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Ecological monitoring
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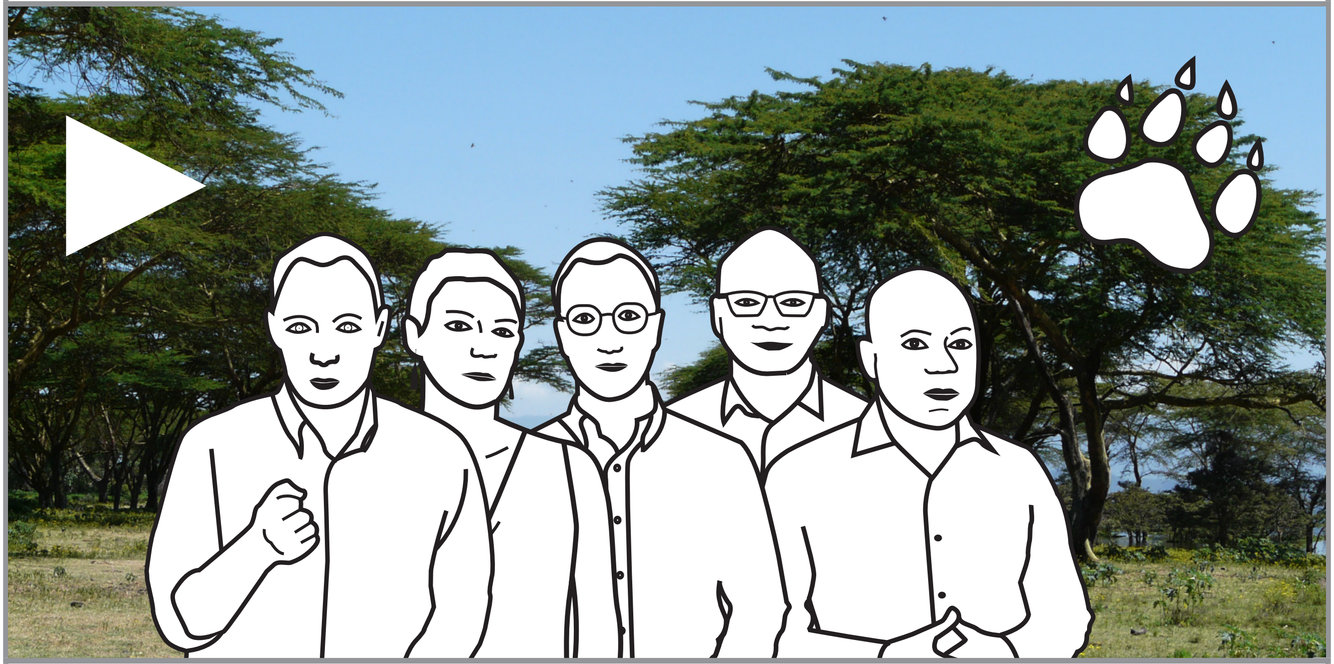
PROTECTED AREA MANAGEMENT IN AFRICA:

ECOLOGICAL MONITORING



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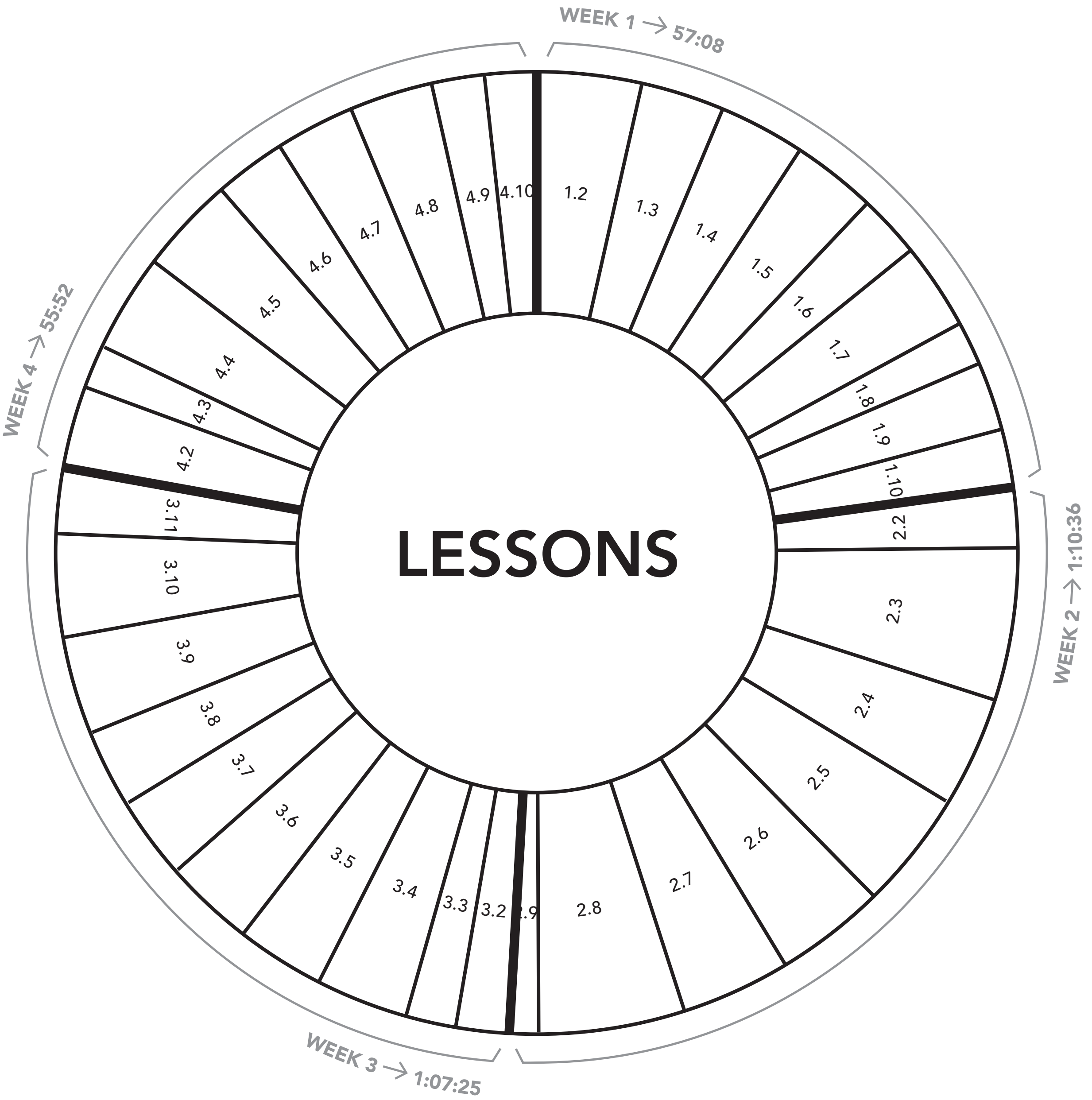
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LESSONS

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WEEK 2: STATISTICS

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1.2 WHY DO WE MONITOR?

Protected area (PA): *a clearly defined geographical space, recognized, dedicated, and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values.*

PA value: *elements conserved by the PA. Often they include animal or plant species, and ecosystems.*

THE ROLE OF ECOLOGICAL MONITORING (EM)

EM's primary goal is to provide information related to the species and ecosystems found within a PA and to guide managerial action. On this basis, EM measures variations in space and time in the short, medium, and long term. EM also helps to understand interactions, assess the impacts of pressures and threats, and raise public awareness regarding conservation.

PROTECTED AREAS: AN ENVIRONMENT FACILITATING EM

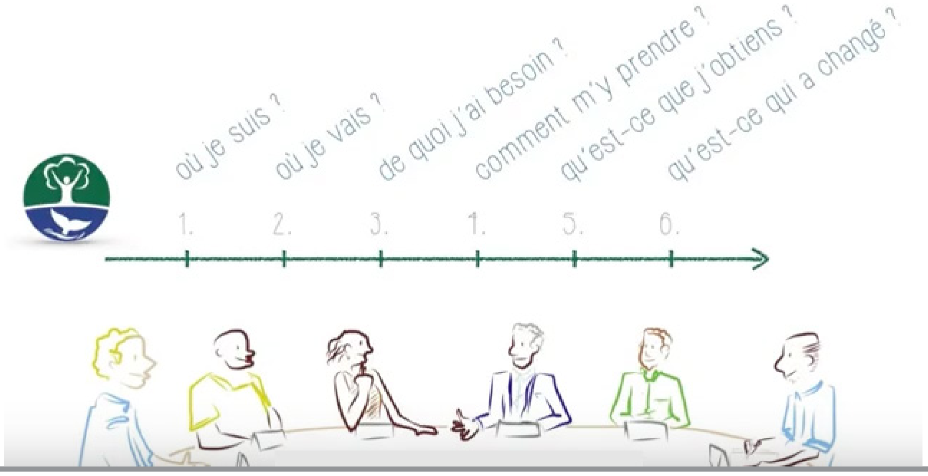
"A clearly defined space": since PAs contain complete or significant ecological processes, they are ideal spaces for EM to be implemented.

"Managed": PAs offer a good working base with means and infrastructures, and sometimes with available and qualified staff.

"Long-term conservation": PAs allow for long-term monitoring, thereby providing historic data and increasing knowledge.

EM AND THE MANAGEMENT PLAN

PA management is based on a management plan established in a participatory way; it has clear goals, physical activities, and assigned responsibilities. EM ought to be part of the preparation of this plan to make sure relevant indicators are selected and to guarantee successful implementation. EM must be discussed, shared, and understood by all involved in its execution, and the park manager must take ownership of the plan from the very start. Monitoring is also part of the process assessing the site's effectiveness.



FINANCIAL VALUE

Monitoring is also a powerful tool when it comes to PA fundraising. By providing reliable and transparent information on the state of conservation and the progress made, it justifies the use of the funds received.

VALUE FOR STAFF

- A vector for internal organization: EM is multidisciplinary and depends on everyone in order to be successful—collaboration between the different services of a PA is thereby stronger (admin, research, surveillance, etc.).
- Staff motivation: EM empowers rangers, eco-guides, volunteers etc., and includes them in management not as mere implementers but as providers of information that is at the very heart of the decision-making process.
- Staff training: by giving access to new tools such as cyber-trackers or GPS, EM broadens agents' jurisdiction. And since they are also in touch with researchers, they develop their personal knowledge.

1.3 WHAT IS ECOLOGICAL MONITORING?

EM is based on series of data collections repeated over time. It has a specific goal and answers the following type of question: “What is the condition of the park through the seasons?”. EM can be classified in three categories:

- Monitoring out of curiosity: gaining better knowledge of the environment without necessarily having a problem to solve.
- Mandatory monitoring: regular follow-up of indicators that are almost essential to management.
- Action-oriented monitoring: aims at solving a problem and is therefore developed specifically in relation to this problem.

INVENTORY

Inventory is a form of census. The goal is not to answer a specific question, but simply to provide information on the condition of the environment at a certain point in time. It can be qualitative (what species are present in the PA?) or quantitative (how many individuals of this species exist?). The minimal information gathered from the inventory is of the presence/absence kind, such as the existence of a given species at a specific place and time.

SURVEILLANCE

In the context of conservation, surveillance can cover two dimensions:

- Descriptive: an inventory program systematically repeated in order to provide a time series of measures, with no preconceived idea on the evolution of the parameters that are being assessed.
- Control: related to the control of activities taking place in the park, such as the fight against poaching.

There is a very fine line between monitoring and surveillance. Monitoring is developed according to a specific target—it is there to answer a management question. On the other hand, surveillance may simply be a repeated process of collecting information that may or may not be used subsequently.

RESEARCH

A research program is based on a starting assumption, which it aims to validate after having processed data and analyzed results. Part of it can be experimental and takes a step back from the data collected on the field. Research is thus a main component of the management scheme but goes further than simply covering the needs of PA management.

1.4 WHAT IS IT FOR?

HAVING EXACT KNOWLEDGE OF THE TERRITORY

- Monitoring species: EM gathers precise information on animal and plant species in the PA.
- Assessing the changes induced to the site: knowing the initial state of the environment is key to identifying the changes inflicted or induced by management, but this baseline condition is of little relevance if it is not linked to the ideal state in which the PA should be.

