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Markus J. Peterson

Wildlife Study Design

Second Edition

Springer

Dr. Michael L. Morrison
Texas A&M University
College Station,TX
USA
mlmorrison@ag.tamu.edu

Dr. William M. Block
Rocky Mountain Research Station
USDA Forest Service
Flagstaff, AZ
USA

Dr. M. Dale Strickland
Western EcoSystems Technology, Inc.
Cheyenne, WY
USA

Dr. Bret A. Collier
Texas A&M University
College Station, TX
USA

Dr. Markus J. Peterson
Texas A&M University
College Station, TX
USA

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Preface

We developed the first edition of this book because we perceived a need for a compilation on study design with application to studies of the ecology, conservation, and management of wildlife. We felt that the need for coverage of study design in one source was strong, and although a few books and monographs existed on some of the topics that we covered, no single work attempted to synthesize the many facets of wildlife study design.

We decided to develop this second edition because our original goal – synthesis of study design – remains strong, and because we each gathered a substantial body of new material with which we could update and expand each chapter. Several of us also used the first edition as the basis for workshops and graduate teaching, which provided us with many valuable suggestions from readers on how to improve the text. In particular, Morrison received a detailed review from the graduate students in his "Wildlife Study Design" course at Texas A&M University. We also paid heed to the reviews of the first edition that appeared in the literature.

As for the first edition, we think this new edition is a useful textbook for advanced undergraduate and graduate students and a valuable guide and reference for scientists and resource managers. Thus, we see this book being used by students in the classroom, by practicing professionals taking workshops on study design, and as a reference by anyone interested in this topic. Although we focus our examples on terrestrial vertebrates, the concepts provided herein have applicability to most ecological studies of flora and fauna.

We approached this book from both a basic and applied perspective. The topics we cover include most of the important areas in statistics, but we were unable to go into great detail regarding statistical methodology. However, we included sufficient details for the reader to understand the concepts. Actual application might require additional reading. To facilitate additional research on the topics, we included extensive literature reviews on most of the areas covered.

A primary change in the second edition was division of the original Chap. 1 into two new chapters. Chapter 1 now focuses on philosophical issues as they relate to science. The philosophy of science provides a logical framework for generating meaningful and well-defined questions based on existing theory and the results of previous studies. It also provides a framework for combining the results of one's study into the larger body of knowledge about wildlife and for generating new

questions, thus completing the feedback loop that characterizes science. The new Chapter 2 retains many of the elements present in the first chapter of the original edition, but has been fully revised. In this new Chapter 2, we focus on the concept of basic study design, including variable classification, the necessity of randomization and replication in wildlife study design, and the three major types of designs in decreasing order of rigor (i.e., manipulative experiments, quasi-experiments, and observational studies).

Throughout the remaining chapters we expanded our use of examples and the accompanying literature. In particular, we added considerable new material on detection probabilities, adaptive cluster methods, double sampling, sampling of rare species, and effect size and power. We expanded our coverage of impact assessment with recent literature on disturbance and recovery. One of the changes highlighted by student reviewers of the first edition was the need for more material on what to do "when things go wrong." That is, what can one do to recover a study when the wonderful design put down on paper cannot be fully implemented in the field, or when some event (e.g., natural catastrophe or just plain bad luck) reduces your sample size? We also added a glossary to assist in reviewing key terminology used in study design, as requested by student reviewers.

We thank Janet Slobodien, Editor, Ecology and Environmental Science, Springer Science + Business Media, for guiding both editions through to publication; and also Tom Brazda of Springer for assisting with the final compilation and editing of the book. Joyce Vandewater is thanked for patiently working with us to create and standardize the graphics. We thank the reviewers selected by Springer for providing valuable comments that strengthened this edition. Angela Hallock, Texas A&M University, completed the task of securing copyright permissions for material used in the text. Nils Peterson, Damon Hall, and Tarla Rai Peterson provided incisive reviews of Chapter 1 that greatly improved the final version.

We also thank those who assisted with the first edition, because the valuable comments they made were retained through to this new edition: Rudy King, Rocky Mountain Research Station, US Forest Service; Lyman McDonald, Western EcoSystems Technology, Inc. In particular we thank first edition co-author William L. Kendall for his valuable contributions.

