites in one reserve and seven sites to one in the other). In short, each of these exercises was essentially a *post-hoc* power analysis for detecting trends in the monitored wildlife populations under different sampling intensities and designs.

Ghana's monitoring program recorded not only abundances of wildlife species, but also the number of hunters encountered in reserves during monthly patrols. In addition to the analyses of four wildlife species, we also quantified changes in hunter numbers from 1975 to 1994 in the two reserves. Using the same sub-sampling protocol described above, we examined how *post-hoc* reductions in spatial and temporal sampling intensity affected our ability to detect changes in abundance of hunters over time.

Methods

Nature reserves and species

Approximately monthly, the Ghana Wildlife Division conducts counts of all large mammals along 10–15 km foot patrols around ranger posts in each of Ghana's reserves (Brashares et al. 2001). Here, we focused our analyses on recorded observations of four species of mammals observed in Mole National Park (Mole N.P.) and Kalakpa Resource Reserve (Kalakpa R.R.) from 1975 to 1994. This 20-year period provides more continuous monitoring data than the period immediately before or after. Mole N.P. (4840 km^2) is the largest reserve in Ghana, and Kalakpa R.R. (325 km^2) is one of the country's smallest. Both reserves are described as dominated by 'guinea savanna' habitat, however, each possesses a range of habitat types ranging from dense riverine forests to open grasslands. Wildlife counts were conducted monthly at 29 ranger posts in Mole N.P. (ca. 1 post/160 km^2; Figure 1) and 7 posts in Kalakpa R. R. (ca. 1 post/45 km^2).

The four species chosen for analyses occur (or occurred) in both Mole N.P. and Kalakpa R.R. The first species chosen, the olive baboon (*Papio anubis*), is among the more abundant large mammals in the two reserves with local densities higher than 40 animals/km^2 in places. Troops ranging in size from five to 80 animals are patchily dispersed throughout open forest and savanna habitats. This species is diurnal, and relatively easy to identify and count. Simple regression and time series analyses of the long-term count data reveal a significant increase in baboon abundance in several areas of Mole N.P. and Kalakpa R.R., with abundance in other areas of the reserves remaining stable over time. The overall, reserve-wide trend for these populations shows a significant increase in both reserves during the period 1975–1994 (Simple linear regression of annual counts (average of 12-monthly counts from all monitoring sites pooled) against time: $R^2 = 0.90$ and 0.84 for Mole N.P. and Kalakpa R.R, respectively, $n = 20$ years, $p < 0.001$ for both reserves; Figure 2).

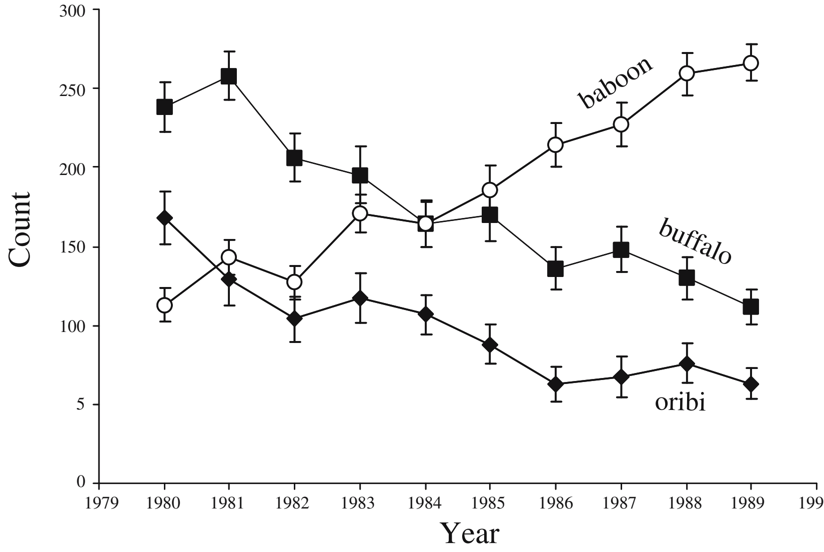


Figure 2. Annual counts of three wildlife species in Mole National Park, Ghana, over a 10-year period. Each point represents the mean of monthly count totals ±SE.

