TOS SCIENCE DESIGN FOR
BREEDING LANDBIRD ABUNDANCE AND DIVERSITY

PREPARED BY	ORGANIZATION	DATE
Katherine M. Thibault	SCI	04/17/2018

APPROVALS	ORGANIZATION	APPROVAL DATE
Kate Thibault	SCI	05/30/2018
Mike Stewart	SYS	05/29/2018

RELEASED BY	ORGANIZATION	RELEASE DATE
Judy Salazar	CM	06/01/2018

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1 DESCRIPTION

1.1 Purpose

NEON design documents are required to define the scientific strategy leading to high-level protocols for NEON subsystem components, linking NEON Grand Challenges and science questions to specific measurements. Many NEON *in situ* measurements can be made in specific ways to enable continental-scale science rather than in ways that limit their use to more local or ecosystem-specific questions. NEON strives to make measurements in ways that enable continental-scale science to address the Grand Challenges. Design Documents flow from questions and goals defined in the NEON Science Strategy document, and inform the more detailed procedures described in Level 0 (L0; raw data) protocol and procedure documents, algorithm specifications, and Calibration/Validation (CalVal) and maintenance plans.

1.2 Scope

This document defines the rationale and requirements for Breeding Landbird Abundance and Diversity sampling in the NEON Science Design.

1.3 Acknowledgments

The design of the breeding landbird abundance and diversity sampling for NEON described herein is the result of invaluable input from the original Breeding Landbird Abundance and Diversity Technical Working Group, including Jennifer Blakesley, Richard Chandler, Tom Gardali, Allen Hurlbert, Paul Lukacs, Ken Pollock, Kathryn Purcell, Ted Simons, and Susan Skagen, the leader of the NEON Tiger team for breeding birds, Andy Hansen, as well as the decades of effort and dedication of countless field ornithologists and citizen scientists. Thanks to Tanya Chesney for her thorough copy-editing and formatting of the document.

2 RELATED DOCUMENTS AND ACRONYMS

2.1 Applicable Documents

Applicable documents contain information that shall be applied in the current document. Examples are higher level requirements documents, standards, rules and regulations.

AD[01]	NEON.DOC.000001	NEON Observatory Design
AD[02]	NEON.DOC.001282	Introduction to the TOS Science Designs
AD[03]	NEON.DOC.000913	TOS Science Design for Spatial Sampling Design
AD[04]	NEON.DOC.002652	NEON Level 1, Level 2 and Level 3 Data Products Catalog
AD[05]	NEON.DOC.014041	TOS Protocol and Procedure: Breeding Landbird Abundance & Diversity

2.2 Reference Documents

Reference documents contain information complementing, explaining, detailing, or otherwise supporting the information included in the current document.

RD [01]	NEON.DOC.000008	NEON Acronym List
RD [02]	NEON.DOC.000243	NEON Glossary of Terms

2.3 Acronyms

All acronyms used in this document are defined in RD[01].

3 INTRODUCTION

3.1 Overview of the Observatory

The National Ecological Observatory Network (NEON) is a continental-scale ecological observation platform for understanding and forecasting the impacts of climate change, land use change, and invasive species on ecology. NEON is designed to enable users, including scientists, planners and policy makers, educators, and the general public, to address the major areas in environmental sciences, known as the Grand Challenges (Figure 1). NEON infrastructure and data products are strategically aimed at those aspects of the Grand Challenges for which a coordinated national program of standardized observations and experiments is particularly effective. The open access approach to the Observatory's data and information products will enable users to explore NEON data in order to map, understand, and predict the effects of humans on the earth and understand and effectively address critical ecological questions and issues. Detailed information on the NEON design can be found in AD[01], AD[02].

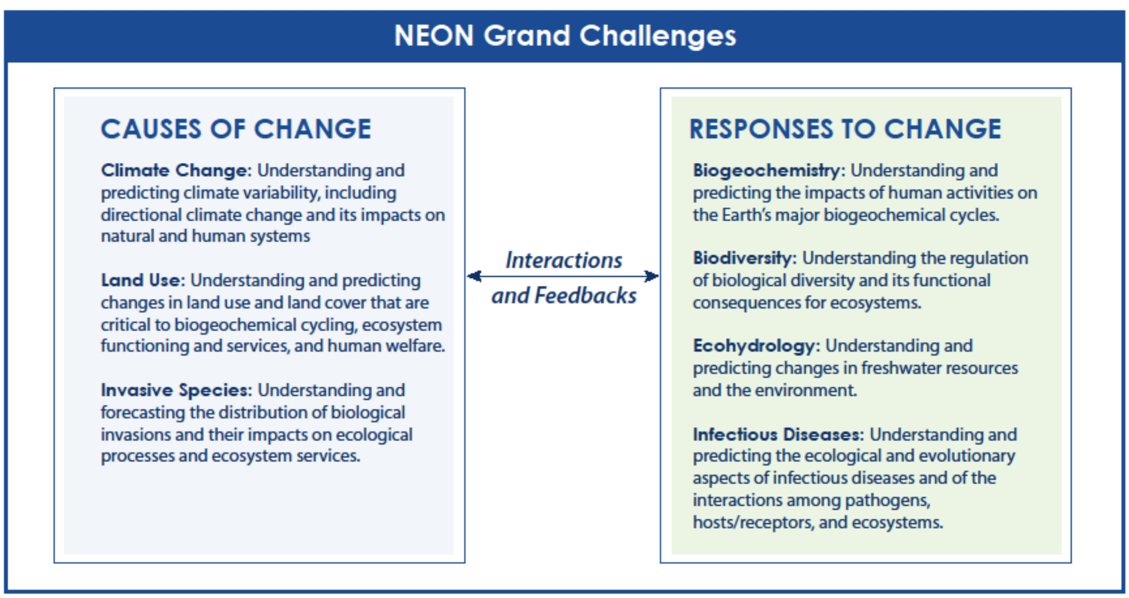


Figure 1. The seven Grand Challenges defined by the National Research Council (2001)

3.2 Components of the Observatory

There are five components of the Observatory, the Airborne Observation Platform (AOP), Terrestrial Instrument System (TIS), Aquatic Observation System (AOS), Aquatic Instrument System (AIS), and Terrestrial Observation System (TOS). Collocation of measurements associated with each of these components will allow for linkage and comparison of data products. For example, remote sensing data provided by the Airborne Observation Platform (AOP) will link diversity and productivity data collected on individual plants and stands by the Terrestrial Observation System (TOS) and flux data captured by instruments on the tower (TIS) to that of satellite-based remote sensing. For additional information on these systems, see Keller et al. 2008, Schimel et al. 2011.

3.3 The Terrestrial Observation System (TOS)

The NEON TOS will quantify the impacts of climate change, land use, and biological invasions on terrestrial populations and processes by sampling key groups of organisms (sentinel taxa), infectious disease, soil, and nutrient fluxes across system interfaces (air, land, and water) (AD[01], AD[02]). The sentinel taxa were selected to include organisms with varying life spans and generation times, and wide geographic distributions to allow for standardized comparisons across the continent. Many of the biological measurements will enable inference at regional and continental scales using statistical or process-based modeling approaches. The TOS sampling design captures heterogeneity representative of each site to facilitate this inference when possible. Plot and organism-scale measurements will also be coordinated with the larger-scale airborne measurements, which provide a set of synergistic biological data products at the regional scale. The standardization of protocols across all sites is key to the success of NEON (and its novelty) and must be maintained at all sites through time. Thus, although specific techniques may be required at some sites (e.g., due to different vegetation types), protocols have been developed to ensure data comparability. Details of these design elements and algorithms can be found in individual design documents available through the NEON website (www.neonscience.org).

The TOS Science Designs define the scientific strategies leading to high-level sampling designs for NEON sentinel taxa, terrestrial biogeochemistry, and infectious disease, linking NEON Grand Challenges and science questions to specific measurements (AD[02]). The TOS Spatial Sampling Design document describes the sampling design that collocates observations of the components of the TOS (AD[03]). TOS Science Design documents were developed following input from the scientific community, including discipline-specific Technical Working Groups, and the National Science Foundation (AD[02]). Science Designs will be reviewed periodically to ensure that the data collected by NEON are those best suited to meet the requirements of the observatory (AD[01]), are (to the extent possible) consistent with standards used by the scientific community, and fit within the scope of NEON. Additional information on the development and review process can be found in AD[02].

4 INTRODUCTION TO THE BREEDING LANDBIRD SAMPLING DESIGN

4.1 Background

Field studies of birds have played a key role throughout the history and development of both natural resource management and ecology. For example, the year 1900 marked the passage of the first U.S. law to significantly restrict the exploitation of wildlife, the Lacey Act, primarily in response to observed declines in game bird populations, as well as the initiation of the Christmas Bird Count, a citizen science effort that now represents 'the longest-running and geographically most widespread survey of bird life in the Western Hemisphere' (Dunn et al. 2005b). Soon thereafter, the foundational concept of the ecological niche was first described in relation to the California thrasher (Grinnell 1917), and subsequently furthered in a classic study of coexistence in warblers (MacArthur 1958). The pivotal role that birds have played results in no small part from the combination of their charisma, relatively conspicuous visual and aural displays, and diurnal activity (Hutto and Young 2002). Moreover, birds are ecologically significant as (a) primary and secondary consumers, (b) indicators of highly-functioning food webs (Hechinger and Lafferty 2005), and (c) reservoirs for zoonotic pathogens (Claas et al. 1998, LaDeau et al. 2007). Recent studies have also described the diverse ecological services that birds provide, including pollination and seed dispersal (Sekercioglu 2006, Anderson et al. 2011).