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Glossary

Format of glossary: Key terms used throughout the text are listed below with a brief definition; cross-reference to associated terms is provided where appropriate. The number(s) following each term refers to the chapter(s) in which the term is defined or otherwise discussed.

Abductive Reasoning (1) For our purposes, see *retroductive reasoning*.

Accuracy (2, 5) Combination of bias and precision that measures the conformity of a quantity to its true value. See also *bias*, *precision*.

Adaptive management (7) Planned series of events including monitoring the effects of implementing land management activities on key resources, and then using monitoring results as a basis for modifying those activities when warranted.

Adaptive sampling (4, 5) Sampling procedure in which the proba bility for selecting units to be included in the sample depends upon the values and locations of the variables of interest during the survey period.

Aesthetics (1) The branch of Western philosophy dealing with the nature of beauty, art, and taste, and also the creation and appreciation of beauty. See *axiology*.

Analysis of covariance (3) An analysis using the concepts of analysis of variance and regression that considers the added influence of variables having a measurable influence on the dependent variable when analyzing the dependent variables response to a treatment.

Analysis of variance (2, 3) An analysis of the variation in the outcomes of an experiment to assess the contribution of each variable to the variation.

Anthropocentric (1) Human centeredness; interpreting the world in terms of human values and experiences.

Anthropogenic (1) Of, relating to, or resulting from the influence of human beings on nature.

Area of interest (3) Area to which statistical and deductive inferences will be made.

Attributable risk (6) Defined as the proportional increase in the risk of injury or death attributable to the external factor.

Axiology (1) The branch of Western philosophy that studies the nature, types, and criteria of value and quality (includes value judgments, aesthetics, and ethics).

BACI (2, 3, 6) The before–after/control–impact, or BACI, design is the standard upon which many current designs are based. In the BACI design, a sample is taken before and another sample is taken after a disturbance, in each of the putatively disturbed (impacted) sites and an undisturbed (control) site.

BACIP (3, 6) BACI design with paired sampling, or BACIP. The BACIP design requires paired (simultaneous or nearly so) sampling several times before and after the impact at both the control and impacted site.

Before–after design (3) A relatively weak design appropriate when measurements on the study area before the treatment area are compared with measurements on the same area following the treatment and independent control or reference data are lacking.

Bias (2, 3, 5) Difference between estimator's expectation and the true value of a parameter being estimated. Tendency of replicated parameters to differ systematically from the true parameter value. See also *precision*, *accuracy*.

Blocking (3) Partitioning of variance.

Biodiversity (1) In its most general sense, biodiversity refers to all aspects of variety in the living world. More specifically, the term may be used to describe the number of species

(species richness), the amount of genetic variation, or the number of biotic community types present in an area of interest.

Bioequivalence testing (3) An alternative paradigm for data analysis that reverses the burden of proof so that a treatment is considered biologically significant until evidence suggests otherwise.

Biological population (1, 3) A group of individuals of one species in an area at a given time that potentially could interbreed. The size and nature of the area is defined, often arbitrarily, for the purposes of the study being undertaken.

Biological resources (6) Quantifiable components of the systems such as organisms, populations, species, and communities.

Biometry (9) See *biostatistics*.

Biostatistics (9) Biostatistics in general focuses on statistical applications to biological and ecological data ("ecostsatistics" is not generally used). Many biostatics textbooks are written so as to not require mathematical education beyond elementary algebra, or are written in a "nonmathematical" manner.

Biotic community (1) The assemblage of species populations that occur together in space and time.

Capture–recapture (2, 7) Method used to estimate size and vital rates of ecological populations using the rates of capture and recaptures for unique individuals.

Case study (6, 3, 8) Case study is work that focuses on a specific location or species and is often short term in duration. There are situations in which a biological study was too localized or too brief in duration to warrant a full research article and can be focused as a case study.

Central limit theorem (2) Statistical theory which states that n random variables will assume a normal distribution as the number of variables collected goes to infinity.

Census (1) The process of obtaining information about every individual at a specific time and place.

