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Accounting for incomplete detection: What are we estimating and how might it affect long-term passerine monitoring programs?

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ABSTRACT

A primary objective of ecological monitoring programs typically includes the efficient detection of population trends. Passerines as a group are important ecological indicators and are often included in such programs to provide information on multiple species with a single survey technique. However, commonly used field and analytical approaches may not provide appropriate inference or sensitivity due to assumption violations and differences in the proportion of the population exposed to sampling. Recent methodological developments utilizing repeated point counts and an N-mixture modeling approach for analysis may produce more consistent and interpretable estimates applicable to the superpopulation of individuals using a site during the breeding season. These estimates should be more useful for monitoring because they are not conditioned on presence or availability as are most single-visit approaches. We used repeated count data collected in Denali National Park and Preserve, Alaska (Denali) between 1995 and 2009 from 12 common passerine species to assess variation in presence and availability throughout the season, estimate trends in superpopulation abundance, and provide recommendations for the design of future monitoring programs. We found that variation in detection due to presence and availability was large and differed among species. After accounting for these sources of variation, we estimated abundance of Wilson's warblers (*Wilsonia pusilla*) had declined by approximately 48% and fox sparrow (*Passerella iliaca*) abundance had increased by approximately 250% over 15 years. Combined, our results suggest that if trend estimation is a priority, passerine monitoring programs should formally address all components of the detection process, including the probabilities of presence and availability.

1. Introduction

While valuable and necessary for conservation, many long-term monitoring programs have suffered from poor planning and study design (Lindenmayer and Likens, 2009, 2010; Reynolds et al., 2011; Thompson et al., 2011). Lack of detailed thought and direction during the design phase of a monitoring program can prevent proper inference for the population or system of interest and limit utility for management (Nichols and Williams, 2006). Similarly, improper or incomplete understanding of the type of inference that can be made based on the field sampling methods and associated analyses can further reduce the utility of monitoring data, potentially leading to erroneous conclusions or delays in appropriate conservation decisions. The development of suitable monitoring schemes for passerine birds, and the problem of incomplete detection have received much attention in the scientific literature in recent years (e.g., Alldredge et al., 2007a; Farnsworth et al., 2002, 2005; Nichols et al., 2009; Rosenstock et al., 2002), but uncertainty in the appropriate direction for long-term passerine monitoring programs remains.

The comparability of estimates of detection probability (p) and abundance based on different field methods is largely dependent on those components of the detection process addressed by each method and the validity of the assumptions made regarding those remaining. A recent methodological review by Nichols et al. (2009) identified 4 primary components of p: (1) the probability that the bird's home range includes at least a portion of the sampling unit, p_s, (2) the probability that the bird is present within the sample unit during the survey period, p_p, (3) the probability that the bird is available for detection during the sampling event, p_a, and (4) the probability that a bird is detected given that it is present and available, p_d. The first, p_s, was identified as a part of all detection methods that is generally dealt with through study design. The remaining three components must be addressed explicitly, or one must assume that the unaddressed components of p do not vary across time and space, otherwise inference will apply to an undefined segment of the population. These assumptions may not be reasonable in many situations and can lead to large differences

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in inference and conclusions. In addition, because each of the most commonly applied field techniques addresses different components of incomplete detection, the definition of the 'population' to which the resulting abundance estimates apply varies. This limits meaningful comparisons of estimates based on different field methods, and leads to further confusion regarding which 'population' is being monitored.

Unadjusted point counts are one of the most commonly used field sampling approaches for long-term monitoring of passerine populations in North America (e.g., Peterjohn, 1994; Ralph et al., 1995; Rosenstock et al., 2002; Sauer et al., 2003) and were generally developed with the broad goal of identifying and assessing changes in the abundance of breeding passerines at large scales (e.g., Hutto, 1998; Peterjohn, 1994). These methods implicitly assume that p_p, p_a, and p_d vary little (or not at all) relative to population trends (Anderson, 2001; Nichols et al., 2009; Ralph et al., 1995; Rosenstock et al., 2002). The raw counts are treated as an index of abundance across space and time (Johnson, 2008) and are used to assess population trajectory (e.g., Ralph et al., 1995). Despite widespread use, these index surveys often violate the assumption of a relatively constant p (Burnham, 1981; Farnsworth et al., 2002; Thompson, 2002; Wilson and Bart, 1985), and a reliance on standardization to meet the assumptions of constant p is unreasonable in most circumstances. Unexplained variation in p can produce biased estimates of abundance and trends (Kéry et al., 2005; Pollock et al., 2002) and can reduce efficiency in estimating population change (Sauer et al., 2003). The inclusion of covariates related to systematic changes in detection components through the use of Bayesian hierarchical models has been shown to reduce bias for large-scale passerine monitoring programs based on simple point count data (Link and Sauer, 1997, 1998, 2002). However, this approach cannot account for covariates such as succession or arrival timing that may also be associated with trends in abundance (Nichols et al., 2009). This approach may likewise be less efficient than methods directly addressing components of p, particularly for programs at local-scales. This emphasizes the need for appropriate data collection and statistical model use to avoid unnecessary and unsupportable assumptions about perfect or homogeneous detection (Conroy et al., 2011).