Consequently, birds are one of the most surveyed taxa, with an estimated 2,000 programs implemented in the U.S. and Canada alone (Bart 2005). These programs include an unparalleled number of regional-, national-, and continental-scale data collection and compilation efforts, including the North American Breeding Bird Survey (BBS; Sauer et al. 2011), the Monitoring Avian Productivity and Survivorship (MAPS) program (Saracco et al. 2008), the California Avian Data Center (http://data.prbo.org/cadc2/), Rocky Mountain Bird Observatory's (RMBO) Integrated Monitoring in Bird Conservation Regions (IMBCR) program (White et al. 2012), the Christmas Bird Count (National Audubon Society 2002), the Avian Knowledge Network (AKN) and eBird (Sullivan et al. 2009), and the Partners in Flight (PIF) Landbird Population Estimates Database (Blancher et al. 2007). The information gained by these diverse efforts have revealed declines and emergent threats to bird populations, with Partners in Flight identifying 192 species of the 448 landbird species in the U.S. and Canada as Species of Continental Importance, in need of conservation action or additional information (Rich et al. 2004).

Box 1. What is a breeding landbird?

According to Ralph et al. 1993, a landbird is "the general term used for the generally smaller birds (usually exclusive of raptors and upland game birds) not usually associated with aquatic habitats." Landbirds are typically censused during the first half of the breeding season, when birds are "most active, paired, on territories, and vocal" (Ralph et al. 1993). For the remainder of this document, 'bird' and 'breeding landbird' are used interchangeably.

The quantity of data available for birds has allowed for more targeted research needs to be identified. For example, PIF delineated the high priority needs for species-specific range-wide monitoring of 295 landbird species in North America, including increasing intensity of BBS sampling routes in certain areas and habitats and increasing temporal coverage of sampling beyond May to July (Dunn et al. 2005a). Bart (2005) highlighted the need for increased demographic data, such as those collected by MAPS, and for integrated sampling of birds and additional ecological variables. The U.S. North American Bird Conservation Initiative (NABCI) recommended in a recent report that increased statistical rigor, coordination of efforts, and improved data management and sharing were critical to advancing the efficacy of bird monitoring efforts (U.S. North American Bird Conservation Initiative Monitoring Subcommittee 2007, White et al. 2012). NEON's bird sampling should be designed with these needs in mind with the intent that some, albeit not all, of them can be addressed in part by the efforts of the Observatory.

4.2 NEON's Contribution

Breeding landbirds (Box 1) were chosen to be a component of NEON's suite of biodiversity measurements (Kao et al. 2012), because breeding birds, in addition to the aforementioned characteristics, (a) have proven useful in large-scale modeling of climate change impacts (Stralberg et al. 2009, Tingley et al. 2012); (b) are consumers of other NEON taxa (i.e., insects, plants); (c) serve as reservoirs for mosquito-borne diseases of interest to NEON (e.g., West Nile Virus; LaDeau et al. 2007, McKenzie and Goulet 2010); (d) can be impacted by nest predation by small mammals (also a NEON target taxon; Schmidt et al. 2008); (e) are vulnerable to climate change (Gardali et al. 2012); and (f) respond strongly to land-use change (Luther et al. 2008, Newbold et al. 2012, Jongsomjit et al. 2012). Moreover, the long history of data collection at the regional and national scales allows for the integration of NEON sampling into larger datasets to examine regional and continental-scale and decadal-scale trends (e.g., Bart et al. 1995, Saracco et al. 2008).

Given that NEON will be conducting terrestrial sampling at only 47 sites (compared, for example, to the >5,000 routes in the BBS), NEON will be able to use an intensive, statistically rigorous survey method that will provide more robust estimates of bird populations at smaller scales to complement the BBS data (Kao et al. 2012). The combination of the NEON bird data with existing regional- and continental-scale breeding bird datasets, and with the collocated, standardized suite of diverse measurements included in the NEON TOS, TIS, and AOP will provide unprecedented power to track changes in population densities, community composition, and biodiversity among habitats and land-use types through time, as these patterns relate to climate, invasive species, and infectious disease (e.g., Box 2). Finally, these data will be freely available and accessible on the internet, and can be integrated into existing databases, such as the AKN.

Box 2. NEON Use Case: Breeding birds and Infectious disease

Since the beginning of the West Nile Virus (WNV) outbreak in 1999, there is a signal of cyclical patterns in the intensity of the epidemics each year that is significantly linked to bird community composition (e.g., McKenzie and Goulet 2010). NEON data would be ideal for addressing the underlying drivers of that cyclical pattern. For example, in the context of the 2012 WNV epidemic, if all NEON sites were up and running, we could link climate data to mosquito populations, mosquito infections, and bird community data. --Dr. Valerie McKenzie

4.3 Purpose and Scope

The purpose of the NEON breeding bird sampling is to capture interannual variation in the abundance, diversity, and distribution of breeding birds within each domain and across the continent to answer key questions in continental-scale ecology (Table 1).

This document details the approach used to derive a scientifically rigorous, logistically feasible sampling design based on point counts that meets the goals of the Observatory. Acoustic monitoring has been considered as a complementary method to collect data on bird diversity and phenology (e.g., Celis-Murillo et al. 2009, Blumstein et al. 2011), but is contingent on advances in machine learning algorithms to automate species identification of bird songs and calls.

Table 1. Example science questions that could be addressed with NEON data.

How do breeding bird communities vary both within core sites and across land use types and ecoregions?
Which bioclimatic and habitat factors best predict the species composition of breeding bird communities?
How do invasive terrestrial plant species and their biogeochemical environments impact the community composition of breeding birds?
How do bird species distributions shift in response to climate change?
How are the rates of geographic spread and population growth of introduced bird species affected by land use and climate change?
How do changes in bird community composition alter the dynamics of West Nile Virus?

5 SAMPLING FRAMEWORK

5.1 Science Requirements

This science design is based on Observatory science requirements that reside in NEON's Dynamic Object-Oriented Requirements System (DOORS). Copies of approved science requirements have been exported from DOORS and are available in NEON's document repository, or upon request.

5.2 Data Products

Execution of the protocols that stem from this science design generates raw data satisfying NEON Observatory scientific requirements. These data and samples are used to create NEON data products, and are documented in the NEON Data Products Catalog (AD[04]; Figure 2).

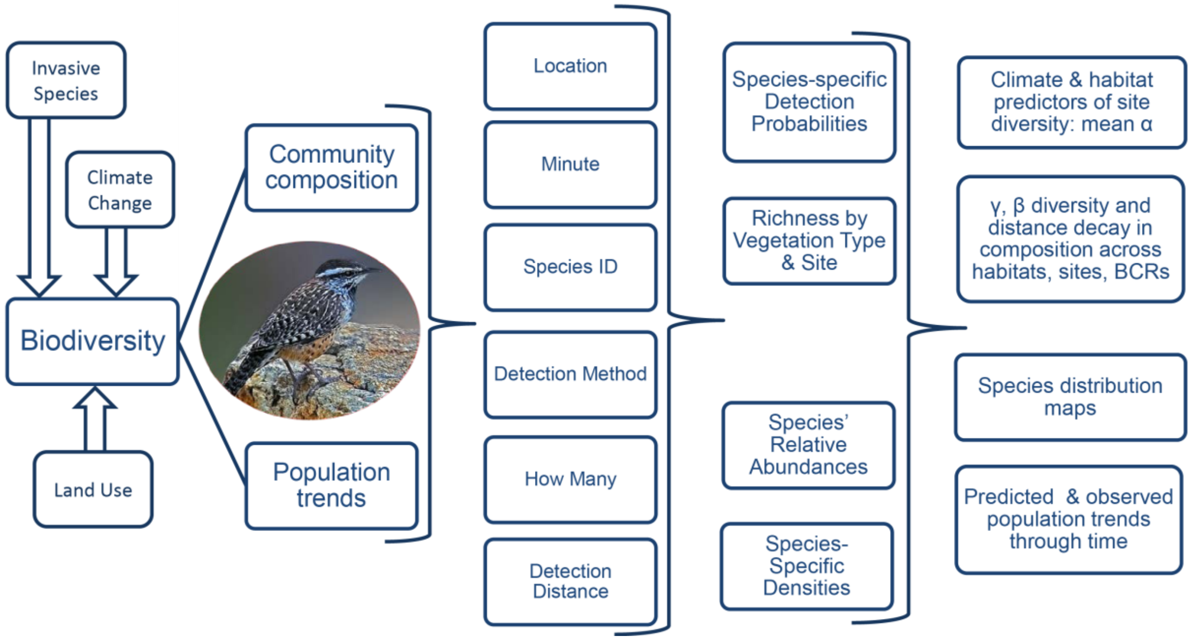


Figure 2. Conceptual map from Grand Challenges to key derived data products for breeding birds. The current vision for derived data products includes leveraging the additional data resources of the Avian Knowledge Network (AKN) and the North American Breeding Bird Survey (BBS) either for increasing spatial and temporal coverage of the data products or for comparative hypothesis testing.