Chronosequence (7) A way to examine time (short to long) effects of a disturbance or activity over a sequence of time without having to track a set of plots through time. Done by locating various plots representative of conditions at different times post-disturbance. By sampling enough areas you could draw inferences as to possible short- and long-term effects on wildlife.

Cluster sampling (4) Probabilistic sample in which sampling units are selected based on the distribution of organisms within the sampling frame.

Completely randomized design (3) The random application of two treatments to a group of experimental units.

Compliance monitoring (7) Done when mandated by law or statute to ensure that actions are in compliance with existing legal direction. An example of compliance is monitoring established within a biological opinion provided by the US Fish and Wildlife Service during interagency consultation under the Endangered Species Act.

Community metrics (7) Indices of quantitative values that are related to numbers, degree of association, diversity, and evenness of species.

Concomitant variable (3) See *covariate*.

Conceptual model (1, 3, 7) A theoretical construct that represents the system of interest; it includes a set of variables and logical qualitative and sometimes quantitative relationships among them.

Confidence intervals (3) When estimated with the data for an observed effect size, a CI represents the likely range of numbers that cannot be excluded as possible values of the true effect size if the study were repeated infinitely into the future with probability $1 - \alpha$.

Confounding variables (3) Random variables that are likely to influence the response variable in a manor typically out of the control of the biologist including landscape issues (e.g., large-scale habitat variables), biological issues (e.g., variable prey species abundance), land use issues (e.g., rapidly changing crops and pest control), weather, study area access, etc.

Control (controlling variable) (2, 3) A standard for comparison in ecological studies. Controls are typically experimental units on which no treatments have been assigned so that treatment effects can be evaluated on other experimental units. Control can also be achieved by standardization of related variables.

Covariate (3, 4) Random variable collected during the course of a research study which the researcher hypothesizes influences the response variable.

Cross-over design (3) The random assignment of two or more treatments to a study population during the first study period and then the treatments are switched during subsequent study periods so that all study units receive all treatments in sequence.

Deductive reasoning (1) The form of inference where the conclusion about particulars follows necessarily from general or universal premises.

Design/data-based studies (3) Studies where basic statistical inferences concerning the study areas or study populations are justified by the design of the study and data collected.

Detectability (2) A parameter that describes the probability that an individual organism will be detected (seen or captured) during some specific time or place.

Disturbing variables (2, 3) Extraneous variable that can bias the results of a study.

Dose-response regression (3, 6) Analysis in which dose is a measure of exposure to the impact and response is a measure of the biological system. See also *gradient design*.

Dynamic equilibrium (6) Incorporates both temporal and spatial variation, where natural factors and levels of resources usually differ between two or more areas being compared, but the differences between mean levels of the resource remain similar over time. Contrast with *steady-state system* and *spatial equilibrium*.

Effect size (3, 7) A measure of the difference among groups. From a statistical point of view, it is the difference between the null and alternative hypotheses.

Effectiveness monitoring (7) Used to evaluate whether or not a management action or decision met its stated objective.

Element (2) Basic unit on which some measurement is taken in ecological studies.

Empiricism (1) A theory that all knowledge originates in experience; discounts the notion of innate ideas.

Environmental impact studies (3) Field studies that look at the environmental response to unplanned perturbations, as opposed to manipulative experiments, although manipulative experiments and smaller observational studies aid understanding of the mechanism of impact.

Epidemiology (3, 6) The study of the occurrence of disease, injury, or death, usually in reference to human populations.

Epistemology (1) The branch of Western philosophy that studies the nature and scope of knowledge.

Estimator (2, 3, 4) A function of observed sample data that is used to estimate some unknown population parameter.

Ethics (1) The branch of Western philosophy dealing with values and norms of a person or group; addresses concepts such as right and wrong, good and evil, and moral responsibility. See *axiology*.

Experimental units (1, 3) The basic units, such as individual plots and organisms, upon which experimental data could be collected and which determine sample size.

Expert opinion (9) Expert opinion can be formalized into a process that seeks the council of many individuals with expertise in the area of interest. Contrast with *personal opinion*.

