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Cover photos. Monitoring wildlife, rare plants, and their habitats is conveyed through three photos: (1) *Peromyscus maniculatus*, on Pesola scale (photo credit: Dean E. Pearson); (2) western prairie fringed orchid (*Platanthera praeclara*) (photo credit: Carolyn Hull Sieg); and (3) measuring a ponderosa pine (*Pinus ponderosa*) log in Idaho (photo credit: Victoria A. Saab).

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Chapter 1. Overview

1.0 Overview and Purpose

The purpose of this technical guide (hereafter referred to as the Species Protocol Technical Guide) is to provide guidelines for developing **inventory**[1] and monitoring (I&M) protocols for wildlife, fish, and rare plants (WFRP) using the U.S. Department of Agriculture (USDA) Forest Service technical guide format. In particular, this publication will accomplish the following:

- Facilitate the development of WFRP I&M protocols for species and groups of species at national and regional levels.
- Provide expectations for presenting the protocols in Forest Service technical guide format.
- Provide technical information on sampling designs, measure selection, and analysis tools that will aid in designing specific I&M protocols.

Chapters 1 and 2 use the Forest Service technical guide format to describe the expected content of WFRP inventory or monitoring technical guides (see the box entitled Suggested Outline for WFRP I&M Protocols). Chapter 3 provides additional supporting material relevant to the design of I&M projects and describes various data analysis approaches to give protocol developers a starting point for their own literature reviews for designing I&M protocols. The information in chapter 3 is also intended to provide a basis for early consultations with statisticians familiar with the design of biological investigations and subsequent analysis of data. We urge all protocol developers to enlist the assistance of such statisticians early in the process and to keep them involved throughout the process. This publication is not intended to be a comprehensive guide to these topics. Numerous other resources exist to serve those roles (e.g., Nielsen and Johnson 1983, Bibby et al. 1992, Heyer et al. 1994, Wilson et al. 1996, Elzinga et al. 2001, Thompson et al. 1998).

Suggested Outline for WFRP I&M Protocols

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[1] Terms indicated in **bold typeface** are defined in the glossary in appendix B.

The major headings of chapters 1 and 2 provide the format for subsequent WFRP I&M technical guides and are mandatory for development of any Forest Service I&M technical guide. Some major headings include recommended subheadings. As we present each subheading, we describe why it is recommended and give suggestions for content. For example, the Planning and Design section addresses the importance of clearly articulating the inventory or monitoring questions and gives examples of the types of questions likely to be addressed in subsequent protocols. It is intended that Forest Service sponsored teams will use this guide for preparing inventory and/or monitoring plans at national, regional, and local scales for species and their habitats.

1.1 Background and Business Needs

This section of each WFRP I&M technical guide will provide the ecological and/or social history that created an interest or need to conduct an inventory or to develop a monitoring program for the subject species or species group. This section should begin with a description of the species or species group targeted by the technical guide, including scientific names and, if appropriate, subspecies names. If the technical guide is for a species group, this section will identify each of the species in the group and provide a rationale for treating the group as an assemblage. It should include brief information about the known or suspected impacts from management actions, the current legal or conservation status (Federal, State, and Forest Service), and the history of petitions to list the species under the Federal Endangered Species Act (ESA) or other actions. More specifics about the effects of management actions should be included in section 2.2.1., Species Life History and Conceptual Model.

As an example of a background section, we present the background for the Species Protocol Technical Guide as follows. The Forest Service, through the Ecosystem Management Coordination staff, has undertaken a multiyear effort to improve the consistency of inventory and monitoring throughout the agency. All resource areas have participated in this effort. The tasks for improving I&M are outlined in the National Inventory and Monitoring Action Plan (Inventory and Monitoring Issue Team 2000). Task 8 of the action plan is to "ensure [that] scientifically credible **sampling,** data collection, and analysis protocols are used in all inventory and monitoring activities" (Inventory and Monitoring Issue Team 2000). To achieve this task, various resource areas within the Forest Service are establishing protocols for how data are to be collected, stored, analyzed, and reported. Protocols with national or regional application will generally be written as technical guides within the Forest Service directives system.

To inventory and **monitor** the diverse WFRP resources found in national forests and grasslands, many protocols will need to be developed. As a result, several technical guides will be prepared. Each guide will be designed for a species or a group of similar species. National protocols will be developed for species that occur across several administrative regions. In most cases, however, protocols will be developed by or at the request of Forest Service administrative regions to meet needs unique to each region. In some situations, protocols may be developed for use in a single forest or adjacent forests.

"Business needs" are the motivating reasons for undertaking an activity. Many WFRP I&M activities are prompted by existing laws and policies (table 1.1). For example, if the I&M technical guide is for a federally listed species under the ESA, the Business Needs section should provide the ecological and/or social reasons explaining why the species is federally listed and should reference the recovery plan for that species. In addition to addressing legal business requirements, the Business Needs section might address a variety of other business needs that require inventory or monitoring information, such as whether the distribution of the species is well established, a current petition to list the species under the ESA exists or is expected, an interagency agreement to monitor the species is in place, or the public has expressed high interest in the status of the species.

In the case of this Species Protocol Technical Guide, the Forest Service identified a need for guidelines to help develop I&M technical guides similar in format, content, and level of detail. Also, the Forest Service recognized the need for specific information on setting objectives, choosing a sampling design, and conducting data analysis so I&M protocol development teams would meet standards required under the Data Quality Act. This Species Protocol Technical Guide was created to meet these needs.

1.2 Key Concepts

The introductory chapter of each I&M technical guide will include a section describing the key concepts related to I&M of the targeted species or species group. For example, if a species is migratory and if monitoring will occur only during the breeding season, a key concept is the limited nature of the data, because it provides information on population status only during the breeding season. Other key concepts might relate to specific aspects of the species' life history that affect the inventory or monitoring design, such as colonial nesting, the use of leks, or territoriality.

A key concept of this Species Protocol Technical Guide is the term "protocol," which is often used to refer to standards for collecting field data. The Forest Service Inventory and Monitoring Issue Team has recommended a broader interpretation of the term *protocol* to include all aspects of an inventory or a monitoring plan: the sampling design, data collection methods, data analysis methods, and reporting structure. We have followed this recommendation and have included these topics in our descriptions of inventory and monitoring protocols in the following chapters.

Table 1.1. *Forest Service inventory and monitoring business needs pertaining to wildlife, fish, and rare plants.*

Business need	Target group	Type of information needed	Analysis scale	Type of report
To provide information on MIS for forest planning (NFMA 1982 reg. & Dept. reg. 9500-004)	MIS (may be any taxa)	Population trends in relation to habitat	The planning area: usually national forest or multi-forest/ grassland	Forest plan; annual monitoring and evaluation reports
To provide information for Forest Plan revision	Any species, as needed	Data and information needs to be identified through scoping	The planning area	Forest plan and associated EIS
To aid in the recovery of species listed under the ESA	Federal threatened or endangered species	Population trends, habitat trends, trends in affecters/stressors	Species range or a significant portion of their range	Annual reports of recovery plans or in biological opinions
To avoid Federal listing of plant and animal species (FSM 2670)	Plant and animal species designated as Sensitive by the Forest Service	Distribution, status, and trend of species and their habitats	Not specified	Conservation agreements and progress reports
To aid in the conservation of birds protected by the MBTA	All bird species protected by the MBTA	Not specified; information, as needed, to be shared with other agencies	Not specified	MOUs with USF&WS and associated progress reports
To provide information for the environmental analysis of proposed projects (NEPA)	Primarily TES and MIS species, but may be species without formal status	Availability of suitable habitat and species' presence in project area and larger landscape context	Usually the project area and larger landscape context	Project EA and post-activity monitoring reports as specified in EA
To gather subsistence harvest data, in compliance with the Alaska National Interest Lands Conservation Act	Species harvested for subsistence uses	Population trends	Subsistence harvest units in Alaska	Regulations for subsistence harvest
To work cooperatively with States in the conservation of selected species	Any species identified for conservation through a MOU between a State and the Forest Service	Information specified in the MOU; States usually collect population data and the Forest Service usually collects habitat data	A State or the range of a species within a State	Progress reports as specified by the MOU

EA = environmental assessment.
EIS = environmental impact statement.
ESA = Endangered Species Act.
FSM = Forest Service Manual.
GPRA = Government Performance Review Act.
MBTA = Migratory Bird Treaty Act.
MIS = management indicator species.
MOU = memorandum of understanding.
NEPA = National Environmental Policy Act.
NFMA = National Forest Management Act.
TES = threatened, endangered, and sensitive species.
USF&WS = U.S. Fish & Wildlife Service.

1.3 Roles and Responsibilities

Each WFRP I&M technical guide will contain a section on each administrative level's roles and responsibilities in carrying out the specific inventory or monitoring plan. The following lists of roles and responsibilities apply to all aspects of WFRP I&M protocol development and implementation.

1.3.1 National Responsibilities

- Develop a Species Protocol Technical Guide and provide a review of the guide at 5-year intervals to ensure it contains timely and relevant information.
- Develop I&M protocols for species and species groups with inventory and/or monitoring needs that are shared by two or more regions and that require consistency in the regions' inventory and/or monitoring approaches.
- Provide criteria for administrative regions to evaluate existing protocols' comprehensiveness and capability of meeting Forest Service I&M protocol requirements.
- Facilitate information sharing and collaboration across administrative regions, with other Federal and State agencies, and with Forest Service Research and Development efforts to avoid development of duplicate protocols.
- Provide adequate funding for protocol development at regional levels and for collaboration with other agencies.
- Obtain technical and administrative review of protocols developed at a national level. Provide timely technical and administrative review of protocols developed for multiregional use.

1.3.2 Regional Responsibilities

- Ensure the use of the Species Protocol Technical Guide during the development of inventory and/or monitoring technical guides at regional and local scales.
- Develop technical guides for species and species groups with inventory and monitoring needs shared by several forests and grasslands.
- Use nationally developed criteria to evaluate existing protocols' comprehensiveness and capability of meeting Forest Service I&M protocol requirements.
- Facilitate information sharing and collaboration within the region, with adjacent regions, with other Federal and State agencies, and with Forest Service Research and Development efforts to avoid the development of duplicate protocols for the same species.
- Include protocol development in regional I&M program plans.
- Obtain technical and administrative review of protocols developed by the region.
- Provide timely technical and administrative review of protocols developed for use within the region.

1.3.3 Forest and Grassland Responsibilities

- Obtain a list of protocols applicable to species on the forest or grassland with inventory and/or monitoring needs.
- Participate in regional or bioregional monitoring efforts as described in applicable protocols.
- Ensure the use of established protocols for I&M of species occurring on the forest or grassland.
- Develop protocols for species and species groups with I&M needs that are local in nature and for which regional or national protocols are not available.
- Use nationally developed criteria to evaluate existing local protocols' comprehensiveness and capability of meeting Forest Service I&M protocol requirements.
- Use the Species Protocol Technical Guide during the development of I&M protocols at the local scale.
- Facilitate sharing of information with adjacent forests/grasslands and regions to avoid developing duplicate protocols.
- Obtain technical and administrative review of locally developed protocols.

1.4 Relationship to Other Federal Inventory and Monitoring Programs

Each WFRP I&M technical guide should explain how the technical guide fits in with other Federal I&M programs developed by the Forest Service and other Federal agencies. For example, an I&M technical guide for a bird species should describe how the monitoring program complements existing Forest Service regional land bird monitoring programs. Such a guide also should explain the monitoring protocol's relationship to the U.S. Geological Survey (USGS) Breeding Bird Survey program.

WFRP I&M technical guides should also describe the relationship between the protocol and the Forest Service Natural Resource Information System (NRIS). The NRIS is a set of corporate databases and computer applications designed to fulfill many of field-level users' information needs (NRIS 2005). NRIS databases contain basic natural resource data in standard formats designed for application within the Forest Service computing environment. This unified system is organized into seven NRIS modules; six focus on different resource information areas and one develops applications and analysis tools for the other six modules. It is anticipated that WFRP inventory or monitoring efforts will be entered into the NRIS FAUNA Module as basic **survey** data and as basic observation data.

The remainder of this section describes the relationship of this Species Protocol Technical Guide to other Federal I&M programs.

1.4.1 Forest Service Programs

The Forest Service has been developing several other I&M technical guides concurrently with this technical guide: Terrestrial Ecological Unit Inventory (Winthers et al. 2005), Aquatic Ecological Unit Inventory, Existing Vegetation Classification and Mapping (Brohman and Bryant 2005), Multiple Species Inventory and Monitoring (Manley et al., in press), Northern Goshawk Inventory and Monitoring (Woodbridge and Hargis, in press), and Social and Economic Profiles. We anticipate that WFRP I&M technical guides could use the Terrestrial Ecological Unit Inventory, the Aquatic Ecological Unit Inventory, and the Existing Vegetation Classification and Mapping protocols to classify and map habitat. We also anticipate a relationship between monitoring designs targeted for individual species and the monitoring design described in the Multiple Species Inventory and Monitoring Technical Guide.

1.4.2 Programs in Other Federal Agencies

The Species Protocol Technical Guide does not currently have an equivalent in other Federal agencies. Several agencies, however, have developed I&M Web sites that contain information about protocol development. Comprehensive Web sites are maintained by the National Park Service (DOI NPS 2005) and the USGS Patuxent Wildlife Research Center (USGS PWRC 2005). In Canada, the British Columbia Ministry of Sustainable Resource Management has published a Species Inventory Fundamentals guide that contains information that is similar to the content of this technical guide (Ministry of Environment, Lands and Parks 1998). The Web sites that describe these efforts may be located through a search engine.

1.5 Quality Control and Assurance

This section should briefly describe processes that have been used to ensure the technical guide meets Data Quality Act standards. It does not need to describe quality control and assurance for specific field protocols; this topic is addressed under each specific I&M chapter. Instead, this section should describe the technical guide peer review process, list the credentials of those who prepared the technical guide, and reference the use of peer-reviewed protocols that served as the basis for the specific I&M protocols described in subsequent chapters.

To ensure the quality of every WFRP I&M technical guide, all aspects of each inventory or monitoring strategy (including setting the objective, selecting population and habitat measures, selecting a sampling design, and selecting analytical tools) should be done in consultation with a statistician as well as those experts who are knowledgeable about the targeted species or species group. The draft strategy should then be reviewed by statisticians and other experts on the organism's biology. The design must be statistically sound and biologically meaningful. External review of the design can help identify sampling design features that may limit usefulness of the data in the monitoring program's analytical phase. It is much better to be thorough when developing the design phase and minimize the risk of making errors at that point than to find out after a year or more of data collection that the results are biased, not independent, or are too variable to make inferences.

Biologists, research scientists, and statisticians involved in developing a specific inventory or monitoring strategy will be listed in section 2.6 of the chapter in which the strategy is presented. If the list of preparers is the same for all chapters, the list will follow the title page of the technical guide. Reviewers will be acknowledged on an introductory page before the Contents page.

The quality control and assurance for the Species Protocol Technical Guide is as follows. The concepts for this technical guide were developed by a Forest Service team consisting of wildlife ecologists at the national and regional levels with assistance from Forest Service research scientists. A Request for Proposal to develop this technical guide was advertised in November 2002. After reviewing potential developers' credentials, the Forest Service selected Pacific Wildlife Research, Inc., a consulting firm with expertise in ecological principles and biostatistics, to develop this technical guide in cooperation with Forest Service personnel. Credentials of the Pacific Wildlife Research, Inc., staff and associates are posted on the company's Web site.

The content of this technical guide is based on more than 150 published references from ecological, statistical, and biometric literature and on the authors' expertise. The draft technical guide was internally reviewed by the initial team of Forest Service wildlife ecologists and research scientists who developed the concept and outline. Two Forest Service research statisticians then reviewed the draft to ensure statistical concepts were accurately portrayed.

1.6 Change Management

This section describes how the technical guide will be kept current and what circumstances will trigger the decision to update the document. The potential for regional supplementation of the technical guide, if appropriate, also would be addressed here.

Anticipated actions that may require changes in an I&M technical guide include the publication of a new Federal regulation to guide planning on national forests and grasslands; the regulation will likely change monitoring requirements in support of forest planning. Roles and responsibilities for protocol development may also change as WFRP I&M technical guides are completed and implemented. Aspects of data collection, storage, analysis, and reporting may need to be updated to accommodate changes in technology or new information. Each WFRP I&M protocol will describe anticipated changes in protocols and provide a timeframe for incorporating these changes. At a minimum, each WFRP I&M technical guide should state that it is a draft until the protocols have been field tested for at least one season. The Change Management section should state approximately when field tests are planned and when final publication of the technical guide is expected. The Change Management section might also describe monitoring techniques, vegetation mapping, or analytical tools that are under development and that could require subsequent changes to the protocol.

Change management for the Species Protocol Technical Guide is as follows: Because this technical guide provides guidelines for developing subsequent WFRP I&M technical guides, the general format is not expected to change for many years. New developments in biostatistics and new tools for I&M, however, would trigger the need to update the technical guide. For example, this technical guide mentions genetics as a tool for determining species distribution and estimating minimum population size. Because the use of genetics is advancing rapidly, future guide revisions would certainly include recent applications of genetic data to I&M. This technical guide will be reviewed 5 years after publication by Forest Service wildlife ecologists and research scientists; their recommendations for changes will be incorporated in an updated revision.

Chapter 2. Specific Inventory and Monitoring Strategies

Each WFRP I&M technical guide will likely contain two or more chapters following the introductory chapter. Each chapter will address a specific inventory or monitoring objective for the species or species group. The title of each subsequent chapter will be the title of the specific objective. Suggested chapters are:

- Chapter 2. Bioregional or Other Broad-Scale Monitoring Objective
- Chapter 3. Forest or Multiforest Monitoring Objective
- Chapter 4. Protocols for Project Surveys

The subheadings of each chapter will be Objective, Planning and Design, Data Collection, Data Storage, Data Analysis, and Reporting. Using this format, we describe the expected content of each section.

2.0 Objective

This section should contain a clear, concise statement of the current chapter's specific inventory or monitoring objective. Here are some examples of objectives:

- To conduct a single or multiple species inventory of a specific area.
- To estimate the distribution of a species in a specific area.
- To monitor the status and trend of a species in a specific area.
- To monitor the effects of management activities on a species in a specific area.

The objective section should also include the following:

- The desired levels of **precision.** What confidence level is desired or necessary to provide managers with useful information?
- The desired (or anticipated) power to detect change (if the objective is monitoring). How much sensitivity to change is necessary to determine whether a modification of management practices is appropriate?
- The estimated level of change (**trigger point**) that would result in management modifications.
- The **scope of inference.** The **spatial** and **temporal scales** over which the inventory or monitoring results are to be applied should be identified. In most cases, the spatial scope of inference is the area from which a random sample of the selected population and habitat attributes was taken. The temporal scope of inference may be affected by anticipated rates of change in human influences (e.g., urbanization), habitat (e.g., succession), or climate (e.g., drought periodicity) and may affect the period of time over which the monitoring or inventory occurs.

Detail and focus are crucial to a well-designed inventory or monitoring protocol. The use of vague or unclear terms, broad questions, or unclear spatial and temporal extents will increase the risk that the data collected will not adequately address the key questions at meaningful scales. Furthermore, clearly articulated questions ensure that data collected are adequate to address specific key knowledge gaps or assumptions. In addition, clearly articulated questions provide the basis for identifying response thresholds, or trigger points, that indicate management actions that need to be changed.

