Module 7

Monitoring wildlife populations for management

Emma J Stokes, Arlyne Johnson &

Madhu Rao

Table of Contents

1. BIOLOGICAL MONITORING IN A MANAGEMENT CONTEXT

Conservation managers devote a considerable amount of time and resources to preserving wildlife populations. In recent years there has been a growing recognition amongst conservation practitioners, donor agencies, international conservation organizations and the scientific community of the need to measure the success of our efforts in meeting conservation or policy objectives, and evaluating if conservation resources are well spent (Pullin & Knight, 2001; Sutherland et al., 2004; Ferraro & Pattanayak, 2006; Kapos et al., 2008).

In this context, wildlife monitoring programs should form a core component of any conservation management project and, if integrated fully into the project management cycle and decision-making process, monitoring can play three important roles:

i) firstly, it can provide managers with information on the status of wildlife populations before deciding on the appropriate course of conservation action to take;

ii) secondly, monitoring programs can evaluate the effectiveness of management actions relative to stated objectives; and

iii) thirdly, in an adaptive management setting, monitoring programs can provide the important feedback loop for learning about which actions lead to the success or failure of a particular conservation approach, in order to specifically inform and improve upon management practice in the future (Nichols & Williams, 2006; Lyons et al., 2008).

Understanding the role of monitoring in this context can help inform the design of monitoring programs. Monitoring data should not be collected haphazardly in the hope that one day this might be useful for conservation. With limited budgets and staff, managers instead need efficient monitoring programs that are focused on providing precisely the information needed to make the right conservation decisions [see Box 1]. To this end, the formulation of ***clear and explicit monitoring objectives*** is a key first step in the planning of any wildlife monitoring program (Yoccoz et al., 2001; Legg & Nagy, 2006; Nichols & Williams, 2006; MacKenzie, 2009).

Box 1: Targeted monitoring vs. Surveillance monitoring *(from (Yoccoz et al., 2001; Nichols & Williams, 2006)*

Targeted monitoring is defined as monitoring that is integrated into conservation practice. The ideal example of this is provided by an ***adaptive management*** framework, which is an iterative process that directly addresses the uncertainty in biological systems by incorporating a set of competing models about how the system responds to management interventions. Adaptive management typically involves 5 components: 1) Clear management objectives, 2) potential management actions to meet the objectives, 3) models of system response to different management actions, 4) measures of confidence in the models, and 5) a monitoring program to a) provide estimates of system state and other relevant variables to make periodic management decisions, and b) discriminate between competing models about how the system works and adjust our confidence in different models accordingly.

Unlike targeted monitoring, **surveillance monitorin**g is not guided by *a priori* hypotheses about how the system responds. Surveillance monitoring in conservation typically involves a two-step process. First, population declines are identified by monitoring data by means of a statistical test of a null hypothesis of no decline versus a decline. Following the statistical detection of a decline, either of two actions is recommended as a second step. One is to initiate active conservation immediately, and the other is to initiate studies to understand the 'cause' of the decline, followed by active conservation. Key to both is the detection of a population decline as a trigger for initiating management actions. This approach to monitoring is considered by some as inefficient and frequently ineffective and has been criticized as resulting in a 'too little, too late' scenario.

In this module we provide general guidelines for the design and implementation of management-orientated wildlife monitoring programs. We do not aim to provide an exhaustive list of all possible survey methodologies. Rather, we highlight **common pitfalls and potential sources of error in the design and interpretation of wildlife monitoring data,** and provide recommendations for addressing these issues directly, using examples from different survey techniques in different contexts.

In many parts of South-East Asia the technical challenges of designing effective wildlife monitoring programs are confounded further by over-hunting of wildlife, resulting in severely depleted populations which themselves are often the subject of management and recovery programs. At very low densities, the design of wildlife monitoring programs **needs to strike an important balance between technical rigor on one hand and cost-effectiveness on the other**. We provide some recommendations for redressing the balance in such situations. Finally, the technical challenges of designing wildlife monitoring programs are confounded in the tropics by the logistical challenges of accessing vast and remote forests with low technical capacity and thinly stretched budgets. We therefore also consider the criteria for **ensuring the long-term sustainability of monitoring programs**.

2. What to monitor: Setting conservation targets for monitoring

Deciding on what we want to monitor depends largely on the management objective or the particular questions you want to ask. There are two aspects to the question of what to monitor: **what variable (or variables) need to be monitored**, and **what measure should be used.**

The management and monitoring of biological systems encompasses a variety of different biological variables of interest, ranging in scale from species to ecosystems and including a variety of quantitative and qualitative measures of biodiversity and populations. In this module we focus on quantitative measures of wildlife populations, and specifically large mammals, but the guiding principles outlined here can be equally applied to other taxa.

2.1. What species or groups of species to monitor?

Box 2: Examples of rationale for selection of **target species** to monitor in Nam Kading National Protected Area, Lao PDR *(from Strindberg et al., 2006).*

1. **Tiger** covers all habitat types defined for the Nam Kading landscape and is impacted largely by the threats of 'hunting for trade as medicine/trophies' and 'prey depletion'. It is assumed that if these two threats are reduced that tigers will increase in the NPA.
2. **Wild Pig** is dependent on the 'seasonal streams and pools' habitat in the NPA and is heavily impacted by the three types of hunting, namely 'hunting for trade as food', 'hunting for subsistence consumption', and 'hunting as a result of conflict from crop raiding'. It is assumed that if seasonal streams and pools are maintained and if hunting is reduced that wild pig will increase in the NPA.
3. **Great Hornbill** is threatened by 'logging' and 'shifting cultivation' in the NPA due to loss of big nesting trees that are important for their survival. It is assumed that if habitat loss is reduced, as well as hunting, that great hornbill populations will increase in the NPA.
4. In addition to the threats mentioned for the previous three species**, White-Cheeked Crested Gibbon** is also extremely vulnerable to the threat of 'habitat fragmentation'. It is assumed that if habitat fragmentation is reduced, as well as other threats listed, that gibbons will increase in the NPA.

For management programs aimed at a particular wildlife species, such as recovery of tigers to a particular level in a protected area, the conservation target for monitoring must clearly include the species under management. However, for some management programs it might also be important to include additional variables that bear some functional relationship to the conservation target. For the example of recovering wild tiger populations, a conservation manager also needs to ensure that there is an adequate prey base, and so the abundance of key prey species might be a key variable to monitor in addition to the size of the tiger population.

For more general management objectives that relate to the integrity of protected areas or preservation of key habitats, the choice of what species or group of species to monitor requires careful consideration and the selection of those species that will provide the most useful and indicative information about how the system is responding to a particular management intervention or strategy. These decisions can be made in a number of different ways and based on a number of key biological and conservation criteria (e.g. (Redford et al., 2003)), but at a minimum should include a series of ***a priori*** **hypotheses** or assumptions about how the species will respond to a particular management intervention (see Box 2 on selection of what species to monitor and assumptions about their response to management)

2.2. What measure to use?

Both the specific management objective and the selection of appropriate species or taxa to monitor have direct implications for the attribute to be measured. For example, wildlife managers are frequently interested in measures of ***abundance***, and specifically in ***density*** (number of individuals/unit area) or population size (total number of individuals in a defined area). However, population size or density is typically one of the most costly measures to obtain, and for rare or elusive species in particular, is often precluded by the effort required to obtain rigorous estimates that are meaningful as a monitoring tool.

In such instances, alternative measures of abundance can be used, including ***relative abundance*** (typically an index or proxy measure that has some constant relationship to abundance) or ***occupancy*** (proportion of area occupied by a particular population (Mackenzie et al., 2002) (See Box 3). Whilst the decision of which measure to use is ultimately determined by the management objective it must also be considered in terms of cost and available budget. The choice of different measures will in turn have implications for the design of monitoring programs (Williams et al., 2002), but these different measures should still subscribe to a minimum standard of statistical rigor, as we discuss in Section 3.

Box 3: Examples of **Relative Abundance** and **Occupancy** from protected areas in Lao PDR.

An example from Nam Et-Phou Louey NPA of ***relative abundance*** is number of camera trap photos of tiger per camera trap day (Johnson et al., 2006). In this case, a camera trap day is defined as each 24-hour period that a camera trap is operating to capture photos of a tiger in the NPA. This measurement does not tell us how many tigers live in the NPA but provides a relative measurement that can be compared with other areas where camera traps are used to monitor relative abundance of tigers.

An example of ***occupancy*** from the Nakai-Nam Theun NPA is that monitoring along line transects in 200 km^2. of the Nam Chae catchment in 2007 found that Douc Langur occupied 87% of the area (Johnson and Johnston 2007). Note that this measure of abundance does not estimate how many Douc Langur live in the Nam Chae catchment in terms of density (individuals per km^2) but provides and estimate of the proportion of the area that is occupied by Douc Langur.

The types of measures we have been describing so far are known as **state variables**. A state variable is a metric that summarizes the status of a population of interest at a particular time. Species richness, abundance, even simple presence of a species, are examples of commonly used state variables. These types of variables are typically of most immediate interest to management programs. However, there is now a growing interest by managers in the dynamic processes that influence the response of state variables, and to include specific measures of **rate parameters** such as reproduction, immigration or emigration in their monitoring programs (Yoccoz et al., 2001). To continue the example of a recovering tiger population: our primary objective is to determine if tiger numbers are increasing over time in response to management interventions, and so we monitor tiger population size over time as our state variable. However, at the same time we might also be interested to see if increasing tiger numbers are due to increased breeding amongst the resident population, or increased immigration into the protected area from outside. This in turn can have important implications for the spatial scale at which recovery programs are targeted.

3. How to monitor: Designing monitoring programs

Managers need to have reliable information about the status of wildlife populations and their response to interventions in order to make informed decisions. As we have seen, monitoring programs can play a key role in providing this information, by evaluating our assumptions about the status of populations, or how they are responding, relative to a stated objective or target. Developing clear monitoring objectives and targets is just the first step in the implementation of effective monitoring programs.

All too frequently however, the potential of monitoring programs to inform management decisions is wasted during the design phase. Results from poorly designed monitoring programs are misleading, due to poor quality information, and in some cases can do more harm than good if conservation effort is invested poorly as a consequence (Legg & Nagy, 2006). It is therefore critical that careful consideration is given to the statistical design and analysis of monitoring programs *before* substantial investment is made on their implementation and data collection. To this end, the bridge between science and management is an important one, and managers should be encouraged to seek appropriate scientific advice on designing monitoring programs at the outset.

An underlying premise of successful monitoring programs is that the design is **simple** and the measures are **straightforward**, **unambiguous** and **replicable** (Legg & Nagy, 2006). Overly ambitious monitoring programs suffer from being unsustainable both financially and in terms of technical staff capacity (Danielsen et al., 2005);(Poulsen & Luanglath, 2005). Most often however, monitoring programs suffer from 'cutting corners' on the measures they use, largely in a bid to save on limited conservation or management funds. Whilst cost is one of many practical considerations to be taken into account in designing monitoring programs, we outline here some minimum standards for the statistical design of monitoring, which, if met, will not only ensure a minimum level of rigor and thus usefulness of the results, but also improve cost-effectiveness in the long-run.

There are two common sources of error in population estimates that need to be taken into account in the design phase: ***detection error*** and spatial variation or ***sampling error*** (Yoccoz et al., 2001; Williams et al., 2002). Furthermore, we consider the importance of ***sample size*** and ***sampling efficiency*** in determining the ***capacity of monitoring programs to detect true changes*** in the target population with adequate statistical power [see Box 4].

Box 4: Accuracy and Precision

A major concern with the design of monitoring programs and the estimation of population parameters (e.g. abundance) is the **accuracy** and **precision** of the survey results.

Accuracy refers to the magnitude of systematic errors or degree of ***bias*** associated with an estimation procedure. This affects how well the estimated value represents the true value. Systematic errors may or may not be measurable and can cause estimates to consistently under or over-estimate the true value. ***Detection error*** and ***sampling error*** are examples of two sources of error that can result in biased estimates.

Precision refers to the ***variability*** in estimates. High precision means that random variation associated with the collection procedure is minimized. Generally larger sample sizes provide greater precision than small sample sizes. If comparing estimates over time, high variation (or low precision) makes it difficult to determine if there are statistically significant trends in the population. Therefore, it is important to carefully choose sampling techniques and develop sampling schemes that both meet the necessary assumptions and minimize the variation between samples

In designing a monitoring program we are generally looking to ***minimize bias*** and ***increase precision*** of our estimates. Acceptable levels of accuracy and precision should therefore be determined prior to conducting a survey.

3.1. Detectability or detection error

Many wildlife monitoring programs assume that, if animals or signs of animals are present, then they will always be detected. This assumption is implicitly made with simple indices of count data as a measure of relative abundance. For example, in presence/absence counts a survey team visits a site and records if the species was present or absent. Similarly with count data on transects survey teams count the total number of animal signs or sightings per distance of transect walked. The resulting index of relative abundance assumes a constant relationship with actual abundance *N*. None of these measures account for the eventuality that signs or individuals were present but undetected. In reality, few survey methods permit 100% detection of all signs of a species, or all individuals in a population (see Box 5).

In such circumstances, the estimated abundance of a population can be represented as:

$$\hat{N} = \frac{C}{\hat{p}}$$

Where $\hat{N}$ is the abundance estimate, C is the count statistic and $\hat{p}_i$ is the estimated detection probability (e.g. (Thompson, 1992; Lancia et al., 1994; Williams et al., 2002)

The probability of detecting a sign or individual animal can vary over space and time, for example with habitat type, time of day or different observers. This, in turn suggests that sampling designs that fail to account for probability of detection, or detection error, will result in biased population estimates and are therefore unreliable as a tool for monitoring true changes in populations over time.

Box 5: Sampling and detectability

x	o	o	o	x	o	x			
o	o	x	x	o					
x	o			x					
x	x		x						
x	x	x		x					
o	x								
o		x							
	x		x	x					
x									

This box shows a forest divided into 100 units.

X = occupied cell where species is detected.

O = occupied cell where species is not detected.

Blank = cell where species does not occur.

Thus the observed occupancy is 0.2 or 20% of the forest. But the true occupancy is 0.3 or 30% of the forest. The difference is due to not detecting species when it is present.

3.2. How to incorporate detectability into a monitoring design?

There are a number of accepted and standardized methods for incorporating imperfect detection into survey designs for monitoring programs [see Box 6]. The gold standard for these methods is distance sampling (Buckland et al., 2001) and mark-recapture techniques (Otis et al., 1978; White et al., 1982; Pollock et al., 1990), which incorporate detection error into estimates of population density and true abundance.