Expected value (2, 3) A mathematical expectation of a random variable that equals the sum (or integral) of the values that are possible for it, each multiplied by its probability.

Experimental design (3) The combination of a design structure, treatment structure, and the method of randomization included in an experiment.

Explanatory variable (2, 3) A variable that is used in a statistical relationship to explain or predict changes in the value of another variable.

Factorial experiments (3) Multiple-factor experiments where all possible combinations of factors of interest are tested and these tests are possibly replicated a number of times.

Finite (4) Bounded or limited in magnitude, spatial, or temporal extent.

Gradient design (3, 6) This class of designs analyze an impact along a continuous scale and use regression techniques to test for an association between level of impact and response by the animal. See also *dose-response regression and response gradient design*.

Gray literature (8) The graduate thesis or dissertation, a final report to an agency, in-house agency papers, and the like are not publications per se and are termed gray literature because they are usually not readily available, and they do not usually receive independent peer review.

Habitat (1, 3, 7) The physical space within which an organism lives, and the abiotic and biotic entities (e.g., resources) it uses and selects in that space. Because habitat is organism-specific, it relates the presence of a species, population, or individual (animal or plant) to an area's physical and biological characteristics.

Hypothesis (1, 3) See *research hypothesis*, *scientific hypothesis*, and *statistical hypothesis*.

Hypothetico-deductive model of science (1) The model of science popularized by Karl R. Popper that argues scientists should formulate one or more hypotheses to explain an observed phenomenon, then deductively derive a number of explicit predictions that should be observed as a consequence of each hypothesis. Observations contrary to those predictions lead the researcher to conclusively falsify the hypothesis which then should immediately be rejected. Observations in agreement with the deductive predictions only imply that the hypothesis is still viable.

Impact (3, 6) Impact is a general term used to describe any change that perturbs the current system,

whether it is planned or unplanned, human-induced, or an act of nature.

Impact assessment (1, 3) Studies designed to determine the influence of a change that perturbs the current state of a system of interest; these impacts can be planned or unplanned, human-induced, or acts of nature.

Impact-reference design (3, 6) The basic design mimics a classical experimental treatment and control design, where random samples are taken from sites within the disturbed area and from other nondisturbed reference sites.

Implementation monitoring (7) Used to assess whether a directed management activity has been carried out as designed.

Incomplete block design (3) An experiment that uses blocking of variance, although each block has less than a full complement of treatments.

Independent data (3) Data that are neither contiguous in time or space.

Index (2, 7) A numerical value used to compare values collected over time or between areas.

Indicator species (7) Index or represent specific environmental conditions or the population status of other ecologically similar species.

Inductive reasoning (1) The form of inference where a generalized conclusion is reached based on a collection of particular facts or instances.

Inventory (1, 3, 7) Studies designed to determine the distribution and composition of wildlife and/or wildlife habitats.

Knowledge (1) In philosophy, knowledge generally was defined as "justified true belief" from classical times (Plato) until the 1960s. Since then, philosophers have been unable to agree on a single definition for various reasons. In general, knowledge now can be considered society's accepted portrayal of a proposition under consideration. Thus, for the society of scientists, knowledge still remains justified true belief.

Latin square design (3) An extension of the randomized block design to control for multiple sources of variation.

Level-by-time interaction (6) The term "level" refers to the fact that specific categories (levels) of the impact are designated; used in a level-by-time design. Contrast with *trend-by-time interaction.*

Local extinction probability (1) The probability that a species currently present in a biotic community will not be present by the next time period.

Logical empiricism (1) See *logical positivism*; reflects the affinity of later members of this movement for the writings of Locke, Berkeley, and Hume.

Logical positivism (1) An early twentieth century philosophical movement that holds that all meaningful statements are either (1) analytic (e.g., mathematical equations) or (2) conclusively verifiable or at least confirmable by observation and experiment, and that all other statements are therefore cognitively meaningless.

Longitudinal studies (3) Repeated measures experiment common in wildlife telemetry studies, environmental impact studies, habitat use and selection studies, studies of blood chemistry, and many other forms of wildlife research, where logistics typically leads to repeated measures of data from study plots or study organisms.

