# **Review paper** A review of study designs and data collection protocols in wildlife research

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# Abstract

Choice of methods and intensity of data collection largely determine the reliability and strength of interpretation in wildlife field studies. As nature is complex and habits of individual species vary in space and time, field biologists have developed several techniques offering various options to meet the challenges of ecological investigations. This paper is a synthesis of diverse field research methods in wildlife science and addresses the basic issues in this discipline, aiming to benefit wildlife researchers and field managers.

Keywords : count methods, landscape ecology, monitoring, population, wildlife

# **INTRODUCTION**

Wildlife studies continue to be of great interest due to aesthetic, ethical and economic considerations and the perceptible link between ecological balance and human survival. This field of science has seen a phenomenal growth in the past few decades influenced by persuasive theoretical advancements in ecology (Real and Brown, 1991) and enhanced need for scientific inputs to conserve and manage natural resources (Pimm, 1991). It is a challenging field of science, fraught with severe uncertainties due to inherent complexities in the natural systems.

Wildlife science, drawing principles from ecology, is essentially the study of distribution and abundance of target species and the factors influencing them. Most concepts and methods in ecology tend to be centered on explaining why a species occurs particularly in some location, and what makes them to be in varying numbers in space and time (Andrewartha and Birch, 1954; Rosenzweig, 1995; Krebs, 2001). Like any research, wildlife science involves significant fiscal and human resources, and so, it is important to strive for maximum returns in terms of credible knowledge.

In the past, scientists mainly relied on opportunistic observations and surveys to gather data on wild species and explaining its pattern. In fact, meticulous records of such observations termed as 'natural history records' overwhelmed the wildlife literature earlier (Ratti and Garton, 1996). However, the progress in this field has been both rapid and radical over the years, marked by the transition from opportunistic documentation to comprehensive research adopting rigorous sampling and analytical frameworks, supported by sophisticated techniques and tools. Popper's (1963) landmark

publication 'Conjectures and refutations: the growth of scientific knowledge' had profound effect on the importance of stating and testing hypothesis (hypothetico-deductive approach). Though Popperian philosophy still dominates wildlife studies, it is regularly confronted by difficulties in formulating testable hypothesis about the natural world, and that most of the experiments are geared to explain the pattern in probabilistic terms (Peters, 1991). There are still situations where information is inadequate even for formulating hypothesis and therefore, importance of inductive knowledge by way of natural history observations and descriptive studies can not be ignored. However, if efforts are to provide any reliable gain, it must have uncompromising scientific rigor (Romesburg, 1981). Emphasizing this, Anderson (2001) specifically argued for getting the basics right in wildlife studies, and subsequently made suggestions to raise the bar (Anderson et al., 2003).

Literature on wildlife study designs and data collection protocols are found mostly scattered in various sources and with limited access to wider sections of people, (Cochran, 1977; Bookhout, 1996; Krebs, 1999; Boitani and Fuller, 2000; Sutherland, 2000; Sutherland *et al.*, 2004). In an effort to bridge the gap, this paper reviews and brings together the data collection and analytical procedures in wildlife studies to cater to the needs of wildlife researchers especially the beginners, field managers relying on scientific inputs and also the professionals of other disciplines such as sociology, economics, and genetics involved in wildlife studies.

# TARGETS AND FIELD METHODS

Data is required for various reasons such as establishing presence/absence, species discovery, documenting diversity and distribution, estimating abundance, monitoring abundance and habitat conditions, describing ecology and behavior, etc. Each of these targets

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requires specific data collection methods, although each may complement the other. The following are the broad categories of targets and methods common in wildlife science.

# **Inventory and Spatial Distribution**

Surveys could be undertaken along existing paths/ roads in targeted areas, or by searching an area systematically to establish presence/absence of a species and its distribution patterns. Visuals counts and indirect signs such as calls, tracks, faeces, hairs, feathers, active burrows or den, etc., would provide basis for confirming the occurrence of a species. Interviews with local people and others active in the areas (e.g. forest staff, researchers, military) would be of immense value. If searches were made in scientific fashion and information recorded adequately including of geographic coordinates (using topographic maps or Global Positioning System - GPS), the data could be used to describe and map distribution status of the species. Other option is to grid the entire study area or landscape and then to undertake survey in the selected grids. Species-habitat relationship could be analyzed and modeled using specialized software in Geographic Information System, and distribution surface could be created (Gough and Rushton, 2000).