These methods are expensive to implement and require well-trained personnel combined with adequately large sample sizes, which often precludes their use over very large areas or at very low population densities such as found in many areas of Lao PDR. In these situations, indices of relative abundance are frequently used. There exist approaches for dealing with detectability for indices of relative abundance (Conroy & Nichols, 1996); these approaches typically rely on identifying sources of variation in detection probability (such as time of day and other environmental conditions) and reducing them in the survey design.

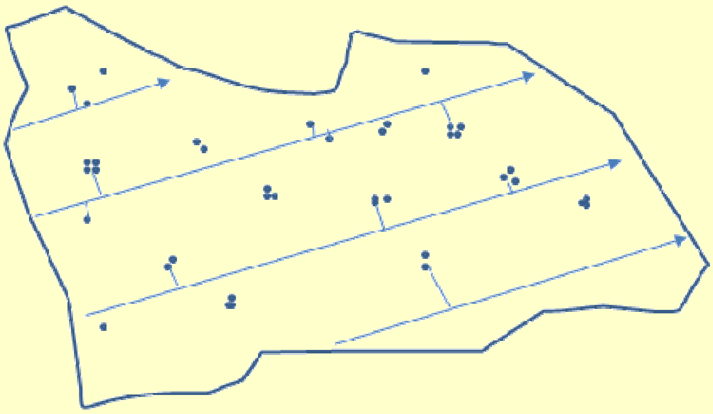
A useful alternative in low-density situations or at large geographical scales is occupancy-based methods, which have been successfully used for monitoring wildlife populations over time in the Nam Et-Phou Louey NPA, Nam Kading NPA and Nakai-Nam Theun NPA (Strindberg et al., 2007, Johnson and Johnston, 2007, Johnson et al., 2008). Occupancy surveys incorporate imperfect detection into presence/absence data, and permit estimates of the probability of detection and the proportion of area occupied (Mackenzie et al., 2002; MacKenzie et al., 2006). Proportion of area occupied is often used as a surrogate for abundance but is also useful as an alternative state variable for the population of interest, and a metric with which to monitor changes in the status of a population over time.

Box 6: Examples of methods that incorporate imperfect detection into sampling design

Estimating absolute densities of tiger prey species using line transect sampling *(from Karanth & Nichols, 2002)*

Line transects sampling is an example of an abundance estimation approach known as distance sampling (Buckland et al., 2001). During a line transect survey, the observer walks a series of lines and counts any animal or a given species that he/she detects. For every animal detected the observer measures the *perpendicular* distance from the animal to the survey line. In line transects we do not assume that all animals can be detected. However, a fundamental assumption is that all animals on the survey line are detected with certainty. Intuitively we would expect that the further away animals are from the survey line then the harder they are to detect. The key to distance sampling is to fit a *detection function* to the observed perpendicular distances and use this to estimate the proportion detected ($\hat{p}$).

Figure 1 Diagrammatic representation of a transect survey. A number of transect lines within the study area are 'walked' and perpendicular distances recorded to all animal clusters (groups of animals) detected. Note that not all clusters are detected.



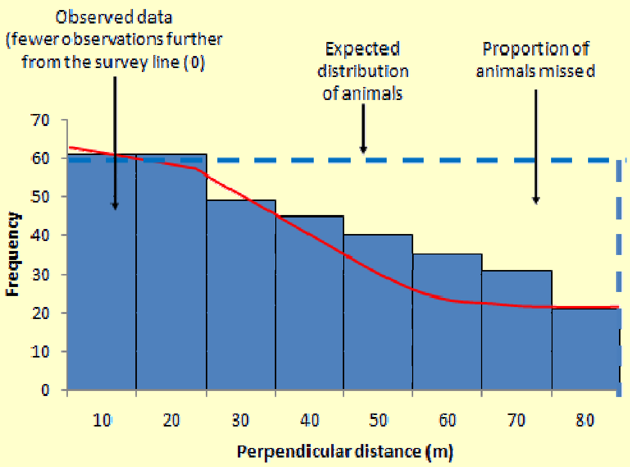


Figure 2. Conceptual basis for line transect sampling. The red curve represents the detection function that has been fitted to the real data. The area under the curve represent the animals seen and the area above it represents the animals missed. The proportion seen, *p* is estimated from the area under the curve divided by the total area.

Box 6 (cont.)

Estimating absolute densities of tigers using capture-recapture sampling *(from Karanth & Nichols, 2002)*

Capture-recapture is a survey method in which the total number of animals caught is counted and the associated detection probability is the probability of being captured. Capture-recapture methods also require that an individual animal can be reliably identified. A ‘capture’ can mean an animal is physically caught and marked with a tag to identify it or it can mean that an animal is captured in a photograph for example and identified by unique markings such as stripes on a tiger. The detection probability is estimated by the pattern of captures/re-captures for each animal on each sampling occasion over the entire survey period. To ensure that all individuals have a chance of being captured, the survey design has to ensure that no ‘holes’ exist in the sampled area. For example, when applying camera traps to estimate tiger abundance, sampling locations have to be sufficiently close together to ensure a tiger could not pass between them and avoid being captured.

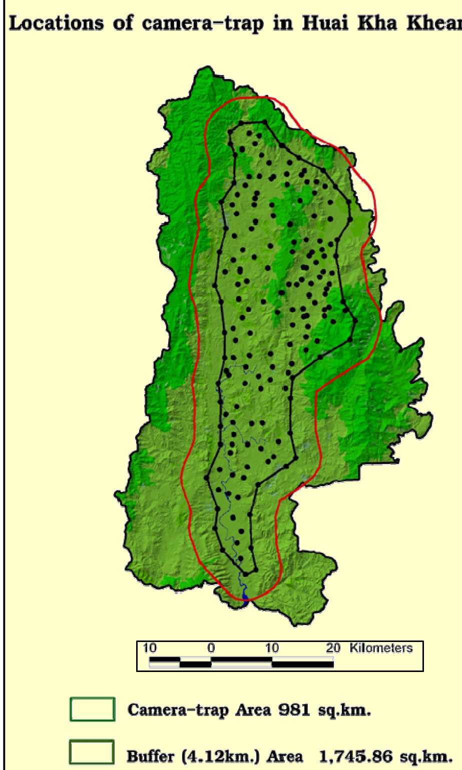


Figure 3. Example of a capture-recapture camera trapping design for estimating tiger abundance in Huai Kha Khaeng Wildlife Sanctuary, Thailand:

Camera-traps ● = 180 locations (3-4km spaced)

Camera-trap area ▬ = 981 km²

Effective area ▬ = 1745.9 km²

Box 6 (cont.)

Estimating occupancy rates of a species using repeat presence/absence surveys *(from Mackenzie et al., 2002)*

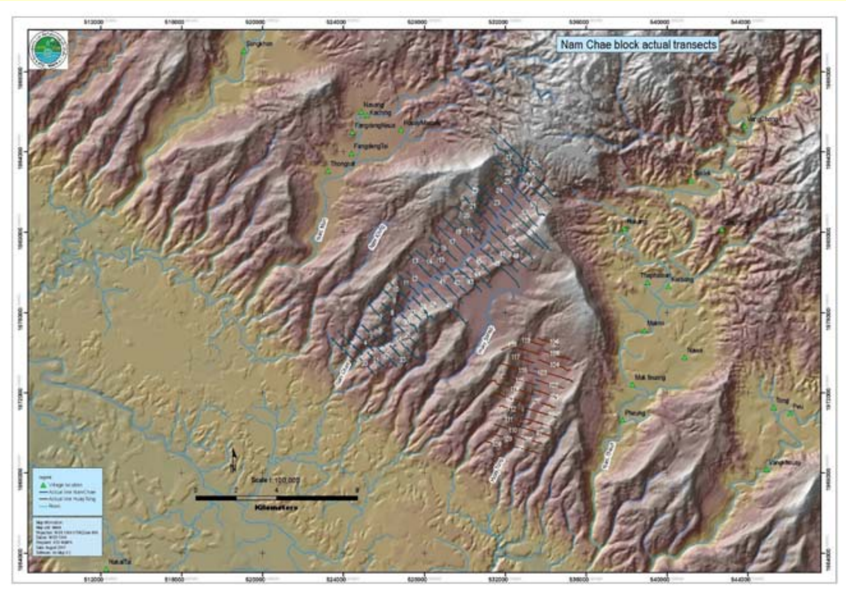
Occupancy surveys or 'presence-absence surveys' involve a sampling method that requires multiple visits to sites during an appropriate time-period when a species may be detected. However, a species may go undetected at these sites even when present, resulting in 'false absences'. The patterns of detection and non-detection (presence/absence) over repeat visits permits estimation of detection probability and the parameter of interest, proportion of sites occupied. At each sampling occasion (visit) at each sampling site, observers can apply a number of different sampling methods to detect the species of interest. Unlike capture-recapture techniques, detection histories are compiled for a particular site rather than an individual. These can be compiled through repeat visits by a single observer to a site over time, single visits by multiple observers to a site, or visits to multiple locations in a site during a single time period.

3.3. Spatial variation or sampling error

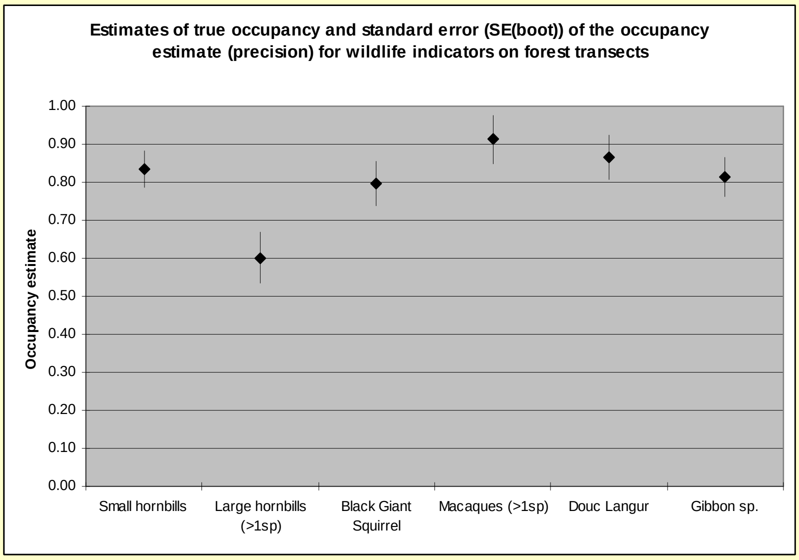
It is often logistically difficult or costly to survey entire protected areas or large landscapes. As a result, sampling locations are frequently selected, and then used to make inferences over a larger area, encompassing the population of interest (see Box 8 below). There is often considerable spatial heterogeneity in natural systems, which if not accounted for in sampling schemes, can introduce substantial bias or sampling error in measures of your target population (Dixon, 1998; Yoccoz et al., 2001; Pollock & Farnsworth, 2002). Ensuring adequate spatial coverage or spatial representativeness is therefore an important consideration in the design of monitoring programs. Furthermore, spatial coverage should be considered at an appropriate ecological scale for the species under study.

Let us continue our example of a tiger recovery conservation program. We are interested in monitoring a tiger population to assess progress towards a defined increase of, say, 50%. Let us assume our target population encompasses a landscape of 4,000km^2 including a national park and a large multiple-use buffer zone. We suppose that tiger densities are lower in the multiple-use zone than in the protected area because of substantial hunting of tigers and their prey – we therefore have already made the assumption that there will be spatial variation in the distribution of tiger abundance at the landscape scale. If we are interested in monitoring a tiger population increase at the landscape scale then we must account for this spatial variation by adequately sampling across the landscape. For example, if we sampled only in the protected area and then tried to extrapolate our population estimates across the entire landscape, we would have ignored spatial variation or sampling error and our population estimates at the landscape-scale would be biased, and in this example, overestimated. In summary, care should be taken to define precisely the ***target population*** of interest (defined here as the scale or area at which inferences about the population are to be made), and that this, in turn, is then used to design sampling schemes at spatially appropriate scales. The question of scale is also of ecological relevance as management information needs will likely vary over different geographic scales for different species. For example, wide-ranging or migratory species may need to be monitored over a much broader geographic area.

Box 7: Example of estimating occupancy rates of species using repeat presence / absence surveys in the Nakai-Nam Theun NPA, Lao PDR *(from Johnson and Johnston 2007)*



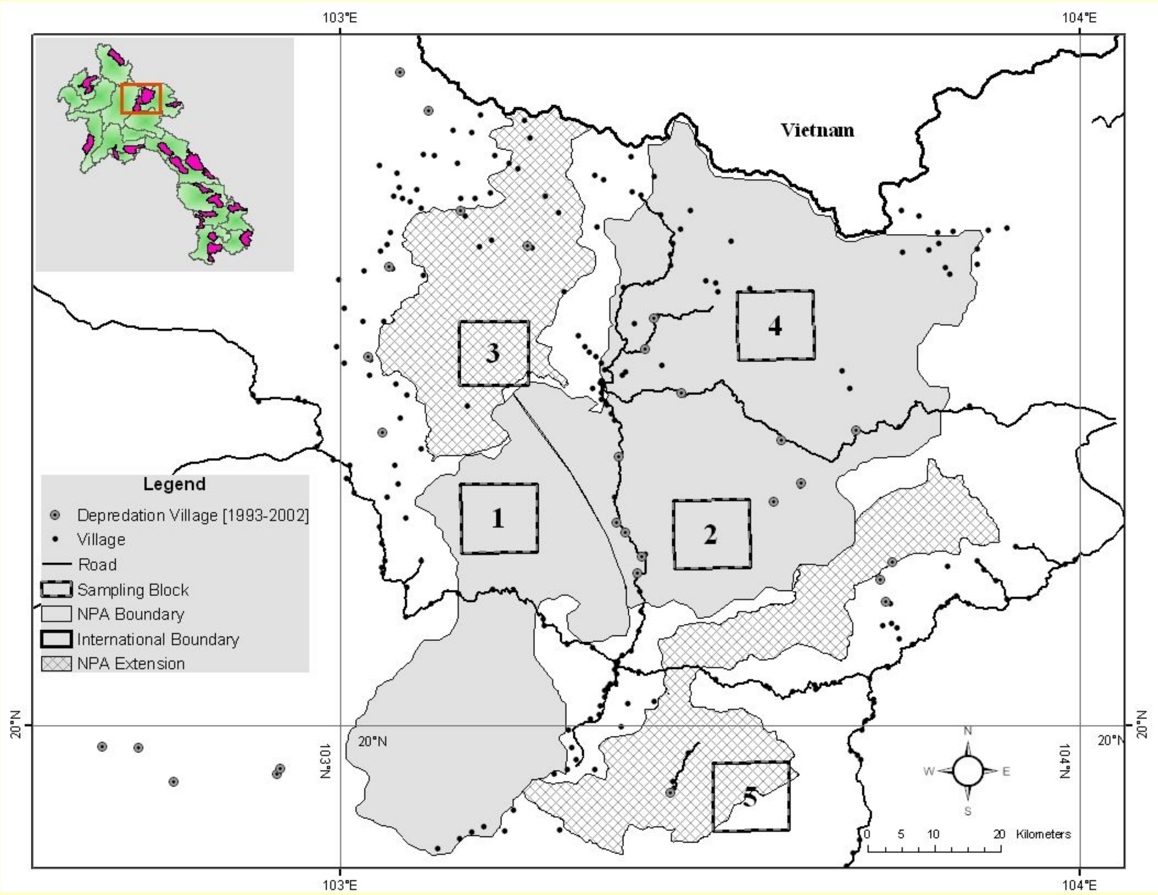
Forest transects for arboreal mammals and hornbills in Nakai-Nam Theun NPA are focused on six indicator species groups: Brown Hornbill – a small hornbill; large hornbills including Rufous-necked, Great and Wreathed Hornbills; Black Giant Squirrel, Douc Langur, White-cheeked Gibbon, and macaques. In the field, teams conduct surveys from 0600 to 1100 with observers moving slowly and silently along the transects scanning the treetops and openings for signs and sounds of indicator species. Teams monitor along each transect for four consecutive mornings before moving camp to the next transects. While moving along the transects, the team leader records all observations on the field data form.