5.3 Priorities and Challenges for Breeding Landbird Abundance and Diversity

The sampling design for the breeding bird component of the NEON TOS must meet the following criteria:

1. Must be able to be employed at most, if not all, NEON sites, within the existing budgetary and logistical constraints.
2. Must be standardized across the Observatory and compatible with existing datasets, in order to enable continental-scale analyses.
    - The BBS is of particular significance due to its unique temporal and spatial extents (Hansen 2008). Although NEON aims to be compatible with BBS (e.g., species richness detected within 3-minute point counts in a region), this does not require that NEON design its sampling with the same biases inherent to the BBS (see section 5.3.1, below).
3. Must yield robust estimates of diversity, abundance and density at each site, in order to be able to address the science requirements and questions presented above. Given the range of spatial scales covered across NEON sites, many sites do not allow for a study design that can yield robust estimates of occupancy. Moreover, such variability in site sizes also prevents meaningful comparisons among site-level occupancy metrics.

5.3.1 Breeding Bird Survey

The Breeding Bird Survey (BBS; Sauer et al. 2011) is a standardized sampling effort that began in 1966 and has since occurred annually, typically in June. In recent years, the BBS has included >5,000 sites throughout North America (Sauer et al. 2011). The BBS sampling protocol is based on a 39.4 km roadside route, along which 3-minute point counts are conducted by one volunteer, experienced observer every 800 m on one day of the year, for a total of 50 counts per route. The BBS was designed primarily to provide landscape-scale, long-term insights into population trends of breeding birds (e.g., Thomas and Martin 1996, Sauer et al. 2003, Sauer and Link 2011). The spatial scale of a BBS route is not well suited for making inferences at the scale of many NEON sites and is not sufficiently fine to meet the NEON goals related to collocation with the other NEON taxa (Hansen 2008). Moreover, BBS data are limited by the biases associated with roadside sampling and the absence of techniques that allow for estimation of detection probability and habitat data (O'Connor et al. 2000, Rosenstock et al. 2002, Hansen 2008). Nevertheless, BBS data are often used for regional to continental bird monitoring because they are the most complete and accurate data available (Sauer et al. 2003, Hansen 2008).

5.3.2 Scaling Up: The IMBCR Program of RMBO

Also of particular interest to the design of NEON sampling is the sampling design developed by the Rocky Mountain Bird Observatory (RMBO) and its partners for their program, Integrated Monitoring in Bird Conservation Regions (IMBCR; White et al. 2012). This randomized, spatially balanced breeding bird sampling program was developed in concert with a diversity of federal, state, and non-profit partners with the specific intent of enabling inference across spatial scales, from small land management units to states and Bird Conservation Regions (BCRs). BCRs were developed on behalf of the North American Bird Conservation Initiative (NABCI), and are similar in concept to NEON domains, as they represent geographic areas with similar land management, habitats, and bird communities (Figure 3; NABCI 2000). They have been adopted as a standardized spatial framework for bird conservation across agencies and countries (NABCI 2000).

The IMBCR sampling design has been implemented throughout the central and western US, with support from government agencies and NGOs, such as the Wyoming Natural Diversity Database, Boise State University's Idaho Bird Observatory, and the University of Montana's Avian Science Center. The sampling design is intended to provide statistically robust estimates of density and occupancy across large spatial scales (White et al. 2012, Pavlacky et al. 2012). In this design, the study area of interest is covered with 1 km x 1 km grid cells, of which a subset is selected using generalized random-tessellation stratification (Stevens and Olsen 2004), with stratification based on land ownership (White et al. 2012) rather than vegetation type (as in the NEON design – AD[03]). Spatially-balanced sampling allows for estimating spatial autocorrelation structure in the data which can improve density estimation (Stevens and Olsen 2004, White et al. 2012). Cells are treated as sampling units, with each cell containing 16 sampling points (4 x 4 with 250 m spacing). In occupancy estimation, points within a sample unit are treated as spatial replicates (Pavlacky et al. 2012). Six-minute surveys that include distance measurements to observed individuals are conducted at each point; data are analyzed using three 2-minute sampling intervals to estimate detection probabilities using a removal design in occupancy estimation (MacKenzie et al. 2006, Pavlacky et al. 2012) and these detection probabilities are also used for density estimation (White et al. 2012).

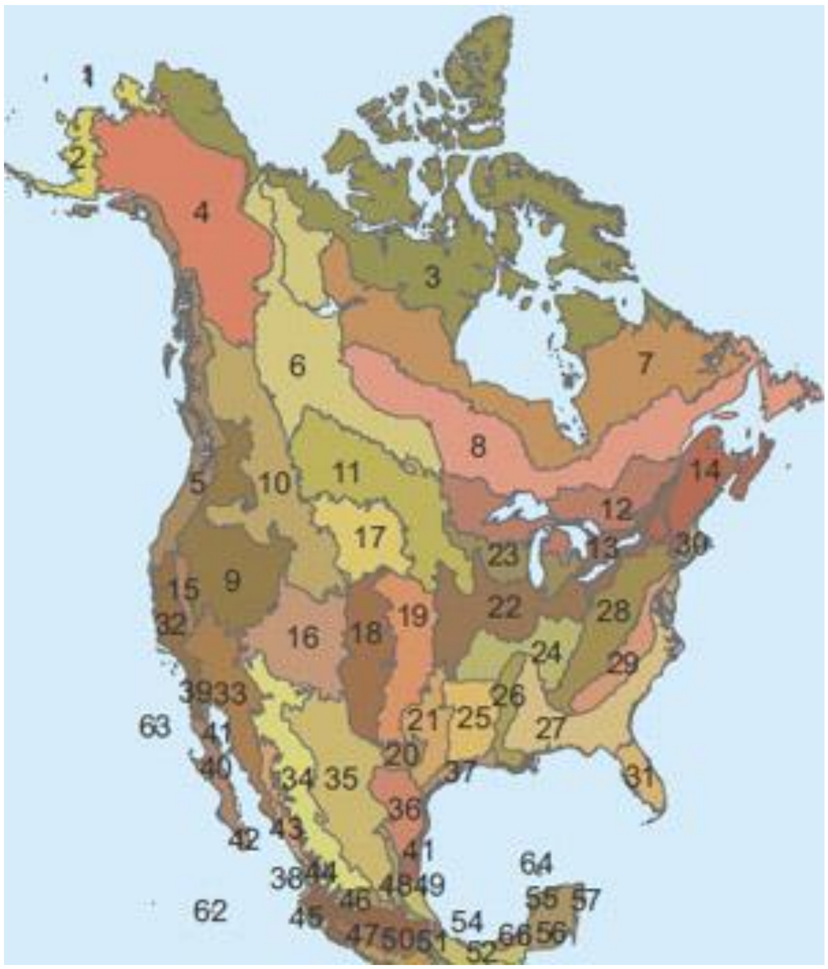


Figure 3. Map of the 66 Bird Conservation Regions (BCRs) in North America. www.stateofcanadasbirds.org (accessed 29 September 2013)

6 SAMPLING DESIGN FOR BREEDING LANDBIRD ABUNDANCE AND DIVERSITY

6.1 Sampling Design for Breeding Landbird Abundance and Diversity

In North America, there are over 650 species of breeding birds, and many approaches have been developed to sample them, given their diversity of habits and habitats (Bibby et al. 2000, Fancy and Sauer 2000). As a result of this diversity, no single sampling method can be used with equal efficacy on songbirds, seabirds, waterfowl, and raptors (e.g., Ralph et al. 1993, Fancy and Sauer 2000). The breeding bird component of the NEON TOS is designed to sample songbirds and other birds that are diurnal, resident in, or migrating through terrestrial habitats, commonly referred to as landbirds (see Box 1 above). The most common methods for sampling breeding birds are spot mapping of territories, area searches of specific sites, strip transects along predetermined routes, nest searches, and point counts (Ralph et al. 1993, Nur et al. 1999), as well as mist-netting for marking and recapture (Figure 4). The relative utility and efficiency of these methods vary with the objectives of the study (see Nur et al. 1999 and Fancy and Sauer 2000 for thorough discussions of these methods and their uses).

Figure 4. A banded indigo bunting (*Passerina cyanea*) captured in a mist-net

6.2 Sampling Methods

Point counts are the most commonly used method of sampling birds (Bibby et al. 2000, Rosenstock et al. 2002), and they have been described as 'the most efficient and data rich method of counting birds' (Ralph et al. 1993). Point counts are a method that involves an observer standing at a point for a predetermined amount of time (typically 3-20 minutes), typically during the peak of singing activity that occurs in the early morning, and recording all of the individuals seen or heard (Ralph et al. 1995; Figure 5). The original design for NEON bird sampling formulated by the group of experts known as the Tiger team included point counts as the method of choice (Hansen 2008).

