General Constraints on Sampling Wildlife on FIA Plots

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Abstract.—This paper reviews the constraints to sampling wildlife populations at FIA points. Wildlife sampling programs must have well-defined goals and provide information adequate to meet those goals. Investigators should choose a State variable based on information needs and the spatial sampling scale. We discuss estimation-based methods for three State variables: species richness, abundance, and patch occupancy. All methods incorporate two essential sources of variation: detectability estimation and spatial variation. FIA sampling imposes specific space and time criteria that may need to be adjusted to meet local wildlife objectives.

Traditionally, wildlife sampling programs have sought to document species distribution or abundance and monitor changes in those patterns over time. Management tended to focus on species thought to be declining (the "Declining Species Paradigm," Caughley 1994). Modern wildlife sampling programs focus on either management or scientific objectives (Yoccoz *et al.* 2001). Managers need survey data to understand population status, to evaluate the effects of current or past management actions, or to assist in predicting the consequences of proposed management actions. Scientific objectives generally focus on change in population in response to experimental manipulations or environmental change. The field of adaptive management combines science and management objectives by analyzing wildlife surveys to differentiate among competing scientific hypotheses of a system's response to management actions.

Recent criticism of wildlife sampling programs has focused on two main issues: 1) the lack of clearly defined goals; and 2) the need for estimation-based sampling methods (Olsen *et al.* 1999, Yoccoz *et al.* 2001). Researchers must consider their sampling objectives, and then choose a State variable to characterize the status of their biological system of interest. A State variable can be any variable within the system used to characterize and monitor the state of the system (e.g., population, species diversity, or biomass) (Yoccoz *et al.* 2001). Sampling methods must provide information adequate for estimating the chosen State variable. Traditional, entrenched sampling methods, such as point counts (birds) or time-constrained searches (amphibians and reptiles), are usually inappropriate for most sampling goals (Barker and Sauer 1995). While "standardization" of protocols is important to sampling, it does not ensure consistency in detection rates of most vertebrate species (Barker and Sauer 1995). Estimation-based methods that accommodate detectability differences and spatial variation are necessary to meet most wildlife sampling objectives.

The choice of an appropriate State variable depends on the sampling program's objectives, scale, and resources. Investigators must consider the biological level of the program's objectives and the spatial scale of the proposed sampling. For example, common State variables include species richness for community level analysis, abundance for population analysis, and patch occupancy rate for landscape or patch level analysis. Choosing a State variable also depends on the feasibility and efficiency of the sampling methods. Abundance is often the most expensive State variable to estimate in terms of time and effort and thus is rarely used in large programs. Occupancy and species richness estimation are less expensive and may be more appropriate for landscape-level studies. Occupancy estimation requires multiple visits to the same sites within a season, but only requires the collection of detection/nondetection information (MacKenzie *et al.* 2002). Species richness can also be estimated from detection/nondetection information from repeated visits (Boulinier *et al.* 1998) or using the counts of individuals of each species from one sample per location (Burnham and Overton 1979, Boulinier *et*

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al. 1998). However, species richness estimation is often ineffective in systems with small species pools.

Regardless of the State variable, sampling "protocols" should address two design components: the sample frame and detectability. The sample frame is a complete list of all possible sample units (i.e., plots, transects, quadrats, FIA points). Usually researchers cannot sample all possible units, so a subset of units is selected in some type of probabilistic manner (e.g., stratified random sample). Results from this subset of units are used to draw inferences about the entire area of interest. Likewise, survey methods rarely detect all the individuals or species in an area during the sampling interval. Detection probability, or "detectability," accounts for the proportion of animals or species missed during sampling. Historically, researchers have resisted estimating detection probability, claiming that it complicates field logistics and data analysis. Today, estimation methods are more accessible and new approaches are currently being developed. In the next section we detail current estimation-based methods for three common State variables.