Long-term study (5, 3, 7) A study that continues "…for as long as the generation time of the dominant organism or long enough to include examples of the important processes that structure the ecosystem under study... the length of study is measured against the dynamic speed of the system being studied" (Strayer et al. 1986).

Levels (6) Levels are measures of a resource such as abundance, diversity, community structure, and reproductive rates. Hence, levels are quantifiable on an objective scale and can be used to estimate means and variance and to test hypotheses.

Magnitude of anticipated effect (3) The magnitude of the perturbation or the importance of the effect to the biology of the species, which often determines the level of concern and the required level of precision.

Manipulative studies (3) Studies that include control of the experimental conditions; there are always two or

more treatments with different experimental units receiving different treatments and random application of treatments.

Matched pair design (3, 6) This design reduces the confounding of factors across sites. Under this design, sites within the impacted area are randomly selected and nonrandomly matched with similar reference sites.

Mechanism (2) A physical or chemical process involving how a natural phenomenon works.

Mensurative studies (3) Studies involving making measurements of uncontrolled events at one or more points in space or time with space and time being the only experimental variable or treatment.

Meta-analysis (3) Analysis of a series of independent studies addressing a specific research question.

Metaphysics (1) The branch of Western philosophy concerned with explaining the system of principles underlying a particular subject or discipline. Recently, in common parlance, the term often refers to topics beyond the physical world.

Metapopulation (1) A population subdivided into segments occupying patches of habitat in a fragmented landscape. Individual patches are separated by an environment hostile to the species of interest, and movement and presumably gene flow between patches is inhibited, but still exists.

Model-based studies (3) Studies that predict the outcome of experiments using models. In the extreme case of model-based analysis where no new data are available, all inferences are justified by assumption, are deductive, and are subject to counterarguments.

Monitoring (1, 3, 7) Studies designed to determine rates of change or the influence of management practices on wildlife population dynamics and/or habitats.

Multiple-factor designs (3) Experiments when one or more classes of treatments are combined with one or more classifications of experimental units.

Multivariate analysis (3) Analysis that considers several related random variables simultaneously, each one

being considered equally important at the start of the analysis.

Natural factors (6) Physical and chemical features of the environment that affect the level of a resource at a given time and location, such as temperature, substrate, dissolved oxygen, and total organic carbon.

Nested experimental design (3) A design that uses replication of experimental units in at least two levels of a hierarchy.

Nonresponse error (5) Occurs when one fails to record or observe an individual or unit that is part of the selected sample.

Normal science (1) A term employed by Thomas S. Kuhn that characterizes periods where there is general consensus within a scientific community regarding theory, methods, terminology, and types of experiments likely to contribute useful insights – the articulation of a paradigm.

Nuisance parameters (3, 4) A parameter estimated by a statistic, which is not needed except for the calculation of the parameter of interest.

Number of colonizing species (1) The number of species currently in the community that were absent during the last time period.

Observer drift (8) Part of *quality assurance*, observer drift refers to the gradual change in the way observers collect data through time and can affect all studies regardless of the precautions taken during observer selection and training.

Observational studies (3, 4) See *mensurative studies*. Studies that have no specific sampling design, and the researcher has little or no control over how observations on the population were obtained.

One-factor experiment (3) An experiment that uses one type of treatment or one classification factor in the experimental units in the study, such as all the animals in a specific area or all trees of the same species in a management unit.

Ontology (1) The branch of metaphysics (see above) that studies the nature of reality, being, or existence.

Optimal study design (6) If you know what type of impact will occur, when and where it will occur, and have the ability to gather pretreatment data, you are in an optimal situation to design the study. Contrast with *suboptimal study design*.

Overdispersion (3, 4) A statistical occurrence when the observed variance of the data is larger than the predicted variance. Fairly common in analysis using Poisson and Binomial regression techniques.

Paired study design (3) A study that typically evaluates changes in study units paired for similarity.

***P*-value (2, 3)** Probability of obtaining a test statistic at least as extreme at the observed conditional on the null hypothesis being true.

Personal opinion (9) Personal opinion implies a decision based on personal biases and experiences. Contrast with *expert opinion*.