Thanks to this in-depth knowledge of the site, monitoring helps to:

- Set the PA’s heritage values that should be targeted by management actions.
- Identify pressures and threats to the values, as well as their scope, their importance, and their evolution.
- Provide information related to interactions between all identified factors—biotic and abiotic—in space and in time.
- Provide information on the evolution of indicators; this helps to assess the protection of values in the face of threats.

EM AND MANAGEMENT PLAN

The management plan should have a section describing the EM strategy. In doing so, it is key to consider the needs, skills, and means at hand. This plan will:

- See that the species presenting an interest stay within acceptable limits for their conservation.
- Make sure that pressures and threats are contained and redirect management according to the changes detected.
- Prioritize means allocated to conservation based on their effectiveness and on pressures that arise, communicate the successes that have been achieved, and learn from past mistakes.
- Directly assess the manager’s ability to implement the plan and obtain the expected results, and give an unbiased assessment of the quality of the work.
- Show the necessity of managers and scientists working together for the best adaptive management possible.

EM IS A LONG-TERM INVESTMENT

EM impact is not visible immediately, and therefore it can be perceived as having a poor cost-benefit ratio. It is, however, crucial to develop strategies leading to actions that promote the ecosystem’s long-term survival.

1.5 VALUES AND ECOLOGICAL ATTRIBUTES

KEY ECOLOGICAL ATTRIBUTE (KEA)

***Key ecological attribute:** consists of the key characteristics of a value's ecology. Alterations of said characteristics cause the loss of the value.*

Three main ecological attribute categories characterize species and their habitat:
- The size of the natural habitat or the abundance of the considered value on the territory.
- The condition of the value: assessing its biological makeup, its structure, and its defining interactions.
- The context in which the value evolves.

DEFINING THE INDICATORS

Attributes are descriptors that are too vague to be measured cost-effectively, hence the necessity for setting relevant indicators providing information on the state of the values over time. A good indicator should be:
- Measurable (quantitatively or qualitatively) by processes producing reliable, repeatable, and precise information.
- Predictable over time, meaning that the indicator should always have the same meaning for everybody, no matter when.
- Specific: the indicator is always associated with said ecological attribute in a non-ambiguous way, and it is not significantly affected by other factors.
- Sensitive and vary significantly (so it is detectable) in response to variations, threats, or conservation actions.
- Conducive to detection and quick reaction to changes occurring within the assessed ecological attribute, in such a way as to enable making management adjustments on time.
- Easy to collect without needing operators or expensive tools and having the best cost-effective ratio possible.
- A tool communicating results: it needs to be easy to understand so that the public can understand the PA's health through its attributes.

Once the indicator is identified, the first step is to determine its current state, which will serve as the baseline condition, then, the desired state needs to be defined. This way, EM results can be analyzed in light of the values' baseline condition, and management can be guided accordingly.

Acceptable levels of variation: there is a fluctuation band within acceptable limits. These variation thresholds define a normal level of change of the considered value, and thereby determine the level of alteration of the KEA deemed too severe, which will require a remedial action plan.

Steps defining the indicators to follow for EM are as follows:
- Identify the KEA of each value.
- Select relevant indicators for each attribute and observe the indicator to define the baseline condition of the KEA.
- Determine the indicators' acceptable levels of variation.

1.6 WHICH METHOD TO USE?

The chosen method to carry out measurements on the field depends on the KEA to measure and on its ecological characteristics. The approach should be sensitive enough and allow for detailed detection of KEA variations.

DIRECT AND INDIRECT METHODS

- Direct methods: focus on the attribute itself (e.g., the number of individuals of a species).
- Indirect methods: focus on a variable connected to the attribute (e.g., the number of tracks on the ground, nests, damage done to trees, etc.).

DIFFERENT WAYS OF COLLECTING DATA

Whichever method is used, the data collected should be:

- Qualitative: of the presence/absence kind or classified in categories such as “rare, occasional, frequent, abundant, etc.”
- Quantitative: these data are more precise but require more effort to collect.

A RELIABLE METHOD

The choice of counting method also depends on its reliability given the PA context—it is important to choose a method generating as little bias as possible. Some biases are inevitable, and it is important to estimate whether or not they are likely to affect the validity of EM final results. It is therefore vital to have identified all possible sources of bias beforehand, in order to control or reduce them.

1.7 WHICH SAMPLING METHOD SHOULD BE USED?

Sampling is the assessment of a portion of the monitored value (the sample), so that the results can be extrapolated to the entire population. It particularly affects sites covering a large surface area, and for this reason it can be irrelevant to smaller PAs.

DEVELOPING THE SAMPLING PLAN

– First step: choosing sampling sites.
  This involves choosing portions of the PA where data related to the considered habitat or species will be collected. To ensure the sample is an accurate representation of the total population, sampling should be carried out at random (stratified or cluster sampling). Stratified sampling is best for more precise results and to target specific habitats. It consists of dividing the studied area into clusters referring to different characteristics of monitored KEAs. Then, the combination of estimations per cluster results in an estimation of the entire PA which takes into account the biological variations of the considered species.

– Second step: determining the size and the number of samples to collect.
  For greater precision, more samples need to be collected. However, the bigger the sampling, the more expensive it will be.

– Third step: setting a calendar for data collection campaigns.
  This involves defining the times of the year and of the day, as well as the frequency of collections. These choices essentially depend on the monitored value’s biological cycles.

1.8 EFFECTIVE MONITORING AT THE BEST COST

COLLECTION EQUIPMENT, DATA STORAGE, AND ANALYSIS

Monitoring involves equipment acquisition and maintenance expenditures. To some parks this is of minor importance, but for others, these expenditures weigh heavily on their budget.

TRAINING STAFF TO USE EQUIPMENT

Training staff to properly use the equipment and to learn collection techniques can be gratifying, but at times, this can prove itself of little use (e.g., when trained rangers are relocated before being able to make use of their newly acquired skills). Likewise, the risk connected to some tasks should be taken into consideration before sending unprepared staff to carry them out (e.g., banding birds in their nests). Finally, the ability of staff to fill in sheets properly needs to be checked, or another data reporting technique should be implemented for the use of the observer.

NUMBER AND FREQUENCY OF DATA COLLECTION CAMPAIGNS

This aspect of the sampling plan has a cost in working time, traveling, mobilizing vehicles, logistics, and so on.

EXTERNAL EXPERTISE

Some specific monitoring steps require outside intervention. In this case, the EM protocol is measured in time and cost of outside expertise. However, to guarantee its long-term sustainability, EM should be done by the manager personally and by a properly trained team.

The protocol to implement should therefore match the human and financial resources available in the PA in the medium term, while guaranteeing it will be effective enough to detect indicators to measure with as little bias as possible. To avoid working on unrealistic hypotheses or on monitoring that will not be sustainable over time, assessing the cost of monitoring should be done as EM planning and implementation unfolds.

1.9 DATA COLLECTION AND ANALYSIS

The general PA monitoring program is made of protocols related to each value of the PA. Implementing these protocols involves data collection, storage, and analysis by staff in charge throughout the year according to the established schedule.

AIM OF EM SPECIFICATIONS

Clear specifications guarantee the comparability of data and the reproducibility of the methods used over time. They describe all the protocols that are being followed and track data from the time of collection through to its analysis.

ORDER OF SPECIFICATIONS

1. Description of the data-recording method used on the field.
   The choice of medium used (paper, recordings, Cyber-tracker, mobile application, etc.) depends on the quantity of information to collect, the means available, and the most relevant tool for staff on the field.
2. Defining the data storage method.
   The database should be easy to use, and the data should be easily extractable for analysis (Microsoft Access, Excel, etc.).
3. Choosing a sustainable data storage method.
   It is vital to save back-ups on an external hard-drive and to guarantee the safety of the database.
4. Data analysis and choice of responsible staff.
   The brief should state the person in charge of data analysis. This responsibility requires strong statistical knowledge and common sense when it comes to choosing the analysis method.
5. Result interpretation and presentation.
   The results should meet the targets that monitoring was implemented for in the first place, namely informing decision-makers on the condition of PA values. Thus, EM quality is also assessed by its ability to be understood by decision-makers and thereby to guide PA management and change management practices if needed.

1.10 PLANNING ECOLOGICAL MONITORING

A PA's EM focuses on assessing the condition of the site's values. These values are defined by ecological attributes that are described by indicators, and EM follows a protocol detailing the sampling plan and method used.

The different steps to implement EM:
– Step 1: identify the values to monitor
– Step 2: set the KEAs
– Step 3: set relevant indicators
– Step 4: identify the acceptable variation limits of the KEA
– Step 5: choose a collection method
– Step 6: define a sampling plan
– Step 7: collect data following the chosen sampling method
– Step 8: organize data storage
– Step 9: analyze data and results obtained
– Step 10 : decide and take action to manage the PA
– Step 11: continue monitoring and adapt the strategy accordingly.

This cycle should be repeated as many times as needed to feed adaptive management decisions, because monitoring is essentially just part of a larger cycle intended to better manage the territory.

2.2 GENERAL NOTIONS OF STATISTICS

Statistics derive information from data in the presence of uncertainty. To illustrate the different concepts, we will use the example of a population of elephants in a park.

***Population**: the object of interest, e.g., the population of elephants in a park.*

***Statistical variable**: a measurable characteristic of each member of the population. This refers to the KEA or the indicator to assess in order to find out the state of the monitored value. In our example, we will be looking at the "age" variable of elephants.*

***Sample**: a subset of the population.*

The aim is to find out the distribution of the variable at the scale of the population, in other words, the proportions of the different age groups at the scale of the elephant population. Given the difficulty of measuring the "age" variable of thousands of elephants, we need to select a subset of elephants—the sample. To guarantee a good representation of the population, this selection should be made at random. After having determined the ages represented within the sample, the next step is to infer the age distribution of the global population and to establish the degree of confidence associated with this inference.

STATISTICAL VARIABLES

Qualitative statistical variables (e.g., the color of elephants):
- Nominal: they have no intrinsic ordering.
- Ordinal: admits a certain order.

Quantitative statistical variables (e.g., elephants' age):
- Discrete: they can take any value from a discrete set of prescribed values.
- Continuous: they can take an infinite number of values.

To simplify, quantitative variables can be converted to qualitative variables. For example, sorting the elephants by general age group (young, adult, and old) rather than individually by age (see fig. 1 and 2).

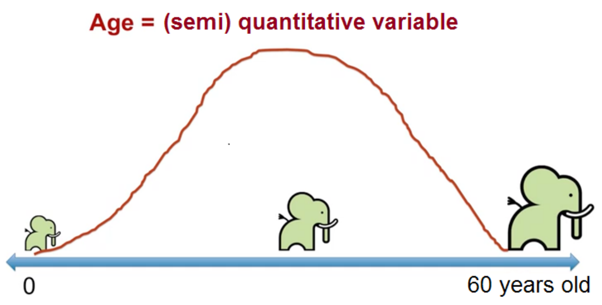


FIGURE 1

1:47 5:37

Representation of a quantitative variable.

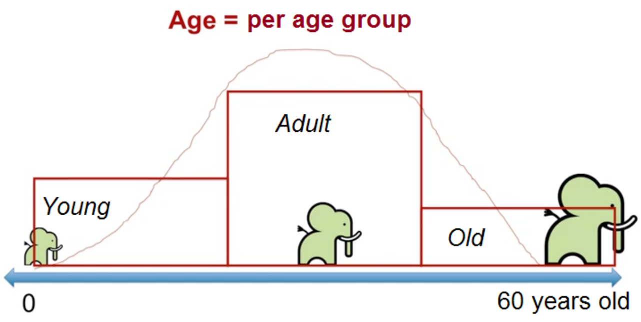


FIGURE 2

1:52 5:37

Representation of a quantitative variable converted to a qualitative variable.

2.3 NUMERICAL SUMMARIES

The set of *n* values (measured from the sample's variables) are used to explore the characteristics of the sample distribution through graphical and numerical summaries.