# **Abundance Estimation**

Total count and sample count are the two broad strategies being employed in most wildlife field studies. The term 'count' is only semantic referring to all possible data collection procedures (e.g. counts, measurements, observations). In wildlife studies, total count is uncommon except in cases of very rare species with small population size and small areas of open fields and ponds (Rodgers, 1991). However, for group-living species and those that congregate at some point of time (e.g. water birds, harriers, bats, and sea turtles), total count would be efficient to obtain reliable data (Bibby et al., 2000). However, because these species choose several such sites for feeding, roosting and breeding etc., the total count in a single site is essentially a sample for the entire population, unless each and every locality within the study area was searched and total counts were made. Total count is perhaps unavoidable in a situation where the species population is very low or faces extinction risk, as it is critical to detect even the smallest change in population status.

Most wildlife studies adopt sample count (sampling), owing to practicality and cost-effectiveness, and there are several sampling procedures available to guide biologists (Caughley, 1977; Burnham *et al.*, 1987; Eberhardt and Thomas, 1991; Bookhout, 1996; Krebs, 1999; MacKenzie *et al.*, 2006). Most of these methods could be placed under two broad categories; (1) random sampling, and (2) systematic sampling.

# **Random Sampling**

In random sampling each observation or record has equal chance of capturing the target information and is not influenced by each other or by convenience of the observer. The area is divided into smallest possible sampling units (e.g. point, quadrat, circular plot, transect) and sampling units are chosen randomly. Alternately, the area could be classified into meaningful strata or blocks (e.g. wetland, woodland) and then carry out random sampling appropriately – this procedure is called stratified random sampling.

# Systematic Sampling

In systematic sampling, the sampling units are placed systematically on equidistance or on some order of selection (e.g. every third nests in a colony for estimating clutch size) in the entire study area or after stratification (stratified systematic sampling). Other sampling procedures include; (a) multistage or hierarchical sampling and (b) cluster sampling, but these methods are executed essentially following the above two methods (random and systematic). In multistage or hierarchical sampling, sampling units are either sub-sampled (e.g. analyzing only a portion of scat samples in tiger food habit study) or distributed in spatially varying scales (Toepfer et al., 2000; Cole et al., 2004) (e.g. tree density enumeration on quadrats within hectare plots, or landscape > forest patches > micro-habitat type). Cluster sampling involves intensive data collection by placing adjoining sample units on various directions, and cluster sampling is also referred to data collection that targets group of individuals. Recently, a modified cluster sampling known as 'adaptive cluster sampling' has found increasing use in ecology. In this method, once the species is located after random or systematic search, sampling is intensified and expanded around the area to obtain adequate information on the species (Thompson, 1990). Adaptive cluster sampling is suited for rare species or habitat specialist with patchy distribution (Noon et al., 2006). All these sampling procedures are designed to capture accurate, precise and unbiased information about the target under study, and a compromise on any of these will likely result flawed outcome and interpretation.

Sometime researchers attempt to collect data consciously in areas of high accessibility (convenient sampling) or high chance of sighting a species based on prior experience (judgmental sampling), or when chanced upon a species (opportunistic sampling). Researchers also tend to place sampling units arbitrarily, here and there (haphazard sampling). These methods of data collection are neither random nor systematic, and yield largely unreliable results, particularly for extrapolation or generalization.

#### **Replicates and Pseudo-replicates**

Accuracy and precision of any estimate is directly related to the number of replicate and pseudo-replicate samples, and the way these are spread in the field. It is unlikely that single or fewer plots or carrying out observations from one spot or fewer spots, would yield accurate results. Researchers often use a map of the target area and randomly or systematically spread a number of sampling units, i.e. plots or observation points/routes across the area. The number of spatially independent sampling units is called replicates. In case of mobile species, the accuracy and precision of data from each sampling unit is subject to local movement of the animal, disturbance, etc. Multiple sampling in the same units would improve precision, thereby the confidence level. This is true for any sampling methods, including presence/absence surveys. These multiple visits or repeated sampling are generally called pseudoreplicates (or repeated measures) (Hurlbert, 1984; Heffner et al., 1996). In cluster sampling method, the number of adjoining plots from the initial plots is sometimes considered pseudo-replicates, since these are not independent of each other in terms of species-habitat association. By repeated measures, the chance of detecting the target (e.g. occurrence of species and encounter rate) is increased, and this allows computing probability of detection or occurrence in given sampling unit or locality. Detection probability measures are now increasingly being used in presence/absence surveys for determining species occurrence, particularly of rare or secretive species (MacKenzie et al., 2002; MacKenzie and Royle, 2005). Some methods (e.g. line transects/ distance sampling) use detection probability to correctly estimate population density based on detection-non detection ratio in relation to sampled area (Buckland et al., 1993; Thompson 2002).