Estimation-based Methods

Species Richness

Well-developed statistical theory exists for species richness estimation using capture-recapture methods (Boulinier *et al.* 1998, Williams *et al.* 2002). Each species is treated as an "individual" and either sample occasions (Boulinier *et al.* 1998) or spatial sample units (Nichols *et al.* 1998b) are treated as the "capture occasions." Models allow for detection probability to vary among sampling occasions (i.e., time), among species (heterogeneity), or by some "behavioral" response, or a combination of these factors (Boulinier *et al.* 1998). Behavioral response may occur when a species becomes more abundant or visible at some point during the sampling season, or if an observer's ability to detect a species increases with his/her exposure to that species (Boulinier *et al.* 1998). Sample units may be visited once or on multiple occasions. If units are visited only once, relative abundance data (counts of individuals for each species) can aid in species richness estimation (Boulinier *et al.* 1998, Burnham and Overton 1979). Theory exists for estimating spatial differences in species richness and community composition (Nichols *et al.* 1998b), and community dynamics such as extinction and colonization rates (Nichols *et al.* 1998a). Numerous computer programs for species richness estimation are available online at http://www.mbr-pwrc.usgs.gov/software.html. (See programs CAPTURE, SPECRICH, SPECRICH2, and COMDYN.)

Abundance Estimation

Extensive literature deals with abundance or population estimation (see Lancia *et al.* 1994, Nichols and Conroy 1996 for brief reviews). These methods can be categorized as either count-based or capture-recapture (or re-sighting) methods. Count-based estimation methods have seen a number of recent advances including distance sampling (Thomas *et al.* 2002), double-observer sampling (Nichols *et al.* 2000), temporal removal methods (Farnsworth *et al.* 2002), and replicated counts (Royle and Nichols 2003). Thompson (2002) reviews many of these methods and their application to sampling terrestrial bird populations.

Capture-recapture methods have existed for over two centuries (Seber 1982) and are typically classified as those suitable for closed (population constant during sampling) or open (population varying among sample periods) populations. Pollock *et al.* (1990), Pollock (2000), and Buckland *et al.* (2000) briefly review many of the capture-recapture models, including key references. There are many options for abundance estimation, and investigators should pay close attention to model assumptions and how they apply to their own systems. Combining estimation methods can increase model flexibility and help resolve problems with restrictive assumptions (Alpizar-Jara and Pollock 1996, Farnsworth *et al.* 2002, Powell *et al.* 2000).

There is an increasing variety of software availabe for analyzing abundance data including programs MARK (White and Burnham 1999, http://www.cnr.colostate.edu/~gwhite/mark/mark.html), DISTANCE (Buckland *et al.* 1993, http://www.ruwpa.stand.ac.uk/distance/), and others (see http://www.mbr-pwrc.usgs.gov/software.html). Most of these software packages have good technical assistance and online user's manuals.

Occupancy Estimation

For many species it is difficult to estimate abundance, but it is often feasible to estimate the proportion of the sample area where a species occurs. MacKenzie *et al.* (2002) developed a statistical-based method for estimating patch occupancy rates when species detection probabilities are less than 1. The method utilized detection/non-detection data from multiple visits to sites within a sampling season. Parameters include species-specific detection probabilities and the proportion of sites occupied. Sites can be discrete sampling units (ponds or patches of forest) or plots or quadrants chosen from an area of interest (MacKenzie *et al.* 2002). Occupancy rates may be modeled as a function of site-specific (habitat) covariates, while detection probabilities can be modeled as functions of both site-specific and time-specific covariates (e.g., sampling occasion, temperature, weather conditions) (MacKenzie *et al.* 2002). Theory also exists to estimate extinction and colonization rates, and occupancy change over time (MacKenzie *et al.* 2003). Current areas of research include estimating species co-occurrence rates, which could prove valuable in multi-species monitoring programs such as the Multiple-Species Inventory and Monitoring (MSIM) approach described in other papers from this forum. Program PRESENCE is specialized software designed for estimating and modeling occupancy rates using detection/nondetection information. It is available at: http://www.proteus.co.nz, and versions of the model have also been incorporated into program MARK (http://www.cnr.colostate.edu/~gwhite/mark/mark.html).