Transects in 2007 regularly detected all six wildlife indicator species (forest hornbills (large and small), Black Giant Squirrel, Douc Langur, gibbon and macaque). The analyses provided estimates of the true occupancy for all of the indicators ranging from a low of 60% (SE 0.07) for large hornbills to a high of 91% (SE 0.06) for macaques. Detection probabilities for all six indicator species ranged from a low of 0.38 for macaque to a high of 0.60 for small hornbills. The precision of the estimates for all species was high (SE <0.07).

Box 8: Selecting sampling locations in the Nam Et-Phou Louey NPA *(from Johnson, Vongkhamheng, et al., 2006)*

In the NEPL NPA, tiger and prey surveys were conducted using 50 camera traps set in five 100 km^2 sampling blocks in the interior and proposed extension areas of the NPA as far away from enclave villages as possible (see map below). In this case, sampling locations were selected to be representative of the least disturbed areas of the NPA. Sampling blocks were spaced from 15-30 km apart. Each block was divided in 25 subunits of 2 km^2 and a random coordinate was chosen within each subunit. A pair of cameras, to photograph both sides of individual tigers, was placed in an optimal location near active animal trails within 500 m of the random coordinate.



The potential for spatial bias in the design of monitoring programs can manifest itself in a number of different ways. The above example refers to the error in extrapolating inferences about populations outside the sampled area. In addition, systematic spatial bias can be introduced into a survey design if care is not taken in the selection of sampling locations. For example, if a particular species of interest was monitored only from roads, as these were logistically easier for field teams to access, then all we could infer from our population estimates would be the abundance (or other state variable) of the population on roads. If our population of interest was at the landscape-scale, then this measure would neither be spatially representative nor particularly useful given that roads are a specific habitat feature, which are frequently associated with hunting and other threats to wildlife. Rather, a sampling design should identify and explicitly incorporate any potential gradients in wildlife abundance, associated with vegetation or human factors. Given that most spatial variation in both natural and human systems is often un-systematic, then selection of sampling sites on a simple random or systematic (with a random starting point) basis is often sufficient to incorporate spatial variation and address sampling error.

3.4. How much sampling effort is enough?

Recommendations on the amount of sampling effort required often have to balance the need to collect sufficient data to make valid statistical inferences with the need to minimize cost and time expenditures. The actual number of points, transects, sites etc. that should be sampled and the number of times each should be revisited during a particular field season will vary depending on the rarity of the species, variability of habitat and the objectives of the monitoring program.

Ideally, the monitoring objectives, or the particular question you are interested in answering, should dictate the scale, intensity, and accuracy and precision of the monitoring estimates. Once these are identified the resources required to accomplish the surveys can be estimated. However, because resources are often scarce, methods and specific objectives may have to be adjusted to what is affordable.

In general, the cost of collecting data increases as the scale broadens, the focus intensifies and/or the demand for accuracy and precision increases. The cost of implementing surveys, as well as the need for skilled and highly trained staff, will also typically increase from measures of occupancy and relative abundance being the least expensive, to estimates of absolute abundance or density being the most expensive. In reality there are often trade-offs to be made between all these factors. Mathematical equations are available to estimate the sample sizes required to produce a reliable estimate of a population parameter. The technique used to estimate sample size will vary according to the particular method used, for example line transects (Buckland et al., 2001), mark-recapture (White et al., 1982; Pollock et al., 1990) or occupancy surveys (Mackenzie & Royle, 2005) and even for a particular method, e.g. occupancy surveys, the estimation of sample size will depend on the underlying assumptions of the distribution of abundance (Royle & Nichols, 2003; Joseph et al., 2009), for example whether a species is typically randomly distributed or in a clumped distribution, which in turn is likely to vary between species and between habitats. In summary, determining the optimum number of samples needed should be an initial step of every wildlife population survey or monitoring program, regardless of the state variable (e.g. occupancy, abundance etc.) that is being measured (see Box 9 for an example of determining sample effort for the wildlife monitoring program in the Nakai-Nam Theun NPA in Lao PDR).

Box 9: Determining sample effort for wildlife monitoring along forest transects in the Nakai-Nam Theun NPA *(from Johnson, O'Brien, et al., 2005)*

To determine the sampling effort for wildlife monitoring along forest transects in the Nakai-Nam Theun (NNT) NPA, patrol reports by Village Conservation Monitoring Unit (VCMU) teams were compiled to estimate how frequently wildlife were encountered along trails in various sectors of the NPA (Table 1). The VCMU data indicated that wildlife populations were severely depressed and infrequently encountered. For example, arboreal mammals and birds were encountered at rates ranging from 0 to 10.63 for every 100 km of transect. By comparison, the encounter rates for small and large hornbills in the Bukit Barisan National Park in southern Sumatra are 2 times and 10 times greater. The NNT VCMU data sets indicated that extensive sampling effort would be required to accurately estimate the occupancy of arboreal mammals and hornbills along the dry season forest transects.

Table 1. Encounter rates (sign or observation/100 km of transect) for arboreal mammals and hornbills during VCMU patrols between 2000 and 2002.

Species	Thameuang	Navang	Xonglek	Makfeuang	Teung	Nameuy
Km. Transects	1,537	1,543	923	2,631	1,832	837
Giant squirrel	5.46	4.67	10.30	6.00	5.29	10.63
Douc Langur	2.80	1.23	3.79	4.03	1.04	7.05
Gibbon	6.90	4.80	4.88	2.58	1.09	2.39
Large Hornbills	4.50	2.66	8.34	3.76	0.87	4.78
Small hornbills	4.10	2.85	4.12	4.67	5.18	7.77

To estimate the sampling effort, the VCMU encounter data was used to simulate the detection of an indicator species on a forest transect. For instance, if small hornbills have an encounter rate of 0.05 per km on transect walks, we specified sampling designs of different lengths of transect, different number of transects and different intensities of visits to the transect. Hornbill detections were assigned randomly to transects and visits such that detections summed to 0.05/km over the sampling design. If we assume 100 transects of 5-km transects were visited 5 times, we would expect to encounter hornbills 0.25 times per transect or 125 times over the entire survey. The simulated data was then used to estimate detectability for an encounter rate under different levels of occupancy and sampling intensity. This allowed us to estimate the minimum and maximum detectability we could expect and then apply the range of detection probabilities to estimate precision and accuracy of occupancy statistics that result from different levels of sampling. The result of the simulations was a set of tables (see Appendices 2-4 in Johnson et al., 2005) that track the accuracy and precision of sampling under different levels of occupancy, transects and visits, modeling the performance of sampling x transects on y visits under the assumption of true occupancy and a detection probability. In this way we answered the question of how much effort was needed to estimate occupancy accurately and precisely and how much sensitivity there would be to detect change in the system over time.

3.5. Determining statistical power to detect change over time

For long-term monitoring programs, we are interested in not only estimating a population parameter in a single field season, but also in detecting changes in the population parameter towards a desired target over time. Statistical estimates of sampling effort required to detect changes or trends over time tend to focus on the concept of ***statistical power*** (Field, 2005; Legg & Nagy, 2006). In this instance, statistical power refers to the *probability of detecting a true change if present* (1-β). In general, the power of a test is influenced by the probability of **Type 1 error** (α), which is the probability of falsely detecting a change when one isn't present (a 'crying wolf' scenario), the probability of **Type 2 error** (β), the probability of failing to detect a true change when one is present, **sample size** (n), v**ariability or precision of the population estimate**, and the strength of the trend or magnitude of the desired change to be detected, also called the **effect size** (often denoted as ***r***, or rate of change). The relationship between these parameters depends on the ecological process producing the trend and the techniques used to detect it. For this reason, the selection of an appropriate model to evaluate power is critical (Gerrodette, 1987), see Box 10).

Conducting an *a priori* power analysis during the planning of a monitoring program can provide guidance on designing sampling schemes that ensure adequate sample size. This exercise will help to prevent the implementation of a monitoring program which is too weak and unable to discriminate a meaningful difference over time. This is often due to a sample size that is too small and/or has high variability in the study population. It is possible, and indeed a recommended approach, to account for and reduce some of this variability with improved efficiency of sampling design (see below) or by increasing the number of replicates or sampling occasions (see Box 10).

Whilst a power analysis is essentially a statistical process, it requires meaningful input from managers or scientists (Lenth, 2001). In this context, a good starting point is to ask the question: ***"What change (or effect size) do I expect – or hope - to see?"*** Meaningful effect sizes in turn need to be both biologically feasible for the species under study as well as for the given time-frame of the study. They also need to be of direct relevance to the management objective. In our tiger recovery example, we have explicitly stated that our overall objective is a 50% increase in our tiger population over 10 year. We can them examine various scenarios of sampling schemes with different sampling effort to evaluate if our proposed monitoring design is able to detect this defined change with adequate statistical power. Bear in mind that, in general, reducing the effect size will *increase* the amount of sampling effort required, and that reducing the effect size for a given level of sampling effort will reduce the statistical power to detect change (see Box 10).

Statistical power becomes particularly important when the information resulting from the monitoring program will go on to influence management recommendations. For example, a particular monitoring objective might be to detect a decline in an endangered species in an area under a particular logging practice. Failure to detect any true decline due to low statistical power provides ‘evidence’ that forest-cutting is having no effect on this species and thus the recommendation is for this management practice to continue.

Recently many free user-friendly software packages have become available for power analysis, such as TRENDS (http://swfsc.noaa.gov/textblock.aspx?Division=PRD&ParentMenuId=228&id=4740; (Gerrodette, 1987) and MONITOR

(http://www.mbr-pwrc.usgs.gov/software/monitor.html) (see also (Thomas, 1997) for a review).

Box 10: Power analysis for detecting trends in sea otter populations under different sampling scenarios using TRENDS *(from Gerrodette, 1987)*

(Gerrodette, 1987) examined the feasibility of monitoring trends in sea otter populations in California, USA using aerial strip transects conducted by plane. They first conducted a pilot study of 7 aerial transects to determine the precision of aerial counts. They estimated the co-efficient of variation (CV) as 0.13. They assumed that CV was proportional to the inverse of the square root of abundance and that sea otter growth was likely to be exponential. They also assumed that $\alpha = 0.05$.

Various sampling scenarios were investigated. Firstly they investigated the ***power*** of detecting various annual rates of increase (r) at ***different sampling intensities*** (number of flights/year) for a monitoring program of 5 year duration **(Fig 1**). Then they supposed that the total monitoring time was not fixed, and wished to know ***how many annual surveys*** would be required to detect a given trend ***at different survey intensities*** (flights/yr), with 95% power (**Fig 2**).

Finally, they asked whether annual surveys were the ***optimal sampling frequency*** and, if the population is growing slowly at 5%/year, would it be more efficient to survey every 2 or 3 years at a level of survey intensity of 2 flights/ survey year (**Table 1**).The number of surveys (and therefore costs) could be reduced by half if done every 3 years rather than every year. However the total number of years to detect a change will increase from 7 to 9 years.

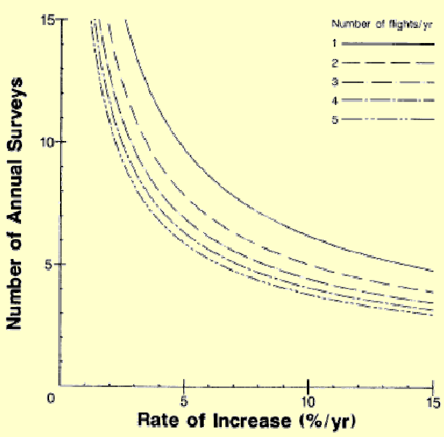
No. yr between surveys (t)	No. surveys required* (n)	Effective % change/ interval ($1.05^t - 1$)	No. yr to detection† [$t(n-1)$]	Total % change‡ [$1.05^{t(n-1)} - 1$]
1	8	5.0	7	41
2	5	10.3	8	48
3	4	15.8	9	55
4	4	21.6	12	80
5	3	27.6	10	63

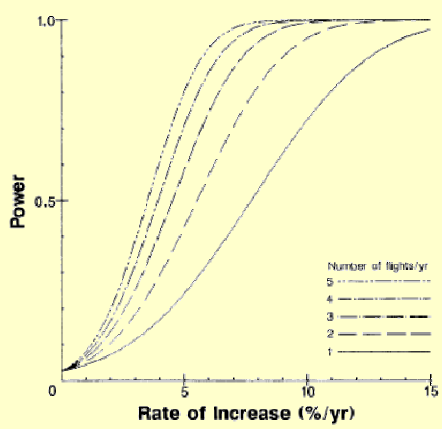
Table 1. Effect of different sampling frequencies on the number of surveys required to detect a mean 5% annual increase in sea otter populations

The additional 'cost' of waiting longer to detect a change (and the potential conservation risks of delaying potential management action) needs to be weighed against the financial benefits of reducing survey frequency. This will depend on your specific objectives and species under study.