Panmictic populations (1) Populations where interactions between individuals, including potential mating opportunities, are relatively continuous throughout the space occupied by the population.

Paradigm (1, 3) A term employed by Thomas S. Kuhn that characterizes a scientific tradition, including its philosophy, theory, experiments, methods, publications, and applications. Paradigms govern what he called normal science (see above). The term also has come to describe a given world-view in common parlance.

Parameter (2, 3) Quantities that define certain characteristics of an ecological system or population.

Pilot study (1, 2, 5, 8) A pilot study is a full-scale dress rehearsal of the study plan and includes data collection, data processing, and data analyses, thus allowing thorough evaluation of all aspects of the study including initial sample size and power analyses. A pilot study is often done with a much larger sample than a *pretest period*. Such studies are especially useful when initiating longer-term studies.

Population (1, 3) See *biological population*, *sampled population*, and *target population*.

Postmodernism (1) It is a truism that postmodernism is indefinable. It can be described as a cultural zeitgeist of

crisis, desperation, anxiety, schizophrenia, nostalgia, pastiche, apocalyptic millennialism, and lassitude. The quintessential postmodern utterance is "Whatever?." The more radical social constructionists (see below) often are called postmodernists.

Postpositivism (1) The stance, based on the writings of Karl R. Popper and others, that human knowledge is not based on unchallengeable empirical foundations as argued by the logical positivists (see above), but is to some degree conjectural. Further, while we do have warrants for asserting beliefs and conjectures, based on the hypothetico-deductive model of science, they can be modified or withdrawn based on further investigation.

Pragmatism (1) An American movement in philosophy founded by Charles Saunders Peirce and popularized by William James and others that is marked by the tenets that (1) the meaning of concepts should be sought in their practical bearings, (2) the function of thought is to guide action, and (3) truth is preeminently to be tested by the practical consequences of belief.

Precision (2, 3) Degree of mutual agreement between individual measurement or the amount of variation between sample estimates arising from the sample sampling process. See also *bias*, *accuracy*.

Press disturbance (6) Press disturbances are those that are sustained beyond the initial disturbance. Contrast with *pulse disturbance*; see also *temporal variance, disturbances affecting*.

Pretesting period (8) Initial field sampling should include tests of data collection procedures; this is often called the pretesting period. Pretesting allows for redesign of data forms and sampling protocols. Pretesting sampling should cover as much of the range of conditions that will be encountered during the study. Some, but seldom all, of the data collected during pretesting might be suitable for inclusion with the final data set. Contrast with *pilot study*.

Preventable fraction (6) The proportion of deaths removed by a preventive step is termed the preventable fraction and is defined as the proportion of injuries or deaths that would be removed if all birds were able to take advantage of the preventive intervention. See also *prevented fraction*.

Prevented fraction (6) Is the actual reduction in mortality that occurred because of the preventive intervention. See also *preventable fraction*.

Preventive intervention (6) Steps taken to prevent an impact (injury or death); used in the context of epidemiological studies. See also *preventable fraction* and *prevented fraction*.

Process variation (2) Variation in population growth irrespective of the methods used to determine population parameters. See also *sampling variation.*

Proportional mortality (6) The proportion of the animals killed.

Pulse disturbance (6) Pulse disturbances are those that are not sustained after the initial disturbance; the effects of the disturbance may be long lasting. Contrast with *press disturbance*; see also *temporal variance, disturbances affecting*.

Quality assurance (5, 8) The purpose of quality assurance (also called quality assurance/quality control, or QA/QC) is to ensure that the execution of the plan is in accordance with the study design. As such it is a process to produce reliable research data with respect to its precision, completeness, comparability, and accuracy. It is important to the successful completion of the study that a formal program of QA/QC is instituted on both the data collection and data processing components.

Quality control (5) The routine application of procedures (such as calibration or maintenance of instruments) to reduce random and systematic errors, and to ensure that data are generated, analyzed, interpreted, synthesized, communicated, and used within acceptable limits.