Methods available for abundance could be categorized into (1) plot method, (2) point method and (3) line method.

#### **Plot Methods**

It includes sampling units that have predefined size and shape such as quadrats and circular plots. These methods are most commonly adopted in studies of vegetation and lower invertebrates (e.g. amphibians) (Mishra, 1968; Muller-Dembois and Ellenberg, 1974; Doan, 2003). These plots are laid either independently or placed randomly or systematically within larger plots (nested plots). Some nested plots centered on a reference point in the plot (e.g. 5m radius plot within 10m radius plot) are called concentric nested plots. In strict sense, fixed radius point count and belt transect (see below) would also typically fall under this plot method category.

#### **Point Methods**

In this method, researchers observe or conduct sampling from point locations, and record data on all sides of the

point. Known as 'point count method', it is a widely used in ornithology for estimating abundance of forest birds (Bibby *et al.*, 2000; Sutherland *et al.*, 2004). The radius within which the count is made are kept either fixed (fixed radius point count) or open (open or variable radius point count). Point count could also be carried out even in huge wetlands or roost sites where total count is impractical or for lower vertebrates such as butterflies.

Mark-recapture method is one among the oldest methods that is now gaining increasing ground in wildlife studies with the use of automated camera traps. Individuals are caught physically (e.g. fish, insect and amphibian sampling) or by camera from a chosen point, and are marked by some means (e.g. bands, color marker or recognizing body parts like stripe or spot patterns in tiger and leopard, respectively). These are then recaptured or re-sighted several times, and abundance is computed using the proportion of marked to re-sighted individuals in relation to total captured individuals (Otis *et al.*, 1978; Karanth, 1995).

# Line Methods

It is a highly popular method, as it could be applied for almost all the species, and in this method, individuals are counted on both sides of a line or road (Burnham et al., 1980; Buckland et al., 1993). Similar to point count, the outer limit of the line is either fixed (closed width line transect or belt transect) or open (open or variable width line transect). In open method, perpendicular distance from transect line to the individual needs to be measured or estimated, and this can be achieved by recording sighting angle (triangle of transect line, observer and animal), and angular distance (observer to individual). These data will provide the area of sampling (sampling effort) for calculating density (number per area). There are other easily executable methods available for counting individuals, like counting from a point or walking along a trail (trail count) (Ramesh, 2003) or dry stream beds (Johnsingh et al., 2004) or by vehicle (road count) (Rodgers, 1991). These methods provide useful index of abundance such as frequency of occurrence (number per point) and encounter rate (number per km walk or per hour searched or distance traversed by vehicle).

All these methods described above are also suited for undertaking indirect count of species, e.g. dung count, call count, pug marks, tracks, etc.

#### Monitoring

Monitoring is the process of gathering information about a target variable in different point in time for drawing inference about changes in the variable over time (Yoccoz *et al.*, 2001). It is an important component of natural resource management, since the trend in spatial and temporal pattern of biological diversity and population status would be useful for guiding and evaluating the efficacy of management practices. Methods of monitoring are among the hotly debated issues in wildlife studies, with some forcefully arguing for rigorous approach (Ellingson and Lukacs, 2003), while others are in favour of index methods (Hutto and Young, 2002; Engeman, 2003; Hutto and Young, 2003). The methods described above consist of both of these approaches, and could be used to compare population status between sites and over time for monitoring habitat condition and population status of the species. Point count and line transect methods perform well under certain assumptions. As these methods capture the variation in the detection due to secretiveness of the species and visibility of the area, the density estimates obtained are reliable for monitoring. The estimates obtained based on index counts such as encounter rate have only limited value, unless the error caused by varying visibility level is accounted for. According to Anderson (2003), index methods rarely constitute reliable information. Yoccoz et al. (2001) advocates designs that incorporates sufficient spatial replicates and detectability for better understanding of changes in biological diversity and the underlying causes.

#### **Ecology and Behavior**

Ecologists relate the abundance with biotic and abiotic factors to understand the patterns of space and time use by a species, since the abundance responds to factors such as climatic variation, disturbance, habitat condition, food supply, competitors, predators and parasites, etc. The methods described above form the basic sampling strategy for studying ecology and behavior of any species, although there are specific methods available for behavioral studies (Altmann, 1974; Lehner, 1996). In general, most studies target individual animals (design I), population (design II), and species as an entity (design III) to explain wildlife-habitat relationship (Morrison *et al.*, 1998) and resource selection function (Lennon, 1999; Boyce *et al.*, 2002; Manley *et al.*, 2002).