Fig 1. Power curves for detecting various rates of annual increase in population size of sea otters in central California using five annual aerial surveys. **More flights per year permit more precise estimates of population size, hence greater power to detect a given rate of increase.**

Fig 2. Minimum number of annual surveys required to detect various rates of annual increase in population size of California sea otters. **More flights permit more precise esti- mates of population size during each survey, hence fewer annual surveys required.**





3.6. Improving the efficiency of sampling designs

For very low density or rare species as in our protected areas in Lao PDR, the amount of effort required to obtain adequate sample sizes with sufficient power to detect change over time can be daunting. The choice of sampling scheme therefore also needs to be evaluated in terms of its efficiency. ***Efficiency*** of sampling design refers to the precision of the resulting population estimate for a given level of survey effort (Yoccoz et al., 2001). Precision, as we have seen, can influence the power of the monitoring program to detect true changes in the status of a population over time, or to detect a true response of a population to a specific management intervention.

The efficiency of a sampling design depends largely on the characteristics of the target population. If the target population can be divided into different spatial units that are relatively homogenous in nature, for example large blocks of different forest types, then ***stratification*** (Thompson, 1992) of sampling by forest type would result in a more efficient sampling design and more precise population estimates by forest type. However, in such cases adequate sample sizes need to be maintained for each stratum (rather than the population as a whole), and for low density populations or rare species, this is frequently not a feasible option. In these situations sampling designs can be tailored to maximize the number of observations (or sample size), for example by standardizing the timing of surveys at a particular time of day or during a particular season when individuals are more visible, thus ***increasing detection probability***, or by employing ***adaptive sampling*** techniques (Thompson, 2004) where the intensity of sampling is dependent on initial sampling results.

3.7. Decision making: matching objectives with available resources

Even after sampling efficiency has been taken into consideration, the level of survey effort required may still be prohibitively expensive for available budgets. In these situations, managers need to re-consider their monitoring objectives and reflect on whether their proposed monitoring design is the most cost-effective approach to take. This is often the most difficult part of the planning process but an all-too-common situation faced by managers seeking to manage low density or depleted populations over large areas. In these situations the following guidelines can provide some assistance:

- Reflect upon whether the parameter to be measured needs to be density or true abundance and if minimum sample sizes can be achieved in order to satisfy the assumptions of these methods. If not, then consider if the objective can be still be met with alternative and perhaps cheaper measures, such as occupancy or presence/absence.

- Consider if the monitoring objective itself can be realistically achieved with the available budget, and trained staff to hand, over the desired timeframe. If not, then objectives may need to be modified either in terms of geographic scale (e.g. reducing the total survey area), or expected outcomes (e.g. adjusting the state variable or effect size you are hoping to measure)

Try to avoid the temptation of cutting corners by ignoring some of the fundamental principles of monitoring design that we have outlined in this module. Whilst certain data collected using opportunistic or ad-hoc methods can often prove useful to managers, for example opportunistic observations of tigers by field patrol teams can be extremely useful in confirming presence of very rare species such as tigers in a particular area, these data should be valued for what they are and not seen as a replacement for carefully designed monitoring programs intended to inform managers about the status of wildlife populations and/or how these are changing over time relative to management objectives.

4. PRACTICAL CONSIDERATIONS IN DESIGNING SUSTAINABLE MONITORING PROGRAMS

It is important to ensure that the design of any wildlife monitoring program is sustainable – or, in other words, to ensure that it can be implemented and replicated reliably over the long-term. In order to achieve this, a monitoring program needs to ensure the availability of **sufficient and adequately trained staff,** a **feasible timeframe** and **workplan** for implementation, and an **adequate budget** that supports all associated costs**.**

4.1 Personnel and capacity building

This addresses the important question of ***who*** will be responsible for implementing the monitoring program. For some protected areas and landscapes there are multiple actors or institutions responsible for management and monitoring implementation, thus it is important to identify which institution is responsible for which part of the monitoring program: ***the design, the field implementation and the analysis and communication of results.***

Different monitoring methods require different levels of training and skills. Advanced method such as mark-recapture techniques or Distance-based sampling require a higher level of skill and formal education than more simple presence/absence surveys for example. Regardless of the methods used, all field staff should receive the necessary training from a qualified trainer in the appropriate **data collection protocols**. Building up a strong monitoring team of trained and experienced field staff is an important component of ensuring the long-term sustainability of a monitoring program.

In addition to identifying the necessary field staff for implementation, it is also important to identify the appropriate and qualified technical support staff to provide advice and oversight on monitoring methods and analysis. Finally, it is important to identify the institutions and personnel responsible for data management and the logistics personnel required for coordinating the implementation of the data collection and ensuring that teams get out into the field when they are supposed to.

4.2 Making a workplan and schedule

Once the appropriate personnel have been identified, it is important to determine the time-frame of the monitoring program and to develop a detailed workplan for help in planning the required resources. Remember also to allocate sufficient time for the design phase of the monitoring program, as well as the field implementation and analysis phase.

It is important also to think about the time-frame of the monitoring program, including how quickly you need the results, and whether this is an appropriate time-frame given the biology and reproductive potential of the species. For example, for conservation targets such as elephants, our monitoring time-frame would need to be much longer to see results of a recovery program than for species such as muntjac, as elephants reproduce slower and populations would take a longer time to increase. Related to this is the question of frequency of surveys: would they be repeated annually, once every two years etc. These are also important issues to address in the design phase, but they often have practical and cost-related implications too.

For each survey year it's important to make a detailed workplan and schedule for implementation. Think carefully about the timing of your surveys and whether this maximizes the potential for observations and increasing sample size. Consider also if the timing is appropriate from a logistical perspective – for example it might not be possible to access certain parts of the protected area in the wet season. Consider also any other potential seasonal impacts on your conservation targets, such as large-scale migrations, breeding cycles or seasonal variation in certain threats, such as hunting. Ensure these impacts are accounted for and minimized by planning your data collection to occur within a particular season, and across the same seasons over multiple years. Finally, consider whether the timeframe of the proposed field implementation is sufficient to ensure that all data can be collected appropriately and at all spatial sampling locations, given the number of field staff you have available and the ease with which they can access and traverse different parts of the landscape. Make sure you also include necessary rest days for field teams as fieldwork can often be physically and mentally challenging.

4.3 Budget planning

Conservation and management budgets are often limited. It is therefore important to ensure that adequate funds are available for the proposed monitoring program design. As we have seen, some monitoring methods are more costly to implement than others, and the design of the monitoring program may need to be rethought if sufficient funds are not available. When planning your monitoring budget, the following costs should be considered:

Personnel – Sufficient staff and support need to be recruited for all stages of the monitoring process (see above)

Training – All staff need to be adequately trained in appropriate data collection methods and analytical procedures. Ensure the appropriate trainers are identified and that training programs and/or workshops are planned accordingly

Implementation – This includes field costs, such as food, camping equipment, navigation equipment (such as compasses, maps) medical supplies, and any specialized field equipment needed for certain monitoring methods (for example GPS units or cameras for photographic mark-recapture techniques, and the batteries needed to run this equipment). Ensure also that the monitoring teams have sufficient materials for recording and analysing field data, for example field notebooks for recording observations and computers with the required software programs installed for managing and analysing data (see below under Data Management and Documentation).

Logistics – Remember that the monitoring field teams need to move around the landscape! Ensure that sufficient vehicles or boats are available, together with an estimate of fuel costs and other logistical support that is needed to achieve the workplan and schedule you have developed.

5. DATA MANAGEMENT AND DOCUMENTATION

All aspects of the monitoring program should be **carefully documented** and stored in a clearly marked and accessible location (for example as electronic files on a central computer or server within the protected area, rather than on a personal laptop). This applies to the monitoring program goals and objectives, the monitoring design and associated assumptions, the data collection protocols and methods and the analytical techniques used. Monitoring programs can be adaptable and may change as new techniques evolve and more information becomes available. To adapt and refine the monitoring methods it is important to have a clear record of the development and assumptions that underly the original monitoring design, to ensure institutional knowledge is retained as new staff are taken on into the program.

A system of **storing and managing field data** is also required to ensure both integrity and quality of data is maintained. If field data are recorded in notebooks or on hard-copy forms, then a system should be made available that transcribes these data into an electronic format that can be stored on a central computer. This will greatly facilitate and speed-up data analysis as well as ensuring that data is not lost following general deterioration or wear and tear of paper forms. The electronic format may take the form of a simple Excel-based database with standardized column headings and pre-defined data entry codes, or, depending on the needs and capacity of the site, it may be in the form of a more sophisticated Access-type database or purpose-built management information system (ie MIST for ranger-based law enforcement data). Regardless, the database should be regularly backed up and the backup copy stored on a separate computer or location, to ensure that data is protected against any computer breakdown or virus.

6. COMMUNICATION AND DISSEMINATION OF RESULTS

Data analysis and communication of the results are the final and important stages in the management cycle. It is absolutely critical that all the hard work, time and effort put into designing and implementing rigorous monitoring programs is not wasted by failing to get the results to the key decision makers in a timely manner. Implicating all stakeholders at the outset and ensuring that monitoring programs are integrated as a core component of management planning and decision-making will greatly facilitate this process.

The presentation of monitoring results needs to assess the findings in the light of the monitoring goals and objectives. Furthermore, accepted and peer-reviewed analytical techniques should be employed wherever possible. It is recommended that the analysis of monitoring data is reviewed by an independent and scientific technical advisor or group to ensure its reliability and utility for management.

Management decision-makers and/or donors might not always be familiar with the technical details of the monitoring methods used. Depending on who the results are being presented to, it may be necessary to modify the format. For example, if presenting to an external or non-technical audience it will be important to ensure that the key results are presented as clearly as possible, using maps and charts wherever possible to facilitate communication of key findings.

Finally, be prepared to assess and review the monitoring design in the light of the results and to adapt and improve the design where appropriate. Monitoring programs are intended to be dynamic in nature and should be able to respond to changes in threats or management action.

Literature cited

Buckland, S. T., Anderson, D., Burnham, K., Laake, J., Borchers, D. & Thomas, L. (2001) *Introduction to Distance Sampling: Estimating abundance of biological populations,* Oxford University Press, Oxford.

Conroy, M. & Nichols, J. (1996) In *Measuring and monitoring biological diversity: Standard methods for mammals* (eds D. Wilson, F. Cole, J. Nichols, R. Rudran & M. Foster), pp. 41-49. Smithsonian Institution Press, Washington, DC, USA.

Danielsen, F., Jensen, A. E., Alviola, P. A., Balete, D. S., Mendoza, M., Tagtag, A., Custodio, C. & Enghoff, M. (2005) Does Monitoring Matter? A Quantitative Assessment of Management Decisions from Locally-based Monitoring of Protected Areas. *Biodiversity and Conservation,* **14,** 2633-2652(2620).

Dixon, P. M., A. R. Olsen, and B. M. Kahn (1998) Measuring trends in ecological resources. *Ecological Applications,* **8,** 225-227.

Ferraro, P. J. & Pattanayak, S. K. (2006) Money for Nothing? A Call for Empirical Evaluation of Biodiversity Conservation Investments. *PLoS Biology,* **4,** 482-488.

Field, S. A., Tyre, A.J. & Possingham, H.P. (2005) Optimizing allocation of monitoring effort under economic and observational constraints *Journal of Wildlife Management,* **69,** 473-482.

Gerrodette, T. (1987) A power analysis for detecting trends. *Ecology,* **68,** 1364-1372.

Johnson, A. and Johnston, J. (2007). Biodiversity Monitoring and Enforcement Project in the Nam Theun 2 Watershed. Final Report V1.1. November 2007. Vientaine, Lao PDR: Wildlife Conservation Society.

Johnson, A., O'Brien, T., Bezuijen, M. R., Robichaud, W. G. and Timmins, R. J. (2005). Recommendations for Wildlife Monitoring Design and Implementation in the Nakai-Nam Theun National Protected Area. 77. Vientiane: Wildlife Conservation Society.

Johnson, A., Vongkhamheng, C., Hedemark, M. and Saithongdam, T. (2006). Effects of human-carnivore conflict on tiger (Panthera tigris) and prey populations in Lao PDR. Animal Conservation 9: 421-430.

Joseph, L., Elkin, C., Martin, T. & Possingham, H. (2009) Modeling abundance using N-mixture models: the importance of considering ecological mechanisms. *Ecological Applications,* **19,** 631–642.

Kapos, V., Balmford, A., Aveling, R., Bubb, P., Carey, P., Entwistle, A., Hopkins, J., Mulliken, T., Safford, R., Stattersfield, A., Walpole, M. & Manica, A. (2008) Calibrating conservation: new tools for measuring success. *Conservation Letters,* **1,** 155–164.

Karanth, K. U. & Nichols, J. D. (eds.) (2002) *Monitoring tigers and their prey: A manual for researchers, managers and conservationists in tropical Asia,* Centre for Wildlife Studies, Bangalore.

Lancia, R., Nichols, J. & Pollock, K. (1994) *Estimation of number of animals in wildlife populations,* The Wildlife Society, Behesda, MD, USA.

Legg, C. & Nagy, L. (2006) Why most conservation monitoring is, but need not be, a waste of time. *Journal of Environmental Management,* **78,** 194-199.

Lenth, R. V. (2001) Some Practical Guidelines for Effective Sample-Size Determination. *The American Statistician,* **55,** 187-193.

Lyons, J. E., Runge, M. C., Laskowski, H. P. & Kendall, W. L. (2008) Monitoring in the Context of Structured Decision-Making and Adaptive Management. *The Journal of Wildlife Management* **72,** 1683-1692.

MacKenzie, D. I. (2009) Getting the biggest bang for our conservation buck. *Trends Ecol. Evol.,* **24,** 175-177.

Mackenzie, D. I., Nichols, J. D., Lachman, G. B., Droege, S., Royle, J. A. & Langtimm, C. A. (2002) Estimating site occupancy rates when detection probabilities are less than one. *Ecology,* **83,** 2248-2255.

MacKenzie, D. I., Nichols, J. D., Royle, J. A., Pollock, K. H., Bailey, L. L. & Hines, J. E. (2006) *Occupancy Estimation and Modeling: Inferring patterns and dynamics of species occurrence,* Elsevier Academic Press.

Mackenzie, D. I. & Royle, J. A. (2005) Designing occupancy studies: general advice and allocating survey effort. *Journal of Applied Ecology,* **42,** 1105-1114.