Quasi-experiments (3) Observational studies where strict adherence to Fisher's requirements for the design of true experiments is impossible or impractical, although adherence to fundamental statistical principles as much as possible is essential and conclusions concerning cause-and-effect relationships are limited.

Randomization (2, 3) The process of selecting a random sample of an ecological population on which to perform a treatment or to take observations.

Randomization tests (3) Computer intensive tests that, for example, involve the repeated sampling of a randomization distribution (say 5,000 times) to determine if a sample statistic is significant at a certain level.

Randomized complete block design (3) An experiment where blocking of variance is used and each treatment is randomly assigned within each block.

Rationalism (1) A theory that reason is in itself a source of knowledge superior to and independent of sense perceptions.

Recovered (6) When natural factors have regained their influence over the biological resource(s) being assessed. See also *recovery*.

Recovery (6) A temporal process in which impacts progressively lessen through natural processes and/or active restoration efforts. See also *recovered*.

Repeated measure designs (3) Experiments where several comparable measurements are taken on each experimental unit.

Replication (2, 3) The process of repeating a study multiple times under similar conditions to confirm findings.

Research hypothesis (1) A tentative explanation for how some process in a system of interest works; a proposed explanation for an observed phenomenon in a given system. Also see *scientific hypothesis* and *statistical hypothesis*.

Response-gradient design (3) Study design useful for quantifying treatment effects when a response is expected to vary relative to the distance or time

from the application of the treatment (gradient of response).

Retroductive reasoning (1) The form of inference proposed by Charles Saunders Peirce where a hypothesis is developed, which would, if true, best explain a particular set of observations.

Retrospective power analysis (3) A power analysis that is conducted after the study is completed, the data have been collected and analyzed, and the outcome is known.

Retrospective study (3) An observational study that looks backwards in time.

Revolutionary science (1) See *scientific revolution*.

Sample (1, 3, 4) A subset of a population randomly selected based on some probabilistic scheme on which measurements regarding the population of interest will be made.

Sampling distribution (2, 3) The frequency distribution of a statistic obtained from a large number of random samples drawn from a specific ecological population.

Sampling bias (3, 5) A systematic bias where a parameter is consistently under- or overestimated.

Sampling intensity (3, 5) Refers to how many, how long, and how often units should be sampled.

Sampled population (1, 3) The subset of the target population that is accessible to sampling.

Sample size (3, 4) Number of samples that must be taken to meet some a priori specified level of precision in the resulting parameter estimates.

Sampling variation (2) Variation that is contributed to the methods used to determine population parameters. See also *process variation*.

Sampling units (1, 3, 4) A unique collection of elements (e.g., plots or organism) on which sample data are collected. See also *element*.

Scientific hypothesis (1, 3) A universal proposition explaining an observed phenomenon. For example, the hypothesis of density-dependent population regulation in ecology. Also see *research hypothesis* and *statistical hypothesis*.

Scientific revolution (1) A term employed by Thomas S. Kuhn that refers to an interruption in normal science (see above), where a shift in paradigm (see above) occurs. Darwin's

work, for example, led to a scientific revolution in zoology–ecology (e.g., Linnaean vs. Darwinian paradigms).

Sequential study designs (3) Unique study designs in which the sample size is not fixed before the study begins and there are now three potential statistical inferences, namely accept, reject, or uncertainty (more data are needed).

Similar (6) In the context of replicated study sites, concerns matching the basic environmental conditions of sites.

Simple random sampling (2, 3) A basic sampling technique where we select a group of subjects (a sample) for study from a larger group (a population). Each individual is chosen entirely by chance and each member of the population has an equal chance of being included in the sample.

Size bias (4) The propensity for organisms of a larger size or grouped together to be detected and sampled at a higher rate than organisms of a smaller size or group.

Social constructionism (1) A theory based on the work of Hegel and others that holds knowledge ultimately is at least in part created through the combined perceptions of society.

Spatial equilibrium (6) Occurs when 2 or more sampling areas, such as impact and reference, have similar natural factors and, thus, similar levels of a resource. Contrast with *steady-state system* and *dynamic equilibrium*.

Species diversity (1, 7) Indices of community diversity that take into account both species richness and the relative abundance of species.