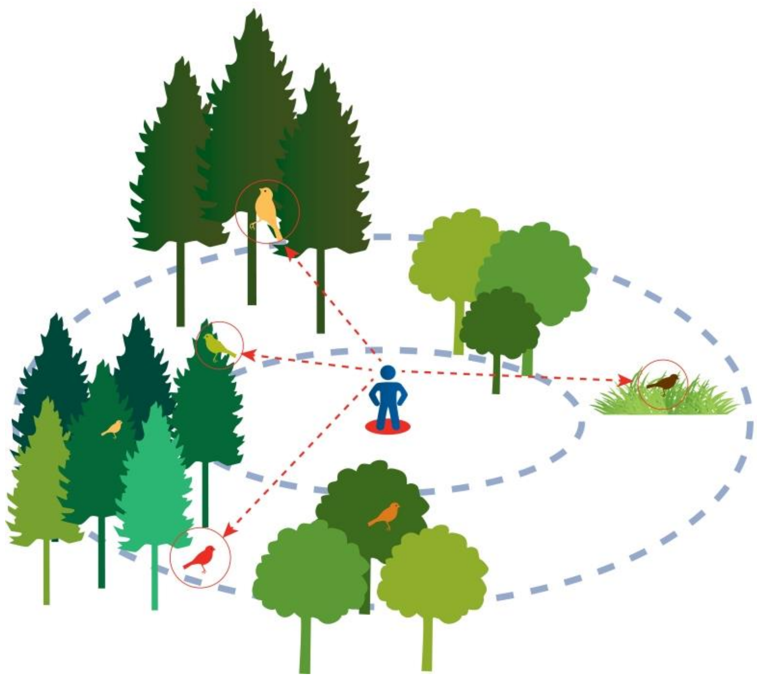


Figure 5. Schematic depicting the point count method of sampling birds. In distance sampling, the distances from the observer to each bird (represented by dashed red lines), as well as the species, sex, and age, are recorded

The advantages of point counts include (1) minimal disturbance to the birds; (2) this single survey method can collect valuable data on a diversity of species (Hutto and Young 2002); and (3) provides comparability with many other datasets, including the BBS. Although mist-netting is the only accepted means to estimate vital rates and determine underlying mechanisms of population changes (Nur et al. 1999, Fancy and Sauer 2000), mist-netting is labor-intensive, beyond the scope of the NEON budget, and the data are not compatible with the BBS, IMBCR, and many other bird sampling efforts.

The major disadvantages of point counts are (1) the need for highly skilled observers for only a limited portion of the year (Box 3); (2) the challenges associated with even highly skilled observers to record all of the necessary data in a 3 – 20 minute count; and (3) the fact that the detectability of birds is not constant across space, time, and species (Rosenstock et al. 2002). Detectability is significantly affected by (1) observers who significantly vary in visual and auditory acuity and experience (Sauer et al. 1994); (2) environmental variables such as weather, light conditions, vegetation, and topography; and (3) the physical and behavioral variation within and among species (Rosenstock et al. 2002). Variation in detectability is accounted for in statistical methods that have been developed to address this issue when estimating abundance and density (e.g., distance sampling - Box 4).

Box 3. Summary of challenges and opportunities in identifying skilled point count observers

Challenge: Skilled Observers for NEON

- Identifying, hiring, and training skilled observers
- Deploying observers in up to 47 unique bird habitats

Option 1: NEON seasonal technicians

- **Pros:** Direct NEON oversight, potentially lower indirect costs, more easily 'plugged in' to NEON data management and domain support facility infrastructure, technicians hired for a longer season to do more than just the bird work
- **Cons:** Increase competition for techs among bird orgs in the US, additional NEON training for technicians is extensive, external contractors may still have to be secured for bird-specific training, current hiring process occurs too late (after most bird orgs) and is too general to secure top tier bird technicians, technicians would have to have the knowledge and experience for multiple habitats

Option 2: Contract with External Bird Organizations

- **Pros:** Hiring, training, and management burdens shifted to orgs with decades of experience, provide support rather than competition for these orgs, larger tech pools could facilitate habitat specialization, improving observer performance
- **Cons:** Potentially more expensive, coordination with sites & equipment and data transfers more complicated, techs could have to switch among different protocols, if assigned to other projects as well, lack of direct NEON oversight might increase chances for error arising from miscommunication

To meet the objectives of providing robust estimates of abundance and density, point counts that are randomly distributed in the areas of interest (i.e., not along roadsides) and that include distance sampling techniques are the recommended sampling method (e.g., Nur et al. 1999, Bibby et al. 2000, Fancy and Sauer 2000, Rosenstock et al. 2002). Distance sampling has become an increasingly common addition to point counts, as it provides for the use of algorithms that account for incomplete detection to yield robust density estimates, rather than just presence data (Box 4; e.g., Fancy and Sauer 2000, Buckland et al. 2001, Rosenstock et al. 2002, Pavlacky et al. 2012). For point counts, this involves measuring the horizontal distance from the observer to each bird seen or heard. This method is often referred to as variable circular plot (VCP) counts (Fancy and Sauer 2000), to distinguish it from fixed radius point counts in which observers only count birds within a specified distance but generally do not record distances to each individual.

Box 4. Overview of Distance Sampling (Excerpted from White et al. 2012)

Distance sampling theory was developed to account for the decreasing probability of detecting an object of interest (e.g., a bird) with increasing distance from the observer (Buckland et al. 2001). The detection probability is used to adjust the count of birds to account for birds that were present but undetected. Application of distance theory requires that three critical assumptions be met: 1) all birds at and near the sampling location (distance = 0) are detected; 2) distances of birds are measured accurately; and 3) birds do not move in response to the observer's presence (Buckland et al. 2001, Thomas et al. 2010).

NEON is fortunate to have many decades of community experience, research, and statistical development from which to draw. Ralph et al. 1993 and 1995 are seminal publications concerning point counting of birds, cited more than 750 and 500 times to date, respectively. Ralph et al. (1995) includes a numbered list of recommendations for the design of point counts, some of which are included below, where appropriate, but these do not prescribe a universally accepted point counting protocol. Of these recommendations, the generally accepted, best practices for collecting the highest quality data when conducting a point count are listed in Box 5. Substantial methodological development has occurred since these publications, however, primarily focused on the analysis of count data to generate more robust estimates of true abundance and density, given variability in the availability and detectability of species under a variety of conditions (reviewed in Nichols et al. 2009). Therefore, it is important to note that some of Ralph et al.'s (1995) recommendations are not applicable to modern methods of density and abundance estimation. The various options available in point count design that do not have an accepted community standard are presented in further detail below to elucidate the rationale and implications for the NEON design.

6.2.1 Point Count Design: Which Birds to Count

Ralph et al. (1995) recommends that all individual birds detected at a station should be recorded; but some consider this to be impossible to logistically accomplish for a human observer (S. Droege, pers. comm.), and scientifically futile when the goal of the study is to assess trends in abundance (Purcell et al. 2005). Moreover, field playback studies have suggested that the performance of observers conducting auditory counts declines with increasing diversity and abundance of birds (Nichols et al. 2009). In light of these concerns, three options warrant consideration.

6.2.1.1 Sample All Birds

The concern regarding the challenges of performing complete point counts effectively, efficiently, and competently are widely-acknowledged. Despite these challenges, however, most studies, including the BBS and IMBCR program, do employ this method, and it is the most widely recommended approach. The BBS includes observers as covariates in their models as a result (Sauer et al. 1994, 2003), while the IMBCR program also relies on an early season training period to enable observers to conduct counts in as standardized a way as possible (White et al. 2012).

Box 5. Ralph et al. 1995 general recommendations

1. Birds previously recorded at another sampling station should not be recorded again.
    a. Note: If distance sampling techniques are used, this recommendation is not warranted.
2. Birds should not be surveyed when it is raining, during heavy fog, or when noise from wind-blown vegetation interferes with counting.
3. Only observers able to identify all the targeted birds by sight and sound should participate in a monitoring or research project using point counts.
4. A standard field form should be used to ensure compatibility of data taken between participants in the program.
5. Juvenile birds or birds that fledged during the current breeding season should be recorded separately.
6. Birds that were detected flying over the station, rather than detected from within the vegetation, should be recorded separately.
7. A bird flushed within 50 m of a station's center, as an observer approaches or leaves a station, should be counted as being at the station if the observer feels that this individual was not seen during the count period.
8. If a flock is encountered during a census period, it may be followed after the end of the period to determine its composition and size. An observer should follow such a flock for no more than 10 minutes. This is especially useful during the winter.
    a. Note: This is not generally considered to be an efficient use of sampling effort for breeding landbirds.
9. A bird giving an unknown song or call may be tracked down after count period for confirmation.
10. No attracting devices should generally be used, except in counts for specialized groups of birds.
11. Latitude and longitude for each location should be recorded at least to the nearest 10 seconds from accurate topographic maps.
    a. Note: The availability of inexpensive GPS units makes this recommendation obsolete.
12. Recording data into a tape recorder can help to minimize the time that an observer spends looking at the sheet of paper while recording, thus maximizing visual observations.
    a. This recommendation no longer receives broad support, given the added time needed for transcription, propensity for errors in transcription, and the lack of utility to double-check that all individuals have been recorded appropriately.

6.2.1.2 Focal Species Approach

Purcell et al. (2005) found that 20 years of sampling yielded insufficient statistical power to detect a 30% decline for 44% of the breeding bird species at the San Joaquin Experimental Range in California. As a result, they advocate for a focal species approach, in which region-specific lists of species that are relatively common, detectable, and sensitive to environmental change are targeted for monitoring, to the exclusion of the remaining species present (Purcell et al. 2005). This approach presumably would result in higher quality data for those focal species, as the observer would have more directed search images and sounds, but would fail to collect data on rare species or provide measures of community diversity.