2.1 Planning and Design

2.1.1 Species' Life History and Conceptual Model

This section should highlight aspects of life history that influence the choice of inventory and monitoring approaches. The life history description should contain sufficient details to support the conceptual model.

Relevant material might include the following items:

- Description. Diagnostic characteristics and behaviors of the species or species group and variation in these characteristics among subpopulations.
- Distribution. The species' geographic range and altitudinal limits; local boundaries (if known) of population distribution within the I&M protocol's geographic scope.
- Habitat. Habitats and environmental conditions with which the species is most closely associated, including fine-scale **habitat elements** (e.g., cobble-type stream substrates, large-diameter conifer trees) required by the species for reproduction or other life requisites.
- Reproduction and ontogeny. Mating strategy, growth patterns (in plants), reproductive and rearing behavior (in animals), differences among life stages or age classes, life span (in animals).
- Phenology (in plants) or activity patterns (in animals). Aspects of natural history that influence the organism's temporal and spatial patterns.
- Intra- or inter-specific relationships. Territoriality, colonial behavior, lek behavior, avoidance of or co-occurrence with other species.
- **Stressors.** Known or suspected factors that affect population status, both those external to Forest Service control and those believed to relate to Forest Service management.

A conceptual model represents a hypothesis regarding the expected response of a species or species group to changes in environmental conditions and/or management. It can help I&M strategy developers identify the states and processes in which we have the least confidence and that may be most directly affected by management activities. A conceptual model predicts *how* a species might respond to a specific activity. Thus, the model suggests ecological **elements** to monitor.

Links between stressors and biotic responses may be indirect; the conceptual model can be a valuable tool to show these pathways (Noon et al. 1999). For example, a management activity could reduce the competitive advantage of a target species relative to another species, which, in turn, could reduce the targeted species' reproductive output. In this case, the conceptual model would suggest monitoring the target species' reproductive output and the competitor's presence or relative abundance.

A conceptual model is integral to a monitoring design. The model can also be useful for developing an inventory strategy. Models of wildlife and plant habitat relationships can help focus on the location where and the time period when a targeted species is likely to occur, and can provide rationale for sampling areas where occupancy is likely but currently unknown.

No inventory or monitoring program will have all the information needed to completely develop a conceptual model for the system under consideration. Available information will have to be extracted from literature, other systems, and expert opinion. Nonetheless, the conceptual model needs to be developed to identify the key gaps in our knowledge, enable clear articulation of the most pertinent questions, provide rationale for selecting population and habitat measures, and establish the link from monitoring results to management actions.

2.1.2 Selected Measures of Population and Habitat

To attain the inventory or monitoring objective in a quantifiable way, population and habitat measures that represent the objective must be selected. If the objective is to monitor a population's status and trend, examples of relevant population measures may include frequency of occurrence, relative abundance, density, or total population size (a complete **census**). If the objective is to estimate changes in reproductive success, examples of relevant measures may include the number of adults with offspring, the number of young (or, for plants, seeds) per reproductive unit, or the number of offspring successfully fledged.

Habitat measures should be drawn from the habitat relationships described in the conceptual model. If a species is affected by **landscape** pattern, some possible measures may include patch size, patch isolation, edge density, or the number of vegetation types and structural stages per unit area. Measures of stand structure include vegetation height, diameter, and species composition. Special habitat features (snags, logs) can be measured by presence, density, size class, volume, or condition class.

2.1.3 Sampling Design

The sampling design provides the approach for selecting individual **sampling units** from a **statistical population** for measurement or observation. The primary functions of a sampling design include the following:

- To ensure that the sample's attributes (particularly the population or habitat indices of interest) accurately represent the attributes of the larger population.
- To ensure that sampling is conducted as efficiently as possible. That is, the sample will have the best statistical properties (usually the lowest variance) that can be achieved within the project's budget and time constraints.

A sampling design that best meets a monitoring plan's objectives should be selected for each monitoring plan. For an area inventory, the sampling design should provide for good spatial dispersion of observations within the inventory area, across all of the targeted species' potential habitats. For cause-and-effect monitoring, the sampling design should include replicates of the management action, if possible, and replicates of sites without implementation of management practices (i.e., controls). This replication is necessary to isolate, as much as possible, the management action as the only difference among treatment and control sites. Also, while not absolutely essential, sampling pretreatment conditions on all sites is important for analyzing cause and effect. Chapter 3 addresses several different sampling designs and their possible application to WFRP monitoring.

The sampling design must also take into account specific aspects of a species' life history and habitats so data collection can be optimized and results can be properly interpreted. Four aspects of life history that might affect sampling design are home range size, territoriality (or conversely, social clumping), seasonal use patterns, and natural population fluctuations. Home range size could influence plot size or the spacing between plots within the **sampling frame.** Territoriality or social clumping could be deciding factors in whether the sampling design is simple random sampling or stratified random sampling. Seasonal use patterns could affect the optimal time of year for detecting a species and for interpreting fluctuations within a season related to the appearance of young of the year. For multiple species monitoring, the sampling design should include sampling several times over the potential sampling season so data are not biased toward early or late seasonal species. Natural population fluctuations affect the ability to detect significant change in abundance, and must be considered when specifying a desired **effect size.** For example, if a 20 percent change in abundance is within the range of normal fluctuations, it may not be relevant to detect a 20 percent change in abundance for management purposes. A larger effect size and, hence, smaller sample size might be adequate.

The size, shape, and spacing of sampling units can have major effects on population or habitat index values. Chapter 3 of this technical guide addresses considerations for determining the optimum configuration of sampling units for a particular project. I&M protocol development teams, however, should also review more comprehensive texts on the subject. Hayek and Buzas (1997), Thompson (1992), and Thompson et al. (1998) are three examples among many excellent references on natural resource sampling designs. Furthermore, I&M teams are strongly encouraged to consult with a statistician early in the design process to help ensure the sampling design matches the scale and objectives of the inventory or monitoring questions.

The Sampling Design section of each WFRP I&M technical guide should address the following elements:

- Definition of the **target population.**
- The sampling frame (i.e., spatial and temporal bounds of sample selection) and statistical scope of inference, and how these elements relate to the target population.
- Sample selection and stratification methods (e.g., stratified random, systematic) and the process for selecting sampling units (e.g., mechanism for random selection of a unit).
- The size, shape, and spacing of sampling units.
- Methods to control or measure observer **bias** resulting from imperfect observation or species **detectability.**
- An estimation of sample size needed to meet the objectives.
- Temporal aspects of the sampling design, annually and over the course of a multiyear measurement cycle, if applicable.

2.1.4 Pilot Studies

This section can be used to describe an intended pilot study of the monitoring strategy or report a pilot study's outcome. If the pilot study has not yet occurred, this section will describe the study's objective and state when, where, and how the pilot study will occur. If the pilot study has already taken place, this section will describe how the data from this effort applies to the inventory or monitoring design. Pilot study data may be valuable in estimating optimal sample size, providing estimates of needed **parameters** (e.g., detection probability, sex ratio of detected individuals), or focusing attention on specific habitats. Pilot study data also might be helpful in the selection of a more effective index of population size (Gibbs et al. 1998). Because early knowledge about data characteristics, logistical constraints, and potential sources of bias can pay huge dividends in the long run, we recommend that all I&M designs begin with pilot studies.

2.1.5 Prospective Power Analysis

The primary purpose of a prospective power analysis is to choose a sample size that will meet the desired levels of precision and power for detecting a biologically significant phenomenon. The ability to meet the inventory or monitoring objective largely depends on the sampling intensity. An insufficient sample is nearly equivalent to not sampling at all, because meaningful inferences are not possible. Statistical power is a function of sample size, effect size, and significance level (α) and can be calculated using a wide range of statistical software (see Thomas and Krebs 1997 for an excellent review of suitable software). Pilot studies can provide the data to use in these calculations; therefore, the prospective power analysis can be included in the Pilot Studies section instead of appearing as a separate section.

2.2 Data Collection

2.2.1 Data Collection Methods

This section should adequately describe all the methods associated with randomly selecting sampling units in the field, observing or trapping target organisms, recording and managing data in the field, and handling voucher specimens. Protocol developers should consider adapting tested and peer-reviewed methods before developing new techniques. A bibliography of selected reference publications for sampling rare plants, fish, and wildlife is provided in appendix C of this technical guide.

The Data Collection section might logically be divided into A. Population Data and B. Habitat Data, since each type of data will require different data collection methods. The subheadings used below may not be necessary if field method descriptions are short, but all the topics listed under these subheadings should be addressed.

Locating Sampling Units

The technical guide should clearly identify field methods necessary for biologists to translate the conceptual sampling design into field procedures for locating sampling units, even under challenging conditions. Criteria or rules for establishing plot boundaries should be described, if required by the design. Consideration should be given to mapping sampling sites using a geographic information system (GIS) and then using global positioning sensors to field-locate them.

Layout and Marking

The dimensions of plots, transects, or other sampling units should be described. Efficient techniques for positioning and measuring sampling units under field conditions should be identified. Providing a diagram or map to indicate the spacing and configuration of sampling units would also be useful. Recommendations for marking and establishing monuments that are resistant to natural disturbances and vandalism should be provided for long-term monitoring projects. Elzinga et al. (2001) provide an excellent review of such techniques.

Field Methods

A comprehensive description of field methods for sampling the target species or habitat element should be provided. This description should include the following elements:

- Observational or capture techniques. This element should include a description of the equipment used and the rationale for the equipment chosen. The rationale should point out the chosen method's advantages and disadvantages with regard to the technique's precision and repeatability. Subtle details of techniques such as guidelines for trap placement, binoculars used, and weather conditions may be very useful in reducing interannual variability in estimates.
- Temporal sampling period. Explain how the temporal framework for sampling interfaces with periods of activity for the species of interest or how it is associated with the function of the habitat element of interest. Point out the advantages and disadvantages of the proposed timing with regards to the precision and repeatability of estimating the index of interest.
- Duration of sampling. This element should ensure the sampling effort is adequate for developing a precise estimate over a period of time that is meaningful to the population of concern.
- Data recording. For each variable, document exactly how data are to be collected. Include references to the significant digits used to record data. Clearly state the taxonomic level expected, the measurement's degree of precision, and the specific techniques used to acquire the data.
- Plant or animal marking techniques. These elements must be considered carefully because any marking technique that introduces bias relative to survival or reproduction can lead to highly unreliable monitoring information. References to standard guidelines for marking plants and animals should be provided. In the case of radio transmitters, make it clear that transmitter mass should not exceed specific guidelines provided in the literature. Bands, ear tags, passive integrated transponder (i.e., PIT) tags, and other markers should not unduly modify the organism's mobility, survival, reproductive potential, or other functions that may result in an unreliable indication of population function.
- Use of equipment and materials. This element should be precisely described. It is better to provide too much detail than too little regarding how equipment should be used, maintained, and stored.

Voucher Specimens

The methods used to handle, prepare, and store plant or animal specimens collected in the field should be described. If laboratory analyses are required for the protocol, the facility where the analyses will be conducted should be identified along with appropriate shipping methods. The museum or university collection that will ultimately house voucher specimens also should be identified.

2.2.2 Personnel Qualifications and Training

One of the most important considerations in planning a biological monitoring program is to ensure that trained technicians, working under the supervision of well-qualified biologists, perform data collection and analytical procedures. Advanced, electronic data loggers and other technological improvements improve good surveyors' efficiency, but cannot make up for the shortcomings of inexperienced or poorly trained personnel. Moreover, different levels of training and experience among survey personnel may be a significant source of observer variability. To ensure reliable and efficient data collection, WFRP I&M technical guides should specify the minimum qualifications and responsibilities for biologists, crew leaders, and crew members involved in conducting the inventory or monitoring study. Establishing written qualifications for personnel is particularly important for multi-year monitoring studies in which a significant amount of turnover among the monitoring program participants is likely during the course of the study.

2.2.3 Quality Control and Assurance

The purposes of quality control and assurance include the following:

- To ensure consistent implementation of an inventory or monitoring design by different Forest Service units or other agencies.
- To maintain the scientific credibility of the results by standardizing materials and methods used during data collection and analysis, thus facilitating independent review and replication of the monitoring design.
- To quantify measurement error associated with implementation of the sampling design.

Forest Service personnel customarily perform remeasurements to verify stand exam data during timber inventories contracted to private surveyors, yet, such data quality assurance methods are infrequently used for WFRP inventories. WFRP I&M technical guide developers should consider the data collection tasks most vulnerable to error and should describe procedures to minimize the likelihood of such errors occurring. For example, the Quality Control and Assurance section might recommend midseason calibration of scales or other instruments, midseason calibration of ocular estimates, and weekly examination of forms for potential errors. Developers could also design data verification tests and recommend their use when the protocol is implemented. They could also recommend that an independent examiner conduct resurveys on a subset of sampling units to measure error rates. This section should also establish criteria for acceptable levels of observer error and describe remedial measures when measurement error is not acceptable.

2.2.4 Data Forms

This section should briefly list all forms needed for data collection, indicate whether each form is optional or required, and refer to an appendix containing templates for these forms. The appendix should also provide a data format sheet that identifies the data type, unit of measurement, and valid range of values for each field of the data collection form. The data format sheet should identify all codes and abbreviations used in the form. We encourage developing digital forms and providing ways to access digital forms (e.g., on a personal digital recorder).

2.2.5 Logistics

This section covers the following logistical considerations for administering and conducting field surveys:

- Types of permits needed and how to obtain them.
- Safety considerations.
- Sources of field equipment.
- Anticipated work schedules.

The Logistics section should also outline the expected content of an annual operation plan that would be prepared by personnel implementing the specific inventory or monitoring design. In general, an annual operation plan should address the following items:

- The current year's status of memorandums of understanding (MOUs) and agreements with monitoring collaborators.
- The current year's status of any permits needed for access to private lands.
- The current year's status of scientific collecting permits.
- Plans for housing field personnel.
- Arrangements for vehicles.
- Radio communications and frequencies.
- The coordination of flagging and marking schemes with other concurrent projects.
- A checklist of field equipment.
- Safety considerations.

Permits

Most States require surveyors to possess scientific collecting permits for studies involving the removal of rare plants or capture of native wildlife. Species listed as endangered or threatened under the ESA receive additional, stringent protection. I&M protocols that target ESA-listed species may require Forest Service personnel to consult with the U.S. Fish and Wildlife Service or National Oceanic and Atmospheric Administration Fisheries Service before beginning work. The Logistics section should identify State and Federal collecting permits that may be necessary for conducting fieldwork, as well as permits that must be obtained to use controlled substances or materials (e.g., immobilizing agents or other drugs, syringes, dart guns).

Safety Considerations

The Forest Service requires a job hazard analysis for each task that is carried out by Forest Service personnel or contractors. The Logistics section should list all potential safety hazards associated with data collection to enable the personnel implementing the specific inventory or monitoring design to develop appropriate job hazard analyses. Examples of potential safety hazards include the following:

- Exposure to animal-borne diseases (e.g., rabies, hantavirus).
- Risk of injury from handling wild animals (e.g., capturing large carnivores).
- Risk of injury from using special equipment or materials (e.g., an electroshocker).
- Hazardous activities (e.g., tree climbing, spelunking).
- Risks associated with weather.
- Risks associated with driving.
- Risks associated with off-trail hiking.

The National Center for Infectious Diseases provides fact sheets for many diseases that biological technicians may be at risk of contracting (NCID 2003). The Logistics section should also describe training or qualifications necessary for performing hazardous procedures.

2.3 Data Storage

Data from WFRP inventory or monitoring programs will be stored in the Forest Service's NRIS (NRIS 2005). Steps in preparing data for entry into NRIS need to be addressed in the Data Storage section. Data storage details may not be known until the inventory or monitoring design has been tested or even implemented, so the Data Storage section could be rudimentary in the first draft of the technical guide. Also, it is expected that NRIS will not have capabilities to store specialized data that might be produced by a specific inventory or monitoring design. Those who develop and test the I&M designs will need to work with NRIS developers to enhance the system to store specific data. They can use the following subheadings to elaborate on various aspects of data storage.

2.3.1 Data Cleaning Methods

Data collected in the field must be reviewed for completeness and errors before entry into NRIS. Concerns and techniques specific to the protocol being developed should be addressed.

2.3.2 Database Structure

This section would describe the entire database, both the variables collected in the field and any derived variables, including how the derived variables are calculated. For each variable, this section would provide the unit of measurement, and the valid range of values.

2.3.3 Metadata Requirements

The term “metadata” refers to “data about data.” Metadata is information about the origins of a database or a map provided by its developer, changes to the work made by secondary users, and quality of the data. WFRP protocol development teams should become familiar with the major elements of the Federal Geographic Data Committee (FGDC) Content Standard for Digital Geospatial Metadata (CSDGM) Biological Metadata Profile (FGDC and USGS 1999), and how these metadata standards are incorporated into NRIS. The FGDC metadata standard includes seven major elements; some are mandatory for every database and map, and some are applicable only to certain types of data. NRIS automates all the mandatory elements of the standards. NRIS developers would work with WFRP I&M technical guide authors to ensure that any other necessary metadata are incorporated into the guide. These metadata could then be summarized in the Metadata Requirements section of the technical guide, as in the following examples:

- Complete descriptions and bibliographic citations for taxonomic, population, or ecological classification systems used in the guide, including identification of keywords consistent with the Biological Metadata Profile, where appropriate.
- Sources of maps, geospatial data, and population information that are used to delineate the monitoring program’s geographic boundaries or locate sampling units.
- Units of measurement.
- Names and qualifications of field personnel and of people who will be responsible for maintaining and distributing data (i.e., data stewards).
- All data codes, variable names, acronyms, and abbreviations used in the protocol.
- An outline or template of the structure of tabular databases.

Additional information about metadata is provided in Section 3.3, Data Storage: Metadata Purpose and Standards.

2.4 Data Analysis

2.4.1 Analysis, Synthesis, and Interpretation

This section will describe the general approach to data analysis, specific statistical tests that will be used, and why they will be used. The rationale for selecting the statistical tests will include the type of data (e.g., continuous, binary), the expected distribution of the data, underlying assumptions, and any other relevant factors.

In WFRP I&M technical guides, this section will be divided into subheadings (e.g., A, B, C) for each analysis objective. For example, a monitoring strategy designed to detect changes in relative abundance in relation to changes in habitat might have three objectives:

- A. Single-Year Estimate of Relative Abundance.
- B. Changes in Relative Abundance Between Two Time Periods.
- C. Correlations Between Relative Abundance and Habitat.

The analysis need not always be statistical. For example, a species list, diversity index, distribution maps, or other graphical techniques may often be sufficient to convey information at a level appropriate for a given objective. Alternative techniques to traditional statistical frameworks such as Bayesian inference (Dennis 1996, Ellison 1996, Taylor et al. 1996), or testing based on confidence intervals also may be recommended (Steidl et al. 1997, Johnson 1999). Analytical Methods, Section 3.4, describes the logic and utility behind selected generalized statistical models that are commonly used to analyze data from inventory and monitoring designs.

2.4.2 Analysis Tools

Use this section to provide information about analytical software that is available for the specific analyses. The vendor information necessary for ordering software could be included to facilitate software acquisition. Countless software packages are available for application of a wide range of statistical tests in ecological applications. Individual products vary in their sophistication, ease of use, computer requirements, and purchase price (see appendix C for references on recommended software tools).