# Design I

In this design, individuals within a population(s) are marked by color banding or attaching radio-tags and are monitored closely. Locating radio-tagged animals (Radio-tracking) is done by following the radio signal emitted from the transmitter in the radio-tag with the help of an antenna and receiver equipment (Kenward, 1987). The method of data collection includes (1) homein or zero in, where the observer spots the animal, and (2) triangulation, where the observer locates the animal from distance records bearing from three locations and connecting these three by straight lines establishes the location of the animal. The records obtained by both the methods are often transferred onto a map of study area to estimate home range or territory of the species (White and Garrott, 1990; Powell, 2002). Close observations of individuals allow recording minute details about the microhabitat use, behaviour including social interactions and foraging strategies of individual animals. This fine scale approach is also known as focal animal design (Block and Brennan, 1993) and site attribute design (Garshelis, 2000) in cases like nest site selection. Such observations on individuals collectively contribute to the understanding of species' ecology and behaviour. However, it is easy to presume that individuals do vary, at least to some extent, and there are distinct differences between sexes and between adults and young ones. If the research following this design has to provide reliable results allowing extrapolation for the species, individuals from each of the social category should be adequately represented, and therefore, it is important to argue for and convince the managers to help mark or radio-collar large number of individuals representing each social category.

# Design II

Here single or few populations of a species are targeted and their estimated abundance is used for understanding species ecology (Stauffer, 2002). This is attempted at varying scales (e.g. relating abundance with habitat types or landscape units or temporal scales) considering that animals choose resources at varying hierarchical order, influenced by innate traits and decision making processes (Allen and Starr, 1982; Block and Brennan, 1993; Peterson and Parker, 1998; Wu, 1999). Most studies dealing with habitat use attempt to quantify density of target species and explain the habitat choice as a function of linear relationship between density and habitat quality. Though it is reasonable to expect higher densities in good quality habitat, assuming a strong density-habitat quality relationship is not always correct (Van Horne, 1983; Railsback et al., 2003), since animals are forced to suboptimal or sink habitat by the dominant or high fitness ones that are generally fewer, occupying the quality habitat. The right approach is perhaps the demographic response design (Garshelis, 2000), wherein survival probability or breeding successes are related to habitat conditions, and incorporating a measure of this property in density estimates might help.

#### Design III

In community studies, the primary focus is on the species, seeking to answer questions like how many species constitute the community. What are common or rare ones? Community studies, though inherently complex, can be credited for advancing theoretical and empirical perspectives in ecology, more specifically contributing to macroecology, biogeography and biodiversity conservation. Taxonomic and mathematical expertise offer substantial help in this area of research, though methods of data collection are largely within the approaches described above. Diversity, richness and

evenness measures, and Rank-Abundance models are commonly used to study the structure and resource use pattern by the species across varying spatial and temporal scales (MacArthur, 1965; Rosenzweig, 1995; Magurran, 1998; Wiens, 1989; Hubbell, 2001; McCune and Grace, 2002).

#### LANDSCAPE ECOLOGY

Traditionally, most ecological studies concentrated in small areas, without regard to the way the resources are arranged on horizontal axis, the effect of neighbors such as influence of adjoining forests and the level of connectivity (corridor) with other elements. Landscape ecology addresses some of these issues, focusing on unprecedented spatial extents (large study area) than the traditional studies in ecology (Forman and Godron, 1986). Focused approach in a single scale (particular site and season) is designed to elucidate finer details about a species or ecological complexities only within the scale of measurement or in a limited area of extrapolation, and therefore, it predicts poorly on the species-environment relationships that are likely shaped by effects at varying spatial and temporal scales (Allen and Hoekstra, 1992). Besides the scale, the importance of 'space' is dubbed as the 'the final frontier for ecological theory' (Kareiva, 1994), given that all ecological process occur in a spatial context (Turner et al., 2001). Studies in macro-ecology (Brown, 1999) have addressed the issues of scale at some level and landscape ecology attempts to provide a clear perspective on the effects of scale, along with spatial configuration of the patterns and processes. Quantifying the effect of these two important correlates of ecological systems require new methods, and some warrant acquiring and processing large quantity of data. Rapid progress in Remote Sensing technology (Lillesand and Kiefer, 2000) and Geographic Information Systems (Burrough and McDonnell, 1998) has been of immense value in this direction and is found increasing use in ecology (Johnston 1998) and biodiversity conservation (Turner et al., 2003). Quantitative methods in landscape ecology evolved in quick pace over the years (Turner and Gardner 1991) and specialized tools (e.g. FRAGSTATS, McGarigal et al., 2002) are now available for map analysis and deciphering the complex spatial pattern in landscapes. Spatially explicit models have also been developed for studying and mapping distribution of species (Erickson et al., 1988; Stockwell and Peters, 1999; Segurado and Arau, 2004; Ferrier and Guisan, 2006) and for directing conservation focus (Jennings, 2000). These developments in ecology and wildlife field studies have influenced landscape scale conservation approaches to a large extent.