Species richness (1, 7) The number of species in the biotic community at a given time.

Split-plot designs (3) A form of nested factorial design where the study area is divided into blocks that are then divided into relatively large plots called main plots, which are then subdivided into smaller plots called split plots, resulting in an incomplete block treatment structure.

Stage-based matrices (6) Used to analyze population growth for species in which it is difficult to age indi-

viduals, or where it is more appropriate to classify them into life stages or size classes rather than by age.

Statistics (2, 3) Mathematical procedure used to measure attributes of a population based on data collected from a sample of that population.

Statistical hypothesis (1, 3) A deductively derived prediction, based on the research hypothesis, of a specific result that can be tested against data using a statistical algorithm. Also see *scientific hypothesis* and *research hypothesis*.

Statistical power (3, 7) The probability that you will reject a null hypothesis when it is false, i.e., the experiment has a small probability of making a Type II error.

Steady-state system (6) Typified by levels of resources, and the natural factors controlling them, show a constant mean through time. Contrast with *dynamic system* and *spatial equilibrium*.

Strata (3, 4) Division in an organized system based on the characteristics of that system.

Stratified sampling (4, 3) A sampling method used to divide a population into homogenous subgroups or blocks of experimental units that are then sampled individually. See also *strata*.

Stressors (7) Natural and anthropogenic events that affect resource distribution or abundance.

Suboptimal study design (6) When no or little pretreatment data are available and the treatment (impact) has not or can not be replicated. Contrast with *optimal study design*.

Syllogism (1) A deductive formal argument where a major and minor premise necessitates a conclusion (e.g., all animals are mortal, northern bobwhites are animals, therefore bobwhites are mortal). See *deductive reasoning*.

Systematic sampling (3, 4) A sampling method in which samples are collected from a population systematically, or by selecting 1 unit of every 10 in order from a random starting point.

Target population (1, 2, 3) A clear and precise definition of the spatial and temporal aspects of the study area as well as a detailed description of the resource on which information is wanted.

Time of interest (3) The period of interest for statistical and deductive inferences will be made, e.g., diurnal, nocturnal, seasonal, or annual.

Take monitoring (7) Assesses whether an activity adversely affects the occupancy or habitat of a threatened or endangered species.

Temporal variance, disturbances affecting (6) Disturbances affecting temporal variance are those that do not alter the mean abundance, but change the magnitude of the oscillations between sampling periods. See also *press disturbance* and *pulse disturbance*.

Theory (1) There are two distinct uses of "theory" in natural science:
a. A proposed description, explanation, or model capable of predicting future occurrences of the same type that can potentially be evaluated empirically.
b. An integrated and hierarchical set of empirical hypotheses that together explain a significant portion of scientific observations. Most ecologists would argue that (1) the theory of evolution through natural selection and (2) *perhaps* the theory of island biogeography are the only theories of ecology under this definition.

Thresholds/trigger points (7) Pre-determined levels of a response variable that when exceeded will lead to an action or correction.

Time-series design (3, 6) In this design it is expected that the response of the animals to the disturbance will decrease over time; the animals are sampled at the same sites over time.

Treatment (2, 3) Any method, technique, or process that is designed to change the way a physical process works.

Trend (2, 7) A change in the trajectory of an ecological population over time.

Trend-by-time interaction (6) Here, continuous variables are used (rather than distinct levels) to compare trends between measures of the resource and levels of change (or impact) over time; used in trend-by-time interaction design. Contrast with *level-by-time interaction*.

Type I error (2, 3) Error that occurs by rejecting the null hypothesis when it is true. See also *Type II error*.

Type II error (2, 3) Error that occurs by accepting a null hypothesis when the alternative hypothesis is true. See also *Type I error*.

Unequal probability (3, 4) A sampling procedure wherein samples are selected based on probabilities that are tied to the characteristics of the organisms' size or location. See also *simple random sampling*.

Unpaired study design (3) A study design that estimates the effect of a treatment by examining the difference in the population mean for a selected parameter in a treated and control population.

Validation monitoring (7) Used to evaluate whether established management direction (e.g., National Forest Plans) provides guidance to meet its stated objectives.