2.5 Reporting

2.5.1 Expected Reports

This section will describe the reports that will result from the inventory or monitoring design and may suggest a format for specific reports. The Reporting section encourages those who implement the design to report results from the standpoint of the inventory or monitoring objective and to recommend how the results might be used to improve and/or validate Forest Service resource management. The Reporting section, however, should clearly differentiate between data results and management recommendations. The discussion of management recommendations should give attention to the Forest Service information needs identified in the Background and Business Needs section.

2.5.2 Reporting Schedule

This section will list a timetable of expected reports, beginning with the pilot study, then the first year of full implementation, followed by annual reports and landmarks at perhaps 5- and 10-year intervals.

2.6 List of Preparers

Each chapter of the technical guide should list the contributing authors, their titles or positions, and their Forest Service units or the organizations where they work. If the list of preparers is the same for all chapters, the list will follow the title page of the technical guide.

2.7 Literature Cited

The Literature Cited section will appear as appendix A following the numbered chapters of the technical guide and will list all publications referenced in the text. The format for literature cited will comply with the standard established and used by the Forest Service.

2.8 Appendixes

The titles of all appendixes to the technical guide will be listed on the Contents page. The following materials may appear in an appendix:

- Glossary.
- Examples of field data forms.
- Identification keys or guides.
- Database structure and data dictionary.
- Copies of contracts, MOUs, and other agreements.

Chapter 3. Further Considerations in Developing Inventory and Monitoring Protocols

The purpose of this chapter is to provide technical assistance for developing each section of a WFRP I&M technical guide. The chapter is organized around the primary headings and subheadings of chapter 2 so protocol developers can locate information relevant to each section.

3.0 Stating the Objective

I&M objectives should be applicable throughout most of the range of the targeted species or species group and should focus on broad information needs that are relevant to management. In addition, those who implement the I&M protocols should be able to narrow certain objectives to address local information needs. Examples of broad objectives are as follows:

- Expand knowledge about the spatial distribution of the targeted species.
- Expand knowledge about habitat associations of the targeted species.
- Expand knowledge about co-occurrence of the targeted species with other species.
- Monitor broad-scale population trends in relation to habitat changes.
- Monitor changes in population in relation to specific management actions.
- Monitor changes in demographic factors in relation to specific management actions.

As part of the objective statement, protocol developers need to determine the level of confidence desired or necessary to provide managers with useful information. For an inventory design, the developers will need to decide whether it is important to know with very high confidence that a species occurs in a specific habitat or specific area or if some lesser level of confidence is acceptable. The level of confidence needed will dictate the sampling design and the intensity with which the area is sampled.

The issue of statistical power is particularly pressing in conservation work and other applications with direct bearing on critical management decisions. Committing a Type II error (β; missed-effect) can have more adverse consequences under these circumstances than declaring statistical significance for an effect lacking biological meaning (Taylor and Gerrodette 1993, Hayes and Steidl 1997, Steidl et al. 1997, Johnson 1999, Roosenburg 2000). For example, if results of monitoring failed to statistically detect the presence of a true adverse effect of forest thinning on a rare amphibian species, failure to take appropriate actions could speed up the species' demise in commercially managed forests. The Data Analysis section addresses retrospective (post hoc) power analysis.

The objective statement also should include an estimated threshold or trigger point that would result in changes in management. Frequently a 20 percent change in population level is adopted as a trigger point for change, but this number is often selected arbitrarily, without ecological considerations. If the population of interest is very small, it may be essential to alter management when only a 10 percent decline has occurred. If the population of interest frequently fluctuates 10 to 20 percent, then a value larger than 20 percent should be selected for a trigger point.

The threshold should apply to a unidirectional change (i.e., declining or increasing, but not both), because a smaller sample size is needed for a one-tailed versus a two-tailed test. Thresholds are usually set for an undesired decline, but they may be set for an increase (e.g., for recovering species at the point when intensive management would no longer be necessary; or the point when an overabundant species might be detrimental to habitat condition).

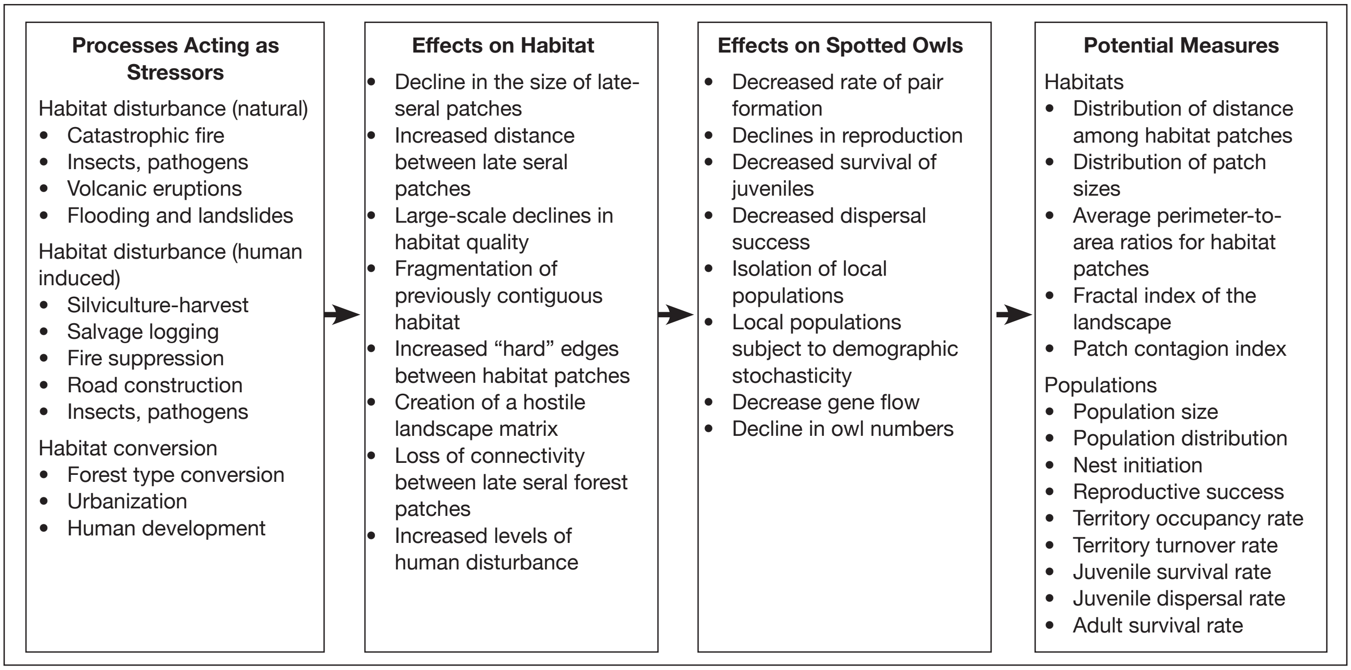
3.1 Considerations for Planning and Design

3.1.1 Conceptual Model

The development of a conceptual model is critical to the development of a successful monitoring program that is scientifically based and founded in ecological theory. Before developing and implementing a monitoring program, it is essential to clearly understand why the proposed monitoring is important, determine which characteristics of the environments are to be monitored, know what that information indicates about environmental quality, and know how to use that information to better manage the landscape (Noon et al. 1999). Conceptual models document the ecosystem components and processes we believe are relevant to the species' well-being, document our assumptions about how those components and processes are related, and identify gaps in what we know about contributing factors (Manley et al. 2000).

Through the development of a conceptual model, the factors that drive ecological systems often become apparent, which enables us to determine which attributes may be important to system function and suggests ecological elements to monitor. These factors can also help us identify the components and processes about which we have the least confidence in our understanding but which might be most directly affected by management activities. This process leads to the identification of parameters that will need to be measured by monitoring. For example, it might be determined through the development of a conceptual model that a change in a species' relative abundance, reproductive output, or genetic makeup may result if proposed management actions are implemented. The parameter that appears to be most sensitive to management actions and to a species' well-being may then be selected as the **monitoring measure** (fig. 3.1). The overall purpose of the model is to provide a logical sequence to the selection and use of monitoring measures.

Figure 3.1. *An example of a conceptual model illustrating relationships between natural and human-induced stressors and their effects on northern spotted owls (after Lint et al. 1999).*



A useful conceptual model will do the following:

- Describe ecological processes of interest and related variables.
- Contribute to understanding interactions between ecosystem processes and selected variables.
- Identify key links between drivers, stressors, and ecosystem response.
- Facilitate selection and justification of monitoring measures.
- Facilitate evaluation of data from the monitoring program.
- Facilitate incorporation of the monitoring program results into management activities.

Gross (2003) provided a step-by-step approach to the development of conceptual models for monitoring programs.

3.1.2 Selected Measures of Population and Habitat

The following discussion distinguishes between data collected in the field and the population or habitat measures derived from the data. For example, counts of individuals are a type of data; the resulting measures are relative abundance, absolute abundance, or density. In the case of habitat, the counts of individual trees and the measurement of their diameters are two types of data used to derive a stand density index.

Conceptual Models[1]

When developing a conceptual model, consider the following points:

- It should represent your current understanding of the system you intend to monitor.
- It should help you understand how the system works. What are the entities that define the structure of the system? What are the key processes? This knowledge often yields a narrative model—a concise statement of how (you think) the system works.
- It should describe the state variables. What mechanisms and constraints will be included, and which will be excluded?
- What assumptions will be made about the system? At what spatial and temporal scales does the system operate? These considerations often result in the construction of a schematic model, perhaps a Forester diagram (a "box and arrow" model). It should provide a framework for generating hypotheses about how the system works. The key states or processes most likely to be affected by management actions should be identified for monitoring.

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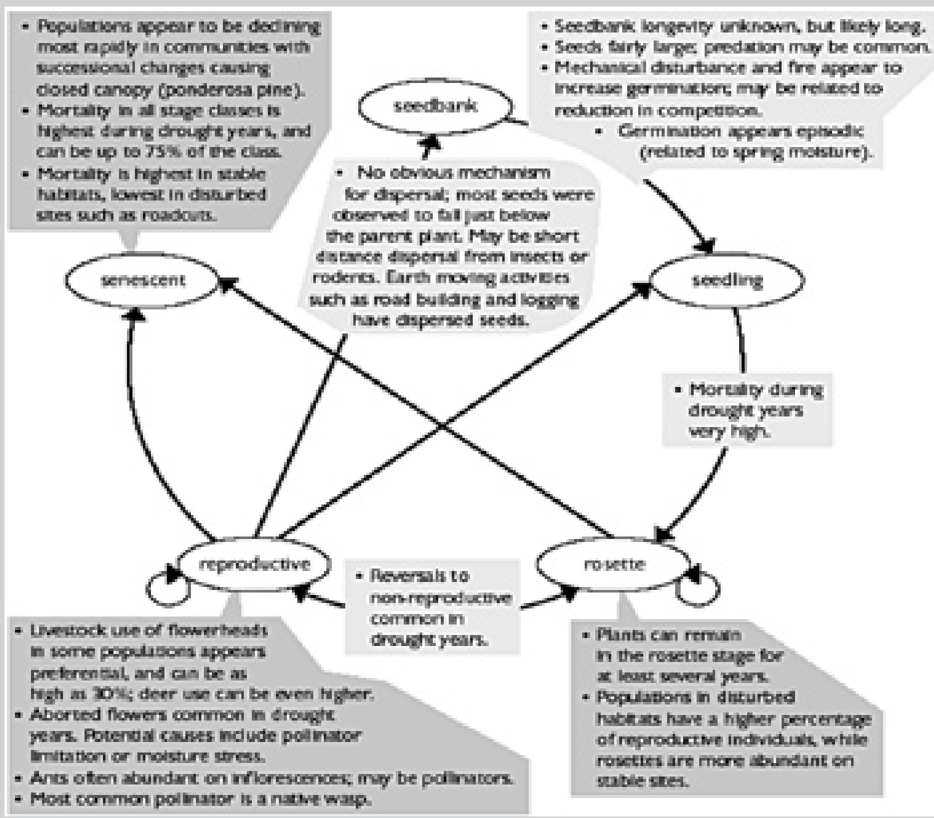


[1] Figure excerpted from Elzinga et al. (2001: 262).

Population and Community Measures

To be meaningful, all population and community measures require an estimate of detection probability, unless surveyors are confident that all individuals present at the sampling unit will be detected each time a survey is conducted. Although detection probabilities are not explicitly addressed here, the concept is integral to all the population and community measures presented. Methods for estimating detection probabilities are presented in Section 3.4, Analytical Methods.

Population measures are derived from the following types of data:

- Detection of unmarked individuals or associated signs (e.g., tracks, scat, hair).
- Detection and location of marked individuals.
- Counts of marked or unmarked individuals.
- Reproductive parameters.
- Genetic data.

Community measures are derived from detections or counts of individuals within species or species groups. The following is a description of common population and community measures and their usefulness in meeting different inventory and monitoring objectives (adapted from Holthausen et al. 2005).

Population Measures

Presence/Absence. Presence/absence is derived from detection data by direct observation or a reliable sign of the species' presence (e.g., vocalization, genetic sample, scat), and is adjusted for bias of imperfect detection. This measure is useful when the objective is to expand knowledge about the habitat associations of a targeted species or to expand knowledge about the co-occurrence of a species with other species. It is primarily an inventory measure that results in species lists and habitat associations.

Frequency of Occurrence. This measure estimates, for a statistical population of survey sites, the proportion of sites with the target species present, based on a random sample of the statistical population. Frequency of occurrence is not spatially explicit, so it cannot be used to map a species' spatial distribution. It can be used, however, to estimate whether the spatial distribution is changing over time; for instance, whether the number of occurrences (as opposed to numbers of individuals) of a rare plant are increasing or decreasing. Frequency of occurrence is a useful indicator of relative abundance if the relationship between frequency of occurrence and population density has been established or estimated (e.g., each survey site represents one breeding pair). If so, then change in frequency of occurrence can be used to estimate change in relative abundance over time.

Abundance or Density. These measures are derived from counts of individuals or from the presence and location of marked individuals. Abundance is either absolute (a complete census or an estimate of total abundance), or relative (number-of-individuals-per-unit effort). Relative abundance becomes relative density when the comparative unit is area (number of individuals per unit of area). Relative density can be estimated from counts of individuals and their detection probabilities. It can also be estimated from habitat associations and average home range size derived from the presence and location of marked individuals. Abundance or density provides more information than does presence/absence about the relative importance of different habitats and about the strength of association in co-occurrence of certain species. Also, it provides greater sensitivity to detect change over time than frequency of occurrence does.

Indices of Relative Abundance. This suite of measures is based on detections or counts of objects, such as pellets, tracks, or vocalizations, which are surrogates for individuals. Thompson et al. (1998) state that any unadjusted partial count of individuals is an index; therefore, relative density without an adjustment for detectability is technically an index of relative abundance. An index can be used for inventory purposes such as mapping spatial distribution and co-occurrence with other species. Caughley (1977) advocated the use of indices for monitoring change in abundance over time, indicating that many studies that used estimates of absolute density could have used density indices without losing information. He suggested that use of indices often results in a more efficient use of time and resources and produces results with higher precision than population estimates do (Caughley 1977, Caughley and Sinclair 1994).

Others have questioned the reliability of index values for monitoring change over time, however, because the relationship between the index and true population abundance usually is not quantified or known (Thompson et al. 1998; Anderson 2001, 2003), and the opportunity for bias associated with indices of abundance is quite high. For instance, track counts could be related to animal abundance, animal activity levels, or both. Capture rates of animals over area and time may be related to animal abundance or to the animals' vulnerability to capture in areas of differing habitat quality. Consequently, although indices of abundance are often used because of logistical constraints, considerable caution must be exercised when interpreting these results. Nevertheless, Engeman (2003) concluded that an index may be the most efficient means to address **population monitoring** objectives and that the concerns associated with the use of indices can be addressed with appropriate and thorough experimental design and data analyses. Moreover, McKelvey and Pearson (2001) found that some indices exhibit lower variance than do population estimators, particularly with small sample sizes or when the estimators' underlying population attributes are largely unknown. Therefore, the choice of an index or an estimator will depend on data quality.

Vital Rates. Vital rates are age-specific birth and death rates or emigration/immigration rates that are derived from evidence of reproduction, such as the number of young per female or the number of seed pods per plant. Vital rates are a cornerstone of population viability analysis. An understanding of vital rates provides insight into population status. Depending on life history, monitoring of vital rates can provide a better measure of population status than do measures of abundance. Furthermore, understanding how vital rates change in response to management provides insight into potential mediation or mitigation. Demographic sensitivity analysis can help identify the appropriate vital rate to monitor.

Range Distribution Measures. Geographic range can be estimated from presence/absence or counts of individuals, while further differentiation of breeding and non-breeding range can be determined from evidence of reproduction. Boundaries of genetically distinct populations can be estimated from genetic data. Range distribution measures are valuable when the monitoring goal is to estimate whether the range of a species is expanding, contracting, or remaining relatively constant. This information is needed for exotic species and endangered species management, where the goal may be to compare the current geographic range to historic distributions. Current research indicates a correlation between a species' abundance and distribution, so range dynamics may provide an effective indication of abundance (He and Gaston 2000).

Genetic Measures. DNA-based inventory and monitoring efforts will provide new insights into fish, wildlife, and plant population health and trends. There are two distinct ways in which DNA and population genetics can be used for inventory and monitoring. First, genetics can be used to bolster other monitoring efforts described above. For example, to delineate an animal's range, traditional methods often call for the use of historical records or the identification of snow tracks; both delineation techniques are highly unreliable and prone to high error rates. Using DNA obtained from hair, urine, or scat associated with snow tracks, however, can provide reliable, positive species identification. In this sense, DNA can augment traditional methods and provide more reliable estimates of abundance, presence/absence, and geographic range. Many examples of such DNA usage exist for estimating abundance (Paetkau 2003, Schwartz et al. 2004), presence/absence (Taberlet et al. 1997, Schwartz et al. 2004), and geographic range (Taberlet et al. 1997, McKelvey et al., in press).

Secondly, data from DNA can be used to abet I&M in a population genetics framework. That is, once samples are collected, the genetic data can be tapped for further information about the population. In particular, the genetic data can be used for the following purposes:

- To examine changes in genetic diversity in the population over time or compare genetic diversity across space.
- To detect recent genetic population bottlenecks.
- To estimate **effective population size** or changes in effective population size over time (detailed in following sections).

Some of these techniques are well established; others will require additional development before implementation. Overall, the genetics field is rapidly advancing, with novel and more precise techniques available each year. In the not-too-distant future, advances in conservation genetics may provide us with unprecedented power to infer change in WFRP populations.

Community Measures

Diversity Measures. Species richness, evenness, or diversity can be estimated from counts of individuals. Research studies have used diversity measures to examine particular questions in community and ecosystem ecology, such as community relationships based on trophic, functional, or taxonomic groupings. Diversity measures pose challenges, however, because they are not easily interpreted. For example, an increase in species diversity could represent restoration of a native community, but it could also indicate loss of rare species and gains of invasive species. These challenges have limited the utility of these measures in resource management monitoring.

Integrity Measures. Karr and Dudley (1981) define biological integrity as the "capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region." The concept of biological integrity has evolved in response to perceived flaws in biological diversity measures. Biological integrity is used to compare current conditions on the landscape with conditions present at a specific instance in history or to a nearby "natural" baseline condition. Because this measure relies on one of the diversity measures described above it is subject to all the strengths and weaknesses associated with those measures.