# DATA ANALYSIS AND INTERPRETATION

Data refers to collection of observations or objects and these observations usually termed as sampling units (Quinn and Keough, 2002) that are measured in (a) nominal scale (yes/no, male/female), (b) ranking scale (greater than/less than), (c) interval scale (class intervals), and (d) ratio scale (number per unit effort). Ratio scale data can take either discrete or continuous numbers with any degree of precision including decimal values.

Krebs (1999) lists ten rules that a field researcher should consider, before embarking on data collection and reporting. As per the rules, it is not always beneficial to record every detail in the field as it adds to redundancy and confusion (Gough and Rushton, 2000); most ecological variables are interrelated and it is possible to explain the pattern even with fewer variables or factors. The core issue is to identify what is useful, asking the relevant questions, and recognizing what is achievable at the present time, given technical and financial support.

The field conditions, vast expanse of the area and behavior of the species never allow 100% accuracy, and it is necessary to report the results along with possible errors. This helps others to use and interpret the results accordingly. Researchers often place high importance on statistical significance (p-values) when interpreting the results, but, this need not always be, since achieving ecological significance is more important than statistical significance (Johnson, 1999). However, this is not to say that one does not need to learn statistics to be an ecologist, rather it is important to learn statistics to be able to recognize the option it presents to improve our understanding (Krebs, 2000). Unless one is extremely careful, statistical significance may yield trivial ecological significance. For instance, large sample sizes would invariably return low p-values suggesting significant difference between tested variables, but, what is more important is to know how large a difference has to be to make it worth detecting (i.e. effect size). In contrast to significant tests that merely detect whether or nor differences exist; effect size reflects the magnitude of the difference between the groups. Besides the Effect Size statistics, the Bayesian and Information Theoretic Models provide important analytical options to interpret ecological data.

The most important component of research is to make meaningful inference from the data collected by hours or years of hard work. It is often the case that very little is extracted out of the efforts made due to improper or inadequate sampling design, want of statistical awareness, lack of access to analytical software, or simply an aversion to these tools. Data analysis should begin by descriptive and exploratory analysis before indulging in detecting statistical significance and constructing models.

It is critical to understand the structure and distribution of data before performing statistical analysis, and most often, only data with large sample sizes offer greater reliability. When large variances (or Standard Deviation) are encountered even with large sample size, it does not always reflect a problem; rather it may unravel an important property of ecological system constituted by patchily arranged attributes. There are also situations where the data does not fit into normal distribution as perceived by central limit theorem, and robust analysis of such skewed data are possible with several nonnormal distribution or distribution free statistics (Siegel and Castellan, 1988). Correlation and regression analyses, respectively, enable understanding and predicting relationships between variables (Sokal and Rohlf, 1981; Fowler et al., 1998; Zar, 1999; Menard, 2002). Several other statistical analyses including multivariate analysis are available to deal with large number of variables, especially in community studies and models with several explanatory variables (James and McCulloch, 1990; De'ath and Fabricius 2000; McGarigal et al., 2000). Given that most ecological processes are correlated at some spatial distances (spatial autocorrelation), recent trend in spatial analysis has implicitly questioned the validity of conventional approaches, by demonstrating the value of documenting and incorporating spatial pattern in the analysis and interpretation (Perry et al., 2002; Haining, 2003).

According to Krebs (1999), it is important to clinically examine the results before drawing inference and making generalization about the study target. Particularly in GIS based studies, it is possible to get carried away by colorful maps, overlooking the bias, because, these maps are often persuasive, unaccompanied by spatially explicit errors. The accuracy of spatial analysis and the interpretation is undoubtedly a linear function of the accuracy of each of thematic input layers (or variables) which are prone to error from the stage of digitization. Unless the source of error was recognized, measured and reported along with the main output, it is likely to mislead or prevent wider acceptability. It is rarely in the ecological literatures that map outputs are presented along with a map of error area. In any case, "Theoretical and applied ecology represent large and complex disciplines, and it is easy to get lost in the details, particularly the analytical details" (Anderson, 2001). One must be cautious, as Charles Darwin puts it "False facts are highly injurious to the progress of science, for they often endure long".