6.2.2 Acoustic Monitoring

Another potential alternative to addressing the challenges associated with logistical limitations concerning the ability of a human observer to keep track of all birds and the distances to them, coupled with observer skill and inherent variability, is to rely solely on acoustic recordings (S. Droege, pers. comm., Celis-Murillo et al. 2009, Blumstein et al. 2011). Acoustic monitoring provides an archivable record of organismal activity and song pattern at a site and the frequency of recording can be set at a schedule that is standardized across sites. Long-term projects within the US Geological Survey such as TWCGRN (Terrestrial Wetland Global Change Research Network) and ARMI (Amphibian Research and Monitoring Initiative) have been using these systems for both bird and amphibian monitoring with success. Moreover, acoustic monitoring would capture additional data products that point counts do not, including breeding bird phenology, insect phenology, and amphibian diversity and phenology. However, (a) acoustic monitoring currently requires a great deal of effort to analyze the data and cannot be used to estimate density without elaborate multi-unit recording systems, (b) some species of interest are not captured acoustically, and (c) the resulting data would not be comparable to the BBS and many other existing datasets. If automated species identification algorithms become available in the future for a diversity of species across habitats, the incorporation of this technology into the NEON bird sampling program will be re-evaluated, with a potential to calibrate acoustic and point count data.

NEON Plan: The NEON design will conform to the general recommendations listed in Box 5, with a couple of exceptions. For example, point counts will only be conducted when ambient conditions do not significantly inhibit detectability (e.g., wind speeds < 10 km per hour, background noise < 10 dB; Simons et al. 2007, Pacifici et al. 2008). Flocks will not be followed after a count ends (#8), however, and paper datasheets or, if efficient, a mobile application, rather than a tape recorder, will be used to facilitate the recording of data (#12). All species will be counted to capture a greater diversity of species, as well as species diversity of breeding bird communities, and to facilitate integration with other datasets.

6.2.3 Point Count Design: Estimating Detection Probability

The biases inherent to point counts are well established, as the fundamental assumption that a constant proportion of what is present is detected is rarely, if ever, met (Thompson 2002). Detectability is affected by both the cues available to detect a bird and the observer's ability to detect the cues accurately (Johnson 2008). The latter includes the observer's skill, hearing and visual acuity, the relative orientation of the bird to the observer, as well as the characteristics of the surrounding habitat, weather conditions, and ambient noise, while the former includes the volume and frequency of each species' song and/or call, the singing rate of each species present, and the abundance of each species (Alldredge et al. 2008). All of these factors vary markedly and often unpredictably across point counts and across a variety of sampling methods for a myriad of taxa.

In recent years, much effort has therefore been put into figuring out analytical and methodological means to mitigate these biases, to produce more reliable estimates of abundance, density, and occupancy (Figure 6). These include distance sampling (see Box 4 above), mark-recapture sampling, time of detection methods, and multiple-observer sampling (e.g., Farnsworth et al. 2002, Alldredge et al. 2007a, Johnson 2008, Riddle et al. 2010, Reidy et al. 2011). All of these options require additional effort and therefore cost (although distance sampling and time of detection methods can be argued to incur only trivial costs), rely on different sets of assumptions, and may not yield estimates that are any more reliable than the original counts (Johnson 2008, Efford and Dawson 2009, Welsh et al. 2013). Recapitulating the myriad methods and corresponding advantages and disadvantages is beyond the scope of this document. Here, instead, only the most widely adopted modifications of point counts, distance sampling and repeat visits, are considered.

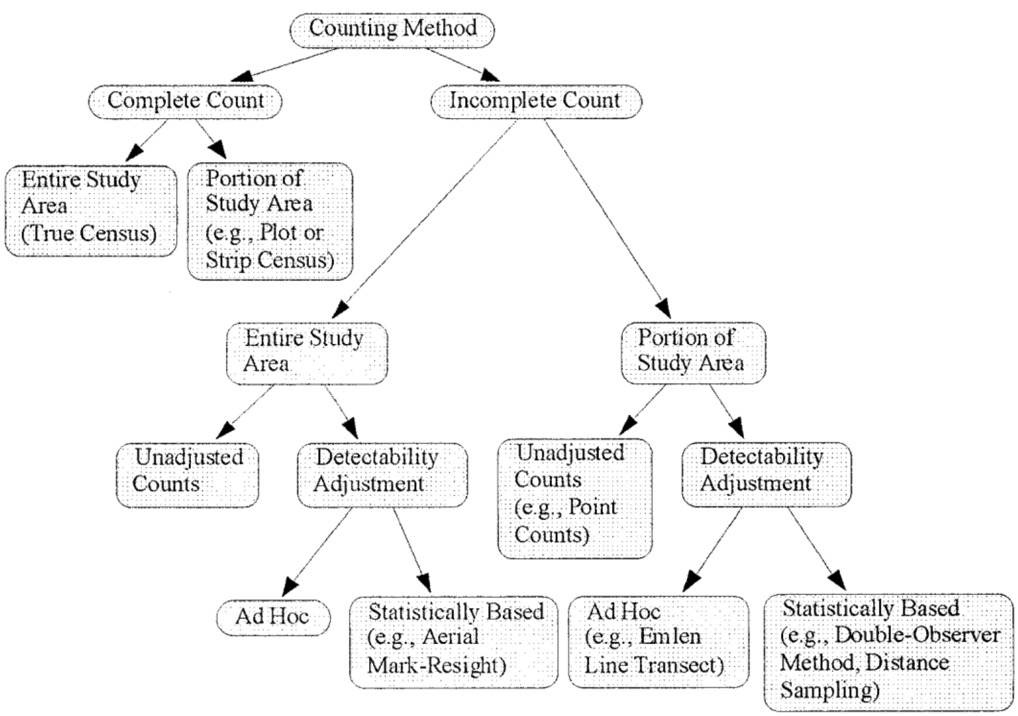


Figure 6. Categorization of counting methods used in bird population studies, from Thompson 2002.

Ralph et al. 1995 recommendations:

1. It is usually better to increase the number of statistically independent sampling stations than to repeatedly count a smaller number of stations.
2. Only one observer should be permitted to count birds at a single station.
3. Birds detected within a radius of 50 m surrounding the census station should be recorded separately from those at all distances.

6.2.3.1 Distance Sampling

The fundamentals of distance sampling were introduced above (see Box 4) and are well described in detail by Buckland et al. (2001). The efficacy of distance sampling methods in conditions under which the key assumptions listed in Box 4 are met has been supported. However, there are a number of limitations that are relevant to the consideration of the application of the method. First, many species are not observed frequently enough in any given study to yield the sample size required (approximately 100) to develop robust detection functions (Fancy and Sauer 2000, Pavlacky et al. 2012). Global detection functions remain an option, but variance in these does not seem to have been sufficiently explored and require extensive data sharing among ornithologists to generate. Secondly, distances measured to birds detected aurally but not visually are notoriously inaccurate (Simons et al. 2007, Alldredge et al. 2008), although training can substantially reduce error (Alldredge et al. 2007b). This is particularly problematic given the predominance of aural detections in point counts (Brewster and Simons 2009). Finally, the method relies on the selection of a particular detection function to be fit (Royle and Dorazio 2008).

The implementation of distance sampling in point counts takes several forms. The IMBCR protocol involves the use of laser rangefinders to measure distances to each individual bird to the nearest meter. Extensive training of technicians is required to produce repeatable, reliable measurements in this fashion (White et al. 2012). Alternatively, many studies categorize distance to overcome the logistical hurdles faced when trying to take individual measurements during the limited sampling window when many birds might be present (e.g., < 50 m and > 50 m; Ralph et al. 1995, Matsuoka et al. 2012). The accuracy of this method can be improved by having observers use a laser rangefinder to demarcate distance categories immediately prior to performing a count (Alldredge et al. 2006). However, categorical distance measures result in greatly reduced flexibility in fitting detection functions during data analysis and would create incompatibility with IMBCR and other data collected using continuous distances.

6.2.3.2 Repeat Visits

Repeated point count sampling at the same locations within a breeding season can be used to estimate detection probability, assuming that the population of interest is closed between visits (Farnsworth et al. 2002). Estimates of species richness can also benefit from repeated samples in order to assess the statistical robustness of the estimates (Field et al. 2002). At small sites, where spatial replication is limited, repeat visits can present an alternative means to increasing statistical power in evaluations of treatment effects (Purcell et al. 2005). For example, Field et al. (2002) found that repeated samples on different calendar days resulted in greater numbers of species detected at a given location, whereas another study found that three repeat visits did not substantially impact richness estimates but did affect abundance estimates (Siegel et al. 2001). Finally, Dettmers et al. (1999) found that bird-habitat models performed better if based on two visits rather than one, with no improvement shown when three visits were included.

Analyses of Prototype Data and Results: In 2011, breeding landbird abundance and diversity were sampled in 9 grids distributed across the Central Plains Experimental Range (a NEON core site – CPER). Despite frequent, inclement weather, 7 of the 9 grids were sampled at least 3 times between May 23 and June 30, 2011. In 2012, 8 grids were sampled 3 times each from May 15 to July 10, 2012, at Rocky Mountain National Park (a NEON relocatable site – RMNP). Density estimates for one common species at each site across each of the three sampling periods within the season were calculated using the R package `unmarked` (Fiske and Chandler 2011). These species were selected for this analysis as they were the most abundant species at their respective sites that occurred on >50% of the sampled plots. Distance measurements were binned into four equivalent linear bins from 0 to 400 meters, and a hazard-rate detection function was used. The densities of each of the common species analyzed did not significantly vary across the repeat visits (Figure 7).