QUALITATIVE VARIABLES

In the case of qualitative variables, values are arranged in a frequency table. The table's purpose is to:

- List all the possible categories of the qualitative variable (see fig. 1).
- List the number of times the sample's variables fall under these categories; this is the absolute frequency (see fig. 2).
- Show the proportion of variables belonging to the same categories; this is the relative frequency (see fig. 3).

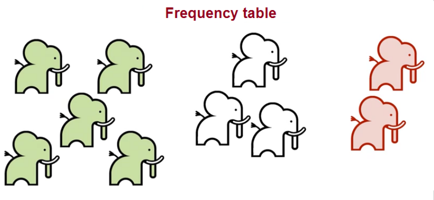


FIGURE 1

0:36 17:22

A sample of 10 elephants ranked by KEA color: green, white, and pink.

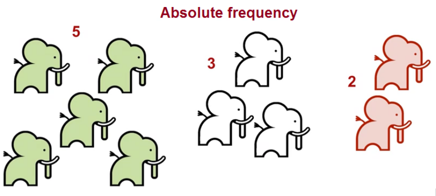


FIGURE 2

0:40 17:22

There are 5 green elephants, 3 white, and 2 pink—absolute frequency.

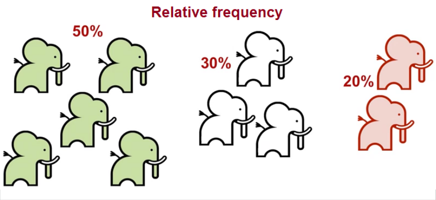


FIGURE 3

0:54 17:22

According to the relative frequency, green elephants are the most numerous.

QUANTITATIVE VARIABLES

In the case of quantitative variables, start by ranking the values in ascending order. The values can then be ordered along an axis and given a visual representation (see fig. 4).

Then, conduct position measurements indicating the center of the sample distribution (mean or median calculation), and distribution measurements showing how the sample values are distributed (variance, quartile/quantile, standard deviation, and interquartile deviation).

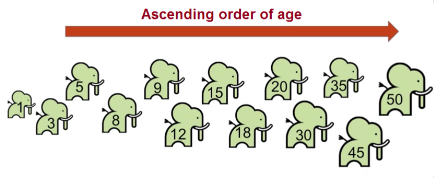


FIGURE 4

1:40 17:22

A sample of 13 elephants ranked in ascending order of age.

– The mean is the sum of observations, divided by the number of observations (fig. 5):

$$\bar{x} = \frac{x_1 + \ldots + x_n}{n}.$$

– The sample's median separates the population into two equal parts (see fig. 6):

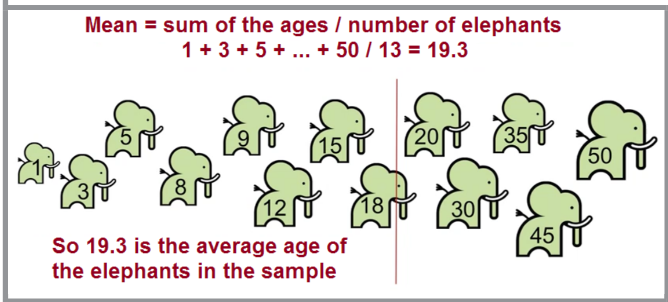
$$\text{med}(x) = \begin{cases} x((n+1)/2), \text{ if } n \text{ is uneven,} \\ x(n/2) + x(n/2+1)/2, \text{ if } n \text{ is even,} \end{cases}$$

– The variance (S^2) gives the distribution of the value around the average (see fig.7):

$$S^2 = \frac{1}{n-1}\left[\left(x_1 - \bar{x}\right)^2 + \ldots + \left(x_n - \bar{x}\right)^2\right]$$

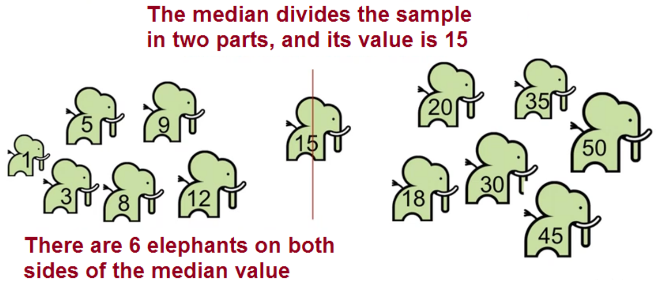
– The standard deviation (S) is the square root of the variance and gives the distribution at the same scale as the value itself: $S = \sqrt{S^2}$ (see fig. 8).

– Finally, the sample can be divided into quantiles, the most commonly used form being quartiles. Each of these account for about a quarter of the sample and illustrate the symmetry of the sample relative to the mean (see fig. 9).



Mean = sum of the ages / number of elephants
1 + 3 + 5 + ... + 50 / 13 = 19.3

So 19.3 is the average age of the elephants in the sample



The median divides the sample in two parts, and its value is 15

There are 6 elephants on both sides of the median value

FIGURE 5

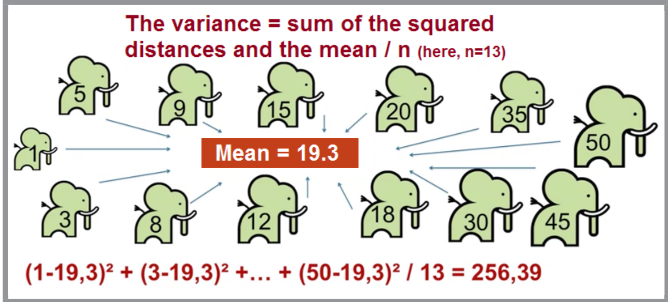
1:45 17:22

Average age of all elephants.

FIGURE 6

2:17 17:22

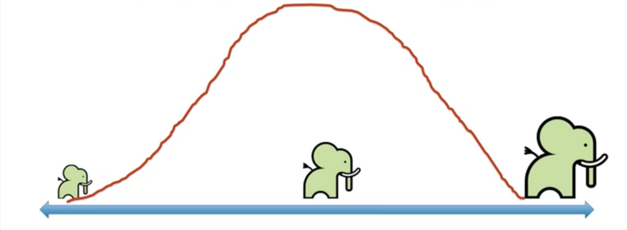
Median of the elephant sample.



The variance = sum of the squared distances and the mean / n (here, n=13)

Mean = 19.3

(1-19,3)² + (3-19,3)² +… + (50-19,3)² / 13 = 256,39



The standard deviation is obtained from the variance = square root of 256.39, in other words 16.01

FIGURE 7

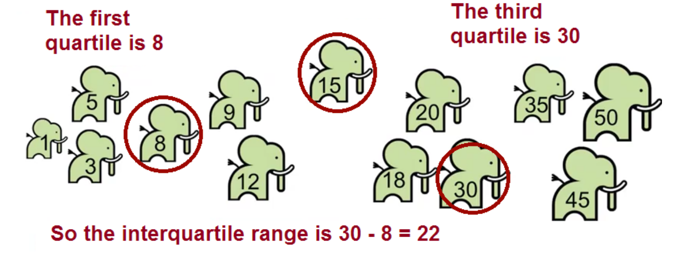
2:29 17:22

The variance calculated from the elephant sample.

FIGURE 8

2:36 17:22

The standard deviation calculated from the elephant sample.



The first quartile is 8

The third quartile is 30

So the interquartile range is 30 - 8 = 22

FIGURE 9

3:02 17:22

Interquartile range calculated from the sample.

2.4 GRAPHICAL SUMMARIES

QUALITATIVE VARIABLES: PIE CHARTS AND BAR CHARTS

Both types of diagrams provide the same information but with different styles.
- Pie chart (see fig. 1): partitions the surface of a disc into sectors. The total surface of the disc represents 100%, and each sector gives the percentage of each category of variable as it appears in the frequency table.
- Bar chart (see fig. 2): separate bars arranged side by side, representing each variable category. Each bar covers a surface that is proportional to the percentage of the corresponding category in the frequency table.

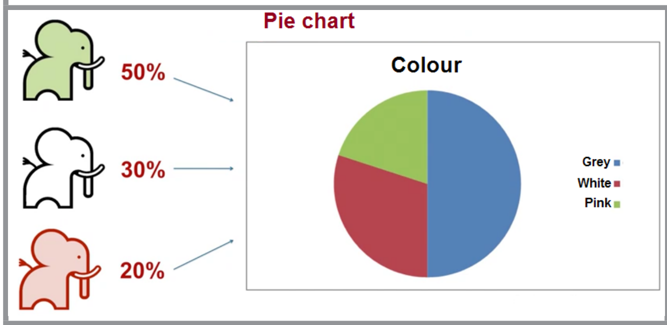


FIGURE 1

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Pie chart based on the frequency table of the attribute elephant "color."

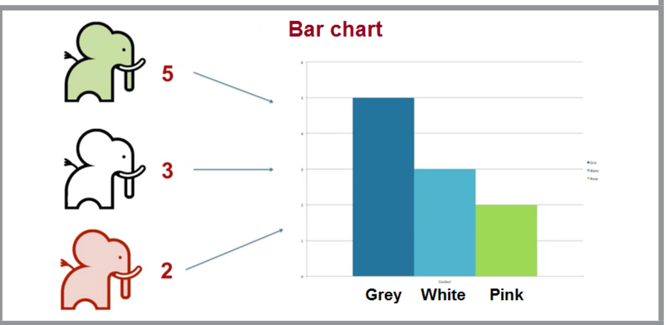

FIGURE 2

0:33 10:49

Bar charts based on the frequency table of the attribute elephant "color."

QUANTITATIVE VARIABLES: HISTOGRAMS

In the case of quantitative variables, the extra goal is to visualize the concentration of certain values along an axis.

To build a histogram (see fig. 3):
- Distribute the data sets in intervals of equal length.
- Measure the proportion of the sample contained within each interval.
- Draw a horizontal line at the level of said proportion.

The height of each bar shows the proportion of observations contained within the interval. The histogram helps to assess the location, the dispersion, and the symmetry (or absence of these characteristics) of the sample distribution.

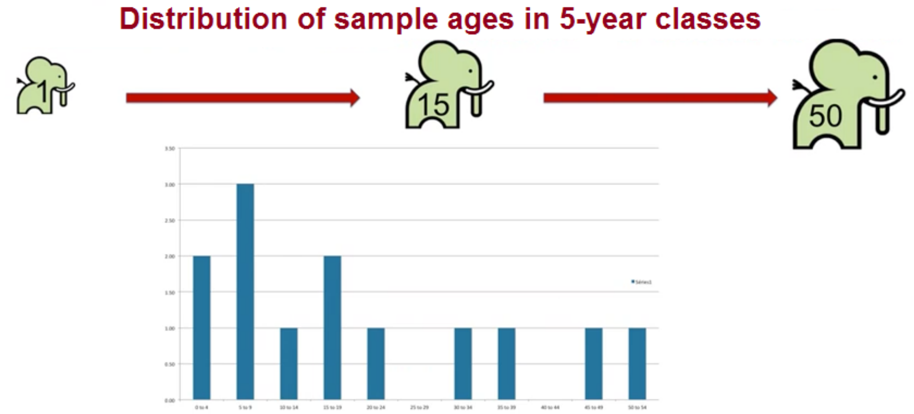

FIGURE 3

1:01 10:49

Histogram from a sample of 13 elephants ranked by age.

QUANTITATIVE VARIABLE: BOXPLOT

To draw a boxplot:

- Arrange the order statistics along an axis.
- Annotate the key values (see fig. 4), which are the first and third quartiles of the sample, by drawing a box and locating the median with a line at the center of the box.
- Draw two lines connecting the sides of the box to the smallest and to the biggest observations located at 1.5 times the box length—these lines are called whiskers (see fig. 5).

The values at the left and right of the median give an indication of the sample distribution. The lines representing the quartiles divide the sample into quarters that can be used to assess the sample distribution, as well as its symmetry or asymmetry. The whiskers show where the biggest part of the sample lies. Observations falling outside the whiskers are called outliers.