Table 1 provides some of the commonly used statistical analysis for various kinds of data, along with relevant source material for further understanding and appropriate use. These statistics and other analysis have been customized in specialized softwares for ease of application, and many of the softwares are freely accessible from internet sources (Table 2).

Krebs (1999) is forthright in proclaiming that even with advanced tools and statistics, only good data will produce reliable details. The rules suggested by Krebs (1999) offer suggestions to avoid many of the problems associated with the field studies, by forcing researchers to plan meticulously from the stage of conceiving the idea and before intensive data collection. In this order, priority is placed on thorough literature review of relevant subject, and a peer reviewed project document containing detailed sampling and analytical frameworks. However, the success of wildlife studies is most often linked to prior knowledge of the species or related species, creativity, critical thinking, hardship and honesty of the researchers, and cooperation from decision makers and field managers.

# CONCLUSION

In wildlife studies, reliability and appropriate interpretations is largely centered on proper design and field methods. It is this necessity that drives biologists to be concerned about proper sampling methods and has led to consideration of several methods and analysis in greater detail (Wiens and Rotenberry, 1981). Although there are several methods available or being evolved, according to Franzreb (1981), an acceptable method is always the one that is reasonably efficient to execute in the field, provides relatively reliable results and rely upon as few assumptions as possible. However, this does not suggest convenient sampling or unscientific methods like judgmental or haphazard methods. Clearly, one needs to combine and decide upon the methods that are capable of producing reliable results, even if it means use of advanced techniques or is of expensive proposition. On its own, quality data collection is unquestionably an important enterprise in wildlife field studies, but its utility and application value enhances manifold when backed by underlying concepts and theories. While understanding basic issues in field studies, researchers perhaps need to consider the scale and space related issues for better understanding and prediction of ecological phenomena. As there are increasing dependency on reliable data, not experiences or opinions, one need to apply rigorous protocol to be able to contribute to 'reliable knowledge' and for influencing policy and management options.

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Table 1. List of commonly used statistical methods for analyzing ecological data.

Methods	Description	Literature
Graphs (e.g. Histogram, Scatter and Box plots)	Discerning and describing observations visually, and is highly useful in reporting results.	Bookhout (1996)
Mean ( $\overline{x}$ ) = $\Sigma(x_1, x_2,, x_n)/n$ Sum of values divided by sample size	Measuring and estimating the central point of the sample and population.	Sokal and Rohlf (1981) Fowler <i>et al.</i> (1998) Zar (1999)
Variance (s <sup>2</sup> ) = $\Sigma(x - \overline{x})^2/(n - 1)$ Sum of squared difference between each observation and mean, divided by sample size minus 1 (degrees of freedom)	Spread of the samples or precision, and reflects the average deviation from the mean. Uniform distribution of any species will have low variance.	Sokal and Rohlf (1981) Fowler <i>et al.</i> (1998) Zar (1999) Quinn and Keough (2002)
Pooled mean ( $\overline{x}$ ) = $\Sigma$ (n <sub>1</sub> $\overline{x}$ <sub>1</sub> , n <sub>2</sub> $\overline{x}$ <sub>2</sub> ,n <sub>n</sub> $\overline{x}$ <sub>n</sub> )/ $\Sigma$ (n <sub>1</sub> ,n <sub>2</sub> ,n <sub>n</sub> ) Sum of mean multiplied by sample size, divided by sum of sample size	This is used in case of repeated measures (pseudo replicates), and pooling information from different localities to represent a single, overall mean.	Sokal and Rohlf (1981)
Pooled variance = $\sum (n_1 - 1^* s^2_1, n_2 - 1^* s^2_2, \dots n_n - 1^* s^2_n) / (n_1 - 1, n_2 - 1, \dots n_n - 1)$ Sum of variance multiplied by degrees of freedom, divided by sum of degrees of freedom	The same function as of variance, but repeated measures (pseudo replicates), and pooling information from different localities to represent a single, overall variance.	Sokal and Rohlf (1981)
Standard Deviation (s) = $\sqrt{s^2}$ Square-root of variance	Taking square-root of the variance brings the value back to the same unit of mean, without loosing information, thus easy to interpret.	Sokal and Rohlf (1981) Fowler <i>et al.</i> (1998) Zar (1999)
Coefficient of Variation (CV) = $(s / \overline{x}) * 100$ Standard deviation divided by sample mean, together multiplied by 100	CV describes the standard deviation as percentage of mean (without regard to measurement unit), and is easy to understand and compare variations within and between populations.	Sokal and Rohlf (1981) Fowler <i>et al.</i> (1998) Zar (1999) Quinn and Keough (2002)
Standard Error (s $\overline{x}$ ) = s/ $\sqrt{n}$ Standard deviation divided by square-root of sample size.	Explains the accuracy of mean. If standard error is high, repeated samples is unlikely to produce similar results (biased estimate about the actual values). Smaller error tells that the estimated mean could be trusted.	Sokal and Rohlf (1981) Fowler <i>et al.</i> (1998) Zar (1999) Quinn and Keough (2002)
(95) Confidence Interval (CI) = $\overline{x} - t_{0.05(n-1)}(s/\overline{x}) \le \mu \le \overline{x} + t_{0.05(n-1)}(s/\overline{x})$ $\mu$ is the population parameter (actual value), and 0.05 is permissible error (5%) or probability (p) value in test statistics.	Given the standard error, it predicts the population parameter with required level of confidence. 95% is the desired level, though 90% ( $p = 0.1$ ) is also fixed in some situations.	Sokal and Rohlf (1981) Fowler <i>et al.</i> (1998) Zar (1999)