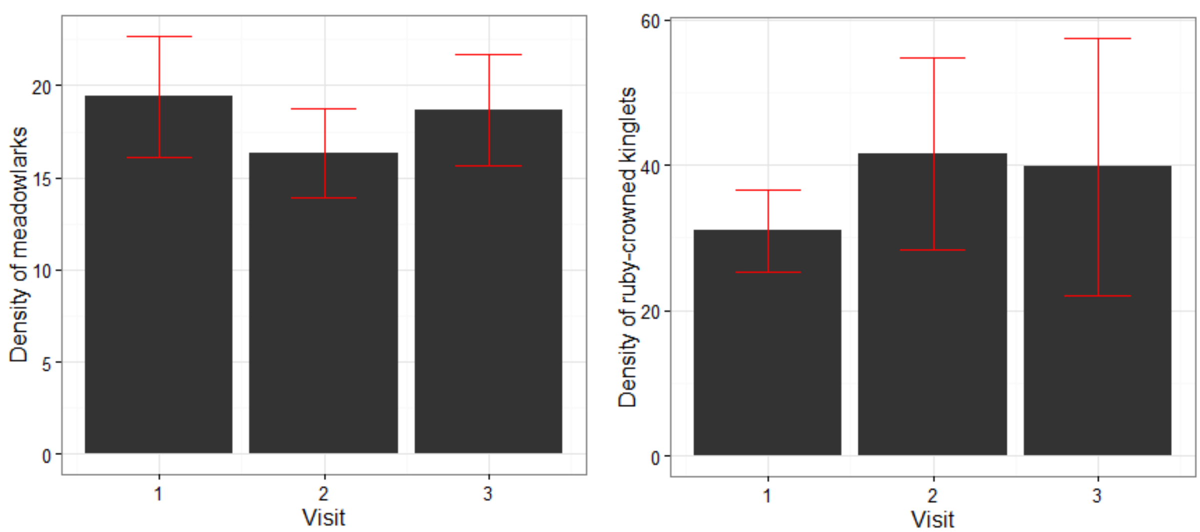


Figure 7. Densities (number of individuals per square kilometer) of Western Meadowlarks at CPER in 2011 (left) and Ruby-crowned Kinglets at RMNP in 2012 (right) estimated on each of three visits to the same point count location within a breeding season. The red bars represent the standard errors

NEON Plan: The IMBCR protocol uses a combination of distance sampling methods and separating the 6 minute point counts into three 2-minute periods for analysis to estimate detection probabilities. This approach allows for greater spatial replication than an approach that would require repeated visitation to the same sites on different sampling days. Repeat sampling will be used at small sizes, however, in order to increase the number of detections as that site, as a reasonable sample is required to fit a detection function. In addition, this approach is more robust than using distance sampling alone, as (1) it is less sensitive to violation of the assumption that all birds at and near the sampling location (distance = 0) are detected (see Box 4), and (2) accounts for detection biases resulting from both distance from the observer and variable singing rates across species and habitats (Farnsworth et al. 2005, Sólymos et al. 2013).

6.3 Spatial Distribution of Sampling

6.3.1 Point Count Design: Array and Points per Array

The options for distributing counts in space are to conduct line or transect counts, to array point counts along a transect (e.g., Siegel et al. 2007), to array point counts in grids, or to distribute points independently according to a statistical design (e.g., the spatially-balanced random sampling design that NEON is using to select sampling locations, using the Reverse Randomized Quadrant-Recursive Raster algorithm; Theobald et al. 2007; AD[03]). Line counts are difficult to conduct when terrain is hard to negotiate and present challenges for inference when habitats are patchy. Random distribution of point counts is inefficient when study areas are large, because of increased travel time between points. However, random distribution can increase replication, as each individual point count is an independent sample given adequate spacing.

In terms of spacing between point counts, Ralph et al. (1993) assert that, ’in virtually all habitats, >99% of individuals are detected within 125m of the observer’, with subsequent analyses providing supporting evidence of this assertion (e.g., Matsuoka et al. 2012). Consequently many sources recommend minimum spacing of 250m between point counts (e.g., Ralph et al. 1993, Fancy and Sauer 2000, Alldredge et al. 2006). As discussed above, the BBS uses point counts arrayed along transects (i.e., roads) with 800m spacing, whereas the IMBCR uses 4 x 4, 1 km^2 grids with 250m spacing between points.

Ralph et al. 1995 recommendation: The minimum distance between point count stations is 250 m.

The NEON TOS spatial design is a stratified-random sampling design based on the National Land Cover Database (NLCD) land cover classification scheme (AD[03]). Sampling locations are distributed in the dominant habitat classes in proportion to their availability at each site, to facilitate inference at the scale of the NEON site. The NEON design also attempts to collocate sampling across taxa whenever possible. Given these goals of characterizing breeding landbird communities across the dominant habitats types at a site and maximizing collocation with other sampling modules, a grid array centered within a given habitat class is preferable to a line transect that is likely to cover a greater diversity of habitat classes (and, therefore, not be amenable to analyzing as a sample per habitat class).

The number of points to include in a grid represents the trade-offs among the number of grids that can fit in the area of study, the number of points that can be visited with a daily sampling window, and the ability to quantify the variance in the sample estimates. The advantages of the 4 x 4, 1 km^2 grids used by the IMBCR include (a) all points can be sampled by one observer during one morning sampling period, and (b) a standardized 1 km^2 grid system exists for the US (Hanni et al. 2010). The advantages of collecting data that are standardized with the broader community are numerous, and therefore NEON's initial prototype sampling efforts (see below) used the IMBCR 4 x 4 grid design. However, NEON sites vary significantly in size and shape, with many sites containing less than 5 square kilometers (Figure 8). Therefore, many sites cannot include a sufficient sample of 1 km^2 grids (i.e., >= 5). Prototype data are used below to examine the impacts of grid sizes on breeding bird parameters of interest to inform the NEON sampling design.

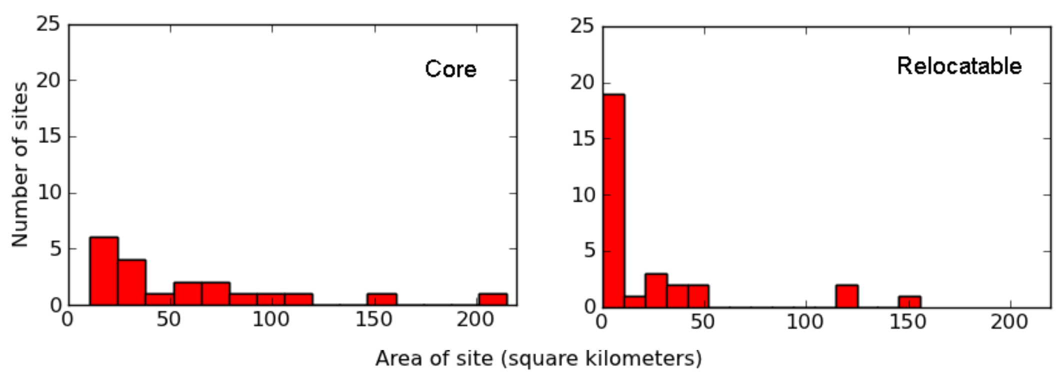


Figure 8. Distribution of sizes of permitted areas across NEON sites in 2013

Analyses of prototype data: In 2011, breeding landbird abundance and diversity were sampled in 9 grids at CPER, and, in 2012, 8 grids were sampled at RMNP. Point count grids consisted of 16 points each, arrayed in a 4 x 4 design with 250 m spacing, yielding a sampling area of 1 km^2 per grid (modeled after White et al. 2012 – the RMBO IMBCR program). Site-level estimates of density and species richness were calculated based on varying numbers of points within each of the grids, to assess the impacts of this aspect of the spatial design at these two sites.

Species richness (S; total number of species detected) was calculated for all possible combinations of all possible numbers of points per grid. The means ± standard deviations of the per grid values are presented in Figure 9. At the heterogeneous, speciose RMNP (total S = 83 species; per grid range = 27 – 56) the number of species detected increased with the number of points sampled per grid, but the rate of increase did decrease at larger grid sizes. However, the lack of an asymptote suggests that additional species were present but not detected at the site. For the more homogeneous CPER (total S = 41 species; per grid range = 13 - 19), the rate of increase in species detected slowed dramatically after about 6 points per grid (Figure 9).

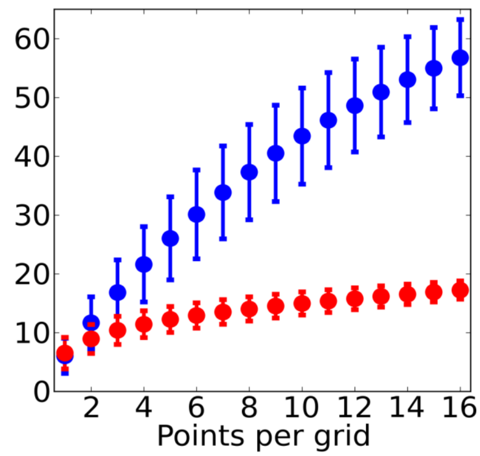


Figure 9. Means ± standard deviations of the total number of species detected per point count grid for all possible combinations of all possible numbers of points per grid. The 2012 data from RMNP are represented in blue, and the 2011 data at CPER in red.