The second species, the African buffalo (~500 kg), is among the largest animals in Ghana and is relatively easy to identify and count. Historically, buffalo were common in mixed-scrub and treed savanna habitats in Mole N.P. and Kalakpa R.R. Monthly count records from 1975 to 1994 reveal a steady decline of buffalo populations in both reserves (Simple linear regression: $R^2 = 0.81$ and 0.83 for Mole N.P. and Kalakpa R.R, respectively, $n = 20$ years, $p < 0.001$ for both; Figure 2), particularly in peripheral areas. Local densities around sampling sites in the core area of each reserve have remained stable.

The third species included in our analyses is a small antelope (15 kg), the oribi (*Ourebia ourebi*). This species occurs in a range of habitats from open grassland to dense scrub and even in small clearings within forests. Oribi were widespread but patchily distributed in Mole N.P. and Kalakpa R.R. Their small size, bland coloration, and wariness of humans make them difficult to identify and count. In Ghana they are most active around dawn and dusk and often 'lie out' hidden in shaded areas by day. Analysis of site-specific counts from 1975 to 1994 reveals that oribi have increased in abundance in areas of both reserves, have declined dramatically in other areas, and have remained stable in others. This fine-scale variation in population trends is supported by independent transect counts of oribi conducted throughout the two reserves (Brashares and Arcese 2002). The overall trend (i.e., all sampling sites pooled) for oribi from 1975 to 1994 is a significant decline (Simple linear regression:

$R^2 = 0.79$ and 0.84 for Mole N.P. and Kalakpa R.R, respectively, $n = 20$ years, $p < 0.001$ for both) in both reserves (Figure 2).

The fourth species we considered, the leopard (*Panthera pardus*), is notoriously difficult to monitor. Leopards are most active at night and spend much of the day in trees. They occur at low densities (e.g., ~1 per 35–50 km^2 in Mole N.P.) and excel at avoiding detection by humans. In the early 1970's they occupied forests of all types and savannas in Mole and Kalakpa (this study). Leopards declined in abundance throughout the period 1975–1994 in Mole (Simple linear regression: $R^2 = 0.68$ and 0.73 for Mole N.P. and Kalakpa R.R, respectively, $n = 20$ years, $p < 0.001$ for both; Figure 3), and the species appears to have declined to local extinction in Kalakpa by 1986.

The last data set included in our analyses was from counts of hunters encountered in Mole N.P. and Kalakpa R.R. Hunters in Ghana are active at night and day, and surveys between 1975 and 1994 show increases in the abundance of people hunting illegally in Mole and Kalakpa (Simple linear regression: $R^2 = 0.91$ and 0.87 for Mole N.P. and Kalakpa R.R, respectively, $n = 20$ years, $p < 0.001$ for both). However, changes in hunter numbers were spatially heterogeneous; areas monitored near reserve borders showed the largest increases over time and encounter rates in areas at the core of reserves remained low.

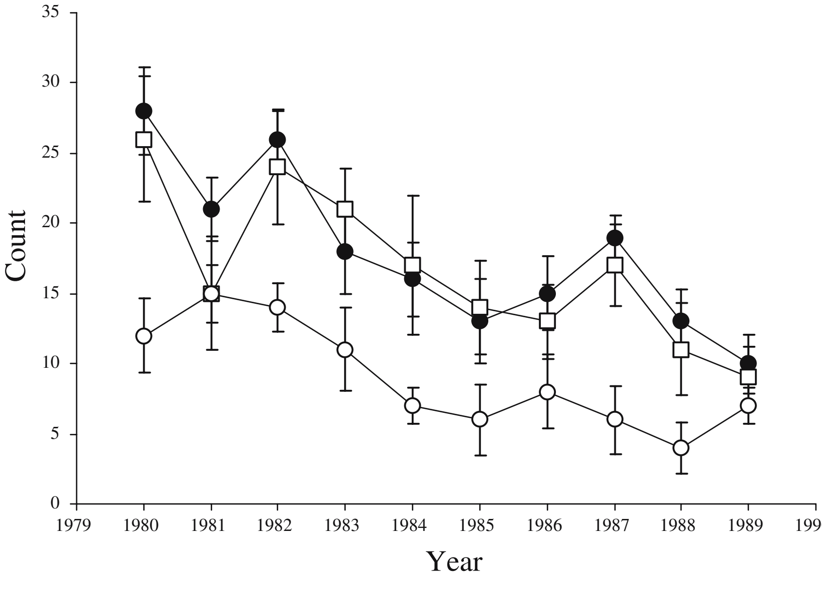


Figure 3. Annual counts of leopards in Mole National Park, Ghana. Each point represents the mean of monthly count totals ±SE. The three data series represent (1) annual counts based on analysis of all monitoring data collected monthly at 29 sites (filled circles), (2) annual counts based on monthly data from one half of Mole N.P.'s monitoring sites (open squares), and (3) annual counts based on data from surveys representing only 6 months of the year (open circles).