Table 1 Contd.,

Community Measures Diversity Richness Evenness	Designed to measure simultaneously richness (number of species) and relative abundance of species in a sample or community. Diversity is analyzed and explained at three levels: (1) Alpha – diversity in individual sample units, (2) Beta – diversity in a collection of sample units, and (3) Gamma – diversity in collection of sampling units across landscapes.	McCune and Grace (2002) Krebs (1999) Magurran (1988)
Species Area Curve Rarefaction Jackknife Estimator Bootstrap	Several analytical methods are available in the literature, and these should be used appropriately, according to situation and the kind of data, as some of the statistics involve strong assumptions.	
Rank-Abundance Models	Rank-Abundance Models are useful for describing community structure.	
Correlation	Detecting linear relationship between variables. It takes on value from -1 (high negative correlation to +1 (high positive correlation. The value of '0' means no correlation. It is done for two variables (bivariate) correlation, more than two variables (multiple correlation) and there is also 'partial correlation' when adjusting for one or more variables in the correlation analysis.	Sokal and Rohlf (1981) Fowler <i>et al.</i> (1998) Zar (1999)
Regression	Modeling and predicting one variable (dependent or response variable) in relation to one (bivariate regression) or more variables (independent or explanatory variables) (multiple regression). It takes on values from 0 (when the predictive ability of explanatory variable is 0%) to 1(when these explain 100%). When the response variable is categorical (e.g. male or female), logistic regression is the suitable technique.	Sokal and Rohlf (1981) Fowler <i>et al.</i> (1998) Zar (1999) Menard (2002)
Parametric Tests One sample t-test Independent samples t-test Paired t-test	This group of statistical methods assume certain pattern of distribution of the data (e.g. normal distribution, like bell shape curve), from randomly taken data. These are powerful tests capable of discerning statistical significance between populations, provided that assumptions are not grossly violated.	Sokal and Rohlf (1981) Fowler <i>et al.</i> (1998) Zar (1999) Quinn and Keough (2002)
Analysis of Variance (ANOVA)	Tests for the statistical significance of the mean for both independent samples, and related samples. When more than two samples and different groups are involved, ANOVA are useful.	

# Table 1 Contd.,

Non Parametric Tests Chi-square test One sample Kolmogorov-Smirnov test Mann-Whitney U test	This group of statistical methods performs on distribution free data. These are equivalent of parametric tests, though less powerful, and computes test statistics by ranking the values.	Siegel and Castellan (1988) Fowler <i>et al.</i> (1998)	
Kruskal-Wallis H test Wilcoxon Signed Ranks test Friedman test Kendall's W tests	Tests for statistical significance between independent and related samples of two or many populations.		
Multivariate Analysis Principal Component Analysis (PCA) Non-metric multidimensional Scaling (NMDS) Correspondence Analysis (CA) Canonical Correspondence Analysis (CCA) Discriminant Function Analysis Hierarchical Cluster Analysis K-Means Cluster Analysis	These are techniques commonly used in ecology (more so in community ecology), where large number of species or variables are involved for describing pattern. These techniques simply arrange items (variables) in an order along a scale (axis) or multiple axes based on similarity or dissimilarly between the items. These are then grouped into a meaningful class or cluster and placed on ecological space or distance metrics.	McCune and Grace (2002) Quinn and Keough (2002) McGarigal <i>et al.</i> (2000) Jamesand McCulloch (1990) De'ath and Fabricius (2000)	
Indicator Species Analysis Two-Way Indicators Species Analysis (TWINSPAN) Classification and Regression Trees (CART)	Statistics such as PCA or factor analysis reduce the dimensionality (grouping the variables) of original variables and create new composite variables (components) based on variance explained by the composites.		
Spatial Statistics Kriging Variogram Moran's I Contagion analysis	These are used for exploring and describing how species populations or communities distribute themselves in space. Typically these are explored either on point-pattern or surface gradient, and are increasingly in use due to GIS. Conventional statistics along with a measure of spatial relationship are used to model and explicitly predict distribution of species in local and landscape scales.	Haining (2003) Perry <i>et al.</i> (2002)	