Density estimates for one common species at RMNP for one visit were calculated using the R package `unmarked` (Fiske and Chandler 2011), and comparisons were made across various combinations of points per grid (Figure 10). Distance measurements were binned into four equivalent linear bins from 0 to 400 meters, and a hazard-rate detection function was used. Standard errors across all combinations overlapped, but only the point subset that included only the corners of a grid consistently deviated markedly from the others, on average.

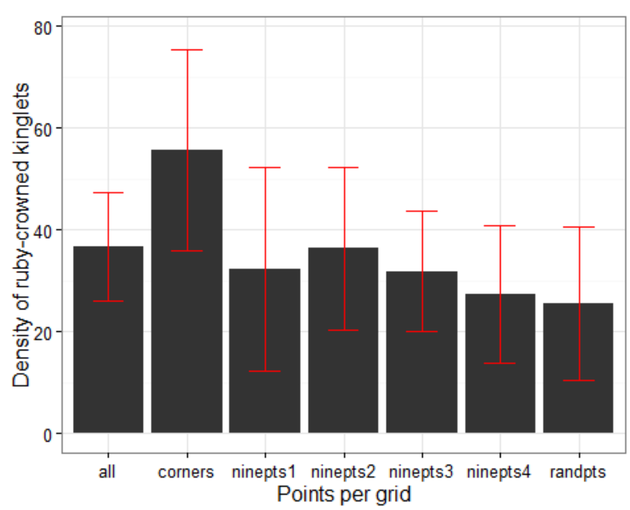


Figure 10. Density estimates per grid (± standard errors, in number of individuals per square kilometer) of ruby crowned-kinglets at RMNP across various combinations of point per grid. The combinations are: all = 16 points per grid; corners (4 corner points only).

NEON Plan: To increase efficiency and accommodate sample sizes of 5 – 10 grids at most NEON sites, point counts will be distributed in 3 x 3, 0.56 km^2 grids, with 250m spacing between points (Figure 11). At sites that cannot accommodate a minimum of 5 grids, points will be distributed randomly throughout the site (collocated with Distributed plots; minimum distance of 250m between points). These deviations from the IMBCR design will not allow for comparable estimates of occupancy across sites, but will still allow for comparable estimates of density across all sites.

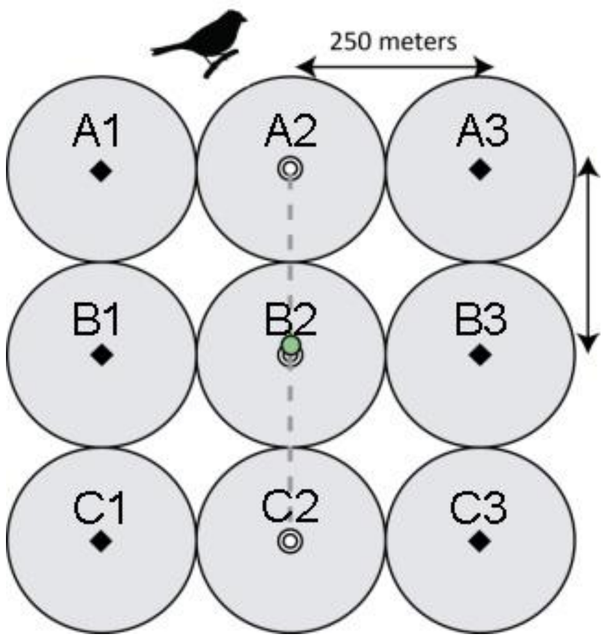


Figure 11. NEON point count grid for sampling breeding landbirds

6.3.2 Point Count Arrays: Number and Distribution in the Landscape

Sample sizes in studies of vertebrates are typically limited by logistical constraints, including area, time, and personnel available to sample. Statistical power is therefore often markedly lacking (e.g., Purcell et al. 2005). Moreover, the diverse objectives of the NEON program, including the ability to track changes in bird abundance and density over time and space and to understand the relationships of bird dynamics with the collocated measurements of other, sympatric taxa, make it difficult to select one objective against which to evaluate the statistical power of the data. Of note, however, is that the IMBCR analyses require a minimum of 2 grids to generate density estimates and 10 for occupancy estimates (White et al. 2012).

Ralph et al. 1995 recommendations:

1. Census stations should be systematically located with a random starting point, either on roads or off roads.

2. Stratification of census stations by habitat should occur only if habitat-specific population estimates are required.
3. Placement of stations for bird-habitat modeling should avoid boundaries between habitat types, if possible.
4. Observers should attempt to carry out censuses primarily on tertiary roads, then secondary roads, avoiding wide, primary roads. Off-road censuses should be carried out in major habitats not covered by road systems. These off-road censuses should be done on trails, if possible.
5. The number of samples necessary to meet the program objectives should be derived from the statistical evaluation of pilot data.

Analyses of prototype data: As above, site-level estimates of density and species richness were calculated based on varying numbers of grids, rather than varying the points per grid (Figures 12, 13). All 16 points within a grid was used for these analyses. At both CPER and RMNP, a minimum of 90% of the total species detected (approximately 37 and 75 species, respectively) was consistently detected with only five 16-point grids (Figure 12).

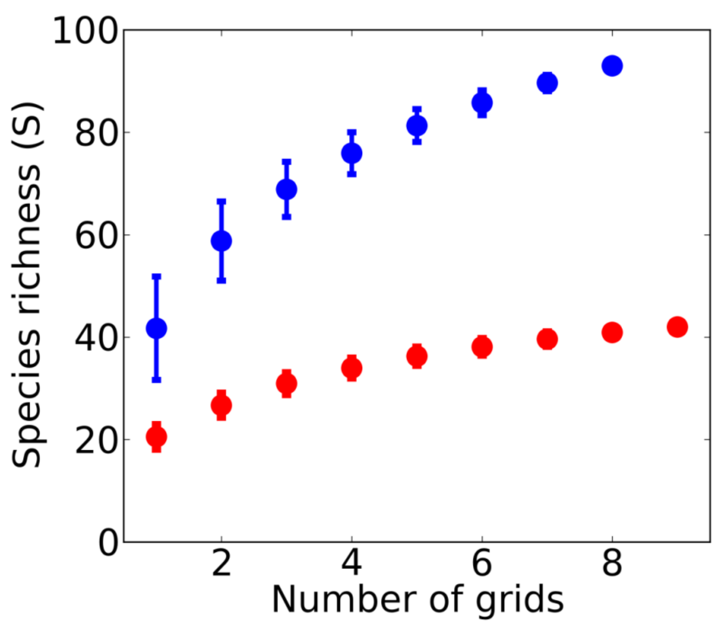


Figure 12. Means ± standard deviations of the total number of species detected per point count grid for all possible combinations for each given number of grids. The 2012 data from RMNP are represented in blue, and the data collected in 2011 at CPER in red.

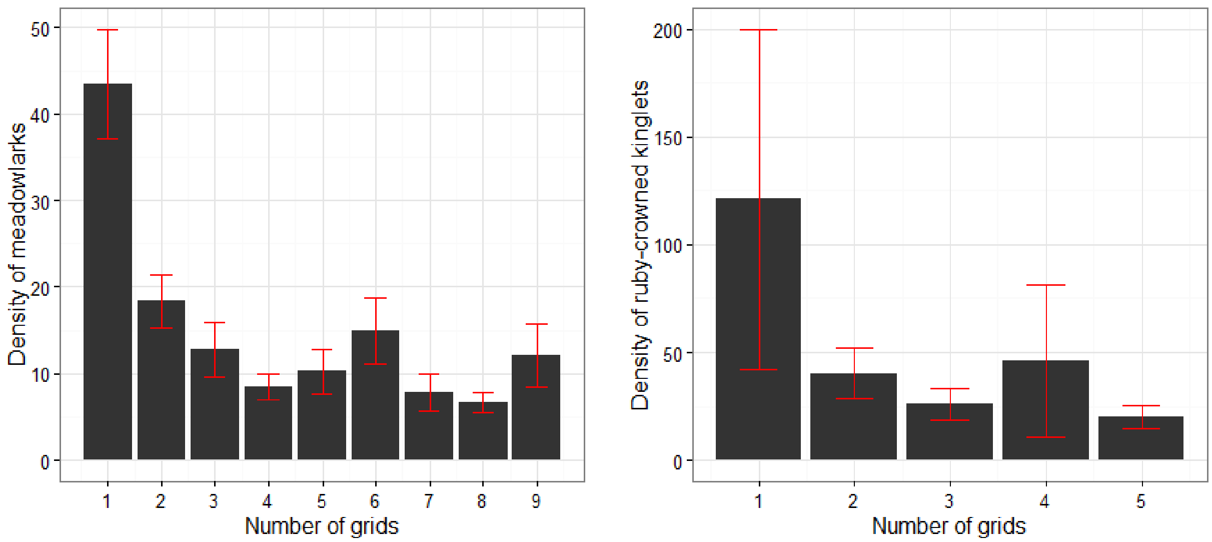


Figure 13. Densities (number of individuals per square kilometer ± standard errors) of Western Meadowlarks at CPER in 2011 (left) and Ruby-crowned Kinglets at RMNP in 2012 (right) estimated based on inclusion of increasing numbers of point count grids.