Habitat Measures

The ability to correlate species and habitat data allows for better predictions of species occurrence and distribution and the effects of management on populations. Two critical elements are needed for an accurate, sound comparison of population and habitat data (Jones 1986). First, both species and habitat data must be collected on the same site and during the same time period. If habitat data are collected at a later date, correlations between species' presence and seasonal changes in the habitat might be missed. Second, the habitat definition must be determined before data collection. If habitat is defined as any set of ecological conditions in which the species is present, then presence/absence data will suffice. If the objective is to identify breeding habitat or differentiate between source and sink habitat, however, then data about the species' ability to survive and reproduce (e.g., mortality, survivorship, predation, parasitism) also must be collected (Cody 1985).

Species respond to habitat availability and quality at multiple scales. Most habitat assessment techniques are designed for assessing vegetation composition and structure within a patch or stand, but many organisms also respond to habitat at landscape scales (e.g., McGarigal and McComb 1995). Concepts such as **metapopulation** dynamics, source-sink dynamics, dispersal capabilities, and landscape heterogeneity have become an important basis for collecting data that characterize landscapes. Examples of such data are mean patch size, patch isolation, and edge density. FRAGSTATS (McGarigal and Marks 1995) provides descriptions and algorithms for a suite of landscape measures. It also provides software for performing calculations on vector or rastor images.

3.1.3 Developing a Sampling Design

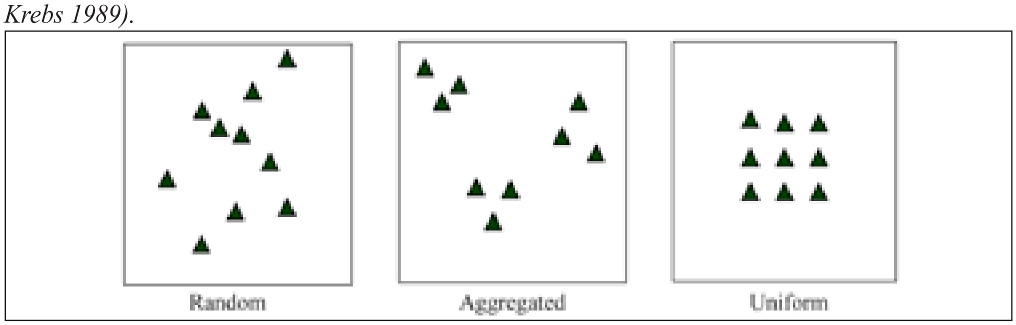
Spatial Patterns of Organisms

The spatial distribution of organisms within a population is an important consideration for sampling design selection. The three basic population spatial patterns are random, aggregated, and uniform (fig. 3.2). Random dispersion, often approximated by a Poisson distribution, is found in populations in which the spacing between individuals is irregular and the presence of one individual does not directly affect the location of another individual. Aggregated (also known as "clumped") populations are characterized by patches or clusters of individuals; the probability of finding one individual increases with the presence of another individual. Count data from populations exhibiting aggregated spatial patterns can frequently be modeled with the negative binomial distribution. Uniform (also known as "regular") distributed populations have individuals that are distributed more or less evenly throughout an area; the presence of one individual decreases the probability of finding another individual closer than the spacing pattern.

Resource distribution and habitat quality may affect the dispersion of individuals and populations (McComb 2001). Random distribution is often found in species that depend on ephemeral resources; species that depend on temporary or seasonal resources may exhibit different types of distribution at different points in their life histories. Social behavior and territoriality may affect vertebrates' distribution. Highly territorial species tend to follow a regular distribution, while more gregarious and colonial nesting species tend to occur in clumps (Curtis and Barnes 1988, Newton 1998). Spatial patterns of organisms, and, consequently, sample distributions resulting from their enumeration, often change with the spatial scale of observations. Populations may appear uniformly distributed at a fine scale, but may show a more random or aggregated distribution throughout their range.

As observed organisms become more numerous and the mean number of individuals per sample exceeds 10, the Poisson distribution begins to approach a normal distribution. Similarly, if the total number of observed individuals (pooled across samples) exceeds 100, the normal distribution can be used to calculate confidence intervals for the population mean (Krebs 1989). Zar (1999) suggested adjusting the sampling unit (e.g.,

Figure 3.2. *Three basic spatial patterns of biological populations (Curtis and Barnes 1988, Krebs 1989).*



quadrat size, length of the sampling period) to increase the probability of detecting more individuals in the habitat. If data counts follow the Poisson or negative binomial distributions, and the primary objective of monitoring is to estimate only the parameter's population mean, the protocol may suggest that the appropriate sample size and confidence intervals be determined using calculations developed specifically for both types of distributions (see Krebs 1989 for examples).

Statistical Population

A statistical population is the entire set of potential sampling units from which a sample is drawn and from which inferences can be made. For example, if bird-count stations are randomly selected from a grid of potential x,y coordinates superimposed over a watershed, the statistical population is the total number of x,y coordinates on the grid. The sample might be 30 stations within a population of 3,000 coordinates. There is not necessarily a correspondence between a statistical population and a **biological population.**

Standard Sampling Designs

As noted in section 2.1.3, sampling designs may have multiple objectives. First, the design should ensure that the sample selected represents the population being monitored or studied. This objective is usually accomplished by incorporating a random selection procedure into the design process so all members of the population have an equal, or at least known, probability of being selected. Randomization is essential for reducing bias and estimating the parameters of a population. Second, the design may seek to maximize the statistical efficiency of data collection by achieving the greatest possible precision for the least cost. The greatest gains in statistical precision are usually attained with increasing sample size, which can be financially impractical for most I&M programs. Therefore, we recommend that the design process include criteria to allocate a sample size sufficient to answer the primary questions of interest with a desired level of certainty.

The following are five sampling designs that have been found to be useful for natural resource I&M projects. This introductory material is meant only to guide protocol developers toward more comprehensive references on sampling design.

Simple Random Sampling. Simple random sampling occurs when a random subset of units are selected as observations from a population in such a way that every unit has an equal chance of being chosen (Krebs 1989). This randomly generated set of observations may be collectively analyzed as representative of the population within the study area. The strength of simple random sampling is that it makes no assumptions about the distribution of features in the landscape being sampled. The weakness of simple random sampling is that unless the sample size is large, it may not represent the range of conditions that occur on the landscape. Consequently, simple random sampling is generally not appropriate for large-scale monitoring because it is not cost-efficient.

Stratified Random Sampling. Stratified random sampling is intended to reduce variation in a sample by allocating observations to individual strata and then randomly locating sample sites within each stratum. Stratification is based on any factor or set of factors that could reduce variability within each stratum, such as habitat types, habitat quality, or topography. Stratification can also be designed to increase the cost efficiency of a sampling scheme (i.e., units of information collected per unit cost). Cost stratification can be placed over any other stratification (Scheaffer et al. 1996). For example, sampling costs might differ among sites depending on the distance of sample sites from roads. Near and far distances from roads may then be used as two strata, with a greater proportion of the total sample allocated to the near stratum to reduce costs. Control of costs via stratification, however, will not necessarily achieve an overall estimate with the smallest variance.

The strength of stratified random sampling is that it can increase efficiency by reducing the number of observations required to reach a desired precision level in an estimate. It is most commonly and effectively used for monitoring species that occur in low numbers, or when different habitats have different probabilities of the organism's presence. For example, the bioregional monitoring design for the northern goshawk (*Accipiter gentilis*) (Hargis and Woodbridge 2006) uses a stratified random sampling design because goshawks' occupancy rates are expected to be higher in primary habitat than in secondary habitat.

The weakness of stratified sampling is that it requires assumptions about the relative spatial and temporal variability of strata and its design is inflexible. Strata should remain fixed on the landscape over time and data should not be restratified based on some other strata of interest that may arise in the future. Sampling designs based on strata that may be ephemeral (e.g., early successional stages for vegetation) may not be useful over long periods of time. Habitat boundaries may change over time or the same habitats may not be present during all sampling periods.

Systematic Sampling. Systematic sampling consists of a fixed, regular pattern of sampling units after random selection of a starting point for the systematic layout. The strength of systematic sampling is that it confers an equal probability of selection for all observations within the geographic area of inference, enabling observations to be aggregated by various strata (e.g., national forests, vegetation types, species ranges, with and without experimental treatments) without having to estimate the probability of selection within strata. In addition, it can be readily augmented by increasing sample site density in strategic locations to reach species-specific sampling objectives (e.g., increase sample site density within specific habitats for species of interest at national forests or larger scales to improve estimates).

A weakness of systematic sampling is that it may over sample some strata of interest and under sample others; systematic sampling is thereby less efficient than a stratified sampling approach for those particular strata (e.g., common, widespread vegetation types). Systematically sampled observations may also be correlated, which increases analysis complexity. Systematic sampling is recommended for forest- and regional-scale monitoring of multiple species because it does not make assumptions about the distribution or abundance of various strata across the landscape and it is flexible in terms of analyzing subsets of observations to address various management questions.

The Multiple Species Inventory and Monitoring (MSIM) protocol (Manley et al. 2004, Manley et al., in press) uses a systematic sampling design based on the sampling grid of the Forest Service Forest Inventory and Analysis (FIA) program. The current FIA sampling design consists of a systematic hexagonal grid across all ownerships in the United States; each hexagon contains approximately 2,403 hectares. One FIA sampling unit is randomly located within each hexagon. At each unit, vegetation structure and composition are scheduled to be surveyed once every 10 to 15 years (Roesch and Reams 1999). The MSIM collects information on a variety of terrestrial and aquatic plant and animal species at plots located 100 meters from the FIA sampling unit in a random direction. In addition to the MSIM design, wildlife habitat information for a variety of species has been gleaned from FIA vegetation data (e.g., Rudis 1991).

When establishing a systematic sample, care must be taken to ensure that the spatial arrangement of observations is not correlated with any regular environmental parameter. For example, in the Midwestern United States, placement of sampling points at 1.6-kilometer (km) intervals may result in a biased sample because the arrangement of roads and agricultural infrastructure in the region is based on a 1.6-km land survey scheme.

Adaptive Cluster Sampling. Many species have a tendency to occur in population clusters because of dispersal mechanisms, behavior patterns (e.g., herding, colonialism), or habitat associations. Under these conditions, it is predictable that monitoring programs conducted according to conventional procedures will expend most of the sampling effort at locations where the species is not observed. Adaptive cluster sampling refers to procedures in which sample selection depends on the values of counts or other variables observed during the course of sampling. Initially, a probability procedure is used to select a set of sampling units in the study area. When any of the selected units satisfy some predetermined criterion (e.g., detection of the target species), additional units are sampled in the neighborhood of the qualifying unit. Sampling is extended until no further units satisfy the criterion.

For rare or highly aggregated populations, adaptive cluster sampling may greatly increase the precision of population size or density estimates when compared to a simple or stratified random design of equal cost (Thompson 1992). Adaptive cluster sampling can be used with quadrats, belt transects, variable circular plots, and other types of sampling units. Pilot studies are strongly recommended to determine the sampling design's optimal scale. Adaptive cluster sampling is more complex to implement than most other sampling designs. Therefore, most teams developing WFRP I&M protocols will need to arrange for a statistical consultant to develop analytical methods appropriate for adaptive sampling. Teams conducting I&M projects will require similar assistance in performing data analysis.

Before-After Control-Impact. The recommended design for monitoring the effects of a management treatment is a before-after control-impact (BACI) design (Green 1979, Stewart-Oaten et al. 1986), which enables comparison of before-and-after effects as well as treatment-control effects. The ideal design consists of before-and-after data on replicates of control and treatment sites, but it is usually not possible to replicate the treatment due to the treatment's large **spatial extent** or its unique nature (e.g., a single power plant, ski area, or dam). The asymmetrical BACI design has a single treatment and one or more controls, with before-and-after data collected from each (Stewart-Oaten and Bence 2001).

Other variants to the basic BACI design are possible, depending on the type of treatment and the anticipated effects. The gradient design involves placing sites at varying distances from the source of the treatment (Ellis and Schneider 1997). The factorial design creates several paired sites within the treatment and the control that share similar attributes; the distinguishing attributes become the factors (Evans and Coote 1993). For example, the factors could be two vegetation cover types and dense versus open stands, with paired sites in and out of the treatment that represent each cover type and stand density combination. Several BACI design variants are presented in Smith (2002).

Size and Shape of Sampling Units

Count data obtained from plots are affected by the sampling unit's size and shape. Square plots and circular plots have smaller boundary/interior ratios than rectangular shapes of equal area. Plots with exaggerated lengths are sometimes referred to as strip transects or belt transects. Under some sampling conditions it might be difficult for the surveyor to determine whether organisms occurring near a plot boundary are inside or outside the plot, resulting in counting errors. In these circumstances, compact plot shapes are preferred. Boundary/interior ratios also decrease as plot size increases. As a result larger plots seemingly offer another approach for reducing counting errors. The tedious nature of counting organisms on a large plot under difficult field conditions, however, may cause surveyors to make mistakes. Counting error is not the only factor to consider when determining plot size and shape. In heterogeneous habitats, data collected on long plots often have been found to have lower statistical variance than data from compact plots of the same total area (Krebs 1989).

The optimum size and shape of a plot will differ according to the species, environmental conditions, and monitoring program objectives. Typically, the optimum plot configuration will be one that provides the greatest statistical precision (i.e., lowest standard error) for a given area sampled. Several investigators have developed approaches for selecting the most appropriate plot size and shape for a particular population monitoring program (e.g., Hendricks 1956, Wiegert 1962). Krebs (1989) provides a useful review of standardized plot configurations.

While the usual notion of a plot is that of an area delineated by a frame or flagging, other techniques may be used to obtain a sample count of target organisms in a given area. For example, cover board surveys have been widely adopted for estimating the relative abundance of amphibian and reptile populations in different habitat types (Grant et al. 1992, Harpole and Haas 1999).

Line-transect and point-transect sampling are specialized plot methods in which a search for the target organism is conducted along a narrow strip with a known area. Rarely can it be assumed that all animals are detected along a transect. If the probability of detection can be predicted from the distance between the animal and the centerline of the transect, however, then a detection function can be used to estimate population density. The approach can be adapted to monitoring programs conducted by foot, snorkeling, and ground or air vehicles. Buckland et al. (2001) provides a complete, although highly technical, introduction to line-transect and point-transect distance sampling methods. The approach has been widely applied to monitoring of vertebrates, including desert tortoises (*Gopherus agassizii*) (Anderson et al. 2001), marbled murrelets (*Brachyramphus marmoratus*) (Madsen et al. 1999), songbirds in oak-pine woodlands (Verner and Ritter 1985), and mule deer (*Odocoileus hemionus*) (White et al. 1989), among many others.

Population abundance can be estimated by a variety of "plotless" monitoring methods that use measurements to describe individuals' spacing in an area. These techniques are founded on the assumption that the number of individuals in a population may be estimated by measuring the average distance among individuals in the population or between individuals and randomly selected observations. One of the most widely used techniques is the point-centered quarter method (Cottam and Curtis 1956). Distance methods have been commonly used for vegetation surveys and are easily adapted to inventories of rare plants or other sessile organisms. The approach may also be useful for population studies of more mobile animal species by obtaining abundance estimates of their nests, dens, roosting sites, or scat piles.

Plotless methods may have some practical advantages over plots or transects, such as the following:

- Plotless methods are less susceptible to counting errors that often occur near plot boundaries; thus, they may yield more accurate abundance estimates.
- The time and effort required to attain an adequate sample of plotless measurements in an area often is less than that required to search for every target organism on a plot; thus, the efficiency of the monitoring program increases.

Field techniques vary depending on the plotless method selected for the monitoring program. All plotless methods use random selection procedures to choose center points and/or compass bearings. Equipment requirements are minimal; usually only a compass, flagging, and measuring device appropriate to the scale of the population and monitoring area are needed. However, data collection protocols may be relatively complicated and sample size calculations may need to be performed in the field. Therefore, a rigorous training program is recommended for personnel conducting the monitoring program. Two useful references for designing inventories based on plotless methods are Seber (1982) and Bonham (1989).

Temporal Aspects of the Sampling Design

The description of the sampling design should include temporal aspects within a sampling period, such as the optimal time period (month or season) for conducting surveys, any daily restrictions in sampling period (e.g., mornings only), and the temporal sequence of within-year sampling (e.g., once a month, every 2 weeks). For monitoring strategies, the design should also describe the resampling cycle. Any restrictions imposed by the sampling design, however, may affect how well the sample represents the adopted target population and/or sampling frame.

Monitoring strategies typically call for resampling the same set of units in each sampling period, thus building a history of site conditions across a consistent set of sites. This approach is effective if the sampling effort is sufficient to represent the range of conditions across the area of inference. It is sometimes called a "single panel" design. The term "panel" describes the set of units that are sampled every sampling period. From the standpoint of statistical analysis of temporal change, data collected for the same units every sampling period will have lower variance than data collected for different units each year. As a result, the sample size needed to detect a change with the desired level of precision and power will be smaller than if the sampling units changed each year. A main attribute of the panel approach is the ability to make estimates for individual years or other points in time. The ability to estimate change, however, is not necessarily improved over a repeated sampling design (see Cochran [1977] for a summary of the tradeoffs). One weakness of repeated measurements of the same sites over time is that through chance (or selection of which sites are being monitored), sites with changes in the monitoring measure may not be included in the sample (i.e., a change may occur during the monitoring period, but the change is not detected because no or too few monitored sites are affected). A new random sample drawn at each time point has a better chance of picking up such a change, but the tradeoff is that the sample size needed each time is larger than that needed for the repeated-measures design.

Over the past decade, the use of rotating panels has gained popularity as an approach to gaining greater representation of ecological conditions across large landscapes (a rotating-panel design is different from drawing a new random sample each time). A resampling design, known as a serial alternating panel approach, involves cycling through a series of panels, each of which contains a set of points that spatially represents the landscape and which, in sum, is more likely to ecologically represent the area of inference. In a panel approach, a systematic subset of points (a panel) is identified for each sampling period. The alternating-panel design generally consists of n sampling units partitioned into m panels. Each panel contains np sampling units ($np = n/m$) and has the same temporal pattern of remeasurement. The remeasurement schedule determines the number of panels; if all sites are visited every 5 years, then there are five panels, one for every year. As an example, the FIA sampling design is based on a serial alternating-panel approach (Lesser and Overton 1994, Thornton et al. 1994, Roesch and Reams 1999). Most FIA regions use 10 panels consisting of 10 percent of the sample, resampled every 10 years.

For cases in which resource conditions vary substantially from year to year and influence the abundance of organisms (e.g., the abundance of mice), it is wise to augment the panel approach with an additional panel that is sampled every year to track annual variation. This additional panel is the augmented serial alternating panel (ASAP) design.

When a series of panels is completed, the strength of an ASAP design is its ability to rival or exceed the statistical power to detect a population trend obtained from the single-panel design while achieving better ecological representation across the landscape. Also, it creates larger data sets for exploring habitat relationships and potential causal factors for observed changes. A weakness of the ASAP design is that the statistical model is not well developed; thus, some uncertainties exist regarding the exact procedure to follow for generating trends. Also, the ASAP design requires consistent funding each year to ensure that each scheduled panel is fully surveyed. Incomplete or unsurveyed panels would further complicate the statistical analysis or could reduce the design to one that simply samples different sites every year. Because of the advantages, however, many broad-scale monitoring programs are moving toward a panel approach (e.g., Reeves et al. 2003). To determine which approach best meets the needs and capabilities of the national forests/grasslands and regions, it is recommended that panel approaches be considered and evaluated against single-panel designs for monitoring population trends.