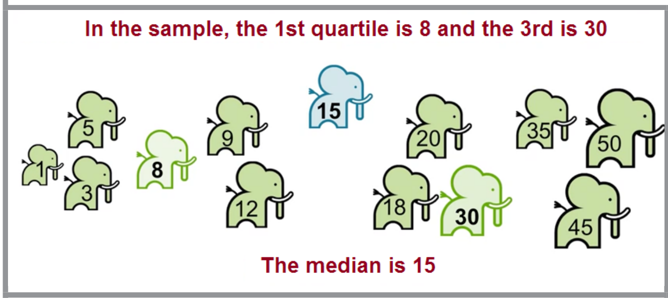

FIGURE 4

1:35 10:49

The key values of a sample of 13 elephants ranked by age.

FIGURE 5

1:53 10:49

Final boxplot of the sample of 13 elephants ranked by age.

2.5 POPULATION DISTRIBUTION MODELS

Let's remember that the goal is to estimate the sample distribution at the scale of the population, and that the histogram is a simple way to visualize the data distribution. The height of each bar reveals the percentage of sample observations falling inside the corresponding bin. Thus, to create a histogram for the entire population, simply create a histogram made of a great number of very narrow bins (see fig. 1).

Once you have the histogram, a "law" of the population allows for the estimation of distribution at the scale of the population (see fig. 2).

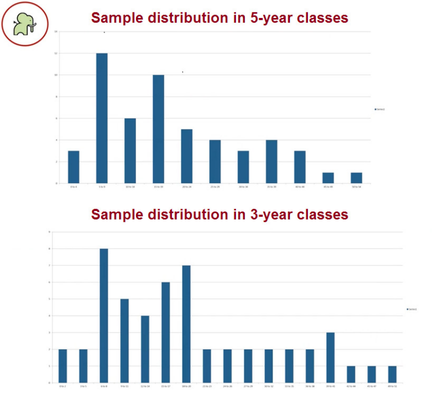

FIGURE 1

0:38 10:37

Distribution of a sample of 52 elephants distributed by age category over 5 then 3 years–precision is gained by reducing the bin-width.

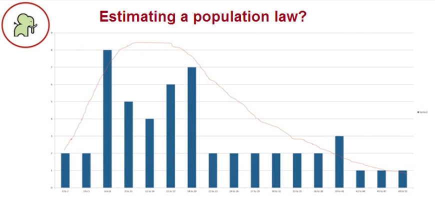

FIGURE 2

0:51 10:37

The histogram allows for the estimation of a curve representing the law of the population in the case of continuous values.

CHOICE OF DISTRIBUTION MODEL

The sample helps to choose the most suitable model for describing the population. Below are some examples of population laws often used in practice:

– Normal distribution: law used with continuous variables:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

Standard deviation = σ
Mean = μ

– Exponential distribution: law used with continuous positive variables:

$$f(x) = \lambda exp\left\{-\lambda x\right\}, x \geq 0$$

Mean = $1/\lambda$

Variance = $1/\lambda^2$

Quantile α% = $-\log(1-\alpha)/\lambda$;

– Poisson distribution: law used for random discrete variables, taking values such as 0,1,2,3, etc.:

$$f(n) = e^{-\lambda}\frac{\lambda^n}{n!}, n = 0, 1, 2, 3, \ldots$$

Mean = λ
Variance = λ

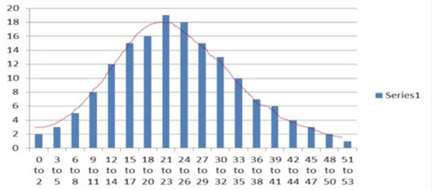

FIGURE 3

2:46 10:37

Distribution of a sample of 52 elephants allowing the normal law to be identified.

NORMAL PERCENTAGE POINTS

Whatever the mean and variance value, the following properties are always true:

- The proportion of population values within 1 standard deviation from the mean is 68%.
- The proportion of population values within 2 standard deviations from the mean is 95%.
- The proportion of population values within 3 standard deviations from the mean is 99%—almost all the population values fall within 3 standard deviations from the mean.

For instance, the sample represented in the histogram below (fig. 3) is a case of normal distribution. The mean is $\mu = 19.3$ and the standard deviation $\sigma = 12.6$. This model informs us that 95% of individuals will be in the $(\mu-2\sigma, \mu+2\sigma)$ interval and 99% in the $(\mu-3\sigma, \mu+3\sigma)$ interval.

The benefit of a model is that it helps calculate everything there is to know about a population, provided we know the value of the parameter(s) on which it is dependent. The problem of statistical inference is to use the sample to better understand the true value of the parameter. The trifecta of statistical inference questions one typically wishes to answer are:

- Point estimation
- Interval estimation
- Hypothesis test.

2.6 POINT ESTIMATION

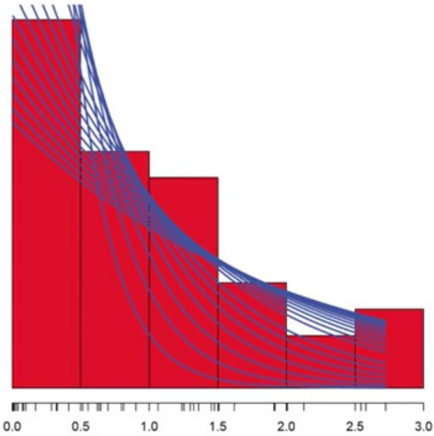

FIGURE 1

2:33 10:02

Histogram showing different exponential distribution models in blue.

Point estimation: *using the sample distribution to infer the unknown parameter of the population model.*

The basic idea is always the same: calibrating the population distribution model according to the sample distribution. For instance, Figure 1 below gives the example of a histogram in red, with different exponential distribution models in blue, each matching a different value of the parameter. The choice of parameter value can be made according to different methods:
– Method of Moments.
– Maximum Likelihood estimator.

METHOD OF MOMENTS

The method of moments sets a parameter allowing for the sample and the population situation to match through the mean. It is a matter of deciding that the population model mean $m(\theta)$ and the sample distribution mean $\bar{x}$ should be the same, and choosing the parameter according to this equality. Using a random sample $x_1, \ldots, x_n$ allows for the calculation of the sample mean $\bar{x}$. This comes down to calculating:

$$m(\theta) = \frac{(x_1 + \ldots + x_n)}{n}$$

MAXIMUM LIKELIHOOD ESTIMATOR

This approach consists of choosing a parameter to match the sample and population distribution at a finer level, so that the sample is as representative of the population as possible. This requires that proportions calculated from the sample histogram match proportions calculated from the population curve as best as possible. This comes down to choosing the θ that maximizes the likelihood function $L(\theta)$:

$$L(\theta) = f(x_1;\theta) \times f(x_2;\theta) \times \ldots \times f(x_n;\theta)$$

METHOD OF MOMENTS VS MAXIMUM LIKELIHOOD ESTIMATOR

The method of moments often helps to find the same estimator as the maximum likelihood estimator. The method of moments is generally simpler to put into practice, but the maximum likelihood estimator is usually preferred, since it allows for better use of data at hand. Another benefit of the of maximum likelihood is that there are some general formulas describing its precision.

2.7 CONFIDENCE INTERVALS

Point estimators aren't always exactly right, no matter their accuracy. Thus, another approach consists in giving the unknown parameter a set of possible values (rather than only one) in the form of an interval.
Interval characteristics:

- Reasonably short: the shorter it is, the more informative it is.
- Guarantee a certain degree of confidence: being sure that the interval constructed on the basis of the sample actually contains the true value. For instance, we'd like to have a method for constructing intervals that guarantees that 95% of all possible samples will produce an interval containing the true value. Such an interval is called a 95% confidence interval.

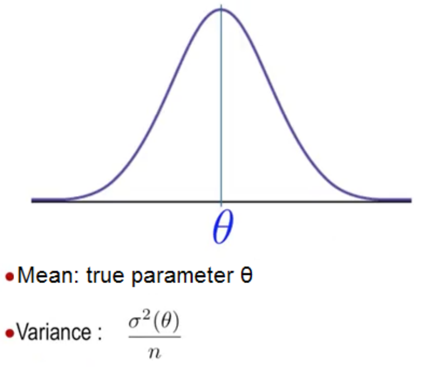

FIGURE 1

2:33 8:46

True parameter θ.

FROM SAMPLING DISTRIBUTIONS TO CONFIDENCE INTERVALS

Suppose a sample $x_1, \ldots, x_n$ from a population modeled according to a model $f(x; \theta)$. Construct the estimator of θ by maximum likelihood, $\hat{\theta}(x_1, \ldots, x_n)$. The interval sought would be centered at $\hat{\theta}(x_1,\ldots,x_n) \pm \delta$, δ being a constant. To choose a constant guaranteeing a 95% confidence, review the sampling distribution of $\hat{\theta}$, which is typically almost normal. As shown by Figure 1 below, the mean of this normal distribution is given by the true parameter θ. The variance is given by an explicit quantity:

$$\frac{\sigma^2(\theta)}{n}.$$

So we know that for 95% of all possible samples of size n, $\hat{\theta}$ would be at a maximum distance of

$$2\frac{\sigma(\theta)}{\sqrt{n}}.$$

The confidence interval formula is as follows:

$$\left[\hat{\theta} \pm 2\frac{\sigma(\theta)}{\sqrt{n}}\right]$$

EXAMPLE: THE ELEPHANT POPULATION
We want to determine the age of the elephant population, which is the ecological attribute to assess. Using the same sample of 13 individuals as previously, the age mean is m = 19.3, the variance = 256.5, and the standard deviation = $\sqrt{256.4}$.

The 95% confidence interval is:

$$2\frac{\sqrt{256.4}}{\sqrt{13}} = \pm 8.9$$

The average age of the elephant population is 19.3 years ± 8.9 years, which isn't very precise (see fig. 1).

This is related to the fact that the sample is very small. If the sample size were to increase, the confidence interval would decrease because the interval is inversely proportional to the square root of the sample size. So, let's take a sample with 4 times as many individuals. The mean of the group made of 52 elephants, instead of 13, is still 19.3 years, but this time, the variance is 159 (the sample narrows around the mean, as shown in fig. 2), and the standard deviation is 12—the confidence interval decreases.

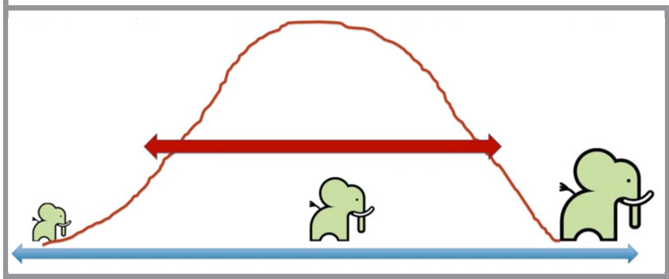

FIGURE 2

1:18 8:46

Confidence interval where age mean is 19.3 ±8.9 years.

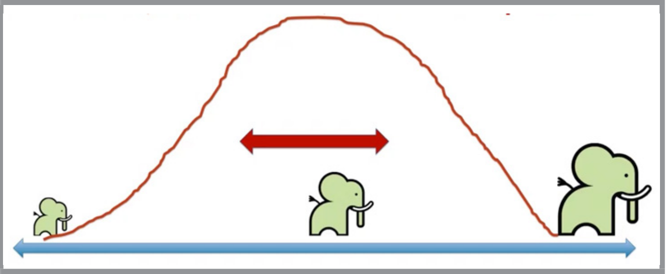

FIGURE 3

2:25 8:46

Confidence interval with a bigger sample.

2.8 HYPOTHESIS TEST

In some cases, before having collected any data, we may have a theory that the parameter of the population distribution should be contained in an interval of possible values that we ourselves have specified. This assertion is called a null hypothesis, denoted by H_0. In this case, we want to see if H_0 is plausible or not, based on the sample. If the behavior of the sample deviates from what would be expected under the hypothesis, we have evidence against the hypothesis—measuring the strength of this evidence and using it to either reject the hypothesis or not is part of what we call a hypothesis test.