Statistical analyses

For each species in each reserve we randomly drew 100 complete data sets, each containing five consecutive years of monthly surveys (e.g., for each species in Mole N.P., each complete data set consisted of 12 counts per year ×29 monitoring sites ×5 years = 1740 surveys per species). We chose 5-year periods because we believed this to be a length of time over which monitoring could realistically be sustained continuously in many developing countries and we hypothesized that this was the minimum period necessary to infer changes in wildlife populations. After pooling data for all monitoring sites in a reserve within each month, we tested for a population trend in each of the 5-year sets using regression analysis (series were too short to allow formal time-series techniques). Thus for example, we drew 100 overlapping 5-year data sets for baboon in Kalakpa R.R. and tested for a trend in each of these sets. The trends identified using these complete (unmodified) data sets were accepted as 'true' ('real'). For all regressions of complete and partial data sets, only trends identified at $p < 0.05$ or less were considered significant.

To identify the minimum sampling effort necessary to detect these true trends, we drew partial (reduced) data sets from the 100 original complete data sets. Each complete data set was reduced in three different ways. First, we reduced the number of monitoring sites per reserve from 29 to two (in steps of three) for Mole N.P. and from seven to one (in steps of one) for Kalakpa R.R. Second, we reduced the number of counts conducted per year per site, in steps of one, from 12 to one for Mole N.P. and from 12 to two for Kalakpa R.R. Last, we reduced the intensity of spatial and temporal monitoring simultaneously, in three steps, corresponding to ~75, ~50, and ~25% of the maximum possible in each reserve. For example, for Mole N.P. the ~75% simultaneous reduction involved us using nine counts per year for each of 21 sites, while for Kalakpa R.R. we used nine counts per year for each of five sites. We next used regression analysis to test the population trends in each of these partial data sets. Finally, for each data reduction scenario, species and reserve (e.g. for buffalo sampled at nine sites each month in Mole N.P.), we calculated what proportion of the 100 partial data sets gave the same trend as their corresponding complete data set, as an estimate of the probability of that level of data reduction identifying the overall population trend.

Results

Analyses of the complete data sets for the four species in Mole N.P. and Kalakpa R.R. showed that consistent and detectable trends characterized changes in populations of all four species from 1975 to 1994 (Table 1). Populations of olive baboons in both reserves increased significantly in all 100 randomly drawn complete 5-year data sets. Oribi and buffalo populations decreased significantly in both reserves in all complete 5-year data sets.

Table 1. Effectiveness of three intensities of monitoring at identifying 'true' changes in abundance of four wildlife species and poachers in two reserves in Ghana.

Species	Reserve	Overall trend using all data or complete 5-year runs[a]	Probability of detecting trend with simultaneous reductions in numbers of monitoring sites and surveys/site/year[b,c]		
			~75%	~50%	~25%
Baboon	Mole	Increase (100%)	1.0 (0; 0)	0.96 (0.04; 0)	0.51 (0.47; 0.02)
	Kalakpa	Increase (100%)	1.0 (0; 0)	0.97 (0.03; 0)	0.74 (0.26; 0)
Buffalo	Mole	Decline (100%)	1.0 (0; 0)	0.83 (0.17; 0)	0.38 (0.62; 0)
	Kalakpa	Decline (100%)	0.98 (0.02; 0)	0.84 (0.16; 0)	0.55 (0.45; 0)
Oribi	Mole	Decline (100%)	0.99 (0.01; 0)	0.85 (0.15; 0)	0.40 (0.46; 0.14)
	Kalakpa	Decline (100%)	0.97 (0.03; 0)	0.74 (0.26; 0)	0.43 (0.48; 0.09)
Leopard	Mole	Decline (98%)	0.94 (0.06; 0)	0.73 (0.27; 0)	0.22 (0.78; 0)
	Kalakpa	Decline (96%)	0.96 (0.04; 0)	0.49 (0.51; 0)	0.04 (0.96; 0)
Hunters	Mole	Increase (100%)	1.0 (0; 0)	0.76 (0.24; 0)	0.26 (0.72; 0.02)
	Kalakpa	Increase (100%)	1.0 (0; 0)	0.79 (0.21; 0)	0.47 (0.53; 0)

[a] The overall trends are those derived using all data for 1975–1994 (see Methods); percentages in parentheses indicate the number of randomly drawn complete 5-year data sets (out of 100) in which there was a significant trend matching the overall trend.