3.2 Data Collection: Biological Study Ethics

Capture, marking, and observation techniques may cause subject animals to experience pain, permanent injuries, and increased mortality rates. Indeed, some animal inventories and monitoring studies depend on lethal traps for the collection of voucher specimens or population data. The justification for such studies must balance the benefits of newly acquired knowledge with the welfare of animals subjected to study methods. Most wildlife, fisheries, and zoological professional societies have adopted guidelines to help field biologists minimize adverse impacts on individual animals and populations (e.g., American Society of Mammalogists 1987; ASIH, AFS, and AIFRB 1988; Gaunt et al.

1997). In some situations, university faculty collaborating with the Forest Service may also be required to maintain the standards prescribed by their universities' Institutional Animal Care and Use Committees. We recommend that protocol developers become familiar with the standards for animal usage in field studies and that the methods be designed with consideration of these standards.

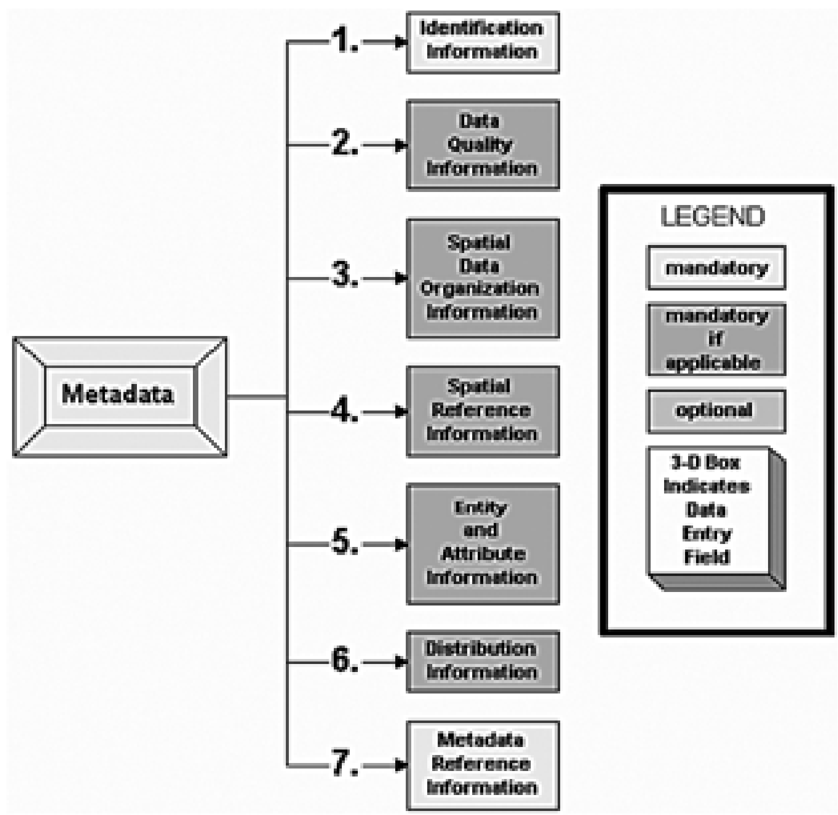
3.3 Data Storage: Metadata Purpose and Standards

I&M data can benefit scientific research and facilitate species conservation programs for many decades. The usefulness of a database is determined not only by the rigor of the methods used to conduct the monitoring program, but also by the ability of future investigators to decipher the variable codes, measurement units, and other details associated with the database. The term "metadata" refers to "data about data." Metadata is information about the origins of a database or a map provided by its developer, changes to the work made by secondary users, and quality of the data. Metadata facilitates information sharing among current users. It is crucial for maintaining the value of data to future investigations. The standardized metadata that will accompany I&M databases should be recognized as one of the principle means to improve the transferability of biological monitoring information among different Forest Service programs and management units.

Since 1995, all Federal agencies have adopted a content standard for geospatial data sets. The standard, called Content Standard for Digital Geospatial Metadata (CSDGM), was developed by the Federal Geographic Data Committee (FGDC); this group also is responsible for reviewing and updating the standard as needed. The currently approved FGDC standard is CSDGM Version 2 – FGDC-STD-001-1998. The FGDC metadata standard includes seven major elements, some of which are mandatory for every database and map; other elements are applicable only to particular types of work (fig. 3.3). Some GIS packages include software tools that automate some metadata documentation tasks; however, most fields must be manually completed by the originator of the database. The process of describing data sources, precision tests, geoprocessing methods, and organizational information can be tedious and add many hours to the preparation of a data set. The initial cost of the labor, however, will ensure that the data can be used for many years, possibly for research or conservation purposes not anticipated by the originator of the data set.

The CSDGM was developed to be applicable to all geospatial databases. The CSDGM framework identifies the originators of the database, describes data sources, and captures spatial reference information. But the generic nature of the CSDGM does not provide for standardization of many attributes commonly shared among biological databases. To extend the effectiveness of the CSDGM framework, the FGDC's Biological Data Working Group has developed the Biological Metadata Profile (FGDC and USGS 1999) to standardize the use of terms and definitions in metadata prepared for biological databases. The Biological Metadata Profile addresses topics such as taxonomic classification, voucher specimens, environmental attributes, and similar issues not considered in the CSDGM. The Biological Metadata Profile is also applicable to nongeospatial data sets.

Figure 3.3. *Graphical representation of major metadata elements specified by the approved Federal standard for geospatial databases (CSDGM Version 2–FGDC-STD-001-1998). (This figure was copied from http://biology.usgs.gov/fgdc.metadata/version2.)*



3.4 Analytical Methods

This section should help familiarize the reader with the basic characteristics and assumptions of analysis models and the circumstances under which they can be employed effectively. The purpose of this information is to help build a well-planned and effective data analysis framework. Since this section deals with complex technical issues, only key elements and concepts of effective data processing are addressed in this technical guide. Protocol developers should consult statisticians and more comprehensive statistical resources to establish a rigorous context for data analysis. General references such as Zar (1999) provide useful guidance for many aspects of analysis.

3.4.1 Data Visualization and Exploratory Data Analysis

The initial phase of every data analysis should include exploratory data evaluation. Graphical display of information is an integral component of every research undertaking. As a first step in evaluating the data's nature, quality, and underlying assumptions, I&M technical guides should encourage a visual exploratory data analysis (Tukey 1977) before statistical testing. The protocol may direct users to excellent examples of graphical display in Spear (1952), Tukey (1977), Tufte (1983), Elzinga et al. (2001), and Ellison (2001). Tufte (1983, 1997, 1990) gives a thorough overview of how to design and use images in a wide range of applications.

Anscombe (1973) advocates several iterations in the process of examining data to reveal unique features. Hilborn and Mangel (1997) recommend plotting data in different ways to uncover "plausible relationships." Numerous types of graphical displays can be used to examine data before analysis and to display summary statistics. The most commonly used include normal probability plots, density plots (histograms, dit plots), box plots, scatter plots, bar charts, and point-and-line charts (Elzinga et al. 2001). The reader can find excellent examples of how to construct and use graphical displays in almost any introductory text on statistical analysis.

According to Tufte (1983), effective graphical displays show the essence of the collected data and should do the following:

- Show the data.
- Induce the viewer to think about the substance rather than methodology, graphic design, the technology of graphic production, or something else.
- Avoid distorting what the data have to say.
- Present many numbers in a small space.
- Make large data sets coherent.
- Encourage the eye to compare different pieces of data.
- Reveal the data at several levels of detail, from a broad overview to the fine structure.
- Serve a reasonably clear purpose—description, exploration, tabulation, or decoration.
- Be closely integrated with the statistical verbal descriptions of a data set.

In some cases, the pattern of the data will actually guide the selection of the model that can be used to describe the relationship in the data (Anscombe 1973, Hilborn and Mangel 1997). For example, refer to the four graphs in figure 3.4. They all display relationships that produce identical outputs if subjected to a simple linear regression analysis (table 3.1).

Figure 3.4. *Relationships between the four sets of x,y pairs (after Anscombe 1973).*

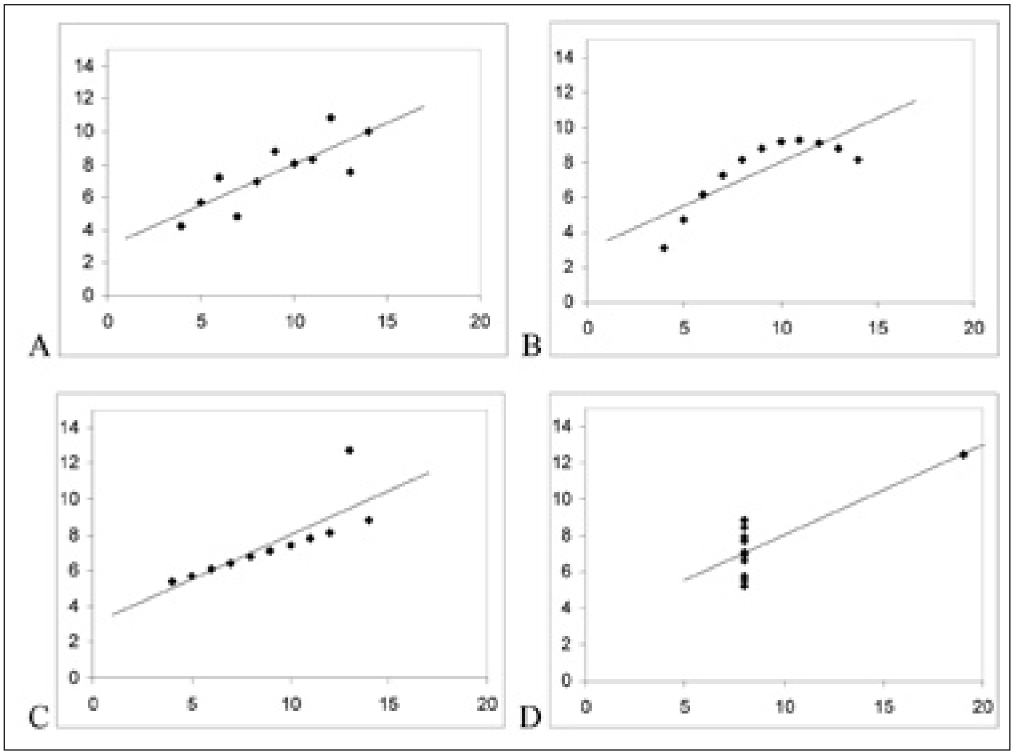


Table 3.1. *Four hypothetical data sets of x,y variable pairs.*

A		B		C		D		Analysis output
X	Y	X	Y	X	Y	X	Y	N = 11
10.0	8.04	10.0	9.14	10.0	7.46	8.0	6.58	Mean of Xs = 9.0
8.0	6.95	8.0	8.14	8.0	6.77	8.0	5.76	Mean of Ys = 7.5
13.0	7.58	13.0	8.74	13.0	12.74	8.0	7.71	Regression line: Y = 3 + 0.5X
9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84	Regression SS = 27.50
11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47	r = 0.82
14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04	R^2 = 0.67
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25	
4.0	4.26	4.0	3.10	4.0	5.39	19.0	12.50	
12.0	10.84	12.0	9.13	12.0	8.15	8.0	5.56	
7.0	4.82	7.0	7.26	7.0	6.42	8.0	7.91	
5.0	5.68	5.0	4.74	5.0	5.73	8.0	6.89	

Source: Modified from Anscombe (1973).

Yet, whereas a simple linear regression model may describe the trend in Case A reasonably well, its use in the remaining three cases may not be appropriate, at least not without an adequate examination and transformation of the data. Case B could be described best using a logarithmic rather than a linear model. The relationship in Case D is spurious, resulting from connecting a single point to the rest of the data cluster. Case C also reveals the presence of an apparent outlier (i.e., an extreme value that may have been missed without a careful examination of the data). This simple example illustrates the value of a visual scrutiny of data before data analysis.

Under some circumstances, visual displays alone can provide an adequate assessment of the data. This approach may even be superior to formal data analyses in situations with large quantities of data (e.g., detailed measurements of demographics or vegetation cover) or if data sets are sparse as a result of inadequate sampling or pilot investigations. For example, maps can be used effectively to present a great volume of information (if a spatial context is relevant to the question of interest). Tufte (1983) argues that maps are the only means for displaying large quantities of spatial data in a relatively small amount of space while still allowing for a meaningful interpretation of the information. In addition, maps allow for a visual analysis of data at different levels of temporal and spatial resolution. They also allow for the assessment of relationships among variables and can help identify causes of the detected pattern.

A simple assessment of the species richness of a community can be accomplished by presenting the total number of species found. Additional information can be acquired by plotting the cumulative number of species detected against sampling effort to assess whether the survey includes all or most of the species in the community. A steep slope of the resulting curve would suggest that additional sampling effort might yield more species, whereas flattening of the curve would indicate that most of the species in the community have been detected (Magurran 1988, Southwood 1992).

Construction of species abundance models such as log-normal distribution, log series, McArthur's broken stick, or geometric series may be used to visually acquire additional information about a particular research area. Individual species abundance models describe communities with unique characteristics. For example, mature undisturbed systems characterized by greater species richness typically display a log-normal relationship between the number of species and their respective abundances. On the other hand, early successional sites or environmentally stressed communities (e.g., those affected by pollution) are characterized by geometric or log series species distribution models (Southwood 1992).

The use of confidence intervals presents another attractive approach to exploratory data analysis. Some even argue that confidence intervals represent a more meaningful and powerful alternative to statistical hypothesis testing since they give an estimate of the magnitude of an effect under investigation (Steidl et al. 1997, Johnson 1999). Confidence intervals can be placed on estimates of population density, observed effects of population change in observations taken over time, or treatment effects in perturbation experiments. They are also commonly used in calculations of effect size in power or meta-analysis (Hedges and Olkin 1985, Gurevitch et al. 1992).

3.4.2 Basic Assumptions of Parametric Models

Parametric statistical models are based on a set of assumptions that are necessary for models to properly fit and describe the data. If assumptions are violated, statistical analyses may produce erroneous results (Krebs 1989, Sabin and Stafford 1990, Sokal and Rohlf 1995). Thus, developers of I&M protocols should consider whether data will likely fit the assumptions of a selected model. Options for dealing with problems of assumption violations should always be presented.

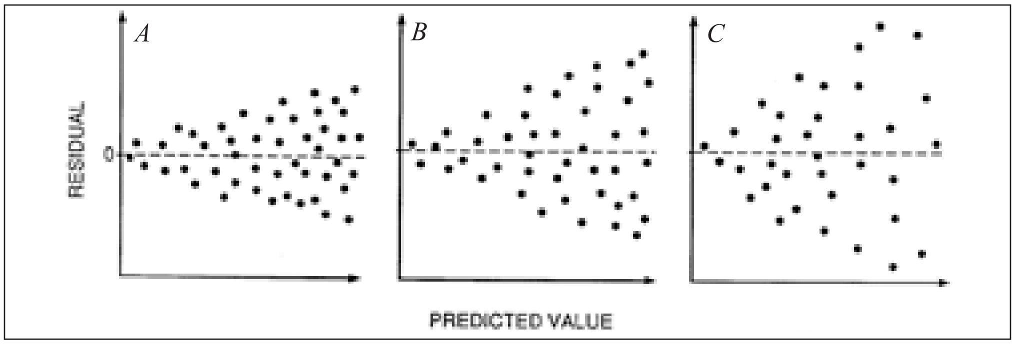
Independence of Observations

An essential condition of most statistical tests is the independence of observations in space and time (usually obtained using random selection). Observations can be counts of individuals or replicates of treatment units in manipulative studies. Krebs (1989) argues that if the assumption of independence is violated, the chosen probability for Type I error (α) cannot be achieved. Analysis of variance (ANOVA) and linear regression techniques are sensitive to this violation (Sabin and Stafford 1990, Sokal and Rohlf 1995). Mixed-model analysis procedures, which are now available in some statistical software packages, allow for some relaxation of the assumption of independence.

Homogeneity of Variances

Parametric models frequently assume that **sampled populations** have similar variances even if their means are different. This assumption becomes critical in studies comparing different groups of organisms, treatments, or sampling intervals. If the sample sizes are equal, then parametric tests are fairly robust to the departure from homoscedasticity (i.e., equal variance of errors across the data) (Day and Quinn 1989, Sokal and Rohlf 1995). In fact, equal sample sizes across treatments should be obtained whenever possible since most tests are overly sensitive to violations of assumptions in situations with unequal sample sizes (Day and Quinn 1989). Plotting the residuals of the analysis against predicted values can reveal the nature and severity of the potential problem. This type of output is a standard feature in many statistical packages. Visual inspection of the data can help determine if transformation of the data is needed and can also indicate the type of distribution (fig. 3.5). Although several formal tests exist to determine the heterogeneity of variances (e.g., Bartlett's test, Levine's test), these techniques assume normal data distribution, which reduces their utility in most ecological studies (Sokal and Rohlf 1995).