Null hypotheses typically come in two forms:
– Simple hypotheses: $H_0 : \theta = \theta_0$.
– One-sided hypotheses: $H_0 : \theta \geq \theta_0$ or $H_0 : \theta \leq \theta_0$.

SIGNIFICANCE LEVEL

In order to either reject a hypothesis or not, we require a rejection rule. A good rejection rule limits the proportion of times that would produce a false rejection. So, when the null hypothesis is truly valid at the level population, the rule should only reject the hypothesis for a small fraction of all possible samples: this proportion is called the significance level and is usually taken to be $\alpha = 5\%$.

GENERAL STRATEGY

On the basis of the sample, we build an estimation of the true θ: $\hat{\theta}(x_1, \ldots, x_n)$. If the estimate satisfies H_0, don't reject the hypothesis. If it does not, we must check following list of conditions, depending on the form of the hypothesis, in all cases for a significance level of $\alpha = 5\%$:
– Reject $H_0 : \theta = \theta_0$ if and only if $\left|\hat{\theta} - \theta_0\right| > 2\sigma(\hat{\theta}) / \sqrt{n}$
– Reject $H_0 : \theta \leq \theta_0$ if and only if $\hat{\theta} > \theta_0 + 1.6\sigma(\hat{\theta}) / \sqrt{n}$
– Reject $H_0 : \theta \geq \theta_0$ if and only if $\hat{\theta} < \theta_0 - 1.6\sigma(\hat{\theta}) / \sqrt{n}$

CHOOSING THE RIGHT SIGNIFICANCE LEVEL AND P VALUE

Choosing a lower significance level reduces the risk of falsely rejecting the null hypothesis. But reducing the significance level will inflate the factors 2 and 1.6 used in the formulas. An alternative approach to prespecifying a specific level of significance is to find the smallest possible significance level for which we would reject the hypothesis for the data at hand and record it—this is the *p* value. In general, the lower the *p* value, the stronger the evidence in the data against H_0.

Note that the *p* value is not the probability that the null hypothesis is true. It is the probability of observing a deviation at least as large as what we would observe if the null hypothesis were true. Rejecting the hypothesis if and only if the p value is lower than α guarantees a significance level equal to α. In other words, to have a 5% significance level, we must compare the *p* value to this value of 0.05 to decide whether to reject or verify the null hypothesis.

EXAMPLE OF THE ELEPHANT POPULATION

For a given population of elephants, we conjecture the average age to be 25 years. We choose a significance level of $\alpha = 0.05$, and wish to test the hypothesis {H_0: the average age of elephants in the population is 25 years}. To not reject H_0 we should have:

$$\left|25 - Average(sample)\right| < 1.96 \frac{\sigma}{\sqrt{n}}$$

We collect a random sample of 52 elephants from this population and measure their ages. The average for the sample is $m = 19.3$ years old, the standard deviation $\sigma = 12.6$, and $\sqrt{n} = 7{,}2$. Since

$$19.3 - 25 = 5.7 < 3.43 = 1.96 \frac{12.6}{7.2}$$

we must reject the hypothesis H_0 at significance level $\alpha = 0.05$.

2.9 THE JOLLY METHOD

Transcect	Elephants	Transect	Elephants
1	10	16	3
2	15	17	26
3	20	18	20
4	5	19	12
5	8	20	18
6	12	21	32
7	22	22	0
8	7	23	9
9	3	24	7
10	30	25	9
11	14	26	13
12	40	27	19
13	25	28	5
14	45	29	39
15	0	30	23

FIGURE 1

0:55 2:37

Table of elephants in each transect of the park.

The Jolly method is especially useful when it comes to processing data from aerial censuses. Let's consider a 1,000 km² park. We want to randomly sample thirty transects ($n = 30$) that are 20 km long and 500 m wide, in other words, a 250 m strip on each side of the plane. Each transect covers a 10 km² surface and the park theoretically contains $N = 100$ transects.

The formula is based on:
- N = number of sampling units in the park.
- n = number of samples randomly collected.
- y = number of animals counted in each sample.
- $S(y)^2$ = sample variance = $\frac{1}{n-1} \times \left[\Sigma(y^2) - \Sigma(y)^2 / n\right]$.
- $\sigma(y)^2$ = population variance = $N \times (N-n) / n \times S(y)^2$.

The table below (fig. 1) shows the number of elephants counted within each transect, 491 in total.

The sampling mean is:

$$\frac{\text{sum of samples}}{n} = \frac{491}{30} = 16.4 \text{ elephants per transect.}$$

The total population is 16.4 × 100 = 1640 elephants in total in the park.

Sample variance = 144.9

Population variance =

$$N \times \frac{(N-n)}{n} \times \textit{Sample variance} = 100 \times \frac{70}{30} \times 144.9 = 33{,}810$$

Standard deviation = 183.9
Confidence interval around the mean: 1.96 × 183.9 = 360.

3.2 ECOLOGY BASICS (PART 1)

The ecological characteristics of animal species to monitor influence EM when it comes to the choice of KEAs, the data collection method, and the sampling plan to implement. There are three kinds of KEAs:
– Size and species distribution
– Population composition and dynamics
– Habitat quality

KEA: "POPULATION SIZE AND SPECIES DISTRIBUTION"
The distribution of a species depends on the habitat quality within the PA, but also on its tolerance in regards to other species and possible threats. It is a good indicator of the park's health condition and of the threat distribution. The Figures below show the concentration—or lack thereof—of an elephant population, based on the presence of threats on the outskirts of the park.

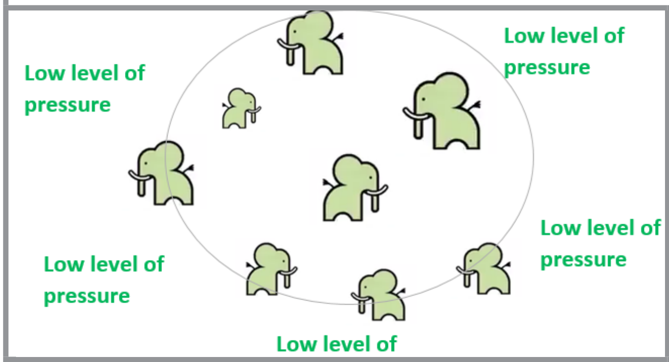

FIGURE 1

2:12 4:52

Good distribution of the population in absence of threats.

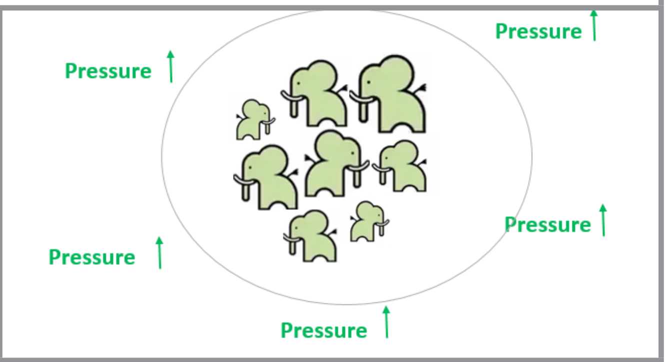

FIGURE 2

2:21 4:52

Concentration of the population in the presence of threats.

KEA: "ANIMAL POPULATION STRUCTURE"
This KEA is defined by the group size, and this size varies depending on the social system of the species in question. Thus, good knowledge of the social structure of different species is required to be able to detect any form of anomaly during the monitoring.

KEA: "SPECIES HABITAT"
This has to do with monitoring the quality of the species' habitat. To survive, animals need a suitable habitat, one in which they can find food, water, and the right conditions for their reproduction.

3.3 ECOLOGY BASICS (PART 2)

The ecological particularities of animal species influence the choice of data collection and the sampling plan to implement.

TYPE OF HABITAT

The type of habitat in which the considered species lives plays a key role in the choice of data collection method in the field. In the case of barely visible species, it is better to choose an indirect method that proves their presence and gives an idea of their number (droppings, nests, tracks, etc.). Larger species living in open spaces can be counted directly on the ground or in the air.

SAMPLING PLAN

The area on which the species is distributed and its daily and seasonal traveling patterns influence the sampling method to choose and the way it should be implemented. To detect a change in the population, a greater number of samples should be collected.

DATA COLLECTION PERIOD

Ecological factors also influence the choice of when the data should be collected. To optimize the chances of observing the monitored species, the collection should take place at the time of year or day that they are most active, and therefore easier to spot and observe.

DATA COLLECTION FREQUENCY

Ecological factors also influence the frequency of data collection. The more the species considered is likely to adapt rapidly to new constraints, the more data collection campaigns should be carried out to detect the changes in time and take the suitable management actions. Conversely, to monitor normal population growth, it is no use carrying out a yearly count of the number of individuals: a five to ten-year surveying frequency is enough.

KEY ECOLOGICAL CONCEPTS

The ecology concepts required to master design of the EM plan of a given species are:
- Its suitable habitat.
- Its social system determining the composition of groups and their seasonal variations.
- The frequency and the way daily and seasonal travel occurs.
- The normal growth rate of the population.
- Its tolerance to threats.
- The type of visible markers that indicate its presence (nests, droppings, tracks, broken trees, etc.).

3.4 MONITORING AN ENVIRONMENT'S ABIOTIC FACTORS

***Abiotic factors** (a = without and bios = life): the lifeless elements of an environment. These include physicochemical factors, which in this case are the climatic, edaphic, and hydrological elements impacting the environment's living beings.*

Monitoring these factors requires the implementation of an observation system in the field that involves:
– A synchronic observation approach, in other words, comparing the state of the environment at a given moment within and between territories.
– A diachronic approach, meaning the long-term comparison over time.

Depending on the factors, three lines of approach in monitoring abiotic factors can be identified.

1: WEATHER MONITORING (CLIMATIC FACTORS)

– Monitored variables: rainfall, daily temperature (maximal and minimal), air humidity (hygrometric content), wind strength, and light.
– Monitoring indicators to test and validate: indices of rainfall, temperature, wind speed, and light intensity.
– Periodicity of climatic data measurements: daily and always at the same time.

2: HYDROLOGICAL MONITORING

In a PA, this type of monitoring is essentially carried out on surface waters.
– Monitored variables: quantity of water in stock, water quality (physicochemical), water flow, and water body siltation.
– Indicators to test and validate: water levels, temperature, pH, oxygen, conductivity, turbidity, height of solid deposits, and flow velocity (rate of flows entering and leaving ponds).
– Periodicity of hydrological measures: seasonal. The data collected helps to elaborate weekly hydrological reports in periods of flooding and monthly reports in low-water periods.

3: PEDOLOGICAL MONITORING (EDAPHIC FACTORS)

Under normal conditions, the soil (edaphic factor) doesn't vary significantly from one year to the next.
– Monitored variables: typology (type of soil), soil degradation, and land use.
– Indicators to test and validate: ratio of land affected by a phenomenon. Data is collected through pedological studies (observation of the field, physicochemical analyses, description of soil profiles, etc.), socioeconomic studies, remote detection, cartography, etc.
– Data collection periodicity: depends on the problematic. Synchronic and diachronic data series should help validating indicators of change. The idea is to proceed to comparative analyses between indicators to understand the shifting trends observed, especially the ones related to living beings in the considered ecosystem.

3.5 MONITORING PLANT BIODIVERSITY

In the context of monitoring plant biodiversity in the long term, it is key to use samples in permanently marked-off areas. To monitor plant communities that do not have strong geological or topographic gradients, it is recommended to use permanent plots—otherwise, use permanent transects.

PERMANENT PLOTS

Permanent plots ground-truth satellite images—square plots are the norm. In the case of forest ecosystems, two sizes of square-shaped plots are recommended: 100 m by 100 m (1 ha) and 20 m x 20 m plots. Ideally, either use:

- at least two 2.5 acre plots per type of forest, or
- at least 5 independent quadrats of 20 m x 20 m.

Plotting the species accumulation curve (see fig. 1) will determine if the choice of surface is large enough. To avoid any bias, the plots should be distributed and selected at random.