Nichols, J. D. & Williams, B. K. (2006) Monitoring for conservation. *TRENDS in Ecology and Evolution* **21,** 668-673.

Otis, D., Burnham, K., White, G. & Anderson, D. (1978) Statistical inference from capture data on closed animal populations. *Wildlife Monographs,* **62,** 1-135.

Pollock, K., Nichols, J., Brownie, C. & Hines, J. (1990) Statistical inference for capture-recapture experiments. *Wildlife Monographs,* **107,** 1-97.

Pollock, K. H., J. D. Nichols, T. R. Simons, G. L. & Farnsworth, L. L. B., and J. R. Sauer. (2002) Large scale wildlife monitoring studies: statistical methods for design and analysis. *Environmetrics,* **13,** 105–119.

Poulsen, M. K. & Luanglath, K. (2005) Projects come, projects go: lessons from participatory monitoring in southern Laos. *Biodiversity and Conservation,* **14,** 2591–2610.

Pullin, A. S. & Knight, T. M. (2001) Effectiveness in Conservation Practice: Pointers from Medicine and Public Health. *Conservation Biology,* **15,** 50-54.

Redford, K. H., Coppolillo, P., Sanderson, E. W., Fonseca, G. A. B. D., Dinerstein, E., Groves, C., Mace, G., Maginnis, S., Mittermeier, R. A., Noss, R., Olson, D., Robinson, J. G., Vedder, A. & Wright, M. (2003) Mapping the Conservation Landscape. *Conservation Biology,* **17,** 116–131.

Royle, J. A. & Nichols, J. D. (2003) Estimating abundance from repeated presence-absence data or point counts. *Ecology,* **84,** 777–790.

Strindberg, S., Johnson, A., Hallam, C., Rasphone, A., Helm, F. V. D., Xiongyiadang, P. and Sisavath, P. (2007). Recommendations for monitoring landscape species in the Nam Kading National Protected Area. A report to the Integrated Ecosystem and Wildlife Management Project. Vientiane: Wildlife Conservation Society (WCS) and the Integrated Ecosystem and Wildlife Management Project (IEWMP).

Sutherland, W. J., A. S. Pullin, Dolman, P. M. & Knight, T. M. (2004) The need for evidence-based conservation. *Trends in Ecology & Evolution,* **19,** 305-308.

Thomas, L., and C.J. Krebs (1997) A review of power analysis software. *Bulletin of the Ecological Society of America,* **78,** 126-139.

Thompson, S. K. (1992) *Sampling,* John Wiley & Sons, New York.

Thompson, W. (2004) *Sampling Rare or Elusive Species: Concepts, Designs, and Techniques for Estimating Population Parameters,* Island Press.

White, G., Nichols, J. & Boulinier, T. (1982) *Capture-recapture and removal methods for sampling closed populations,* Los Alamos National Laboratory Publication, Los Alamos, NM, USA.

Williams, B. K., Nichols, J. D. & Conroy, M. J. (2002) *Analysis and Management of Animal Populations: Modeling, Estimation and Decision Making,* Academic Press, San Diego, California, USA.

Yoccoz, N. G., Nichols, J. D. & Boulinier, T. (2001) Monitoring of biological diversity in space and time. *TRENDS in Ecology & Evolution* **16,** 446-453.

Monitoring and Adaptive Management
Adaptive Management Simulation

Exercise

James P. Gibbs

This material is based on work supported by the National Science Foundation under the Course, Curriculum and Laboratory Improvement program (NSF 0127506), and the United States Fish and Wildlife Service (Grant Agreement No. 98210-1-G017).

Monitoring and Adaptive Management
Adaptive Management Simulation

James P. Gibbs

INTRODUCTION

To be successful, management initiatives need to be flexible, adaptive, and permit the capacity for learning. This exercise deals with single, harvested population. The dynamics of the population are governed by a set of simple rules and relationships that are as yet unknown to you. But by monitoring the system through time, experimenting with harvest levels, and communicating with others also dependent on the population, you will uncover the basic rules governing the dynamics of the population and thereby learn, through adaptive management, how to manage it successfully for all stakeholders involved. The exercise therefore emphasizes three themes: (1) adaptability, (2) experimentation, and (3) communication. The exercise is intended to be as realistic as possible, not in terms of any particular natural system but in terms of the adaptive management process. As you will see, you are the stakeholders in this system. How successful you are will depend on how carefully you monitor the system, analyze it and communicate with the other stakeholders involved.

MECHANICS OF THE EXERCISE

BASICS

The exercise is fairly simple. You are dependent on exploiting a species that undergoes “good” and “bad” years purely by chance. You will track the changes in abundance of this species for one year to the next, specifying harvest levels each year. Note that you might try experimental harvests to test your hypotheses about how the system works. Similarly you may skip harvest entirely for the same reason. Of course, the more individuals you extract from the population, the more revenue you will derive from it, but if you are not careful about setting proper harvest levels you could destroy the population. As each year passes analyze your monitoring data to learn about how the system changes on its own as well as in response to your harvest. How can you represent the changes that occur in nature in a mathematical way for analysis?
Based on what you learn devise ways to better manage it.

First steps
Decide what your management objective is for this species and what specific variable you will measure and monitor to determine if you are meeting your goal.

Remember you are stakeholders who depend on maintaining reasonable levels of this species because you need to make a living from harvesting it. Whatever your goal is, be explicit about it, make sure it is measurable and unambiguous, and write it down.

Running through the adaptive management process

Now let's begin the adaptive management process. You will be deciding how much of your species to harvest each year based on how the population grew from the previous year. The population starts with 250 individuals. First, you will set your harvest level for the year. Your instructor will then flip a coin and tell you whether the ecosystem will experience a "good" or "bad" upcoming year and, accordingly, what abundance your species reaches the next year. One constraint is that you need to harvest minimally 10 individuals per year to remain financially solvent. Repeat this process each year for as long as you need to gain confidence in how the system works and how much you can extract from it. As the years proceed, monitoring data on harvests and species abundance should be assembled in a place where all stakeholders can see and evaluate them (chalkboard, overhead, poster paper, computer with digital projector, etc.) simultaneously. Look for simple relationships between the change in your species' population and whether it is a "good" or "bad" year, as well as changes in population growth relative to potential population thresholds.

Example of table to use in exercise

Year	Population at start of year	Harvest (no. Individuals)	Population at end of year	Conditions (G or B)	New population dependent on conditions and harvest	Profit	Comments/Observed Change in population*
1	250	-100	150	G	600	100	
2	600	-100	500	G	1500	200	
3	1500	-100	1400	G	1500	300	
4	1500	-100	1400	B	350	400	
5	350	-10	300	B	63	440	
6	63	-10	53	G	212	450	
7	450	-100	350	B	87.5	550	
8							
9							
10							

** For example you may notice the population has multiplied by a certain number etc..*

Hint: The population changes by an unknown amount in "good" and "bad" years. One way to analyze this data is to use a simple equation making the unknown change a symbol such as "x"

A word of encouragement

If you are a little confused during the first 10-15 years of this process, particularly because you lack any basis to make decisions, you should be! Welcome to the real world! This is exactly what happens when anybody tries to start managing a system without knowing anything about it. You will have to monitor the patterns of the system and its response to your harvest decisions, and thereby learn from the changes that occur. This iterative “learning-by-doing” should eventually lead you to understanding the system and making decisions that better enable you to reach your management goals. This is, more or less, what adaptive management is all about.

Concluding the exercise

At the end of the exercise, share with your instructor and class your theories about how this system works. Once you have stated your conclusion your instructor will reveal what rules were governing the system. Were you ultimately were successful in meeting your goals?

VARIATIONS ON STRUCTURING THE EXERCISE

To make this exercise even more interesting, split it into small teams or even work as individuals. Work in parallel harvesting a population undergoing the same dynamics. Thus, share the series of coin flips but set your own harvest levels and hence keep track of your own harvest and hence population counts over time, you may like to add a value to your resource too. The “winner” will be the team (or individuals) who figure out the system the most quickly and thereby accrue the greatest total harvest, and profit over a period of time (e.g., 50 years). Thus, tally your annual harvests. As you will see, the smartest manager(s) wins! You may also like to try making 5 or ten year plans. This will contrast adaptive management against the traditional management technique. In this scenario, you will choose your harvest rate for 5 or 10 years and then go though a simulation of these years.

The Mark-Release-Recapture Game

By Chris Hallam WCS

Introduction:

This is a game to be played outside and is similar to a game of "tag". It is a fun game which is very useful in understanding the concepts of the Mark release recapture survey method for estimating population size.

Class size: 20 and above

Equipment: Pen and paper; suitable area for running around

Background:

The Mark Release Recapture (M-RC) technique is a commonly used survey method for estimating population size of mobile animals. It involves the capture and marking of animals, their release and, recapture at a later date. The information is then used to calculate an estimated size for the population. There are many different formulas and ways to calculate the population estimate, some also give information on survival and migration or immigration into a population. These are covered well in Heyer et.al 1994[1] which is available from FoS via Dr Bounnam.

For this exercise we will use Petersen's Equation as it is the simplest form.

$$N = \frac{rn}{m}$$

N= Estimated population size
r= No. animals caught marked and released on day 1
n= Total number of animals caught on day 2
m= Total number of marked animals caught on day 2

The M-RC method is based no the following assumptions:

1. The initial sample is representative of the population as a whole i.e. not biased by age or sex
2. All animals in initial sample are marked and the marks are permanent.
3. When released the marked animals become distributed randomly throughout the population
4. Marking does not affect the probability of recapture or survival

Method:

1. Ask for two volunteers. These two people will become the "taggers" and represent our capture technique: "Tagger 1" and "Tagger 2". The remainder of the students should become the animals in our population. They may decide what they would like to be.

2. "Tagger 1" will go first. 'Tagger 2' should be removed so that s/he cannot see who is tagged. This is to avoid biasing the recapture.

3. A game of tag should be played within a designated space and for a limited time eg: 2 mins.

4. People who are tagged should sit to the side. At the end of the two minutes the names of the captured individuals and the number of people caught should be noted for use in the equation. (this will be "r" in Petersens equation above)

A volunteer will fill in a table like the one below to record the capture results.

Name	1st capture "r"	2nd Capture "n"	Recapture count "m"

5. The captured individuals should then be re-introduced to the playing area and told to "disperse randomly" within the population. "Tagger 2" should then be brought in. The game should then be played for the same period of time again, and in the same manner as before.

6. Captured individuals should again sit to the side, and both total number of captured and marked individuals counted at the end of the game. ("n" and "m" in the above equation respectively)

7. Students should return to a class room and form into groups. Each group should calculate population using the equation and to discuss result with reference to the following questions.

Questions:

- How did the estimate compare to the actual population?
- What was the difference?
- Why was there a difference?
  (Refer to assumptions)
- Why was the second "Tagger" not allowed to see who was marked?
  (See point 4 of assumptions)

---

[1] Heyer, Ronald W., M. A. Donnely, R. W McDiarmid, L. C. Hayek and M. S. Foster eds. 1994 Measuring and Monitoring Biological Diversity: Standard methods for Amphibians Smithsonian institution press. Washington DC London UK

Monitoring wildlife populations for management

Emma Stokes

Madhu Rao

Arlyne Johnson

Kelly Spence

Outline

1. Biological monitoring in a management context
2. What to monitor?
3. How to monitor?
4. Practical considerations in designing a sustainable monitoring program
5. Data management and documentation
6. Communication

Biological Monitoring in a management context

Investment of human and financial resources to preserve wildlife populations

Are scarce conservation resources being well spent?

Are conservation interventions working?

Are wildlife populations increasing, decreasing or remaining the same?

This module…

- General guidelines for design and implementation of wildlife monitoring programs in a management context
- Common **pitfalls** and potential **sources of error** in the design and interpretation of wildlife monitoring data
- How to balance between technical rigor and cost-effectiveness ?
- Criteria for ensuring the long-term sustainability of monitoring programs (low wildlife densities, inaccessible forests)

Why Monitor?

State of the system
(What is the level of illegal hunting in a protected area?)

ACTION: Increase patrolling along the border of the PA

1.Monitoring helps managers in decision-making

Why Monitor?

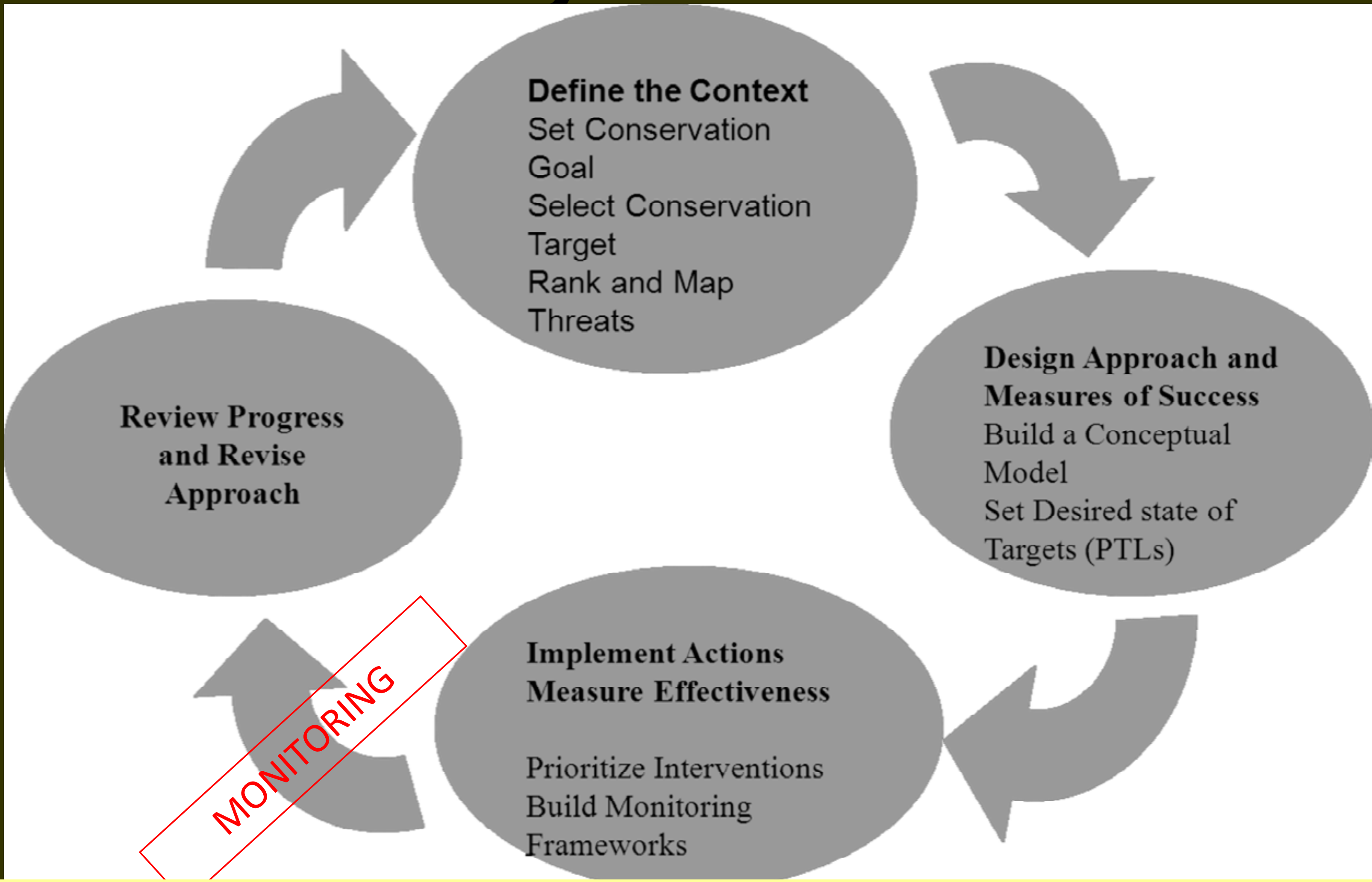
Objective of NPA: To decrease the level of illegal hunting by 90% over a 2-year period

Is this effective in reducing the level of Hunting?