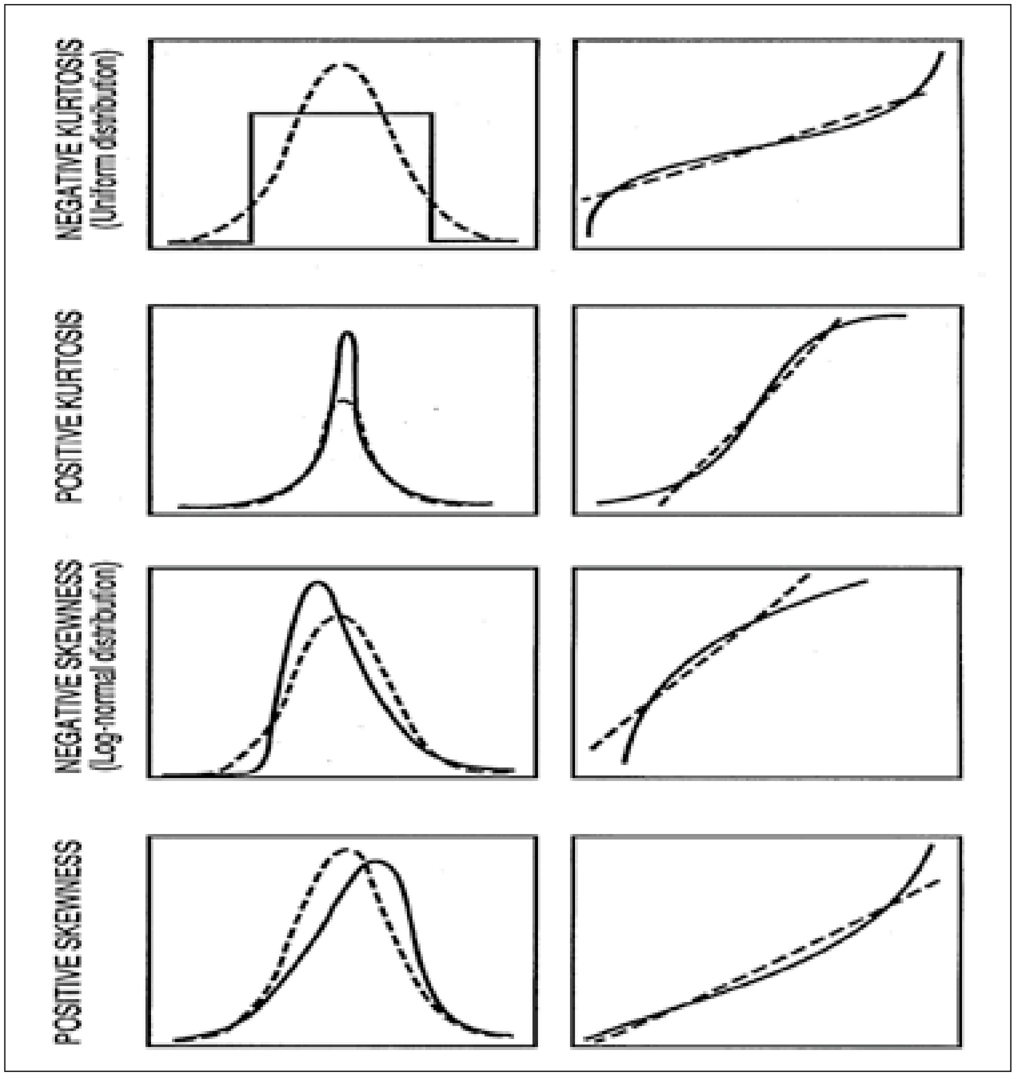
Figure 3.5. *Three hypothetical residual scatters. In Case A, the variance is proportional to predicted values, which suggests a Poisson distribution. In Case B, the variance increases with the square of expected values and the data approximate a log-normal distribution. The severe funnel shape in Case C indicates that the variance is proportional to the fourth power of predicted values (from Sabin and Stafford 1990).*



Normality

Unfortunately, ecological data rarely follow a normal distribution and nonnormality appears to be the norm in biology (Potvin and Roff 1993, White and Bennetts 1996, Hayek and Buzas 1997, Zar 1999). Moreover, the normal distribution primarily describes continuous variables whereas count data, often the type of information gathered during I&M studies, are discrete (Krebs 1989). Although parametric statistics are fairly robust to violations of normality, highly skewed distributions can significantly affect the results. Ideally, the sample size should be equal among groups and sufficiently large (e.g., $n > 20$). The significance of nonnormality can be tested with several techniques, including the W-test and the Kolmogorov-Smirnov D-test for larger sample sizes. Sabin and Stafford (1990), however, argue that the applicability of both tests is limited because they exhibit low power if the sample size is small, and excessive sensitivity when the sample size is large. Graphical examinations of the data are actually more appropriate than formal tests because they enable one to detect the extent as well as the type of the problem. I&M protocols may suggest plotting and scrutinizing data in normal-probability plots (fig. 3.6), stem-and-leaf diagrams, or histograms (Day and Quinn 1989, Sabin and Stafford 1990). Data that are reasonably symmetric about the mean and that do not have a large number of observations in the distribution tails are generally well enough approximated by a normal distribution for most standard analyses for which this is an assumption.

Figure 3.6. *Plots of four hypothetical distributions (left column) with their respective normal probability plots (right column). Solid and broken lines show the observed and normal (expected) distributions, respectively (from Sabin and Stafford 1990).*



3.4.3 Possible Remedies if Parametric Assumptions Are Violated

Data Transformation

If significant violations of parametric assumptions occur, protocol users should be advised to implement an appropriate data transformation to try to resolve the violations. During a transformation, data will be converted and analyzed at a different scale than the original data. Transformations effectively reweight the data and can result in detecting statistical differences when none could be detected otherwise, so it is important to consider the effects of transforming dependent variables on the eventual output. Protocol users must also be aware of the need to back-transform the results after analysis to present parameter values on the original data scale. Table 3.2 gives examples of common types of

Table 3.2. *Some common data transformations in* ***biological studies.*** *Transformations in this table are for dependent (y) variables typically transformed to meet assumptions of statistical tests when testing means. Biologists should be aware of assumptions for each statistical procedure to assess the need to transform variables before transforming variables.*

Transformation type	When appropriate to consider using	Transformation	Back transformation
Square root	Use with count data following a Poisson distribution (figure 3.5A); more generally, when variances are proportional to means. In some instances, addition of 3/8 will improve normality.	$y' = \sqrt{y}$ $y' = \sqrt{y + 3/8}$	$y = y'^2$
Logarithmic	Use with count data when means are proportional to standard deviations (figure 3.5B). A rule of thumb suggests its use when the largest value of the dependent variable is at least 10 times the smallest value.	$y' = \log_e(y+c)$ where c = 0 if all y > 1 and c = 1 otherwise	$y = \exp(y')-c$
Inverse	Use when data residuals exhibit a severe funnel shaped pattern (figure 3.5C), which is often the case in data sets with many near-zero values.	$y' = 1/y$ Note: Inverse transformations will cause very large values to be very small and very small values to be very large. Thus, one must reverse the distribution before transforming by multiplying a variable by -1, and then adding a constant to the distribution to bring the minimum value above 1.0. Once the inverse transformation is complete, the ordering of values will be identical to the original data.	$y = 1/y'$
Arcsine square root	Appropriate for proportional or binomial data. This transformation is beneficial if it improves normality for nonbinomial proportions. Most efficient when most proportions occur at ends of the scale (0.0–0.25 and/or 0.75–1.0), and least effective when proportions are distributed in the middle (0.25–0.75).	y′ = arcsin(square root[y]), where y is a proportion.	$y = (\sin y')^2$
Box-Cox objective approach	If it is difficult to decide on what transformation to use, this procedure finds an optimal model for the data. Box-Cox approaches may address skewed residual distributions and heterogeneous variance.	$y' = \begin{cases} (y^{\lambda} - 1)/\lambda & \text{if } \lambda \neq 0 \\ \log_e y & \text{if } \lambda = 0 \end{cases}$ where, λ is an estimated parameter	$y = \begin{cases} (\lambda y' + 1)^{1/\lambda} & \text{if } \lambda \neq 0 \\ \exp(y') & \text{if } \lambda = 0 \end{cases}$

Source: Modified from Sabin and Stafford (1990).

transformations that may be recommended for use. A wisely chosen transformation can often improve homogeneity of variances as well as produce an approximation of a normal distribution. Sabin and Stafford (1990) and Zar (1999) give good overviews of data transformations in ANOVA and regression models.

A primary reason to avoid transformations is that interpreting transformed variables is very difficult (e.g., what is the arcsine square root of a proportion?). As a result, it is recommended that the data be back-transformed after analysis but back-transformations are not always necessarily at the same scale as the original data. Therefore, practitioners must be aware of the assumptions of the particular statistical model and how transforming will affect their data set. Removing outliers or perhaps using a nonparametric technique may be a better approach than trying to normalize the distribution of data and homogenize variances to meet the assumptions of a parametric model.

Nonparametric Alternatives

If the data violate basic parametric assumptions and transformations fail to remedy the problem, a nonparametric method might be appropriate (Sokal and Rohlf 1995, Conover 1999). Nonparametric techniques have less stringent assumptions about the data, are less sensitive to the presence of outliers, and are often more intuitive and easier to compute (Sokal and Rohlf 1995, Hollander and Wolfe 1999). Since nonparametric models are less powerful than their parametric counterparts, protocols should not advocate the use of nonparametric tests if data meet, or approximate, parametric assumptions (Day and Quinn 1989, Johnson 1995, Smith 1995).

Randomization Tests

These tests are not alternatives to parametric tests, but rather are a means of estimating the statistical significance that relies only on the independence of observations. They are extremely versatile and can be used to estimate significance of test statistics for a wide range of models. Although randomization tests are computationally difficult even with small sample sizes (Edgington 1995), the Forest Service (R. King, personal communication) has developed a Microsoft® Excel macro for randomization tests that is available to Forest Service employees at http://statistics.fs.fed.us. More information on computation-intensive techniques can be found in Crowley (1992), Potvin and Roff (1993), and Petraitis et al. (2001).

Other Approaches

Other parametric techniques such as generalized linear models employ a distribution appropriate for the data instead of trying to normalize them (Ministry of Environment, Lands and Parks 1998). For example, White and Bennetts (1996) give an example of fitting the negative binomial distribution to point-count data for orange-crowned warblers (*Vermivora celata*) to compare their relative abundance among forest sites. Zero-inflated Poisson (ZIP) models and negative binomial regression models are recommended for analysis of count data with frequent 0 values (e.g., rare species studies) in which data transformations are not feasible (e.g., Heilbron 1994, Welsh et al. 1996, Ridout et al. 1998, Agarwal et al. 2002, Hall and Berenhaut 2002).

3.4.4 Statistical Distributions of Plant and Animal Population Data

Poisson Distribution

The Poisson distribution approximates a random spatial distribution common among species with low population density, where the probability of detecting an individual in any sample is rather low (Southwood 1992). As the mean number of individuals in the sample increases, the Poisson distribution begins to approach the normal distribution (Krebs 1989, Zar 1999).

During sampling, the key assumption of the Poisson distribution is that the expected number of organisms in a sample is the same and that it equals μ, the population mean (Krebs 1989). One intriguing property of the Poisson distribution is that it can be described by its mean and that the mean equals the variance (s^2). The probability (frequency) of detecting a given number of individuals ($\bar{x}$) in a sample collected from a population with mean = μ is:

$$P_x = (e^{-\mu} \mu^x)/x!$$

Whether or not the data follow a Poisson distribution can be tested with a simple Chi-square goodness of fit test:

$$\text{Chi-square} = \Sigma \text{ (observed frequency-expected frequency)}^2/\text{expected frequency},$$

or with an index of dispersion (I), which is expected to be 1.0 if the assumption of randomness is satisfied:

$$I = s^2 / \bar{x},$$

where $\bar{x}$ and s^2 are the observed sample mean and variance, respectively.

Krebs (1989) and Zar (1999) provide excellent worked examples of tests for goodness of fit for Poisson distributions. The presence of a Poisson distribution in data can also be assessed visually by examining the scatter pattern of residuals during analysis (fig. 3.5; Sabin and Stafford 1990). If we reject the null hypothesis that observations came from a Poisson distribution, the sampled organisms are either distributed uniformly or regularly (underdispersed) with $s^2 < \bar{x}$, and $s^2/\bar{x} < 1.0$, or they are clumped (overdispersed).

Negative Binomial Distribution

One mathematical distribution that describes clumped or aggregated spatial patterns is the negative binomial (Pascal) distribution (Anscombe 1950, Krebs 1989). White and Bennetts (1996) suggested that this distribution is frequently a better approximation to count data than the Poisson or normal distributions. The negative binomial distribution is described by the mean and the dispersion parameter k, which expresses the extent of clumping. As a result of aggregation, it always follows that $s^2 > \bar{x}$ and the index of dispersion (*I*) > 1.0. The value of k decreases with an increase in the degree of aggregation and vice versa. The value of k can be approximated with:

$$k = \bar{x}^2 / (s^2 - \bar{x})$$

Several techniques exist to evaluate the goodness-of-fit of data to the negative binomial distribution. Good descriptions and examples of their use can be found in Krebs (1989), Southwood (1992), and Zar (1999). Since the variety of possible clumping patterns in nature is practically infinite, neither the Poisson or negative binominal distributions may always adequately fit the data at hand (Krebs 1989).

3.4.5 Analysis Models and Methods

Species' Presence and Frequency of Occurrence

In some cases, simply determining whether a species is present in an area may be a sufficient objective. For example, biologists attempting to conserve a threatened wetland orchid may need to monitor the extent of the species' range and degree of population fragmentation on a national forest. One hypothetical approach is to map all wetlands in which the orchid is known to be present as well as additional wetlands that may qualify as potential habitat. To monitor changes in orchid distribution at a coarse scale, data collection could consist of a semiannual monitoring program conducted along transects at each mapped wetland to determine if at least one individual orchid (or some alternative criterion to establish occupancy) is present. Using only a list that includes the wetland label (i.e., the unique identifier), the monitoring year, and whether the species was present or absent, biologists could prepare a time series of maps displaying all the wetlands on the forest by monitoring year and distinguish the subset of wetlands that were found to be occupied by the orchid (i.e., frequency of occurrence). Such an approach could support a qualitative assessment of changes in the species distribution pattern and generate new hypotheses regarding the cause of the observed changes.

An analysis of species' presence usually requires estimation of the probability of detection because it is rare that individuals of a species will always be detected during a survey. Without estimation of a detection probability, it will not be known whether a lack of detection truly represents a species' absence, or if it represents some probability of the species' presence.

Detection probabilities are estimated from repeated surveys of the same samples, either during a pilot study or during the actual survey (MacKenzie et al. 2002). For example, if a site is sampled three times, with X representing presence and O representing absence, the possible outcomes of three surveys are 3 X's, 3 O's, 1 X and 2 O's or 2 X's and 1 O, in various patterns of XOX, XXO, etc. An average detection probability for all sites sampled can be calculated; the standard error of this average can be estimated using a nonparametric bootstrap method.

MacKenzie et al. (2002) estimated the frequency of occurrence (proportion of sites with species' presence), using a maximum likelihood estimation technique in which the detection probability and probability of occupancy are both estimated parameters. The method is similar to a closed-population, mark-recapture model. In their example, the statistical population was the total number of ponds in a prescribed area and the object was to estimate the proportion of ponds with frogs present (MacKenzie et al. 2002). In a grid-based sample, the total number of grid cells is the statistical population, and the object is to estimate the proportion of grid cells that are likely to be occupied by the target species, given the outcome from a sample of grid cells. This approach has been adopted for estimating goshawk presence over large geographic areas (Hargis and Woodbridge 2006). Recently, new methods such as noninvasive genetic sampling have bolstered our ability to detect presence in grid cells and thus have increased our detection probabilities and precision in presence/absence measures (McKelvey et al. 1999, McDaniel et al. 2000).

Recent studies indicate a positive correlation between frequency of occurrence and species' abundance, because species that increase in abundance also show increases in the number of sites they occupy (Gaston et al. 2000, He and Gaston 2000). As a consequence, presence-absence information is useful for monitoring population trends, (He and Gaston 2000, MacKenzie et al. 2003, MacKenzie et al. 2005).

Assumptions, Data Interpretation, and Limitations. Presence-absence data are binary because each survey site has one of two possible outcomes: presence or absence. A major assumption of presence-absence data is that a species' presence or absence at a site does not change during the survey period because the detection probability is based on a constant state of presence (or absence) during all the visits to the same site. An additional assumption is imposed if the average detection probability for all observations is calculated from pilot data: the detection probability for the actual sample period is the same as that of the pilot study. The detection probability could change, however, if the pilot study took place in a different year, took place at a different time of the same year, used different observers, or was in slightly different habitats. Thus, we recommend that detection probabilities be calculated for each survey period from the actual survey data even though this approach will require multiple visits per site. Survey costs can be reduced by obtaining the detection probability from a subsample of sites as long as the subsample is fairly representative of other sites in terms of factors (such as vegetation density) that could affect detection of the target species.

An analysis of presence or frequency of occurrence works best if the plot size is designed to contain only one or two individuals of the target species because density can affect the detection probability, with higher probability of detections associated with higher densities (Williams and Berkson 2004). When density is consistently high as in a colony or cluster, an analysis of presence based on colony presence rather than individual presence could be meaningful. If density varies greatly among sampling units, the variance around the mean detection probability could be high, thus reducing the precision of the estimate of presence. In this case, it might be better to estimate relative or absolute abundance rather than reduce the data to an analysis of presence.

Abundance and Density

Any analysis of abundance or density should include distance measurements along with counts of individuals whenever imperfect detectability of all individuals is present in a sampling unit. Distance sampling is not simply an analysis tool; it is an integrated approach that encompasses study design, data collection, and statistical analyses (Rosenstock et al. 2002). It is based on research indicating that the probability of detecting an individual declines as distance from the observer increases (Buckland et al. 2001). It also takes into consideration the differences in detectability between point and line transects, because point transects have a larger proportion of observations at distances where detection probability is low than do line transects (Buckland et al. 2001, Rosenstock et al. 2002).

Statistical analyses of distance sampling data can be accomplished with the software package DISTANCE (Thomas et al. 2005), which is available free of charge online from the Centre for Research into Ecological and Environmental Modelling, Research Unit for Wildlife Population Assessment, St. Andrews University, Scotland (http://www.ruwpa.st-and.ac.uk/distance).

After exploratory analysis of distance data, the data are modeled and tested with goodness-of-fit tests. When binomial distance sampling methods are used, goodness-of-fit cannot be tested (Buckland et al. 2001), but Akaike's Information Criterion (AIC) (see the box entitled Akaike's Information Criterion) can be used to select among competing models (Rosenstock et al. 2002).

Mark-recapture models may be used to estimate absolute densities of populations and provide additional information on such aspects as animal movement, geographic

Akaike's Information Criterion

Akaike's information criterion (AIC), derived from information theory, may be used to select the best fitting model among a number of a priori alternatives. AIC can be easily calculated for any maximum likelihood-based statistical model, including linear regression, ANOVA, and other general linear models. The model hypothesis with the lowest AIC value is generally identified as the best model among the identified set of models; models with $\Delta AIC < 5$ are viewed as competing, or equal, models (Burnham and Anderson 2002). Stephens et al. (2005) provide a general perspective on information theory and hypothesis testing. A more in-depth discussion of practical uses of AIC may be found in Lebreton et al. (1992), Anderson et al. (1994), Franklin et al. (2001), and Burnham and Anderson (2002).

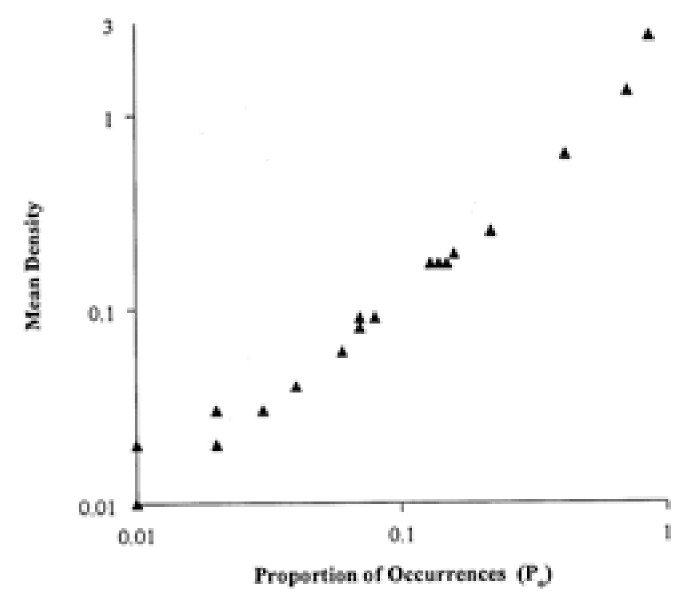
distribution, and survivorship (Krebs 1989). Open mark-recapture models (e.g., Jolly-Seber) assume natural changes in the population size of the species of interest during sampling. In contrast, closed models (e.g., Petersen, Schnabel) assume a constant population size (Krebs 1989). Program MARK (White and Burnham 1999) performs sophisticated maximum-likelihood-based mark-recapture analyses and can test and account for many of the assumptions such as open populations and heterogeneity. The selection of appropriate models to analyze mark-recapture data can be enhanced with the use of AIC (Lebreton et al. 1992, Anderson et al. 1994, Burnham and Anderson 2002). Excellent discussions of absolute abundance techniques can be found in Krebs (1989) and Caughley (1977). Recently, due to the popularity of abundance estimates with genetic data, new mark-recapture models have been created that consider unique properties of genetic tagging (McKelvey and Schwartz 2004, Lukacs and Burnham, in press).