Distance-sampling and associated analytical tools (Burnham et al., 1980, Buckland et al., 2001) have commonly been applied to passerine bird monitoring programs in an effort to solve problems related to incomplete detection (Buckland, 2006; Marques et al., 2007; Rosenstock et al., 2002), by directly addressing p_d and thereby improving estimates of abundance. However, distance sampling surveys based primarily on auditory cues often violate the basic assumptions of the approach and produce unreliable estimates of abundance (Alldredge et al., 2007b; Bachler and Liechti, 2007; Efford and Dawson, 2009; Simons et al., 2009). Double observer methods (Alldredge et al., 2008; Nichols et al., 2000) also address p_d with fewer unmet assumptions, but if only conducted once per season at each site, either method confounds variation in p_p and p_a with variation in abundance. Time of detection methods (Alldredge et al., 2007a, 2007c; Farnsworth et al., 2002) estimate both p_d and p_a, but do not address p_p. Each of these approaches, while providing a defensible estimate of some components of p, must make tenuous assumptions regarding the remaining elements. It is highly likely that p_p and p_a change temporally (e.g., hourly, daily, annually), suggesting that estimates of abundance based on a sampling approach that does not directly address these detection components will be biased by an unknown amount. The risk of bias has obvious implications for long-term monitoring programs, although recent developments in field and analytical methods suggest a potential solution.

Kéry et al. (2005) recently demonstrated that temporally repeated counts could be useful as an alternative field sampling technique for passerines that included the estimation of p_p as part of the overall p. Counts were repeated over multiple days during a relatively short portion of the breeding season, and the series of counts was then analyzed using hierarchical N-mixture models (Kéry, 2008; Royle, 2004). This approach is a direct extension of the methods developed for occupancy estimation (MacKenzie et al., 2006; Royle and Nichols, 2003), and the use of zero-inflated Poisson (ZIP) mixtures can improve fit when individuals are not detected at a large proportion of sampling points (Joseph et al., 2009; Martin et al., 2005; Wenger and Freeman, 2008). One of the primary advantages of these methods is that p_d, p_a, and p_p are all included in the composite estimate of p when sampling is conducted over multiple days throughout the breeding season. The resulting abundance estimates are analogous to "use" in an occupancy framework (MacKenzie et al., 2006; Mordecai et al., 2011) and represent the "superpopulation" of territories used during the season that intersect the sampled space at each sampling location. However, because the area sampled is undefined, superpopulation abundance cannot generally be expressed as density. This is very similar to the definition of the superpopulation used in the capture–recapture literature (Kendall et al., 1997; Nichols et al., 2009; Schwarz and Arnason, 1996; Williams et al., 2002).

The primary advantage to using the superpopulation for inference is that it represents the total breeding population using a site during the season and is not conditioned on presence or availability across time and space for appropriate inference. Patterns in migratory arrival differ among species, and both p_p and p_a are likely to increase to a peak and then decline in differing patterns among species throughout the breeding period. The breadth of this peak may also vary among species with some having high p_p and p_a for a longer periods. Similarly, the timing of peak vocalization likely varies among species. Some species sing primarily early in the morning and become nearly silent later in the day, while others may be more likely to vocalize mid-morning or even sing at a rather consistent rate throughout the day. This suggests that the date and time of any given survey is unlikely to be optimal for all species, and without addressing p_p and p_a directly, it becomes difficult to identify to which population or portion of the population the abundance estimates apply. Monitoring programs are often intended to continue for decades, and the likelihood of p_p and p_a remaining relatively constant through time is low. In addition, if trends in peak arrival or breeding periods were to occur, trends in abundance based on single visit surveys would likely be highly dependent on untestable assumptions about annual variation in survey timing, conditions, and migratory arrival patterns. The subsequent reduction in power would result in longer time periods necessary to detect population trends, increased potential for detecting false trends, and decreased efficacy of passerine conservation programs in general.

Efforts to estimate abundance and identify trends in a suite of passerine birds in Denali National Park and Preserve (Denali) have been underway since 1992 as part of the National Park Service's (NPS) long-term ecological monitoring program. More recently, the passerine monitoring work in Denali was included in the Central Alaska Monitoring Network's program (MacCluskie et al., 2005) as part of the national NPS Inventory and Monitoring effort (Fancy et al., 2009). Past passerine monitoring efforts in Denali consisted of unadjusted point counts and distance sampling surveys but were determined to be unlikely to meet objectives due to identified assumption violations (see Alldredge et al., 2007b; Hoekman and Lindberg, 2012). We used repeated count data collected in Denali between 1995 and 2009 to demonstrate the potential inferential and logistical advantages of repeated point count methods for long-term passerine monitoring programs. Our primary objectives were to: (1) assess the magnitude of temporal variation in p for the most common species in Denali, (2) assess trends