Basic principles for permanent plots:

- Avoid the "edge-effect"
- Respect minimal distances between plots
- Avoid establishing plots where there are strong and unusual variations (lake, field, river, etc.)
- Avoid sites interrupted by roads or path

Data to collect:

- Tag number and species of all standing trees with diameter at breast height (DBH, see fig. 2), equal to or higher than 10 cm
- Location of all numbered trees
- DBH of all numbered trees
- General condition of all numbered trees

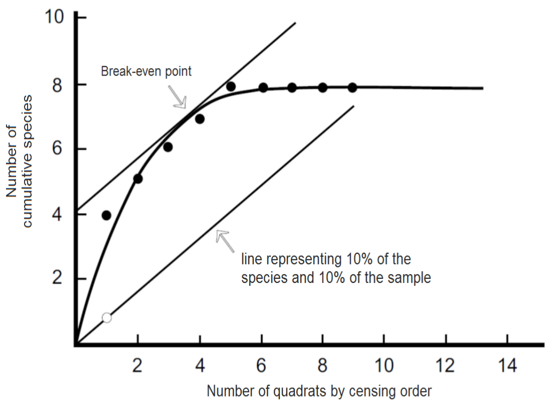

FIGURE 1

3:03 7:35

Relation between the number of quadrats and the number of cumulative species.

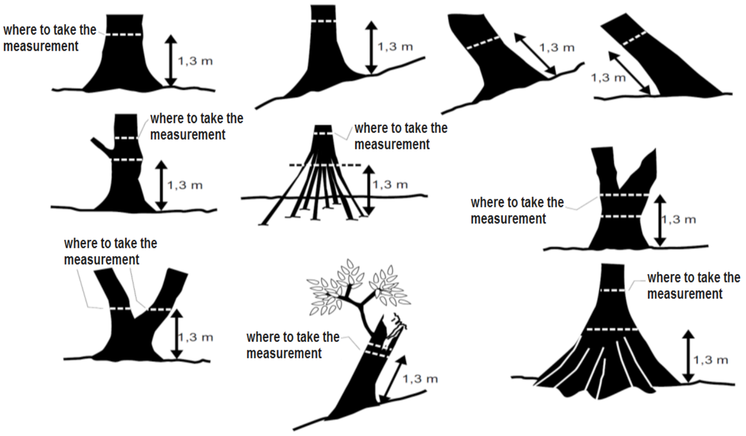

FIGURE 2

5:06 7:35

DBH measurement depending on the type of tree.

Other data to collect and record:
- Height of all numbered trees
- Height of the lowest living branch of all numbered trees
- Age of the stand
- Photographs
- Degree of canopy closure

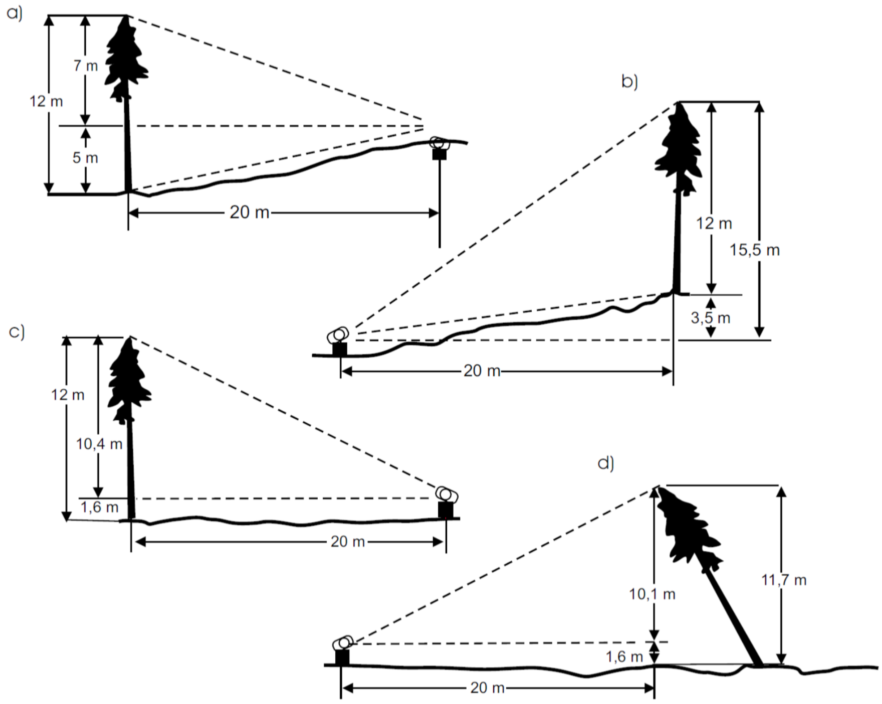

FIGURE 3

5:32

7:35

Height measure depending on the type of tree.

FREQUENCY OF MEASUREMENT

Forest stands should be measured every five years. If they suffer from extreme weather conditions, fire, or other catastrophic events, new measurements should be made.

DATA ANALYSIS

To analyze data:
- List the species of selected standing trees.
- Write down all species found in the plots or in permanent independent quadrats.
- For each species, calculate separately (standing trees only): the abundance, basal area, density and dominance, frequency, relative density, relative dominance, relative frequency, and importance value.

3.6 LARGE MAMMALS: DIRECT MONITORING

Mammals are monitored directly by observing individuals or groups of animals. The point is to monitor the trends of some KEAs of the population.

Among the many techniques that can be used, the following two methods stand out:
- Total count: all the individuals of a population are counted.
- Random animal sampling: in this way, the sample is representative of the total population. The most widely used sampling units are quadrats and transects.

SAMPLING UNIT: THE QUADRAT

Quadrats are based on the idea of visually counting the number of individuals inside a predefined plot, randomly set in the monitored area. Individuals seen outside the plot are not counted. Estimating the total population consists of calculating the sample density and extrapolating this number to the total surface of the studied zone.

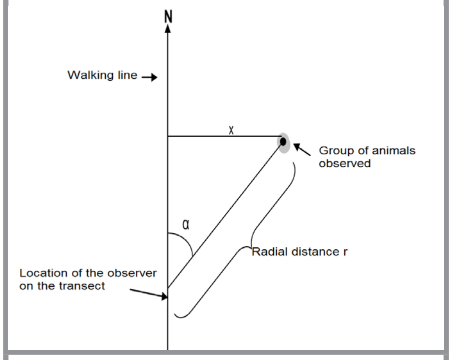

FIGURE 1

4:22 9:38

Counting individuals per line transect.

SAMPLING UNIT: THE TRANSECT

The method consists in looking for animals along a strip of undetermined width. The perpendicular distance between each spotted animal and the transect line is recorded (see fig. 1). For each observation, three measurements are taken:
- The viewing or radial distance
- The viewing angle
- The perpendicular distance

The density estimation is obtained through a formula taking into account the number of observations (contacts), the total transect length, the width of the observation strip (determined by the distance at which the animals are seen), and the probability of detection function.

DIRECT MONITORING METHOD: MARK AND RECAPTURE

The mark and recapture (MR) method is often used to collect data from mobile species. The technique consists in marking and releasing a set number of animals from a particular species.

KILOMETER ABUNDANCE INDICES

Kilometer Abundance Indices (IKA) are observations made during walking surveillance patrols that are adjusted depending on the effort made (e.g., walking time). This method is suited for species existing in low densities.

DIRECT MONITORING METHOD: PUNCTUAL ABUNDANCE INDEX

This method consists of counting animals at certain fixed points (e.g., waterholes) to monitor population fluctuations over time.

DIRECT MONITORING METHOD: MEASURING GROUP SIZES

Regularly monitoring these indicators helps to detect fluctuations in species density. Monitoring a sample will thus provide an estimation of abundance variations without needing to count the entire population.

REQUIRED SKILLS

In all cases, direct monitoring techniques require:

- The ability to identify species and to estimate their number
- Knowledge of these species' biology
- Good conditions for observation.

3.7 LARGE MAMMALS: INDIRECT MONITORING

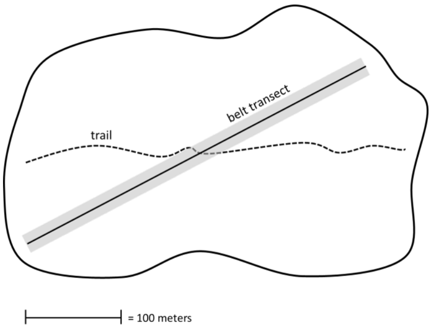

FIGURE 1

1:07 8:32

Belt transect: survey carried out on a predetermined surface on both sides of the axis of progression.

Mammals are monitored indirectly when they are hard to observe. Indirect counting approaches are based on the same sampling techniques as direct monitoring, and survey plans use sampling units such as quadrats, line transects, and belt transects (see fig. 1).

MONITORING FOOTPRINTS

Footprints can be monitored daily, and it is important to remove prints after having recorded them. The population density (D) can then be estimated using a simple formula combining the density of recorded footprints and the average size of the habitat of the considered species.

MONITORING TRACKS

The track recognition method can help recognize an animal and monitor it. Animals can be recognized through scars, sizes, missing claws, etc. Species' footprints vary from one animal to the next, and it is therefore advised to combine direct observations of the animal with track monitoring.

MONITORING BURROWS AND DENS

This method is based on monitoring animals' resting and reproduction sites. In practice, this method consists of identifying the number of abandoned burrows, the ones occupied by the monitored species, the ones occupied by other species, and the number of individuals per burrow.

MONITORING NESTS

This method consists of counting nests in the sampling area where units are often quadrats or transects. Again, there is a relation between the nest density (N), the average nest size, the nest degradation speed (V), and the chimp density (C).

MONITORING FECES

This method consists in counting all the dropping piles in the sampling area, where units are usually quadrats or transects. Each observed dejection is classified in one of the five age categories defined by specialists, going from very fresh to almost completely decomposed. Only relatively fresh droppings are considered in dejection density estimations.

MONITORING SOUNDS

This method is essentially used when monitoring lions. It consists of recording sounds at precise locations, separated by a 13-km minimum interval (to prevent counting the same animal twice). This way, an estimation of the minimum lion population in the surveyed site (N) is obtained.

3.8 MONITORING CARNIVORES

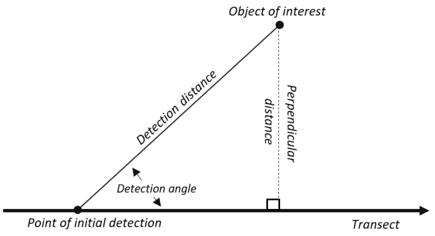

FIGURE 1

0:36 7:01

Detecting carnivores along a transect line.

MONITORING THROUGH DIRECT OBSERVATIONS

By day or by night, two or three observers roam the entire transect lengths. When an animal is spotted, its perpendicular distance to the transect line is recorded (see fig. 1). The number of animals spotted per kilometer traveled gives an indication of their relative abundance. When the sample size allows it, the population density can be estimated thanks to the "distance" program.

MONITORING BY COUNTING DROPPINGS

This type of indirect monitoring is carried out along progression lines. One observer examines the ground looking for droppings, while the others stay focused on the route, measure the traveled distance, and clear the way. There is a relation between the carnivore density (especially big cats), the amount of droppings produced per cat and per day, the dropping decomposition rate, and the density of said droppings.

MONITORING BY COUNTING TRACKS

This method consists of counting the tracks of large carnivores along progression lines. The number of tracks encountered along kilometer transects gives a Kilometer Abundance Index (KAI). Among all the large carnivorous species, there is a correlation between track and population densities, and there are simple methods of calculation.

MONITORING BY PHOTOGRAPHIC RECORDING

Photographic recordings are done through photo traps. The camera should face a trail frequently used by carnivores, and the location should be narrow enough for animals to be obliged to get close to the camera. This type of monitoring provides important information on the species presence in the zone and, sometimes, on the population structure.

MONITORING THROUGH CALLING STATIONS

This technique consists of playing the sound of a species in distress, a young buffalo, for example, to attract lions in the surrounding areas and then count them. These are generally photographed to compare individuals and to differentiate them. Of course, the calling station should be moved around to cover as much ground as possible.