Occurrence data may be used to predict density if the relationship between species occurrence and density is known and the model's predictive power is reasonably high (Hayek and Buzas 1997). For example, one can record plant abundance and species richness in sampling quadrats. The species' proportional abundance, or constancy of its frequency of occurrence (P_o), can then be calculated as:

$$P_o = \text{No. of species occurrences (+ or 0) / sample size (quadrats)}$$

Consequently, the average species density is plotted against its proportional abundance to derive a model to predict species abundance in other locations with only occurrence data (fig. 3.7). Note, however, that the model may function reasonably well only in similar

Figure 3.7. *A relationship between a species sample frequency (proportion of occurrences) and its mean density in habitat (from Hayek and Buzas 1997).*



and geographically related types of plant communities (Hayek and Buzas 1997). Other examples of the use and analysis of relative density data can be found in James et al. (1996), Rotella et al. (1996), Huff et al. (2000), and Knapp and Matthews (2000).

Assumptions, Data Interpretation, and Limitations. Analyses of relative abundance data require attention to data distribution. Since the focus is on count data, alternative statistical methods can be employed to fit the data distribution. Absolute abundance techniques have stringent requirements (Krebs 1989). Given that statistical power negatively correlates with the variability of the monitoring index, choosing an appropriate measure of abundance and estimates of its confidence interval is crucial (Harris 1986, Gerrodette 1987, Gibbs et al. 1999). An excellent overview of a variety of groups of animals and plants for which the variability in estimating their population is known is given in Gibbs et al. (1999).

Vital Rates

The effects of population and habitat management and other environmental factors often directly influence vital rates of populations (DeSante and George 1994). Therefore, an understanding of demographic parameters of populations such as productivity and survivorship is an important element in efforts to monitor any population (Baillie 1990, DeSante and Nott 2000). Information on population density alone may not provide a true indication of population status due to source-sink dynamics (Van Horne 1983). Variation in population size, reflected by density changes, which may potentially be associated with management actions or environmental factors may be confounded by immigration and/or emigration from the surrounding area (George et al. 1992). Monitoring a variety of demographic factors such as age-specific mortality, reproductive rates, age of first reproduction, or number of offspring per female can reveal specific aspects of demography that correlate with observed population changes. These correlations can then be used to investigate whether certain age groups or life events are particularly sensitive to management actions. Furthermore, an understanding of vital rates can provide information about when a population has been stressed in a yearly life cycle. This information may be particularly important to determine if management actions on migratory animals' breeding or wintering areas are influencing the population (DeSante and Nott 2000).

When vital rates are used to monitor population change, efforts must be made to ensure that the vital rates represent the entire population and not a subset of the population that has greater opportunities for survival and reproduction. For example, when estimating reproductive rates or adult survival, the lower rates of senescing adults could be an important consideration (Raphael et al. 1996). Reproductive rates should also include an estimate of the proportion of nonbreeding females in the population. All aspects of population demography must reflect rates associated with low-quality as well as high-quality habitat (Raphael et al. 1996). A good sampling design will reduce potential bias associated with habitat quality.

The ability to use a finite rate of population change (λ) for monitoring purposes is often challenged by a lack of data on juvenile emigration rates. This problem is not trivial, as seen in the case of the northern spotted owl (*Strix occidentalis*), in which original estimates of juvenile survival rates for three study areas were adjusted 42 to 137 percent when researchers were able to incorporate radio telemetry data of juvenile emigration (Franklin et al. 1999, cited in Franklin et al. 2004). In the absence of site-specific emigration rates, Pradel (1996) developed analytical techniques that estimate λ directly from capture-recapture data.

Monitoring efforts associated with land management practices that potentially influence populations should be designed to address the demographic parameters responsible for population change (DeSante 1995). This design may have a higher likelihood of determining the effect of the management practice on the population of interest than relying only on habitat correlations with presence-absence or relative abundance data (DeSante and Rosenberg 1998, Villard et al. 1999).

Emphasis in monitoring populations of northern spotted owls shifted from estimating numbers and densities to evaluating trends of vital rates (e.g., reproduction, survival) (Gutiérrez et al. 1996) because the relationship between land management practices and population trends was considered to be better estimated by vital rates (Franklin et al. 1996). However, a continuing need is recognized for independent estimates of population trend to allow comparisons with, and evaluations of, demographic study results (Bart and Robson 1995, Lint et al. 1999).

Measures of Geographic Range

The principal measures of a species' geographic range are its size, shape, orientation, and internal structure (Rapoport 1982, Maurer 1994, Brown et al. 1996). Estimates of range size at two or more points in time enable analyses of range expansions (Andow et al. 1990, Hastings 1996) or contractions (e.g., Fisher and Shaffer 1996, Flather et al. 2004, Laliberte and Ripple 2004). Range shape is a useful measure for evaluating the influences of physical geography (Rapoport 1982, Brown and Maurer 1989), other environmental limitations (Brown et al. 1996), and factors that result in contractions or expansions (Laliberte and Ripple 2004). Range orientation is less useful for monitoring purposes, but reveals basic relationships between orientation and range size (Brown and Maurer 1989). The internal structure of a geographic range is a measure of discontinuities caused by the number, size, and location of holes and fragments (Brown et al. 1996). Characterizations of internal structure can reveal the processes by which range expansions or contractions take place. Rapoport (1982) observed that home ranges tend to be less continuous toward the periphery, but Channell and Lomolino (2000) found abundant examples of range contractions that left holes within the range's core.

Before conducting an analysis of geographic range, investigators must first decide whether their interest is in the full geographic range, including areas not used by the species, or in only the specific areas where the species actually occurs. Gaston (1991) coined the term "extent of occurrence" for the full range and "area of occupancy" for the areas within the range that actually are occupied. Each of these definitions is associated with different ecological questions. Range maps typically show the extent of occurrence and much of the theory of range size, orientation, and boundary characteristics has stemmed from studies of generalized range maps. In contrast, analyses based on area of occupancy provide information about how the species is distributed within its range. These patterns reveal changes in the internal structure of a geographic range that would not be detectable with generalized range maps. This section highlights three approaches for evaluating changes in a species' geographic range: spatial analysis of occurrence records, spatial analysis of abundance, and analysis of range maps. The first two approaches are based primarily on area of occupancy, whereas the third approach is based on extent of occurrence.

A spatial analysis of occurrence is actually a special case of an analysis of a species' frequency of occurrence as described under the first subheading of this section. The distinction is that the objective is to evaluate all known occurrences, display them spatially, and use them to infer a geographic distribution. For monitoring purposes, a comparison is made of historic and recent occurrences, with historic occurrences based on museum specimens and accounts and recent occurrences based on databases such as the Natural Heritage Programs or on recent field data collected specifically for the purpose of the analysis. For statistical comparisons, occurrences are displayed on a grid or by administrative units such as counties or States. Fisher and Shaffer (1996) mapped historical and current occurrences of amphibians by county in the Central Valley of California and documented statistically significant declines in the number of species currently found in most counties. When mapped, the current distribution of occurrences revealed substantial range contractions for three native species. Flather et al. (2004) used State-level occurrence data to evaluate changes in species' ranges for 1,642 terrestrial animal species in the United States that are associated with forest habitats. Their two sources of historic and current occurrences were NatureServe's central databases and the historic and current geographic range data for all species listed under the ESA. Their analysis showed that the percentage of each taxonomic group now occupying less than 80 percent of historic range was 5.7 percent for mammals, 2.3 percent for amphibians, 1.4 percent for birds, and less than 1 percent for reptiles.

A spatial analysis of abundance takes advantage of abundance estimates obtained from field data across large geographic extents. An estimate of range shape and its internal structure is possible by constructing a probability ellipse based on the likelihood of the species' presence in areas surrounding sites with abundance estimates (Maurer

1994). Rodríguez (2002) used Breeding Bird Survey data to map areas of high and low abundance for 27 species of birds that had undergone significant declines since 1966. He observed range contractions in 22 of the 27 declining species and was able to detect how these contractions affected the internal structure of the geographic ranges.

An analysis of range maps compares changes in the mapped extent of a species' distribution between two or more time periods. This approach is particularly challenging because the mapped image of a species' range lacks precision and **accuracy** and is subject to considerable interpretation. Current and historic maps might exhibit differences in geographic range that are not ecologically meaningful but instead reflect differences in map resolution, mapping rules, and survey efforts between the two time periods. A historic map might simply display the outline of a species' range, whereas a current map might show holes within a range boundary and islands around the perimeter where isolated populations are found (Brown et al. 1996). In spite of these difficulties, a comparison of historic and current range maps is highly valuable because it can reveal an increased risk of extinction for some species and unwanted expansions for others.

Channell and Lomolino (2000) used published range maps as well as authorities' opinions as the basis for comparing historic and current range maps for 309 species of animals and plants. They developed an "index of centrality" to characterize whether the current (remnant) range fell inside or outside the central portion of the historic range. Laliberte and Ripple (2004) compared historic and current geographic ranges of 43 North American carnivores and ungulates using published range maps that they digitized into a GIS. Like Channell and Lomolino (2000), they looked at whether the observed contraction was toward the center or toward the periphery of the historic range. They additionally evaluated whether the pattern of contraction was associated with one or more variables of human influence.

Genetic Measures

Genetic measures are a potential useful monitoring tool because sometimes only relatively small sample sizes are required to make inferences about the population under consideration. (Note: the power to detect a phenomenon can be amplified by increasing the number of genetic markers analyzed and the sample size.) In particular, the following three genetic assays will provide data using only a single sampling occasion (in a single year):

- Changes in genetic diversity.
- Detection of genetic bottlenecks.
- Estimation of effective population size.

Examining differences in genetic diversity, or, more specifically, measures of allelic diversity and heterozygosity, is a powerful approach. It is well documented that in contracting populations, "rare alleles" (rare forms of genes) are rapidly lost; over time this loss is reflected in low levels of allelic diversity and heterozygosity. By comparing allelic diversity or heterozygosity between populations we can assess which populations may be at higher risk of population extinction (Saccheri et al. 1998). If no baseline exists, comparisons can be made across populations.

Furthermore, even without a reference population at time zero for comparison, patterns of allelic diversity (and patterns of allelic diversity combined with heterozygosity) can be used to assess genetic bottlenecks. Luikart and Cornuet (1998) clearly show the detection of previously unknown bottlenecks in natural populations of mountain sheep, wolves, coyotes, brown bears, wombats, and various bird species using single-year samples. Research is currently underway to determine if we can "screen a landscape" to find "cryptic genetic bottlenecks."

Effective population size can also be estimated with a single-year sample. Effective population size is an estimate of population size discounted by demographic factors such as unequal sex ratios in a population and variance in reproductive success. This measure may be more pertinent to managers than abundance estimates because it is the measure that natural selection and other evolutionary forces act upon. Good estimates of effective population size can be obtained with small genetic samples from a population (Schwartz et al. 1998). The measure is more precise, however, if multiple genetic samples can be obtained spanning several generations. Recently, effective population size has been estimated by collecting one sample in a single year and then comparing this sample to DNA obtained from museum specimens (Miller and Waits 2003). One cautionary note is that while DNA can lead to effective population size estimates, it can be difficult to interpret the spatial and temporal scale encompassed by this estimate. The spatial problem is no different than what is encountered when trying to traditionally estimate density. The temporal problem can be used to the manager's advantage as it is probably a more pertinent piece of information than a single-point estimate.

The advantage of using genetic measures as described above or to help estimate geographic distribution, presence-absence, or abundance (see the Population Measures section) is that once the DNA is collected, ancillary information can readily be extracted. For example, without collecting any additional information we can estimate substructure, migration rates between populations, or relatedness between individuals within a population (Manel et al. 2003, McKelvey and Schwartz 2004).

Species-Habitat Relationship Models

Presence-absence data, relative abundance, and estimates of absolute density can be used to build models of species' habitat relationships. The presence and location of marked individuals are especially valuable because the data provide information about species' home ranges and resource usage (Smith et al. 1982, Otis and White 1999, Compton et al. 2002), although such information is usually obtained through specific research studies instead of through monitoring. Regardless of the source, the data must enable a comparison between habitats that were used versus what was available, or between habitats where species were present versus absent, in order to model habitat selection.

Chi-square goodness-of-fit analysis has been widely used to compare observed versus expected use of potential habitat types (Neu et al. 1974, Alldredge and Ratti 1986, 1992). The significance of different explanatory variables (habitat descriptors) in modeling the species' habitat use may be assessed with multivariate techniques (James and McCulloch 1990, Block et al. 1998), logistic regressions (North and Reynolds 1996, Block et al. 1998, Compton et al. 2002), multiple regressions (Orians and Wittenberger 1991, Block et al. 1998), and classic ANOVAs (Orians and Wittenberger 1991) or their nonparametric equivalents such as the Friedman's test and Wilcoxon's signed-ranks test (Alldredge and Ratti 1986, 1992). Additional information on the analysis of habitat selection can be found in Thomas and Taylor (1990), Arthur et al. (1996), Cherry (1996), Garshelis (2000), and McDonald and Manly (2001).

Using a logistic regression, presence-absence data can be used to model the relationship between species occurrence and habitat variables (Breslow and Day 1993, Trexler and Travis 1993, Hosmer and Lemeshow 2000, Agresti 2002). For example, a set of variables to predict the presence of a forest-dwelling salamander species can include such attributes as the percentage of vegetation cover, amount of coarse woody debris, or presence of snags. The resulting function provides an index of certainty regarding species' presence. Cross-validation functions enable the user to identify the probability value that best separates sites where a species was found from where it was not found based on the existing data. Ideally, observations are withheld from formal analysis and used to test the relationships after the predictive relationships are developed on most of the data. A similar model, Poisson regression, is appropriate for data that include counts or the probability of occurrence. This approach is similar to multiple regression except that it models count data from a Poisson distribution (Zar 1999, Agresti 2002). In contrast to the logistic regression, there is no limit on the number of values of the dependent variable in a Poisson regression (i.e., 0 or 1 versus 0, 1, 2, 3…). Count data may also be modeled with negative binominal regressions (White and Bennetts 1996)

Another model that has some utility in modeling presence or absence of a species is discriminant function analysis (DFA), which is a multivariate technique used to determine a set of variables that discriminate between two or more groups. An example is the set of variables that discriminate between surveyed locations where a species is present from locations where a species was absent, with presence and absence being the two groups of interest. Whereas a primary goal of regression analyses is to predict the value of a variable of interest based on a set of predictor variables, a primary application of discriminant analysis is to classify group membership of an observation based on a set of predictor variables (Johnson 1998). A fundamental similarity between DFA and logistic regression is that dependent variables are categorical, while in linear regression they are continuous

(James and McCulloch 1990). DFA assumes that predictor variables are distributed multivariate normal and that across-group variance-covariance matrices for variables are homogeneous (although this assumption may be relaxed), whereas logistic regression does not. Overall, DFA is less efficient than logistic regression because the latter can consider categorical and continuous predictor variables and has fewer assumptions (James and McCulloch 1990, Johnson 1998).

DFA can also be used in an exploratory analysis context, much like principal components analysis. When used in exploratory analysis, relationships are assessed by creating discriminant functions among a group of habitat predictor variables. Scores computed from discriminant functions can be plotted along discriminant axes or incorporated into regression models to further understand their influence on presence or absence of species. Because discriminant function axes are orthogonal to each other, one can compute correlation coefficients between each habitat predictor variable and discriminant axis to provide an interpretation of those variables most influencing variation in a species' presence or absence along a particular axis. Logistic regression is more interpretable than DFA because it computes odds ratios for categorical predictor variables, providing an interpretation of the likelihood of a species being present based on one subgroup in a category in relation to the other subgroups in that category. Logistic regression models, however, are typically limited to analysis of two groups (extension to more than two groups is possible, although more complex).

Assumptions, Data Interpretation, and Limitations. Van Horne (1983) and Block et al. (1998) questioned the general assumption that density estimates alone represent a sufficient measure of habitat quality and, in describing habitat choice, suggested a complementary use of demographic data such as individual survivorship rates and expected future reproduction. For example, the need for this approach could arise in situations in which the species' density may reflect largely past habitat conditions rather than current or long-term habitat quality (Van Horne 1983, Knick and Rotenberry 2000). Additional issues to consider in analyzing habitat selection data include scale-dependency (Orians and Wittenberger 1991, North and Reynolds 1996), subjective decisions about what habitat components constitute potential habitats (Johnson 1980), and species mobility (Rosenberg and McKelvey 1999, Hjermann 2000, Compton et al. 2002).

Species Diversity

The number of species per sample (e.g., 1-m^2 plot) can give a simple assessment of local, α diversity or these data may be used to compare species composition among several locations (β diversity) using simple binary formulas such as Jaccard's index or the Sorensen coefficient (Magurran 1988, Krebs 1989). For example, the Sorensen qualitative index may be calculated as:

$$C_S = 2j / (a + b),$$

where *a* and *b* are numbers of species in locations A and B, respectively, and *j* is the number of species found at both locations. If species abundance is known (number individuals/species), species diversity can be analyzed with a greater variety of descriptors such as numerical species richness (e.g., number of species/number of individuals), quantitative similarity indices (e.g., Sorensen quantitative index, Morisita-Horn index), proportional abundance indices (e.g., Shannon index, Brillouin index), or species abundance models (Magurran 1988, Krebs 1989, Hayek and Buzas 1997). Dyer (1978) describes additional general modeling of species diversity.

Assumptions, Data Interpretation, and Limitations. Species diversity measures can yield results that do not lend themselves to facile interpretations. For example, replacement of a rare or keystone species by a common or exotic species would not affect the community's species richness and could actually improve diversity metrics. The informative value of qualitative indices is rather low because they disregard species abundance and are sensitive to sample size differences (Magurran 1988, Krebs 1989). Rare and common species are weighted equally in community comparisons. Often this assumption may be erroneous since the effect of a species on the community is expected to be proportional to its abundance; keystone species are rare exceptions (Power and Mills 1995).

Trend Data: Change in a Population Measure Over Time

Nearly all types of population measures (e.g., frequency of occurrence, relative density, absolute abundance, vital rates, and a variety of genetic measures) can be used to examine change in population status over time. In this section we highlight a few of the many population measures that can be used to evaluate population trend, and then we provide a brief overview of analytical models.

There is high interest in using frequency of occurrence (proportion of sites with presence) data to evaluate population trends because the data are often easier to obtain than relative abundance or any measure of vital rates. Statistical power simulations, however, indicate that power to detect small changes in the frequency of occurrence is generally low and that managers must be prepared to obtain sample sizes in the hundreds, depending on detection rates, to detect moderate to large changes (Kendall et al. 1992, Zielinski and Stauffer 1996, Strayer 1999). Moreover, possible differences in detection rates from year to year require multiple visits per site to estimate each year's detection probability (MacKenzie et al. 2003). Nevertheless, for species that occur at low densities there is value in pursuing the use of frequency of occurrence data to evaluate trends, at least in the context of broad-scale monitoring designs where adequate sample size is possible.

Relative and absolute abundance and relative density tend to provide greater sensitivity to change than does frequency of occurrence, thus requiring smaller sample sizes to detect change than with frequency of occurrence data. This increased sensitivity brings with it a greater expression of variance, however, creating a challenge to separate a potentially meaningful change in population size from random noise and normal fluctuations in population. Thompson et al. (1998) address the following sources of variation that must be considered when trying to detect trends:

- Sampling variation (uncertainty in each year's population estimate).
- Spatial variation (differences in population size between sites).
- Temporal variation (population fluctuations within a "normal" range).