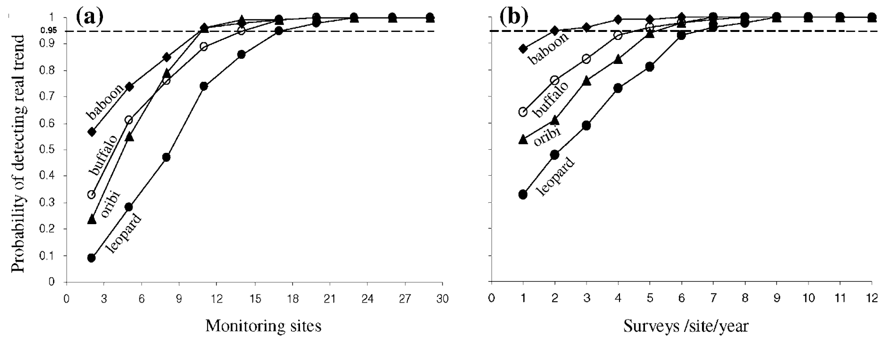
[b] Values in parentheses indicate the probability of detecting no trend when a trend exists, and the probability of detecting the opposite trend.

[c] Values shown reflect analyses in which the number of monitoring sites and surveys/year were reduced simultaneously in three steps from ~75% – ~25% of the total monitoring possible. For example, 50% translates to 14 sites surveyed bi-monthly in Mole N.P. and four sites surveyed bi-monthly in Kalakpa R.R.

Leopard numbers declined significantly in Mole N.P. in 98 of 100 complete 5-year data sets, and in 96 of 100 complete 5-year data sets from Kalakpa R.R. The number of hunters encountered in Kalakpa and Mole increased significantly in all 100 of the complete 5-year data sets drawn for each reserve.

The probability of detecting these 'true' trends with reduced monitoring varied among species, with the level and type of data reduction, and across reserves (see Figures 4 and 5 for reducing either spatial or temporal intensity, and Table 1 for the effect of reducing both simultaneously). The probability of detecting the true population trend diminished with reduced intensity of monitoring for all species (Figure 4). However, the rate at which the probability of detecting the true trend declined differed significantly among species (Figure 4). Changes in populations of species with the highest abundance, detectability and evenness of dispersion within reserves, i.e., baboon and buffalo, were identified at a high probability even at greatly reduced levels of monitoring (Figure 4). In contrast, detecting trends in leopard, and to some degree oribi, populations showed greater sensitivity to monitoring effort (Figure 4). At the lowest levels of monitoring the probability of detecting the true population trend for these two species was less than 0.5 and, in some cases, was similar to the rate at which the opposite (wrong) trend was found to be significant (Table 1).

Mole National Park



Kalakpa Resource Reserve

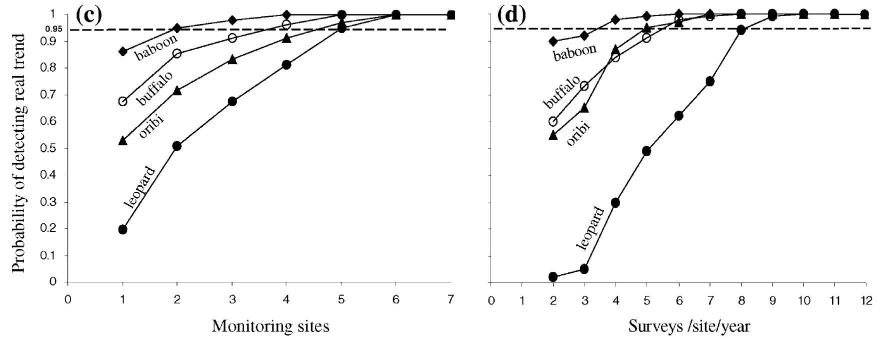


Figure 4. For four wildlife populations in Mole National Park and Kalakpa Resource Reserve, Ghana, the probability of detecting the 'true' trend declines as the number of monitoring sites (a and c) or surveys per year (b and d) is reduced. 'True' trends are those identified by analyses of complete monitoring data sets for each species over periods of 5 years (see Methods). Probabilities below 95% indicate levels of monitoring insufficient to reliably detect changes in animal abundance. The maximum number of monitoring sites (i.e., 100%) is 29 in Mole N.P. and 7 in Kalakpa R.R.