3.9 MONITORING PRIMATE POPULATIONS

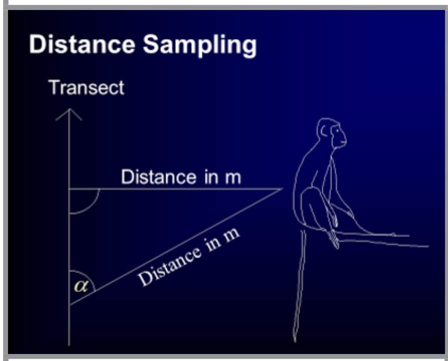
Distance Sampling

FIGURE 1

1:26 9:12

Monitoring through line transects.

DIRECT METHOD: LINE TRANSECTS

Two or three data sets are necessary to analyze data (see fig. 1):
- The distance travelled along the transect line (transect length multiplied by the number of times it was travelled).
- The number of groups encountered (groups counting both male and females).
- The forest surface covered in the process (transect length multiplied by distance covered).

A species' relative abundance can be calculated with the first two data sets (number of groups per kilometer covered). With all three data sets, the population density can be calculated (expressed in groups per square kilometer).

INDIRECT METHOD: NEST COUNTS

The following information is key to capitalizing nest counts per km²:
- The nest construction rate per individual (in view of age differences).
- The time it takes for nests to decay to a point where they can no longer be identified as such.

Once this information is obtained, it is possible to carry out reasonable estimates of the decline rate of gorilla and/or chimp populations.

INDIRECT METHOD: CALL MAPPING

Thanks to their loud calls, certain animals can be detected across great distances. The detection work should be repeated over several days depending on the species, site, season, and weather conditions. Generally speaking, the census should continue to be carried out until coherent results are obtained.

The observer should record the following information:
- The date, time, and species
- The type of shout
- The location of the shout in relation to the observer's position
- The estimated animal-observer distance
- The geographical coordinates of the observer's position.

If the same group can be heard after the observer has moved away, data should be collected once more so that the group's position can be calculated more precisely by means of triangulation.

The data is processed as follows:
- Draw up a precise map of the surveyed area.
- Estimate the distance between the observer and the animal heard and write the information down on the map.
- In the case of animals covering long distances, do not count the same animal twice.
- On the map, take note of animals seen and not heard.

3.10 AERIAL COUNT

There are some prerequisites to choosing the aerial counting technique:
- The surface covered should be large and open.
- The species should be easily detectable.

Aerial counting goals:
- To detect and count certain species.
- To understand the spatial distribution of species and the evolution of the milieu.
- To simplify the detection of pressures and threats.

AERIAL SURVEYING PROS AND CONS

- Pros: overflight is a reliable method that can be implemented quickly. It mobilizes few staff and covers large areas. It also enables access to territories that are not usually surveyed and provides substantial information that is easily geo-referenced.
- Cons: the nature of the surveyed area, the species sought after, and the cost.

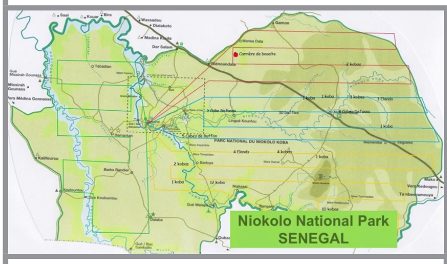

FIGURE 1

4:12 8:17

Niokolo Koba National Park divided in transects.

HOW TO PROCEED?

Aerial count is based on the realization of transects. During the protocol preparation phase (see fig. 1), imaginary strips are calibrated on the plane, and animals seen within those strips are counted. Aerial counts are carried out with a high-winged plane allowing good ground visibility. The counting team is usually made of four people:
- The pilot who plans the flight.
- The navigator who records the information given by the observers and controls the flight parameters.
- Two observers at the back of the plane who are responsible for fauna detection.

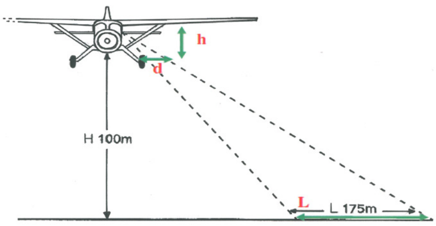

FIGURE 2

5:12 8:17

Example of a plane's ground range.

COUNTING BY SAMPLING

Since a total count increases the risk of counting the same animal twice between overflights, the counting method of choice from a plane is by sampling.
- Step 1: define a counting strip on each side of the plane (fig. 2).
- Step 2: calibrate the plane (with banners attached to the spars) to define the ground range of the desired width.
- Step 3: define an interval between transects according to the desired sampling rate and the width of the projected strip.
- Step 4: during the overflight, only count animals within the strip, and then calculate a theoretical density and extrapolate the total estimated number.

SOURCES OF ERROR AND RISKS RELATED TO OVERFLIGHT

Sources of error and inaccuracy are related to the sampling rate: the more transects there are and the wider the strips, the more territory is covered and thereby the counting precision increases.

Elements influencing the count:
- Species visibility and group sizes
- Weather and general visibility
- Counters' experience and endurance.

3.11 MONITORING MOBILE ANIMALS

TRAVELING OVER SHORT DISTANCES

Depending on the monitored species, ecologists use different methods:

- Radiotracking : a distance monitoring or detection system of animals previously equipped with a radio transmitter. The transmitter is fitted to the animal in such a way as to respect its conformation, environment, and ways of moving about.
- Bands and colored marks: method used on species easily found again. The animal is equipped with a numbered tag and a brightly colored plate to facilitate its identification over a short distance. This enables its recognition within a large group and follows an individual animal's movements and behavior.
- Bleaching a section of the coat.

TRAVELING OVER LONG DISTANCES

Ecologists use:

- GPS (Global Positioning Systems) or ARGOS tags, thanks to which an animal's position can be determined at a distance.
- Bands: especially in the case of migratory birds. This technique requires using the Mark (applying the band) and Recapture (to read the results) technique.

USE OF TAGS AND TRANSMITTERS

Techniques using tags and transmitters are excellent complements to other monitoring techniques. These methods also have some cost-related benefits.

4.2 SCALES OF EM

LOCALIZED MONITORING

EM can be concentrated on part of the PA, and if the indicators are well chosen, localized monitoring can provide relevant information about the entire park. Indeed, conservation conditions are inherently related, and local success depends on global preservation.

MONITORING A PA NETWORK

It is often vital to share monitoring methods and results within a network of parks or between PAs dealing with the same kinds of ecosystems. In this way, general tendencies within a site that are visible at the scale of the entire network can be detected.

MONITORING SPECIES IN ALL THE VISITED AREAS

Many species provide a value for a PA, but their temporal or spatial distribution extends far beyond the PA limits, and it is therefore vital to adapt their monitoring. EM can be extended to all the visited sites, or simply to the moments when the species visit each site. This requires close collaboration between sites, countries, and regions.

MONITORING A SPECIES REGARDLESS OF VISITED SITES

This is a matter of focusing on the species, wherever they are found. Many migratory bird species are monitored globally through bands or tags, because they move about a lot, and variably, from one year to the next.

MONITORING ECOSYSTEMS AS A WHOLE

Satellite images are a tool for monitoring ecosystems at large, and on a massive scale. They provide information on the health conditions of entire blocks of the planet, and by contextualizing this, they help improve understanding of what is happening at a local level.

4.3 EM NRT CONSERVANCIES

The Kenyan PA network includes many community or private PAs with a lack of resources, known as *conservancies*. The Northern Rangeland Trust (NRT) is an organization providing technical support to community conservancies. Its aim is to encourage the implementation of sustainable conservancies that ensure the conservation of natural resources and guarantee safety within these territories.

COMMS TOOLS

NRT provides a set of tools called CoMMS (templates of monitoring sheets, databases, and types of data analyses) that can be adjusted according to the needs of each conservancy. To develop their EM program based on these tools, the managers, eco-rangers, and stakeholders involved proceed as follows:

– Identify a shared vision for the conservancy.
– Identify the species that are likely to provide useful information to reflect the health of the ecosystem.

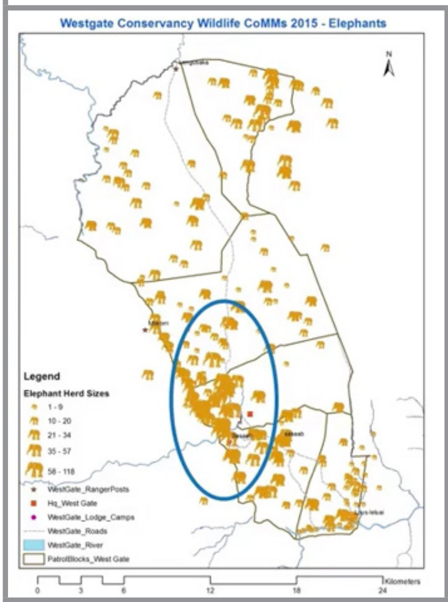

FIGURE 1

3:57 5:29

Elephant distribution in Westgate Conservancy in 2015.

DATA COLLECTION AND STORAGE

Eco-rangers are responsible for the collection of data during their surveillance patrols. Counting is hence carried out on foot, per block, and the tools used for collection are preferably sustainable and affordable (sheets to fill in by hand). The data is then recorded in a database, and the person responsible for it can export reports showing the evolution of the monitored species and their distribution among the different blocks the PA is made up of. Figure 1 below shows the distribution of elephants over a year.

EM REPORTS

Analysis of monthly EM reports helps to reorient the strategy of future patrols to guarantee equal coverage of all the blocks, or to decide on the necessity of manager intervention.

The example of CoMMS shows that it is possible to implement simple EM systems that are affordable and that provide useful information for management decision-making. NRT gives continuous support to conservancies without taking away their autonomy and their legitimacy. Indeed, managers themselves decide on the values to monitor, and they collect, store, and analyze data throughout the year. In this way, managers take full ownership of the EM strategy, which guarantees its sustainability.

4.4 SE EXAMPLE: NAZINGA GAME RANCH IN BURKINA FASO

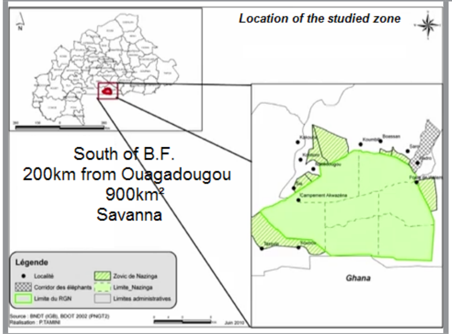

FIGURE 1

0:15 10:21

Nazinga Game Ranch.

The Nazinga Game Ranch (NGR) is located in the southern part of Burkina Faso and covers around 900 km² (see fig. 1). It is entirely set in a savanna zone and is a Category VI PA. The population growth in the many villages around the park is the main threat, since poaching and the demand for space for agriculture weigh heavily on the fauna and flora.

RANCH CONSERVATION STRATEGY

The Ranch has implemented a continuous EM system for certain values in its ecosystem:

- Weather monitoring: helps in understanding the environment's condition and the factors that can affect it.
- Water point monitoring: checks the presence of surface water over time to know its availability for the park's animal species.
- Dynamic fauna monitoring: essentially focused on game from other areas to set collection quotas.
- Monitoring anthropic pressures: carried out on different animal and plant values of the Ranch.
- Monitoring habitat and flora: strengthened by research activities focused on specific themes identified during EM.

ELEPHANT MONITORING

Elephants are an important problem in Nazinga because of the conflict caused in village areas. Monitoring this threat is carried out by collecting information related to the damage done around the Ranch and systematically itemizing this data to better understand the dynamics of the elephant population and to implement suitable preventive actions.

USE OF EM IN NAZINGA

The EM system implemented in Nazinga provides the manager with qualitative and quantitative information. In this way, inter-annual comparisons can be made and the evolutive tendencies of PA values can be assessed. This system also helps to readjust management decisions and valorize natural resources in the PA, namely in terms of game hunting—game being one of the park's key values.