Generalized linear regression models, in which estimates of population size are plotted against time, are commonly used to analyze trend data. A useful exercise is to begin with a least-squares estimation model and examine whether the residuals exhibit a normal distribution. If not, then a simple linear regression model cannot be used for the analysis (Krebs 1989, Zar 1999). Since count data can be approximated by either a Poisson or negative binomial distribution, other forms of generalized linear models, such as a Poisson regression model, are likely to be more appropriate than a simple linear regression model. Thomas (1996) thoroughly reviews four regression models used for evaluating trends in bird populations and the assumptions associated with each approach. He also addresses factors that complicate analysis of trend data, including observer bias and missing data.

If individual measurements in trend data are autocorrelated, regression models can give skewed estimates of standard errors and confidence intervals and inflate the coefficient of determination (Edwards and Coull 1987, Gerrodette 1987). The Durbin-Watson test (Draper and Smith 1981) can be used to test for autocorrelation among least-squares residuals for an entire analysis. However, computation of a Durbin-Watson test within a grouping factor (e.g., for observations within each plot) is not typically available in commercial software. Several applications, however, can estimate models with plot-level temporal correlation. The MIXED procedure in the SAS statistical analysis software package is capable of specifying temporal (and many other) correlation structures within plots, or more generally within a specified grouping structure, for estimation of models assuming normally distributed residuals (SAS Institute Inc. 2004). The GLIMMIX procedure in SAS extends this capability to generalized linear model formulations, such as Poisson and logistic regression models. The GENMOD procedure in SAS supports a more limited set of correlation structures for generalized linear models, but the estimation procedure used is more robust to small sample sizes than the estimation procedure used in GLIMMIX. S-PLUS and R analysis software packages also provide support for specifying correlation structures among observations for linear and generalized linear models (Insightful Corporation 2001, Venables and Smith 2005). Edwards and Coull (1987) suggested that correct errors in linear regression analysis can be modeled using an autoregressive integrated moving-average process model (ARIMA model). Mixed models provide a general framework within which correlated data may be modeled (e.g., Littell et al. 1996).

Alternative analytical approaches may be necessary for some data where large sample sizes are not possible or where variance structure cannot be estimated reliably. This need is particularly true when the risk of concluding that a trend cannot be detected is caused by large variance or small sample sizes, the species is rare, and the failure to detect a trend could be catastrophic for the species. Wade (2000) provides an excellent overview of the use of Bayesian analysis (see the box entitled Bayesian Inference) to address these types of problems. Trend analyses provide information on how populations have changed in the past but cannot be used for projecting change into the future because each trend analysis is limited to the years the data were collected. It is sometimes possible to make short-term projections, but reliability quickly diminishes as the projection is pushed further out. Nevertheless, trend data can be used to estimate future changes in population in the context of simulation models where habitat and other environmental factors are varied to produce a suite of possible population outcomes. An example of predictive population modeling is demonstrated by research done on the northern spotted owl on Washington State's Olympic Peninsula. Fecundity and adult survivorship were varied in relation to the amount of nesting, roosting, and foraging habitat, producing four possible population outcomes (Raphael and Holthausen 2002). In this manner, the uncertainty of future projections can be clearly displayed.

Bayesian Inference

Bayesian inference represents an alternative to traditional statistical methodology. Bayesian methods test hypotheses not by rejecting or accepting them, but by calculating their probabilities of being true. Thus, *P*-values, significance levels, and confidence intervals are moot points here (Dennis 1996, Taylor et al. 1996). Basing their decisions on existing knowledge, investigators assign a priori probabilities to alternative hypotheses and then use data to calculate ("verify") posterior probabilities of the hypotheses with a likelihood function (Bayes theorem). The highest probability identifies the hypothesis that is most likely to be true given the experimental data at hand (Dennis 1996, Ellison 1996). Bayesian inference—

- Takes advantage of pre-existing data.
- May be used with small sample sizes.
- Is relatively easy to calculate.
- Yields results that are intuitively easier to understand and are more relevant to management (Dennis 1996, Ellison 1996).

For example, conclusions of an I&M analysis could be framed as: "There is a 65 percent chance that clearcutting will negatively affect this species," or, "The probability that this population is declining at a rate of 3 percent per year is 85 percent." Bayesian inference can be used in a variety of statistical tasks, including parameter estimation and hypothesis testing, post hoc multiple comparison tests, trend analysis, ANOVA, and sensitivity analysis (Ellison 1996). A more in-depth coverage of the use of Bayesian inference in ecology can be found in Dennis (1996), Ellison (1996), Dixon and Ellison (1996), Taylor et al. (1996), Wade (2000), Burnham and Anderson (2002), and O'Hara et al. (2002). Even though Bayesian inference is easy to grasp and perform, it is still relatively rare in natural resources applications, and sufficient support resources for these types of tests may not be readily available. It is recommended that it be implemented only with the assistance of a consulting statistician.

Cause-and-Effect Data

The value of trend studies lies in their capacity to detect changes in populations. To understand the reason for population fluctuations, however, the causal mechanism behind the observed change needs to be determined. Cause-and-effect studies represent the only appropriate approach to test cause-and-effect relationships and are often used to assess effects of management decisions on populations. Estimation of cause-and-effect requires control of presumed causative factors within a study in which manipulation of these factors is possible.

Many of the population measures addressed above can be used as response variables in cause-and-effect studies, most notably relative abundance, absolute abundance, and measures of vital rates. Additional response variables include characteristics of individuals such as weight, physiology, onset of first breeding, home range size, activity periods, diet, or social behavior.

Experimental design is the critical component in estimating cause-and-effect. Once a design is in place, however, parametric and distribution-free (nonparametric) models provide countless alternatives to interpreting cause-and-effect data (Sokal and Rohlf 1995, Zar 1999). Excellent introductions to the design and analysis of ecological experiments, specifically for ANOVA models, can be found in Underwood (1997) and Scheiner and Gurevitch (2001). In situations in which repeated measurements are taken from the same sampling units (e.g., quadrats, individuals), the assumption of independence among observations is violated and a more appropriate design calls for a special type of ANOVA, the repeated-measures model (Gurevitch and Chester 1986). Hollander and Wolfe (1999) review application of nonparametric models.

Assumptions, Data Interpretations, and Limitations. When using ANOVA models, one must pay attention to parametric assumptions. Alternative means of assessing manipulative studies may also be employed. For example, biologically significant effect size with confidence intervals may be used in lieu of classic statistical hypothesis testing. An excellent overview of arguments in support of this approach with examples can be found in Hayes and Steidl (1997), Steidl et al. (1997), Johnson (1999), and Steidl and Thomas (2001).

Evaluating the Effects of Management Actions

Analysis of BACI design data depends on the specifics of the design and the properties of the response variables. Generally speaking, the analysis will be a form of ANOVA. If the treatment and control are replicated and have before-after measurement pairs, the analysis will be a repeated measures design (Stewart-Oaten et al. 1986, Smith 2002). If the response variable is species abundance, the data might be first log transformed and the subsequent analysis is basically an analysis of ratios of abundance in the control versus the treatment (Smith 2002). If multiple visits are made to each site (for example, three bird point counts per year), the visits would be treated as subsamples and would contribute another error term to the ANOVA. If it is not possible to replicate the treatment, the design might call for multiple sites within the treatment to be paired with sites outside the treatment that resemble each other in some aspect, such as stand density or vegetation type. In this case, the multiple sites would not be considered subsamples but would be treated as a factorial design, with each density category or each vegetation type representing a factor in the ANOVA (Smith 2002). It should be recognized that an unreplicated comparison is essentially a **case study** in which data apply only to the sites that are sampled, not to a larger population (i.e., the population of inference is defined only by the sampled sites). There is a cost in treating subsamples as analysis units because constraints need to be imposed on the inference from the analysis. Other variations and extensions of the basic BACI model and analysis are presented by Evans et al. (1993).

3.4.6 Interpreting the Analysis

When using a statistical hypothesis test, the results should be carefully evaluated for validity. If a statistical test turns out to be non-significant and fails to reject the null hypothesis (H_O); does this outcome truly indicate that a biological change has not occurred? Or, was an effect not detected due to low statistical power, thus committing a Type II (β; missed-effect) error in the process? Confidence intervals can lend insight into test results. If the set of values associated with non-significance range widely from the null value, the rejected hypothesis may not actually represent a "near-null" state (Hoenig and Heisey 2001). Confidence intervals not only indicate whether the effect was different from 0; they also provide an estimate of the likely magnitude of the true effect size and its biological significance (Hayes and Steidl 1997, Steidl et al. 1997, Johnson 1999).

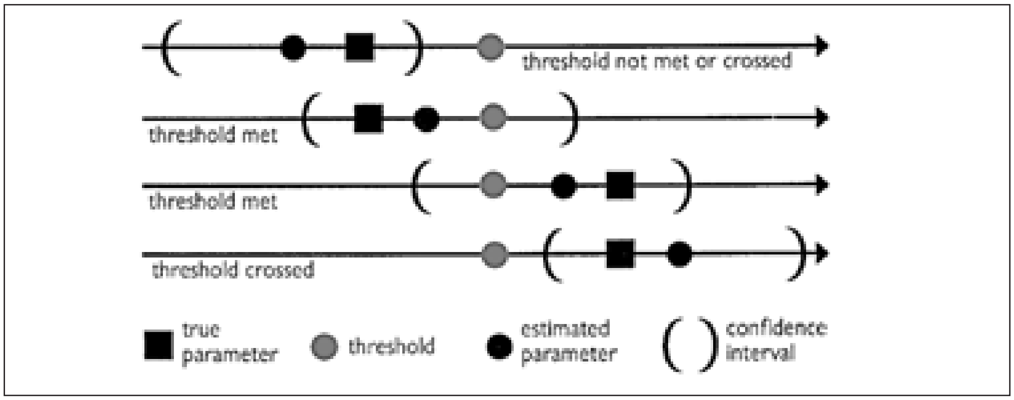
Some researchers advocate the use of retrospective power analysis to interpret test results. Once a confidence interval is constructed, however, power calculations provide no additional insights and can even be misleading (Hoenig and Heisey 2001). If used, retrospective power analysis should be performed only using an effect size other than the effect size observed in the study (Hayes and Steidl 1997, Steidl et al. 1997). In other words, post hoc power analyses can answer only whether the performed study, in its original design, would have allowed for detection of the newly selected effect size.

3.4.7 Assessment of Meeting Management Goals

Two primary goals of monitoring projects are to evaluate whether management objectives are being met and to provide early warnings of unfavorable conditions. The initial step in this process involves comparing the estimates of population indices or parameters acquired during an I&M program against a priori target (threshold) values (Elzinga et al. 2001).

The principle of management goal assessment is illustrated in figure 3.8. In this scenario, a natural resource team wanted to know whether implemented eradication measures (e.g., mechanical plant removal) reduced an exotic plant's population size to a specified level that made further actions (e.g., biocontrol options) feasible. If both the

Figure 3.8. *A decisionmaking process in which an observed population parameter (± confidence interval) is compared against its a priori target (threshold) value (from S. Mori [unpublished data] cited in Elzinga et al. 2001: fig. 9.8).*



observed parameter (e.g., index of relative abundance) and its confidence interval (e.g., 95 percent) were below or above the target threshold value the results would be easy to interpret because the team could be 95 percent confident that the observed value did not reach the target threshold value or it completely crossed the designated target point. Consequently, the management team could proceed with follow up measures designated for either scenario. On the other hand, if the confidence intervals included the threshold value, the interpretation of the monitoring outcome would be less straightforward. One approach is to decide before monitoring that, if any part of the confidence interval crosses the threshold, action will be taken (Elzinga et al. 2001).

3.5 Reporting

The format and content of reports generated from I&M efforts will vary depending on the purpose of the report and the time period of the inventory or monitoring effort that the report represents. Types of reports include reports of pilot studies, interim reports, monitoring and evaluation reports in support of forest plans, final reports at the conclusion of the inventory or monitoring effort, and peer-reviewed publications. Regardless of the reporting purpose, all reports should contain certain elements. The Reporting section provides the opportunity to specify key elements that all reports need to include to meet data quality standards and ensure that the reports are sufficiently thorough.

The following key elements are recommended for inclusion in all reports:

- A statement of the local or regional management problem or policy that prompted the inventory and/or monitoring effort.
- A statement of the inventory or monitoring objective (which could be taken directly from the technical guide that the monitoring effort is based on).

- A description of previous I&M efforts relevant to the targeted species or species group in the management area.
- A description of the area where work was conducted, including a brief characterization of physiography, ecosystems, hydrology, plant communities, and current and past management practices.
- A brief description of the inventory or monitoring design, with reference to a specific technical guide for further details.
- A brief description of how the design was implemented locally or regionally, including the number of sampling units, time period, and any sampling design modifications that were necessary due to local or regional conditions.
- A description of actions taken to ensure data quality (e.g., personnel training, precision checks).
- A detailed description of I&M results in text format and in supporting tables, figures, and/or maps.
- An interpretation of the results, given the limitations imposed by the time period of the inventory or monitoring effort.
- Recommendations for further I&M efforts.

If the report is final or represents a major milestone (e.g., 5 years, 10 years), address the relationship of the inventory or monitoring effort to any preselected threshold value and provide recommendations for how the results may be applied to evaluate or improve management strategies.

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Appendix B. Glossary

accuracy. (1) The closeness of computations or estimates to the exact or true value; (2) the magnitude of systematic errors or degree of bias associated with an estimation procedure that affects how well the estimated value represents the true value (not synonymous with precision).

bias. The difference between the true value of a parameter and its expected value based on sampling. Sources of bias include measurement error (e.g., poorly calibrated instruments) or use of inappropriate estimators for a given sampling design (e.g., failing to correct for a small sample size in estimating the variance of a sample, where $n = 9$).

biological population. A defined group of organisms of one species living in a particular area at a particular time.

biological studies. A wide range of scientific investigations designed to test hypotheses or elucidate ecological relationships. The following two general types of studies are particularly relevant to WFRP I&M technical guides:

- Cause and effect studies—Experiments and rigorously controlled observational studies designed to test whether a change in a specific environmental, ecological, or human factor causes a measurable response in a population.
- Wildlife-habitat relationship studies—The coincidental measurement of a population parameter (or an index) and ancillary measurements of the site or surrounding environment. Qualitative or quantitative analyses are conducted to determine correlative relationships between the population parameter and environmental variables for the purpose of determining species-habitat associations.

case study. The collection and presentation of detailed data from an inventory or monitoring effort that did not replicate treatments and/or did not collect observations in a random fashion. Conclusions may be drawn only about the area in which data were collected and only about the individuals from which observations were made. Case studies do not focus on the determination of findings that are generally applicable, nor do they typically provide cause-and-effect relationships; instead, emphasis is placed on exploration and description.

census. A complete enumeration or count of individuals to determine population size.

detectability. The conditional probability that an individual from the target population will be observed or captured on a sampling unit, given that the species is present. Only in rare situations is it tenable to assume that every individual is detected in a sample or that detectability is uniform across the sampling frame. Pilot studies, double sampling, and capture-recapture methods may be employed to estimate detectability and improve estimates of population size or density.

effect size. The magnitude of a biological effect, often expressed in the original units of measurements as a difference between two means divided by their pooled standard deviation. The power of a statistical test depends, in part, on the effect size identified by the investigator based on biological (as opposed to statistical) significance.

effective population size. The number of breeding individuals in a population.

element. An individual, object, or item of interest that is directly measured, counted, or recorded.

habitat element. Abiotic and biotic features such as rock, soil, elevation, vegetation types, snags, ground cover, and litter that may be ecologically important to a species' welfare.

inventory. (1) The process of collecting data to describe the size, status, or distribution of a population; (2) A survey designed to develop a list of species in a particular area.

landscape. A spatially heterogeneous area, scaled relative to the organism or process of interest.

management indicator species. Those species whose response to environmental conditions is assumed to index like responses of a larger number of species and whose habitats can therefore be managed to benefit a larger set of species; more broadly, species for which a set of management guidelines has been written.

metapopulation. Distinct subpopulations linked by the migration of individuals, which permits the recolonization of an area after the occurrence of a local extinction.

monitor. To watch, keep track of, or check, usually for a special purpose.

monitoring measure. Quantitative criteria for measuring or assessing the attainment of project objectives and/or the effects of project activities. Monitoring measures should be explicit, pertinent, and objectively verifiable.

parameter. A statistical metric that describes the central tendency (e.g., population mean), dispersion (e.g., standard deviation), or other variable of interest for a population. Parameter values are based on a complete set of observations for every member of the population, a circumstance that is very rarely attained in natural resource inventories. Typically, parameter values are approximated using measurements, called statistics, based on data from an incomplete sample of the population.

population monitoring. The process by which a biological population is repeatedly sampled over time for the purpose of detecting changes in abundance, distribution, or demographic parameters.

precision. The closeness to each other of repeated measurements of the same quantity (not synonymous with accuracy).

sampled population. All elements associated with sampling units listed or mapped within the sampling frame.

sampling. The process of selecting and observing (or measuring) a portion of a population for the purpose of estimating a population parameter.

sampling frame. The spatial and temporal limits of the sampled population. A list of all possible sampling units eligible to be selected for sampling.

sampling unit. The basic component of sampling on which observations or measurements are performed. Examples include plots, transects, or individual organisms.

scale, spatial. A measure that is characterized by extent and grain. Extent refers to the area across which the population of interest is distributed. Grain refers to the size of the sampling unit on which observations are made. From a cartographic perspective, the extent is the area of the landscape encompassed within the boundaries of a map, and grain is determined by the size of the minimum mapping unit (e.g., a 25-m pixel).

scale, temporal. A measure of time, usually in years or groups of years.

scope of inference. The scale (of space or time) over which the results can be extrapolated. The scope of inference will depend on the area from which sampling sites were randomly chosen, which is the statistical population or sampling frame. If choice of sites is not random, then the scope of inference is only to those sites and not to other areas (i.e., a case study).

spatial extent. (1) The area over which observations are made (e.g., the boundaries of a study area, a species range); (2) the geographic extent of a geographic data set specified by the minimum bounding rectangle (i.e., xmin, ymin and xmax, ymax).

statistical population. The entire underlying set of individuals from which samples are drawn. The population is defined implicitly by the sampling frame.

stressors. Physical, chemical, or biological perturbations to a system that are either (1) foreign to that system or (2) natural to the system but applied at an excessive [or deficient] level (Barrett et al. 1976: 192). Stressors cause significant changes in the ecological components, patterns, and processes in natural systems. Examples include water withdrawal, pesticide use, timber harvesting, traffic emissions, stream acidification, trampling, poaching, land-use change, and air pollution.

survey. Within the Forest Service, the term commonly refers to inventories performed at a small spatial scale, usually for an individual project. Surveys are distinguished from field checks, site visits, and other casual inspections of an area or a condition because surveys typically have written, systematic protocols for data collection.

target population. All elements representing the species of interest within some defined area and time period.

trigger point. A value of the parameter being monitored. When this value is reached or exceeded, specific, previously defined mitigation measures are implemented.

Appendix C. References

It is beyond the scope of this technical guide to list the thousands of sampling protocols and data collection methods developed by botanists and vertebrate biologists to inventory and monitor biological diversity. However, we offer a short list of references used during the course of our own field work and recommended to us by other plant, wildlife, and aquatic ecologists. We have selected these particular references because of their applicability to a wide range of I&M applications. Authors of WFRP I&M protocols are encouraged to conduct a comprehensive review of existing sampling methods relevant to the particular species of interest before developing new protocols.

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