For Mole N.P. there was some evidence that reductions in spatial intensity of monitoring (i.e., number of monitoring sites per reserve) had a greater effect on our ability to detect true population trends than did corresponding reductions in temporal intensity (i.e., counts conducted per site per year). This was particularly evident for the four wildlife species (compare Figure 4a and b) and counts of humans (compare Figure 5a and b). However, this effect was less obvious for either wildlife or people at the smaller Kalakpa R.R.

Overall, surveying 17 monitoring sites (i.e., 1/285 km^2) monthly or 29 sites (i.e., 1/160 km^2) bi-monthly was the minimum effort necessary to reliably identify (at a probability ≥95%) changes in populations of all four wildlife species and humans in Mole N.P. Five monitoring sites (1/65 km^2) surveyed monthly or seven sites (1/46 km^2) surveyed eight times a year was the minimum effort necessary to reliably identify changes in populations of the four wildlife

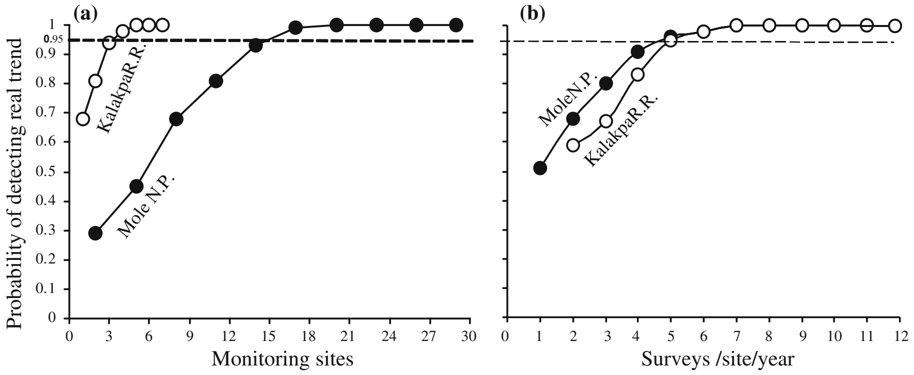


Figure 5. Probability of detecting 'true' increases in the number of hunters encountered in Mole National Park and Kalakpa Resource Reserve, Ghana, across a range of spatial (a) and temporal (b) monitoring intensities.

species and humans in Kalakpa R.R. Simultaneous reductions of spatial and temporal intensity of monitoring showed that using ~75% of sites and surveys per year (but not ~50% or ~25%) was sufficient to identify nearly all population trends (at probability ≥95%) in all four wildlife species and in humans, at both sites (Table 1).

Discussion

For populations of olive baboon, African buffalo, oribi, and leopard in Mole N.P., reductions in the number of sites monitored had a greater negative effect on the probability of detecting the 'true' populations trend than did equivalent reductions in the number of surveys per year; but both factors were influential. Not surprisingly, decreasing the number of surveys per site resulted in greater variance in population estimates and this accounted for the gradual weakening in the probability of predicting 'true' trends (Thompson et al. 1998; Olsen et al. 1999). This was particularly evident for the two species that were seldom observed or difficult to detect, the leopard and oribi (Figure 4). It also was more evident for populations in the smaller Kalakpa R.R. than those in Mole N.P. This presumably reflects the challenge of achieving sufficiently large counts within Kalakpa's smaller wildlife populations (Thompson et al. 1998).

Equally striking was the rapid loss of statistical power that resulted from decreasing the number of monitoring sites (Figures 4 and 5). For example, when data from only 10% of monitoring sites were considered, the probability of detecting the 'true' decline of oribi populations in Mole N.P. (0.24) was far less than the probability of detecting no trend (0.57) and was similar to that of identifying the opposite (i.e., wrong) trend (0.19; Table 1). Reduced intensity of spatial sampling also had an immediate effect on the probability of detecting population trends in Kalakpa R.R. (Figures 4 and 5). Overall, these patterns likely reflect the confounding influence of spatial heterogeneity in species' distributions and population trends (Yoccoz et al. 2001). Each of the four species we studied is present in certain habitats and absent in others. Increasing the density of monitoring sites within a reserve enhances the likelihood that habitats representing all species will be included, and it also ensures that counts will be high enough each year to allow statistical inference (Green 1979; Yoccoz et al. 2001). This is particularly important for species that occur in rare or isolated habitat types that are unlikely to be included in basic monitoring schemes. Implementing a spatially comprehensive sampling scheme is both a greater necessity and challenge when the area to be monitored is large (see also Danielsen et al. 2005 (this issue)).