4.5 MARINE PROTECTED AREAS

Aldabra is an atoll in the Seychelles, located off the northern shores of Madagascar in the middle of the Indian Ocean. It covers around 350 km², primarily composed of a lagoon of which three thirds is dry during low tide. The island has no inhabitants apart from a few researchers in the research station. The island is subject to the strict monitoring of its many values.

MONITORING TORTOISES AND TURTLES

Tortoise ecology is assessed by monitoring hundreds of individuals identified by a mark on their shell; their movements are monitored through GPS tags, and their impact on the environment is assessed through reserved plots where the vegetation growth in the absence of turtles is assessed.

Turtles are monitored through a similar approach. Egg-laying is documented by night on set portions of the beach, which helps evaluate their progression over time. Some turtles are banded or monitored through satellite tags, which provides information on their global dispersion in the Indian Ocean, as well as on their survival rate.

SEA BIRDS

Sea bird colonies, their nests, and the number of chicks are counted yearly and their travels are monitored through tags. The precision of information provided by frigate bird colony monitoring allows us to affirm that today, Aldabra is home to the second largest seabird colony on the planet.

ENDEMIC AND INVASIVE SPECIES

Some endemic species are subject to targeted monitoring; they are frequently counted and banded to track movements and establish the survival rate.

Monitoring invasive species is key to EM in the atoll. This monitoring is preventive and consists of detecting any new species that can arrive and present a local risk—in which case, the species will be immediately eliminated.

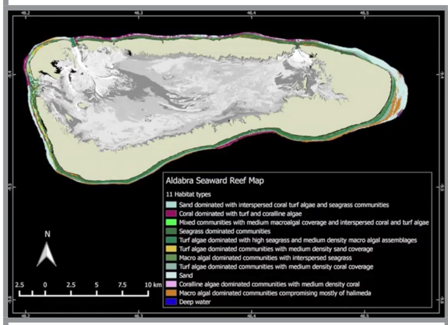

FIGURE 1

6:35 8:22

The atoll's coral reef.

MONITORING THE MARINE ENVIRONMENT

To enable detailed monitoring, the island's coral reef was mapped (fig. 1). Underwater fauna is monitored, fish species are counted, and large mammals are spotted from the coast to monitor the evolution of their frequency of visit. All this provides information on the health of the reef and helps to monitor evolution related to the increase in ocean temperature.

BENEFITS OF EM IN ALDABRA

This EM combines a classic monitoring approach with research. This results in exceptional management performance of the atoll and confirms the importance of carrying out adaptive management based on precise knowledge of the site and the challenges it faces.

4.6 EM IN A FOREST ENVIRONMENT: TAÏ NATIONAL PARK IN CÔTE D’IVOIRE

Taï National Park (TNP) is located in the south-western region of Côte d’Ivoire. It is the largest protected rain forest in West Africa.

MONITORING DUIKERS IN THE TNP

This case study concerns the 10-phase EM program implemented in the TNP from 2005 to 2015. The results considered here are taken from the data related to the “duiker” value, collected during phases 2, 3, and 4 (between August 2008 and February 2009) of the EM. The following ecological attributes were measured:

- The duiker population size in the park.
- The types of attacks suffered by duikers in the park.
- The distribution of these attacks and of duiker populations inside the park.

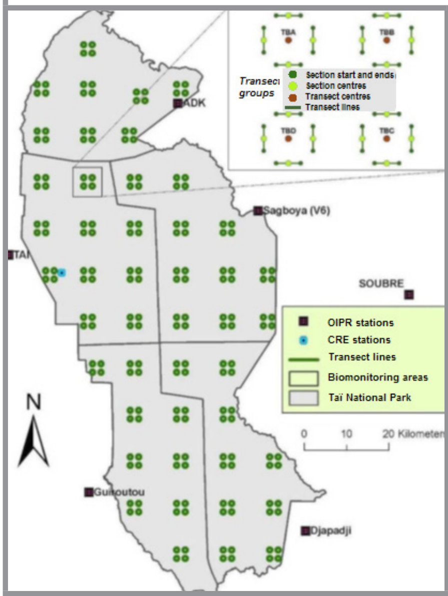

FIGURE 1

2:30 8:38

Distribution of different transect groups throughout the park.

METHOD USED

The EM method used to obtain information on these three ecological attributes was based on a full sweep of the entire park following transects (fig. 1). The aim was to find opportunities for direct and indirect observation of duiker presence and related threats.

DATA ANALYSIS

The data analysis mainly consisted of calculating encounter rates and proportions from rough data to estimate the size of the duiker population in the park.

As a whole, the duiker encounter rate increased in the TNP over the years, while the attack index stabilized or decreased. These results show the impacts induced by management measures to conserve the “duiker” value (taken as an example here) and to reduce the threats they are facing. This shows the success of park management.

4.7 EM EXAMPLE IN THE SAVANNA: COMOÉ NATIONAL PARK (CNP) IN CÔTE D'IVOIRE

CNP CONTEXT

Comoé National Park is located in the north-east of Côte d'Ivoire, and is the largest protected space in west sub-Saharan Africa. This park is reflective of Côte d'Ivoire's savanna biomes. The military crisis the country went through between 2002 and 2011 was manifest in the surge of gold mining activities, illegal transhumance, and poaching, which caused the rarefaction of certain species such as the chimp, elephant, and lion.

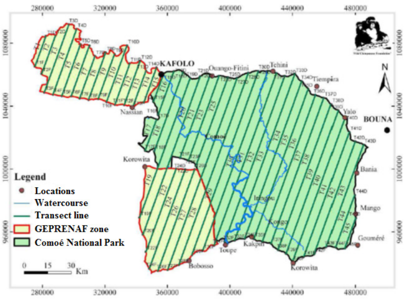

FIGURE 1

2:17 8:33

Comoé segmented in transects.

CNP AERIAL MONITORING

Two aerial surveys were carried out in the CNP in 2010 and 2014, aiming at rediscovering the state of the park and its values, to then be able to reorganize management according to identified priorities. Data collection methodology consisted of systematically overflying the studied zone to sample line transects of variable lengths (see fig. 1).

AERIAL SURVEY RESULTS

Overflying the park has allowed key information related to the state of the main animal species still present (potential PA values) and their attributes (number, distribution, group composition, threats) to be obtained. Repeating the data collection in similar conditions helped to determine evolutive tendencies of these attributes, at a time when it was key to precisely monitor the impacts of a recovering park's management decisions.

Great conservation efforts were made by managers, and inventory data has proven the results (see fig. 2).

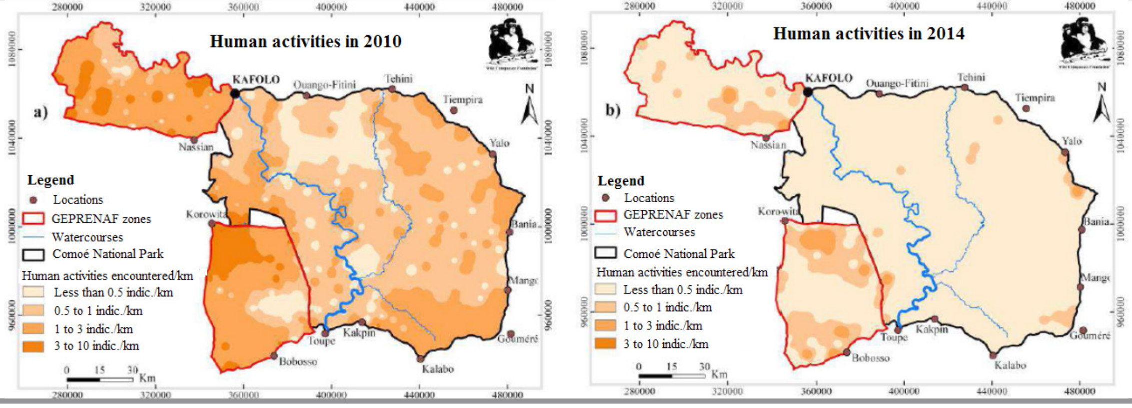

FIGURE 2

6:35 8:33

Evolution of human activity in the park.

4.8 MONITORING WATERBIRD POPULATIONS

Wetlands are ecotones—areas of transition between land and water—fulfilling different functions that give them remarkable biological, hydrological, economic, and sociological value. According to the Ramsar Convention, waterbirds are bird species that are: "ecologically dependent upon wetland."

WHY MONITOR WATERBIRDS?

- They are recognized as indicators of wetland quality.
- They are subject to sustainable use through vision tourism or hunting.
- Monitoring can help draw up or update management plans in wetlands or establish sampling plans coherent with the available resources.

DIRECT WATERBIRD MONITORING METHODS

Monitoring must rely on experienced staff and undergo careful planning. Directly monitoring waterbird populations can be done in different ways:

- Ground count carried out on foot, by bicycle, or by car.
- Monitoring from a boat.
- Aerial survey from a plane or a helicopter.

COUNTING

During each survey, the site is swept on foot, following a pre-determined route based on the same transect every time. Given the abundance of individuals in certain places, the bird count is often done "by block."

OBSERVING BREEDING BIRDS

In the case of a breeding bird colony, it is important to minimize the risk of disturbing them. Observers must avoid getting too close. As for any type of monitoring aimed at detecting temporal variations, the same sites must be counted, season after season, following standardized protocol. Different methods can go from an approximate estimate of the total number of breeding birds to an exact count of the number of occupied nests.

OBSERVING LARGE COLONIES

Again, counting can be done by block. Sampling following the quadrat model can prove useful for colonies breeding over large spaces, where the results are then extrapolated to estimate the total number of birds.

4.9 EM ELEPHANTS

STUDYING ELEPHANT DISTRIBUTION

Studying elephant distribution in and around the PA helps to detect abnormal movements due to anthropic threats. Several techniques can be used:

- Monitoring tracks (droppings, footprints) from transects distributed throughout the PA.
- Using radio-telemetry or satellite monitoring.
- Monitoring damage done by elephants on certain fragile forests of the PA.

STUDYING ELEPHANT DENSITY AND ABUNDANCE

In the savanna, aerial or ground-based (on foot or by car) surveys can be carried out by counting elephants in transects. In Central Africa's dense forests, it is best to stick to ground-based surveys or to use Mark and Recapture techniques through photo traps or DNA extraction on feces. Statistic models further allow elephant abundance and density in the studied zone to be inferred.

Some managers go further and try to detect abnormalities in the mammal's social structure. Group sizes or elephant families can be modified because of the removal of certain age categories, for example.

STUDYING THE THREATS ON ELEPHANTS AND THEIR HABITAT

Monitoring this verifies the effectiveness of management plans. It is carried out by measuring patrolling efforts, offender arrest rates, and following up on their incrimination.

There are multiple, more or less elaborate, and reliable methods to answer different management questions. When resources are limited, it is best to stick with elephant distribution monitoring and the threats they are facing—data collected provide key information to their conservation.

4.10 TWENTY GOLDEN RULES

EM aims at assessing the health of a PA value. This value is characterized by its ecological attributes, which are themselves described by indicators. All this follows a protocol describing the sampling plan and the method used, depending on the context, skills, and means at hand.

Here are some simple rules to keep in mind:
1. EM must have an objective.
2. This goal is clearly stated and is understandable.
3. EM is part of the PA management cycle.
4. EM is built on PA values.
5. EM quality is important and must be assessed.
6. The ecology of features must be understood in order to help choose the right method.
7. EM must be tailored to the features that the PA protects.
8. The proposed sampling must be in accordance with the objective.
9. Sampling must usually be random to be representative.
10. The method used must be sustainable.
11. EM results must be truthful.
12. Initial hypotheses must be kept in mind at all stages.
13. EM methodology must be repeatable over time.
14. EM must give easily interpretable results.
15. EM should lead to meaningful extrapolations.
16. EM must be tailored to the PA and its own capacities.
17. EM must be optimized to last.
18. EM must produce accessible data in the long run.
19. EM favors the sharing of results.
20. EM must be adapted locally by stakeholders in charge.

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