ACTION: Increase patrolling along the border of the PA

2. Monitoring helps evaluate the effectiveness of management actions

Why Monitor?



3. Monitoring provides the feedback loop for learning about the system (For Adaptive Management)

How can we increase the efficiency of monitoring programs?

Clear and explicit monitoring objectives

Targeted monitoring *vs.* Surveillance monitoring

Targeted monitoring:

Defined by its integration into conservation practice.

Example: Adaptive Management

- Clear management objectives
- Potential management actions to meet objectives
- Apriori models of system response to different management actions
- Measures of confidence in the models
- Monitoring program to (a) provide estimates of relevant variables to make periodic management decisions and (b) discriminate between competing models about how the system works and adjust confidence in difference models accordingly

Surveillance Monitoring

- Not guided by apriori hypotheses about system response
- 2-step process

  - population decline identified by monitoring data and a statistical test

  - (i) Initiate active conservation immediately OR (ii) initiate studies to understand the cause of the decline, followed by active conservation

KEY: Detection of a population decline as a trigger for initiating management actions.

Monitoring is inefficient and ineffective- ‘too little, too late’?

What to monitor ?
Setting conservation targets

What variable (or variables) need to be monitored?

Species ………….Ecosystems

What measure should be used?

Quantitative ……….. Qualitative

Module focus: Quantitative measures of wildlife populations (large mammals)

What species or groups of species to monitor?

Examples:

Objective: Recovery of tigers to a particular level in a PA

Monitoring targets:

Size of tiger population + abundance of key prey species

Monitoring integrity of PAs/preservation of key habitat

- *Objective*: Integrity of PAs or preservation of key habitat

Monitoring targets: Select species that will provide most useful and indicative information of system response to management intervention or strategy

What measure/metric to use?

Management objective

Monitoring targets

COST?
EFFORT?

Measures of abundance [METRIC]

Density (number of individuals/unit area)

OR

Population size (number of individuals in a defined area)

Alternative Measures

Relative abundance

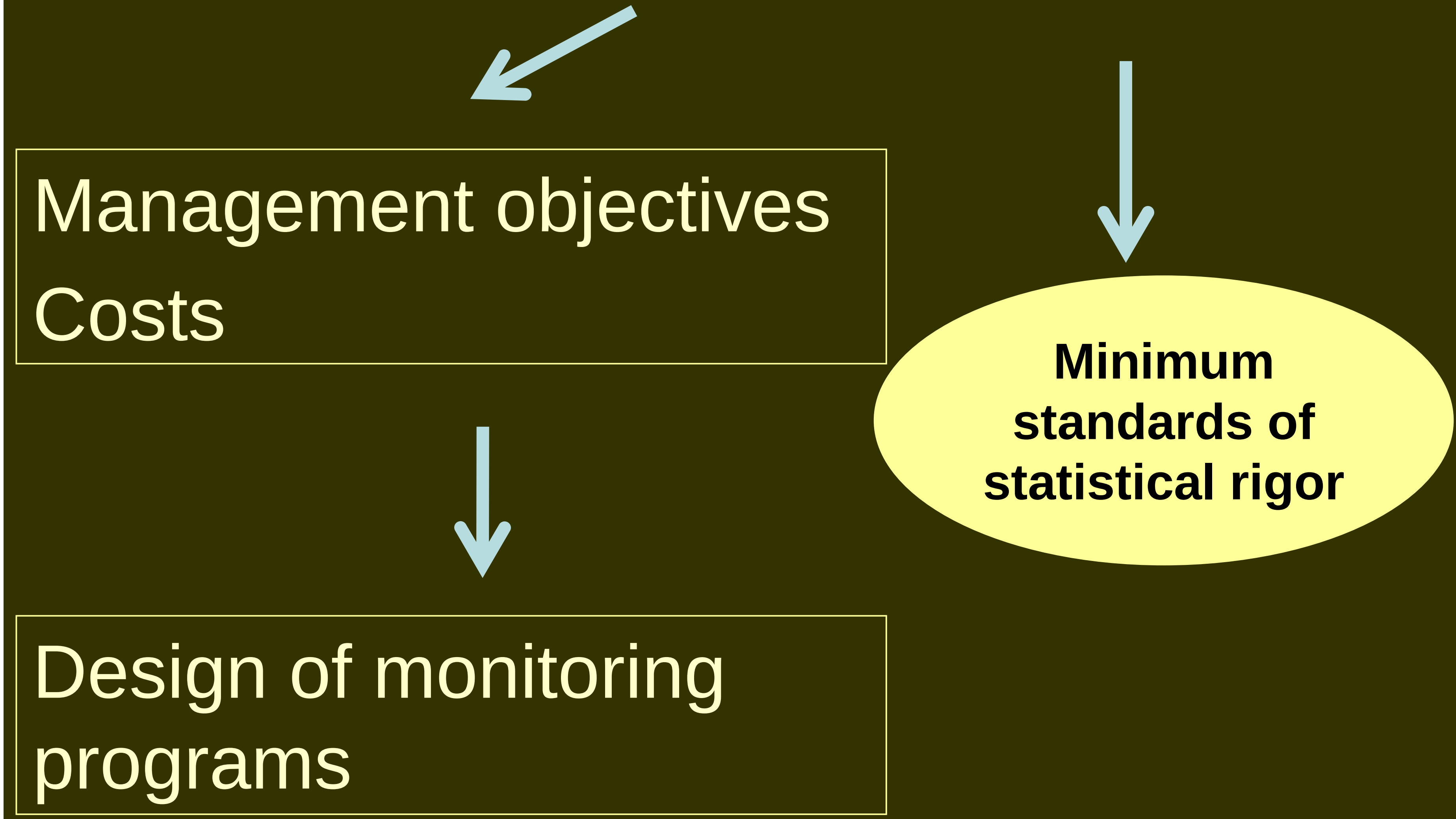
An index or proxy measure that has some constant relationship to abundance

OR

Occupancy

Proportion of area occupied by a particular population

Choice of Measures



Metrics: State variables

Definition: A metric that summarizes the status of a population of interest at a particular time

Species Richness

Abundance

Presence of species

Metrics: Rate parameters

Dynamic processes that influence the response of state variables

Reproduction

Emigration

Immigration

Monitoring Programs: Design Issues

Poor design = poor quality information

- Clear monitoring objectives
- Statistical design and analysis of monitoring programs BEFORE implementation and data collection
- Minimize **bias** and increase **precision** of estimates

Monitoring Programs: Design Issues

Simple Design

Measures-

- straightforward
- unambiguous
- replicable

Overly ambitious

Cutting corners

Monitoring Programs Design Issues

- Common sources of error in population estimates: Detection and Sampling errors
- Sample size
- Sampling efficiency

Capacity of monitoring programs to detect true changes in target populations with adequate statistical power

Accuracy vs. Precision

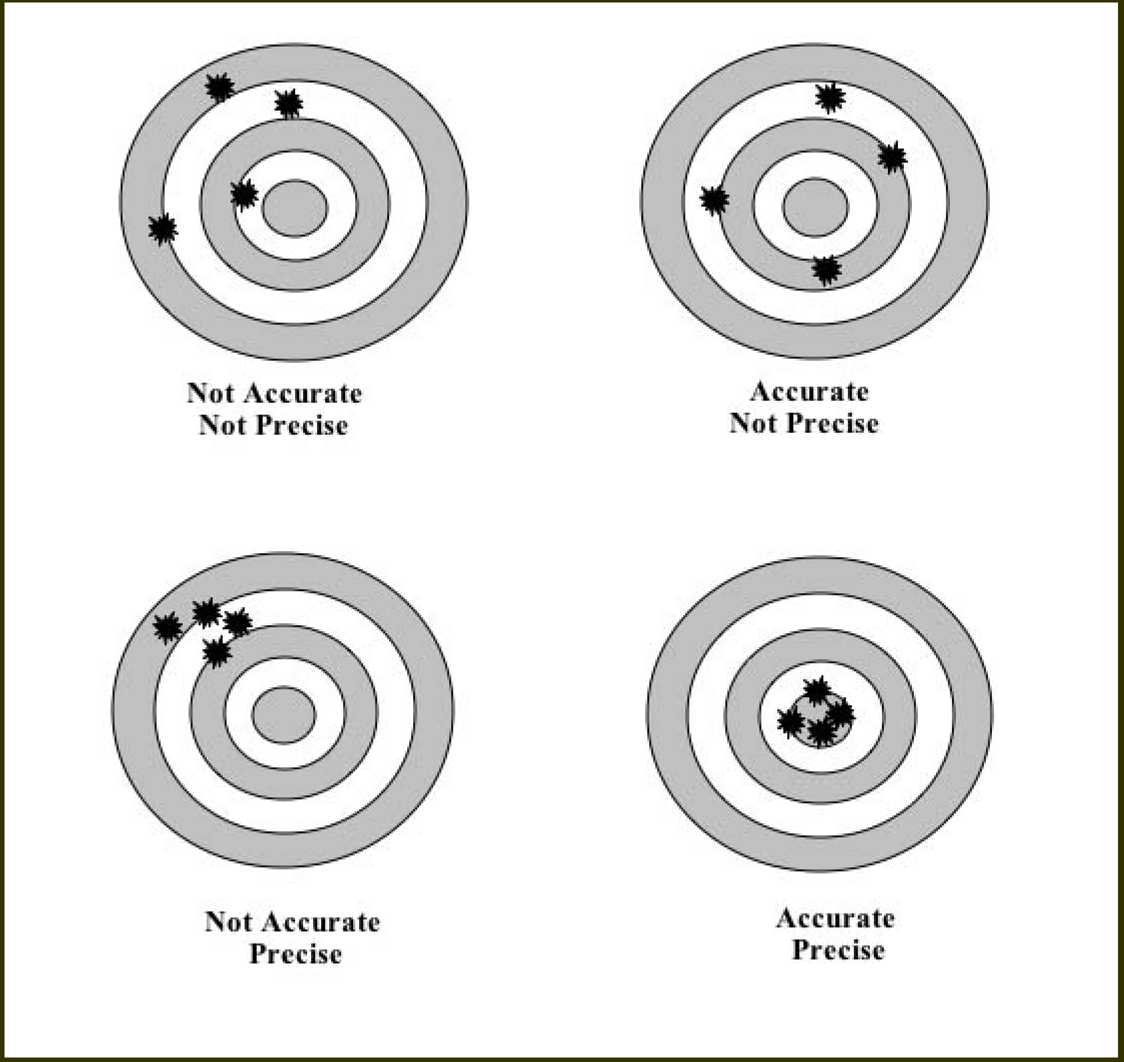
measure of how closely the estimated value agrees with a true value OR degree of bias

measure of the reliability of the estimate or how reproducible the estimate is

BIAS ↓

PRECISION ↑

Accuracy vs. Precision



Monitoring Programs: Design Issues

Common sources of error in population estimates:

- Detection Error
- Sampling Error

Detection Error

- Assumption in Monitoring Programs: If animals or signs of animals are present, then they **will always** be detected.