Similarly important to effective monitoring is the influence of intra-specific heterogeneity of (sub) population trends within a reserve. Monitoring in Ghana and elsewhere shows clearly that the abundance of a given species is unlikely to fluctuate in a synchronous pattern across all habitats and areas in which it occurs (Brashares et al. 2001; Ims et al. 2004). Each of the species monitored in Mole N.P. and Kalakpa R.R. shows localized areas where (sub) populations have remained stable or increased over time, and other patches within the same habitat types (sometimes in adjacent habitat patches) and in the same reserves where local populations have declined drastically over the same period (this study). Some of this variation is due to greater intensity of hunting and other human disturbance within specific areas of reserves (Brashares et al. 2001). Much of this variation also may be attributed to natural, asynchronous population trends typical of any metapopulation dynamic (e.g., Ims et al. 2004). Fine-scale heterogeneity in species' distributions and population trends is a global reality, and monitoring programs must survey broadly enough to characterize the sum of local trends. Failing to account for such variation not only reduces a manager's ability to detect trends, it also increases the risk that the manager will accept a significant trend that is in fact wrong. A fine-scale knowledge of areas of population decline, increase, and stability is also, in its own right, valuable information for conservation and the targeting of management actions.

Quantifying the influence of hunting and collecting is a priority of many monitoring programs in developing countries (e.g., Milner-Gulland et al. 2003). Among other uses, such data are essential for evaluating the success of conservation initiatives (e.g., policing and protection, community conservation, ICDPs, etc). Our analysis of hunter counts in Mole N.P. and Kalakpa R.R. suggests that monitoring human activities in reserves can be combined effectively with wildlife surveys.

Guidelines for effective monitoring

Our results provide no universal, 'hard and fast' rules for successful monitoring, but they do specify sampling minimums for Ghana's reserves. They also provide insight on issues of sampling design and intensity that should have broad applications. Nearly all large vertebrates in Mole N.P. can be monitored effectively with a sampling design that allows for one monitoring site for every 285 km^2. Detecting changes in vertebrate populations in the smaller Kalakpa R.R. requires a minimum of one monitoring site for every 65 km^2. These guidelines assume surveys are conducted at each monitoring site a minimum of nine times per year. These levels of monitoring are required to detect population trends of rare and cryptic species. It may be more cost- and time-efficient to implement additional monitoring tailored to the rarest species if they are of special conservation interest. Focused monitoring on the rarest species would allow less intensive general monitoring of more common species without a loss of reliability.

Price of effective monitoring

A key element of any monitoring program is the funding necessary to maintain it. The Ghana Wildlife Division's extensive monitoring in Mole N.P. and Kalakpa R.R. is achieved at a cost of approximately USD 95,000/year (ca. \$18/km^2 monitored). Rangers in Ghana are paid approximately \$55–65/month and vehicle costs are roughly \$1000/month. Monitoring of wildlife populations is only a positive side benefit of anti-poaching patrols in Ghana. If monitoring was the only goal of the Wildlife Division, it could be achieved at 15–30% (ca. \$3–6/km^2) of current costs with no sacrifice in spatial or temporal intensity of surveys. As seen in Ghana and suggested elsewhere (e.g., Uganda, Tanzania, Zambia, Botswana) (e.g., see African Wildlife Foundation 2004), monitoring can be combined effectively with patrol efforts at minimal extra expense.

Last, Ghana's monitoring program relies on paid employees working in protected areas, but monitoring can be, and is, carried out just as effectively and at lower cost by village stakeholders in mixed-use habitats. Intensive wildlife monitoring is undertaken with success by locals in community forests and private primate reserves in several areas of Ghana (e.g., Buabeng-Fiema Monkey sanctuary). These small-scale monitoring programs (i.e., 2–120 km^2) have endured for decades with funding drawn only from tourism revenues and small grants.

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