Traditional Sampling Example: Limitations and Modifications

Count-based sampling methods are widespread and deeply entrenched in wildlife literature. We use "point counts" as an example of a count-based technique to demonstrate its uses and limitations. We discuss ancillary information that can be collected to estimate detection probability.

Point counts are a traditional bird survey method used in a wide variety of studies including the North American Breeding Bird Survey (BBS). In point counts, a single observer counts the individuals detected (seen or heard) of each species within a fixed time period and sampling radius. Time periods and sample radii often vary among studies.

Species richness and occupancy rates can be estimated using point counts, especially if sites are visited several times within a sampling season; however, point counts are not appropriate for abundance estimation without estimating detectability. Varying traditional point count protocol would allow for detectability estimation including collecting distance information, using two observers, or recording time of detection. Variable circular points (VCP) are modified point counts where the distance to each detected bird is recorded. Detection rate is modeled as a function of distance from the point and used to adjust raw counts and estimate abundance. Unless all birds near the point are detected, a "donut effect" could result, causing biased abundance estimates. Biologists often question the accuracy of distance methods, but measurement error can be reduced by carefully training observers or using rangefinders. Program DISTANCE is a powerful software package designed to aid in analyzing distance sampling data and it can now incorporate GIS information (see http://www.ruwpa.stand.ac.uk/distance/).

Another way to estimate detection probabilities is to use the double-observer approach (Nichols *et al.* 2000). At each point count, a "primary" observer indicates to a "secondary" observer all birds detected. The secondary observer records all the primary observer's detections as well as any birds missed by the primary observer. Observers alternate primary and secondary roles. This approach permits estimating observer-specific detection probability rates that can be used to adjust raw counts and estimate abundance (Nichols *et al.* 2000).

Finally, a time removal method is a good option when most detections are by sound or when singing frequency is believed to be a major factor influencing detectability (Farnsworth *et al.* 2002). The timed point count is divided into intervals (equally spaced, if possible) where all individual bird detections are recorded in each interval. The method can estimate detection probabilities that vary by species, over time, or among observers (Farnsworth *et al.* 2002).

In summary, traditional, nonreplicated point counts are appropriate only for estimating species richness. If points are visited on multiple occasions within season, then both occupancy rate and species richness can be estimated. Further ancillary information is necessary to estimate abundance, but investigators have a variety of options that could be tailored to their specific system of interest.

Application to Forest Inventory and Analysis Plots

The Forest Inventory and Analysis (FIA) program is useful because of its well-defined survey units and large-scale, long-term monitoring history. The ability to coordinate wildlife sampling at FIA points facilitates collection of co-located and historical information that may be important in determining: 1) species distributional range and temporal trends; 2) species-specific habitat associations; and 3) species response to management action. Unfortunately, FIA imposes a sample frame at a specific spatial and temporal scale. This scale is likely insufficient (i.e., too coarse) to meet local wildlife management or scientific objectives. Defining the scope of inference at FIA points in terms of wildlife populations is difficult. One alternative is to define a two-stage sampling procedure in which a group of FIA points constitutes a "local sampling frame" and draw samples from within the area (e.g., National Forests or ecoregions). This is the format used in the MSIM approach discussed in detail in other papers (e.g., Dunk et. al 2004, Manley et. al 2004). MSIM uses estimation-based methods to monitor occupancy rate as the focal State variable, but species richness could also be estimated under the current design. Hypotheses about spatial and temporal variations in these State variables can be tested statistically.

It is useful to consider alternative designs that provide more detailed spatial information at the scale of forests for use in local management. For example, a stratified frame could be developed with forest-scale monitoring of a chosen State variable in which FIA points were treated as a stratum within the forest. Again, the appropriate sampling frame will be influenced by the study's management or scientific objectives, and any sampling "protocol" applied to sites within the frame should incorporate estimation-based methods.

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