- Transect surveys: count total # of animal signs or sightings per distance of transect walked = Index of relative abundance

For example: 4 muntjacs sighted per km of transect walked

Detection Error

- Relative index of abundance assumes a constant relationship with actual abundance *N*
- What happens if signs or individuals were present but undetected?
- Few survey methods permit 100% detection of all signs of a species or all individuals in a population

Abundance Estimates and Detection probability

- Estimated abundance of population

$$\hat{N} = C / \hat{p}$$

N^ = abundance estimate,

C= count statistic

P^= estimated detection probability – can vary over space and time, with habitat type, time of day

Detection Error

- It is important that sampling designs account for probability of detection
- If not, such designs will result in biased population estimates; unreliable as a tool for monitoring true changes in populations over time

Incorporating detectability into monitoring design

- Distance sampling and
- Mark-recapture techniques

Incorporate detection error into estimates of population density and true abundance

Detectability

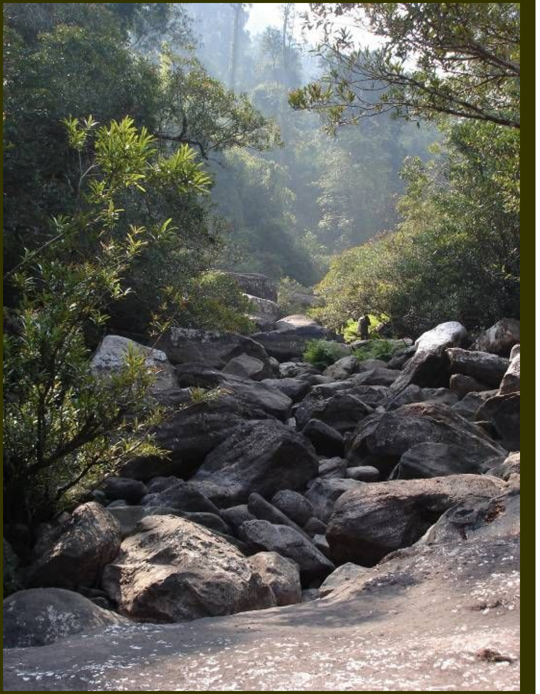
- These methods are:
  - Expensive to implement
  - require well trained personnel
  - Large sample sizes
  - Often precludes use over large areas or very low population densities

Lao PDR

Occupancy based methods

- Conditions of low density or large geographic scale

  [Example: Nam Kading NPA]



- *Occupancy surveys*

  - incorporate imperfect detection into presence/absence data

  - permit estimates of the probability of detection and the proportion of area occupied

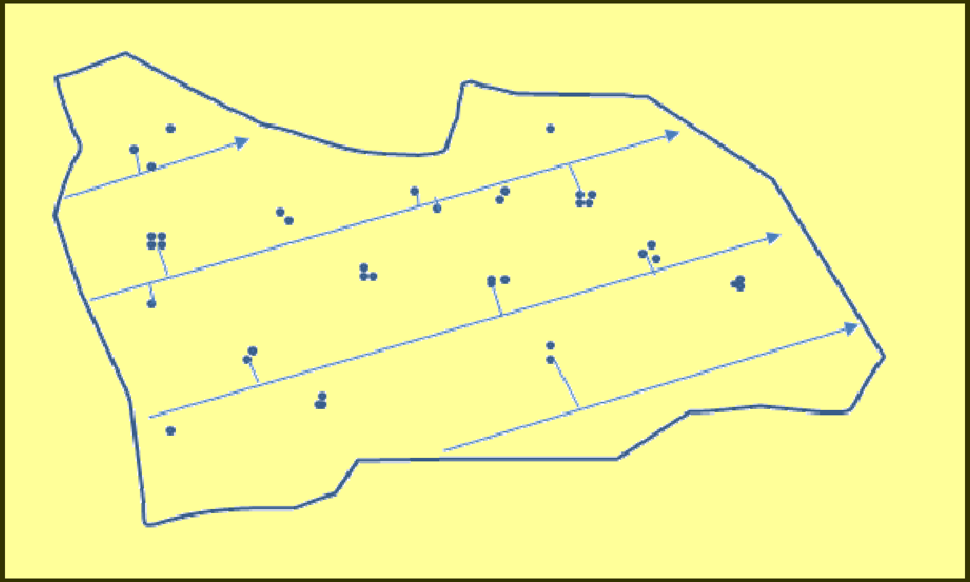
Detection methods that incorporate imperfection detection into sampling design

The following slides will describe detection methods:

- Line Transect sampling

- Capture recapture
- Occupancy rates using presence/absence

I. Line transect sampling



Number of transect lines are walked and perpendicular distances recorded to all animal clusters (groups of animals detected)

Note: All clusters are not detected

Line transect sampling

ASSUMPTION: All animals on the survey line are detected with certainty.

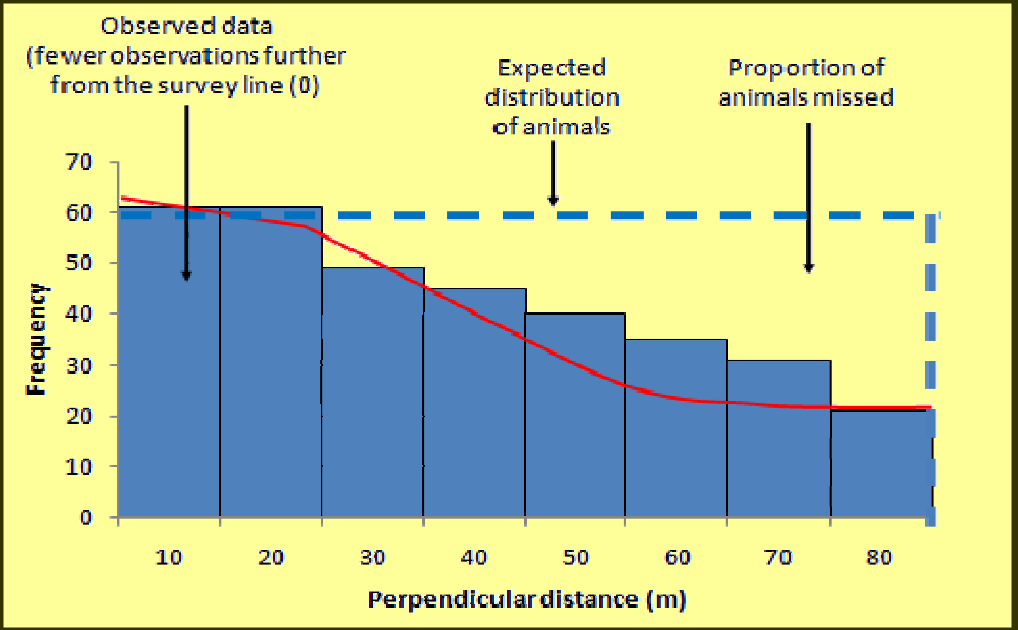
Animals further away from survey line are harder to detect.

[A detection function is fitted to the observed perpendicular distances and used to estimate the proportion detected]

Line transect sampling: Conceptual basis

Red curve represents the detection function that has been fitted to the real data.
Area under the curve represent the animals seen
Area above it represents the animals missed.

The proportion seen, *p* is estimated from the area under the curve divided by the total area.



II. Capture-recapture sampling

Total number of animals caught is counted

Detection probability is the probability of being captured

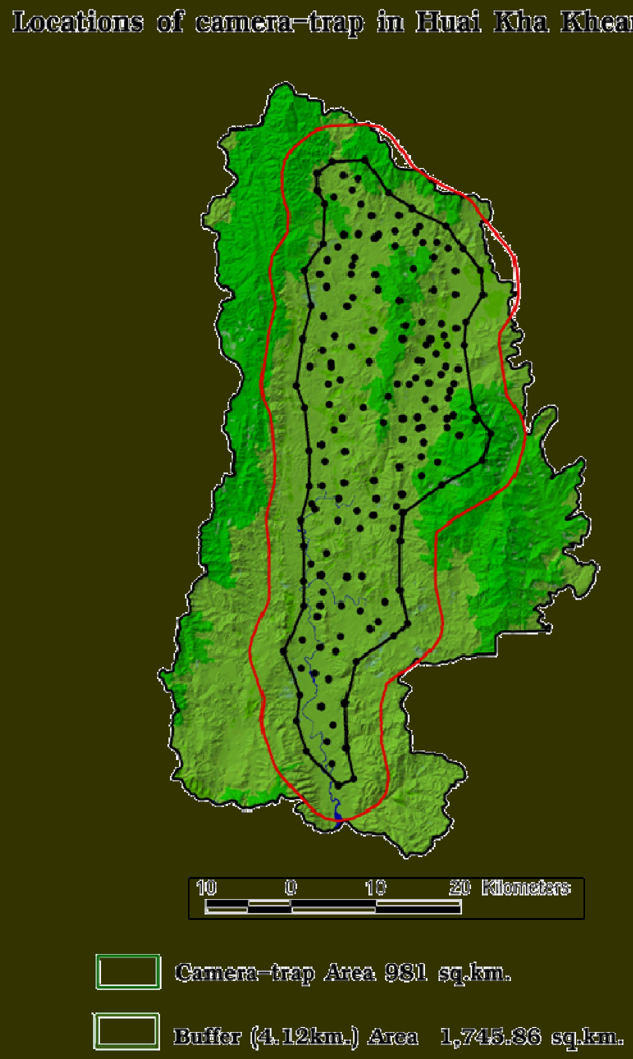
Individual animal- reliably identified (unique markings= stripes on a tiger)

A ‘capture’ – animal is physically caught and marked with an id tag OR animal is photographed

Detection probability is estimated by the pattern of captures/re-captures for each animal on each sampling occasion over the entire survey period

No holes in sampled area (to ensure that all individuals have a chance of being captured)

Capture-recapture sampling



Example of a capture-recapture camera trapping design for estimating tiger abundance in Huai Kha Khaeng Wildlife Sanctuary, Thailand:

Camera-traps = 180 locations (3-4km spaced)
Camera-trap area = 981 km²
Effective area = 1745.9 km²

III. Presence/Absence survey methods

- Multiple visits to site during appropriate time period when species may be detected
  - Species may go undetected (false absence)

- Presence/absence over repeat visits allows estimation of detection probability, proportion of sites occupied or occupancy
  - Detection histories compiled for a site rather than individual

x	o	o	o	x	o	x			
o	o	x	x	o					
x	o			x					
x	x		x						
x	x	x		x					
o	x								
o		x							
	x		x	x					
x									

100 units

X = occupied cell where species is detected.

O = occupied cell where species is not detected.

Blank = cell where species does not occur.

Thus the observed occupancy is 0.2 or 20% of the forest. But the true occupancy is 0.3 or 30% of the forest. The difference is due to not detecting species when it is present.

Spatial variation or sampling error

- Logistically difficult and costly to survey entire PAs
  - Sampling locations are selected with inferences made over larger area

- Spatial heterogeneity in natural systems – not accounted for in sampling → substantial bias or sampling error

- Need adequate spatial coverage and appropriate ecological scale for studied species in design

Monitoring Tiger populations

- **Primary objective** : Are tiger numbers increasing over time in response to management (state variable)?

- Are tigers increasing due to increased breeding amongst the resident population, or increased immigration into the PA from outside?

Monitoring tiger populations

Increase by 50%

Area: 4000km^2

[NPA + TPZ+CUZ]

Tiger densities lower in the CUZ than in the NPA/TPZ?

Spatial variation in the distribution of tigers at the landscape scale (are tigers more likely to be found near roads or in undisturbed habitat?)

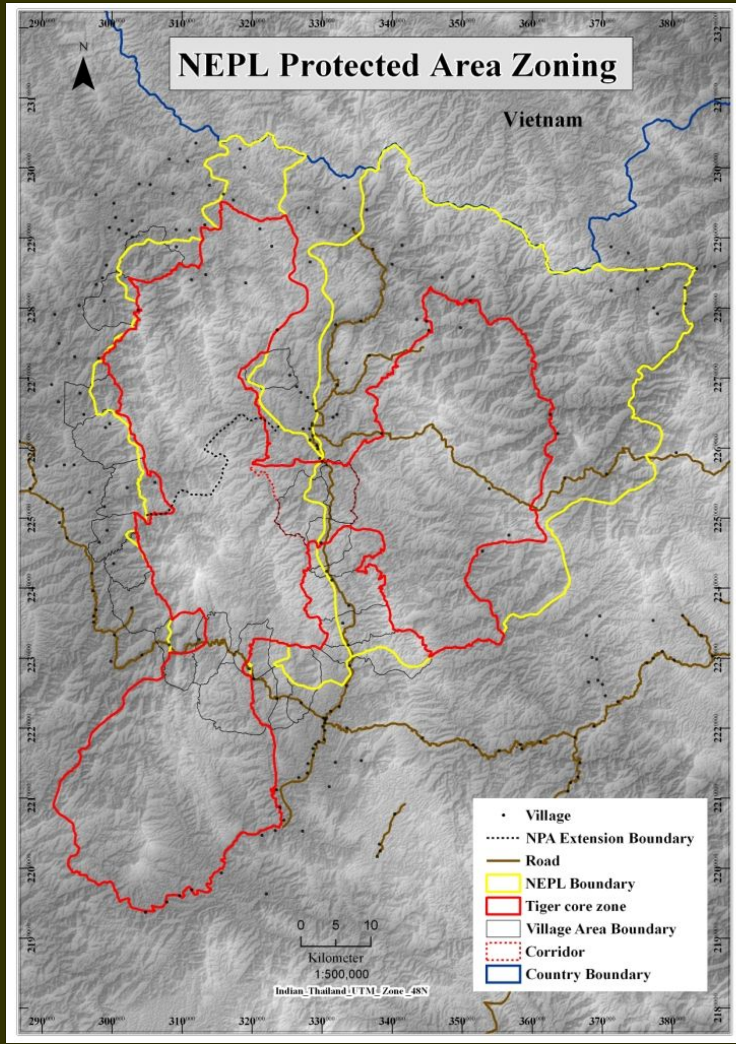
Sample across the landscape

Monitoring tiger populations: Sampling design and spatial error

Can you sample only in the NPA and extrapolate population estimate across entire landscape?

Ignore spatial variation/sampling error

Biased population estimate at the landscape scale (Overestimate)



Monitoring tiger populations: Sampling design and spatial error

Sampling designs should

-Identify and incorporate potential gradients in wildlife abundance associated with vegetation or human factors

Example: If a particular species was monitored only from roads (easy access), then population estimates = abundance/state variable of the population on roads ONLY

➡ ~~spatially representative~~
~~landscape scale~~

Roads - Hunting and other threats to wildlife

Monitoring biological populations

Precise definition of the **target population** (scale or area at which inferences about the population are to be made)

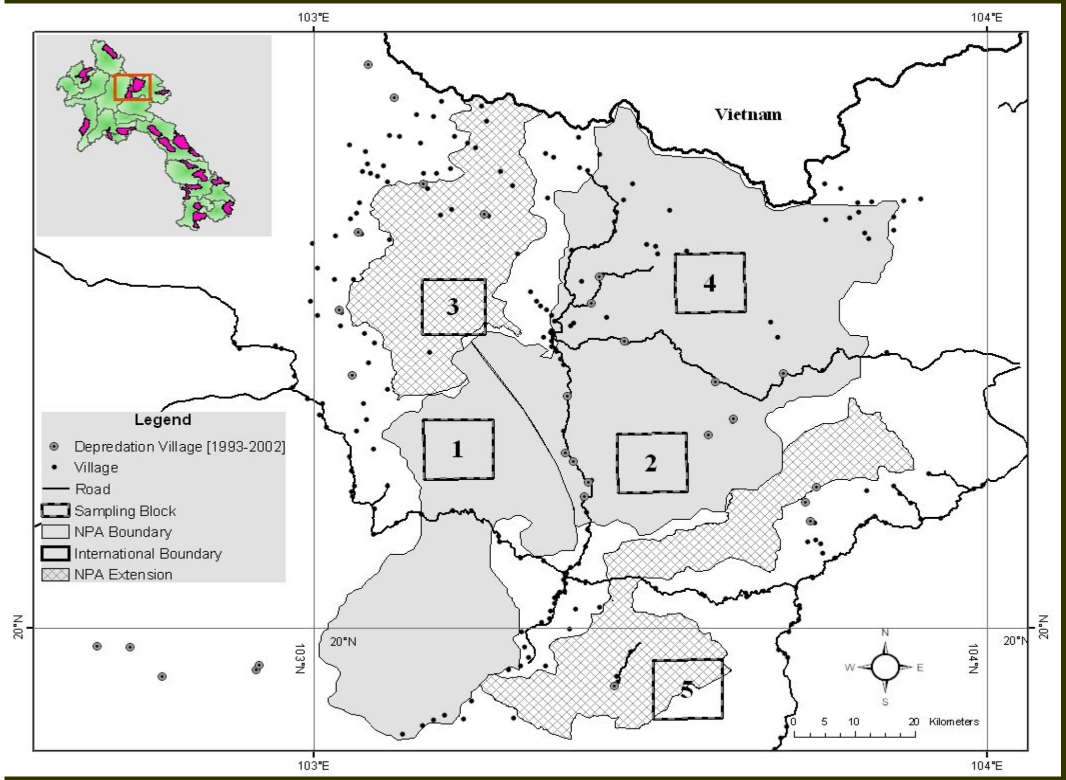
↓

Design sampling at spatially appropriate scales

SCALE: Ecologically relevant

Management information needs- vary over different geographic scales for different species
For e.g.: Wide-ranging or migratory species need to be monitored over a much broader geographic area

Monitoring tiger populations in NEPL NPA: Selecting sampling locations



Tiger and prey surveys using 50 camera traps set in five 100 km ^{2} sampling blocks as far away from villages as possible

Sampling locations– least disturbed areas of the NPA

NB. A sampling design should identify and explicitly incorporate any potential gradients in wildlife abundance, associated with vegetation or human factors

How much sampling effort is enough?