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# Table 2. List of commonly used softwares in ecological investigations

Category	Software	Application	Internet Source
Basic and advance statistics	MS Office Excel	Plots various kinds of graphs. Analysis Toolpak in the spread sheet performs most of the descriptive and test statistics.	http://www.microsoft.com/India/
	SPSS/PC	Most of the basic and advanced statistics, including multivariate analysis.	http://calcnet.mth.cmich.edu/org/spss/index.htm
	R Software*	Performs a wide variety of statistical analysis including linear and nonlinear models, time-series analysis, classification and clustering. Graphics provide well-designed publication-quality plots, including mathematical symbols and formulae.	http://www.r-project.org/
Distribution and abundance	PRESENCE*	Estimates detection and site occupancy probabilities, particularly for surveys and distribution modeling.	http://www.mbr-pwrc.usgs.gov/software/presence.html
estimation	DISTANCE*	Designing and analyzing population estimation based on line transect and point counts.	http://www.ruwpa.st-and.ac.uk/distance/
	MARK*	Computes estimates of capture or sighting probabilities and population estimation, for mark-recapture studies.	http://www.warnercnr.colostate.edu/~gwhite/mark/mark.htm
	RAMAS	Offers range of analytical tools for population viability analysis, linking spatial data with viability parameters, risk assessment at population and community level, etc.	http://www.ramas.com/
Community analysis	Estimates*	Computes a wide range of species richness, diversity and similarity estimators for abundance and presence/absence data.	http://viceroy.eeb.uconn.edu/EstimateS
	BioDiversityPro*	Analyzing multivariate data for computing diversity, abundance and richness, and also clustering algorithms.	http://www.sams.ac.uk/activities/downloads/bd_pro/success.ht ml
	PC-ORD	Performs number of multivariate analysis with emphasis on nonparametric tools, graphical representation, and randomization tests for analysis of community data.	http://home.centurytel.net/~mjm/pcordwin.htm
	JUICE*	Designed for editing, classification and analysis of large phytosociological tables or other ecological data. It includes TWINSPAN, and export of table data into other applications, including mapping packages.	http://www.sci.muni.cz/botany/juice/

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Remote Sensing and GIS	ERDAS IMAGINE	Image processing and geographic information tools, helpful in interpretation and mapping imageries, especially Remote Sensing data.	http://gi.leica-geosystems.com/LGISub1x33x0.aspx
	IDRISI	GIS software, with capabilities of image processing, classification and spatial analysis.	http://www.clarklabs.org/products/index.cfm
	ArcView	GIS software for mapping, integration and spatial analysis (extensions such as spatial analysis and animal movement are highly useful in wildlife studies).	http://www.esri.com/software/arcview/
	ArcGIS	Offers collection of software products that create, edit, analyze, and publish spatial data. Associated products include ArcMap, ArcCatalog, ArcEditor and ArcInfo.	http://www.esri.com/software/arcgis/
Distribution models and mapping	DesktopGarp*	GARP (Genetic Algorithm for Rule-set Production) creates ecological niche models for analyzing and predicting species distribution.	http://www.lifemapper.org/desktopgarp/
	Biomapper*	Biomapper is used to build habitat suitability models and maps for any kind of animal or plant. It is centered on the Ecological Niche Factor Analysis that allows computing habitat suitability models without requiring absence data.	http://www2.unil.ch/biomapper/
Spatial analysis	SAM*	Designed for spatial analysis in macroecology and biogeography.	http://www.ecoevol.ufg.br/sam/
	FRAGSTATS*	Map analysis tool for exploring spatial pattern, and quantifies various patch, class and landscape matrices.	http://www.umass.edu/landeco/research/fragstats/fragstats.ht ml

\* Free, noncommercial versions, for research and academic purposes. More such softwares are increasingly available on web sources

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