- Sufficient data to make valid statistical inferences
- Minimize cost and time expenditure

Amount of sampling

(number of points/transects, sites)

[Rarity of species, variability of habitat and objectives of monitoring program]

Determining statistical power to detect change over time

- Statistical power = Probability of detecting a true change if present.

  It is influenced by the following components

- **sample size**, or the number of units (n)
- **effect size**, strength of the trend or magnitude of the desired change to be detected – rate of change
- **alpha level** (a, or significance level), or the odds that the observed result is due to chance

How much sampling effort is enough?

Monitoring objectives

SCALE, INTENSITY, ACCURACY, PRECISION

RESOURCES
(Cost, need for skilled and highly trained staff)

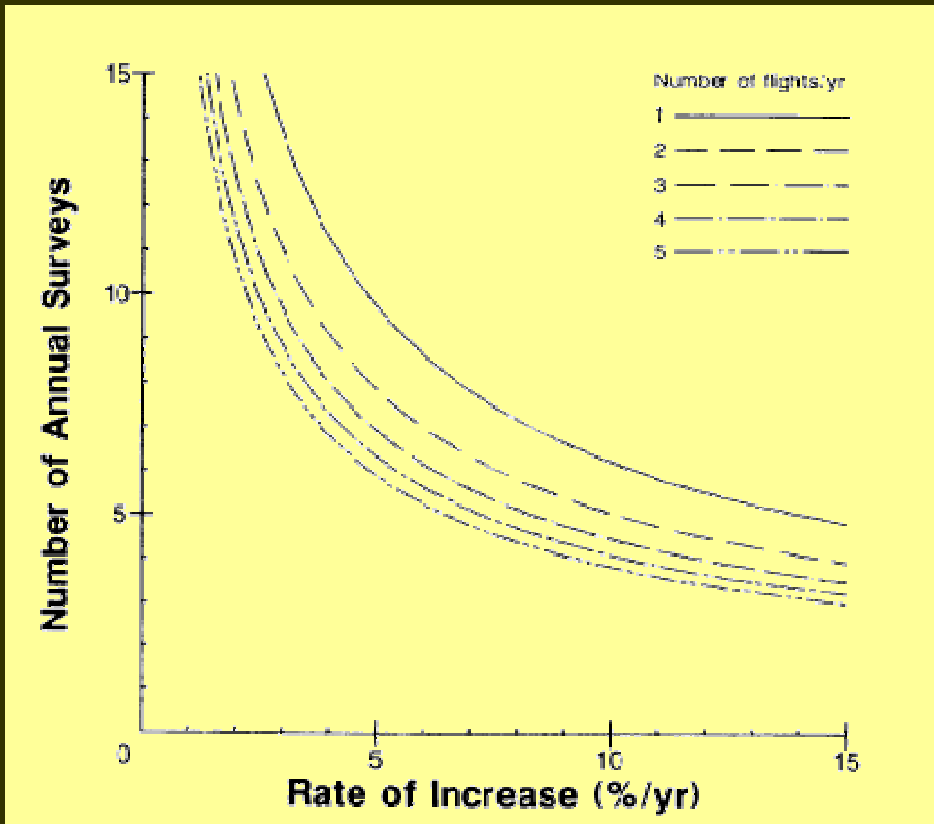
Absolute Abundance/density

Relative Abundance

Measures of occupancy

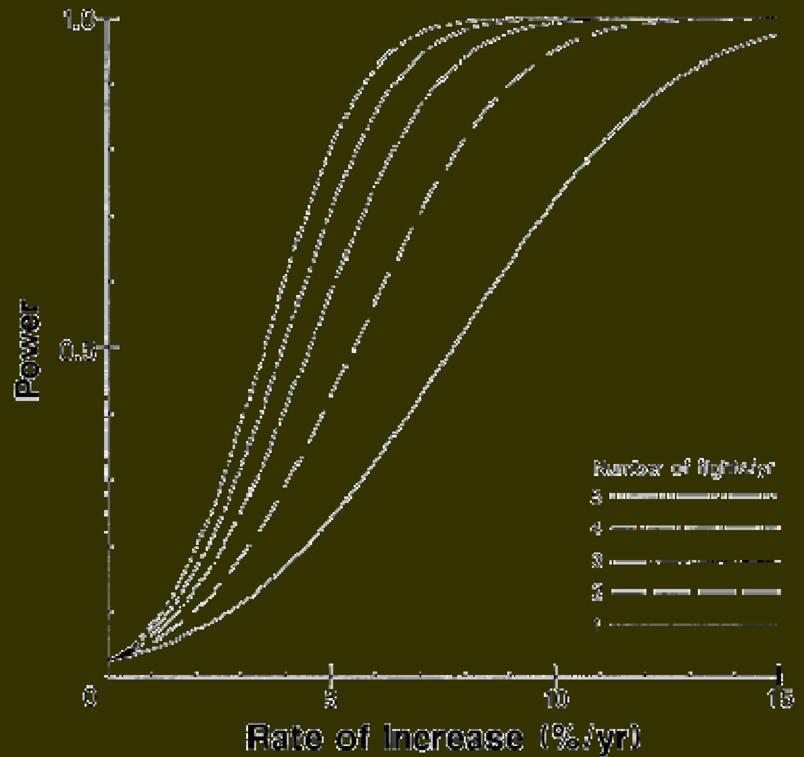
INCREASING COSTS

Example: Monitoring sea otter populations



More flights per year permit more precise estimates of population size, hence greater power to detect a given rate of increase.

Example: Monitoring sea otter populations



More flights permit more precise estimates of population size during each survey, hence fewer annual surveys required.

Improving the efficiency of sampling designs

Efficiency of sampling design: Precision of the resulting population estimate for a given level of survey effort

Power of the monitoring program to detect true changes in population over time

Very LOW density or rare species

↓

HIGH effort required to obtain adequate power to detect change over time

Efficiency of sampling design

- Characteristics of target population
- STRATIFICATION: Target population can be divided into relatively homogenous spatial units (example, large blocks of different forest types)
- For each stratum- need adequate sample size

⬇

Not feasible with rare and low density species

Efficiency of sampling design

- Rare species or species occurring at low densities

- Maximize number of observations, e.g. standardizing timing of surveys (time and season) when individuals are more visible increasing detection probability

- Adaptive sampling – intensity of sampling is dependent on initial sampling results

Decision making:
Objectives ⟷ Resources

- Level of survey effort - $?

- Managers need to reconsider

Monitoring objectives: Is the proposed monitoring design the most cost-effective approach to take?

Decision-making guidelines

- Do you need density or true abundance?

Are minimum sample sizes enough to satisfy assumptions of methods?

OR

Can monitoring objective be met with cheaper measures such as occupancy or presence/absence?

Decision-making guidelines

- Can monitoring objective be realistically achieved (budget, staff, timeframe)?
  - Modify objectives (geographic scale, expected outcomes)

No cutting corners!

Fundamental principles of monitoring design are critical to follow !!

Opportunistic methods--- maybe useful but NOT a replacement for carefully designed monitoring programs


• Practical considerations in designing sustainable monitoring programs

Workplan for implementation

Adequate budget

Designing sustainable monitoring programs

Sufficient & adequately trained staff

Feasible timeframe

Personnel and capacity building

- Who will be responsible for implementing the components of the monitoring program?

- *Design*
- *Field implementation*
- *Analysis and communication of results*

Practical considerations

- Different monitoring methods require different levels of training and skills
- Mark-recapture or Distance sampling - need a higher level of skill than presence/absence surveys
- Field staff need training in **data collection protocols**

Practical considerations

- Building up a strong **monitoring team** of trained and experienced field staff – long-term sustainability of a monitoring program

Technical support staff to provide advice and oversight on monitoring methods and analysis

Workplan

- Time-frame of the monitoring program
  1. How quickly do you need results?
  2. Is this a reasonable time-frame given the biology and reproductive potential of species?

Elephants : longer time-frame

Muntjacs: shorter time-frame

Frequency of surveys

- Frequency: Annual surveys? Once every two years?
- For each survey year– detailed workplan and schedule for implementation
- Timing of surveys - biology of the species, wet season, migration, hunting.
- Timeframe - data collection at all sampling locations? (number of field staff, access etc.)

Budget Planning

Personnel

Training

Implementation

Logistics

Data management and Documentation

- All aspects of monitoring program should be carefully documented
  - Monitoring program goals and objectives
  - Monitoring design and assumptions
  - Data collection protocols, methods, methods
  - Adapt /refine monitoring methods

Storing and managing field data

- Notebooks to Electronic format
- Microsoft Excel, Microsoft Access
- Management Information system (MIST-ranger-based law enforcement data)
- Regular back up of electronic data

Communication

Data analysis and communication of the results are the final and important stages in the management cycle.

↓

Monitoring programs integrated as a core component of management planning and decision-making

Key results to decision makers in timely manner

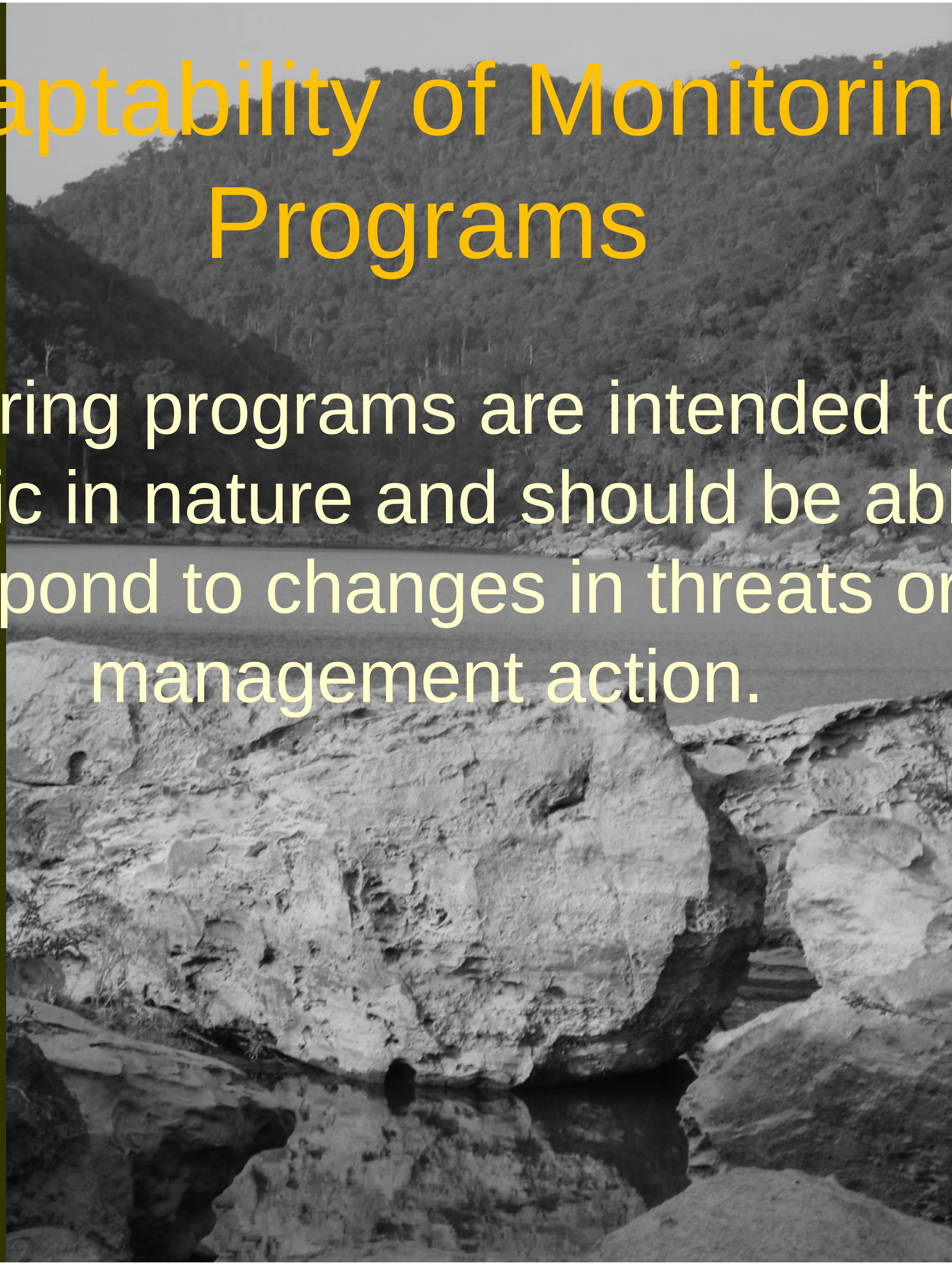
Communication

- Analysis of monitoring data reviewed by an independent and scientific technical advisor or group to ensure its reliability and utility for management.

- Assess findings - monitoring goals and objectives

- Modify format of results according to audience

Adaptability of Monitoring Programs



Monitoring programs are intended to be dynamic in nature and should be able to respond to changes in threats or management action.