NEON plan: Collocation and plot selection

Given the range in sizes of NEON sites, the preliminary results, the IMBCR guidelines on minimum sample sizes, and the current understanding of budget and logistical constraints, breeding landbird sampling will be performed at 5 – 10 grids at most NEON sites. At sites that cannot accommodate a minimum of 5 grids, points will be distributed randomly throughout the site, maintaining the 250m minimum separation. Prior to 2018, up to 15 grids were sampled at NEON sites, but budget constraints compelled a reduction to 10. The number of grids or points being sampled at each NEON site can be found in 7APPENDIX A.

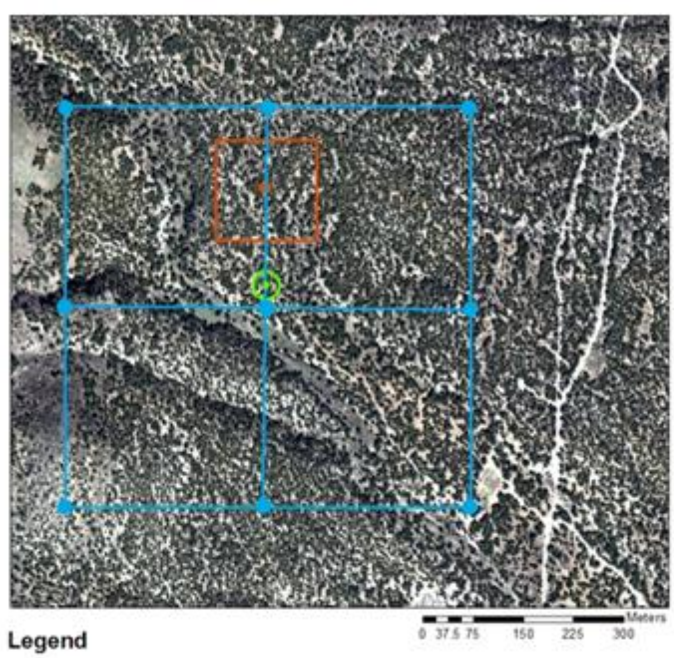
The distribution of these plots is currently intended to be collocated to the extent possible with the TOS Distributed Base Plots (these are the plots at which the greatest diversity of sampling is planned to occur, including plants, soils, mosquitoes, microbes, beetles). There will be 5-30 of these plots at each site distributed via a stratified random design based on vegetation type (AD[03]). The proposed procedure for identifying bird grid locations is described in Box 6, and an example of selected grid locations at one NEON site is shown in Figure 14.

Box 6. Summary of procedure used to select grid locations for breeding landbird sampling

- Where possible, grid locations are selected by placing the grid centers on the edge of the collocated TOS Distributed base plot, or such that the TOS Distributed base plot is contained within the bird grid but does not overlap a point count location, to avoid disturbance to other sampling
- >50% of the grid should be in the same vegetation type as the collocated TOS Distributed plot
- Distribute grids throughout site by proportional habitat availability, up to 10 per site
- Provide extras for contingency, if possible
- Assume that spatial independence requires at least the width of the grid between grids
- 5 – 10 grids per site

Figure 14. Example maps of collocated bird sampling locations. A) Map of a bird (large blue box) and mammal grid (smaller orange box) collocated with each other and with a TOS distributed base plot (green circle); B) Map of sampling locations at Onaqui, stratified by the two dominant habitats (NLCD classes) at the site, evergreen forest and shrub scrub.

A



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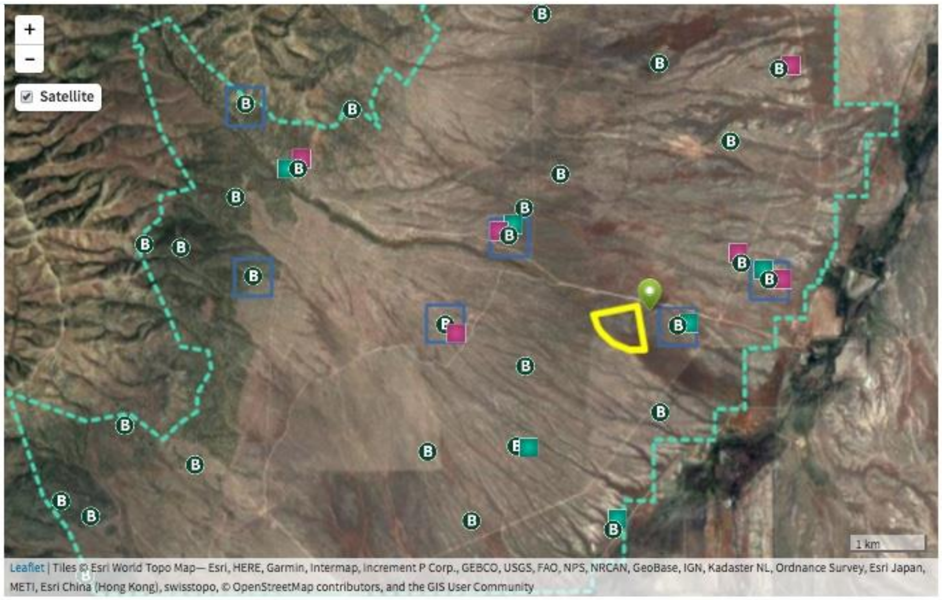

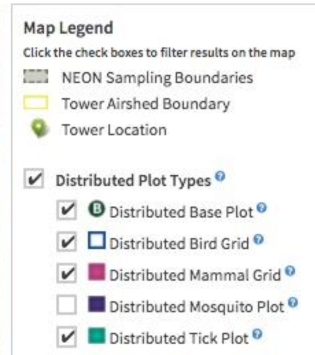

From: http://www.neonscience.org/field-sites/field-sites-map/ONAQ

6.4 Temporal Distribution of Sampling

As discussed in Ralph et al. (1995) and a well-established rule of thumb, the early morning hours of the breeding season can provide a sampling period during which detection rates are high and relatively stable among species. Given the large latitudinal range of NEON sites, the challenge lies primarily in delineating the timing of breeding at each site and the distribution of sampling effort within the breeding window. The ability to detect changes in phenology as a result of concomitant changes in climate require greater temporal resolution of sampling than the budget allows, assuming that change over the course of 30 years will be measured in days, rather than weeks. Any impacts of phenological shifts among years due to long-term or short-term climatic conditions on estimates of abundance and density can be modeled to yield comparable estimates.

Ralph et al. 1995 recommendations:

- Breeding season point counts should be conducted during the time of day and time of year when the detection rate of the species being studied is most stable.
- Most effort expended conducting point counts should occur during the breeding season.

NEON Plan: Except in Alaska, point counts will be conducted only during the early morning, from civil dawn to no later than 5 hours after civil dawn, depending on the intensity of the dawn chorus and weather conditions. In Alaska, timing will follow the guidelines provided by the Alaska Landbird Monitoring Survey (Handel and Cady 2004). The guidelines state “The first count of the day should be started no earlier than 0300 Alaska Standard Time in the Arctic and within 30 min after sunrise if possible elsewhere in the state. A later start time may be necessary if the terrain cannot be traversed safely before sunrise. The last count of the day should be completed no later than 4-5 hr after the first count began, since bird activity declines markedly after that time in most areas."

Breeding season dates will be informed by local experts and, if needed, by eBird data (ebird.org), which is known to provide large amounts of data pertaining to the arrival of spring migrants, particularly in well-populated regions of the U.S. (Hurlbert and Liang 2012). For example, RMBO recommends that breeding bird sampling in Colorado should occur between May 10 and June 15 for sites below 7,500 feet in elevation, and from June 5 to June 30 for 7,500 – 9,300 feet (N. Van Lanen, pers. comm.). The approximate timelines that have been provided in historical NEON documentation are listed in Table 2, with one modification suggested for Domain 17 by Kathryn Purcell.

Table 2. Domain specific schedules for breeding bird observations, to be refined with expert opinion

Schedule for bird observations	Domains	Domain regions
March 21 - April 30	17	Pacific Southwest
April 8th – June 16th	3, 4, 14, 20	Puerto Rico, HI, FL, Desert Southwest
April 23rd – June 28th	2, 6, 7, 8, 10, 11, 13, 15, 17	Mid-Atlantic, Ozarks, Appalachians, Prairie, Southern plains, Southern Rockies, Great Basin, Pacific Southwest
May 1st – July 5th	1, 5, 9, 12, 16	Northeast, Great Lakes, Northern Plains, Pacific Northwest
May 15th – July 20th	18, 19	Alaska

6.4.1 Point Count Duration

Mollon (2010) provided a recent overview of existing studies of point count duration and the implication of varying lengths, as well as a meta-analysis of point count durations used in recent studies (Table 3). The primary considerations when considering point count length are: (1) efficient use of sampling time to balance needs for a complete picture of resident birds with the need for increased spatial replication (e.g., Verner 1988, Dettmers et al. 1999); (2) ensuring that the method accords with the assumptions of the analytical methods – namely, providing a snapshot of the community that avoids double-counting of the same individuals (unless one is employing a generalized time-of-detection method - e.g., Alldredge et al. 2007a) and movement of individuals into and out of the count area; and (3) understanding the effects of point count duration on the parameters of interest (e.g., density or population size estimates; Smith et al. 1997, Lee and Marsden 2008). In terms of efficiency, many studies have reported that the large majority (>70%) of individuals are detected in the first 5 minutes of a point count (e.g., Fuller and Langslow 1984, Shiu and Lee 2003, Vergara et al. 2010). In terms of parameter estimation, count lengths can have significant impacts on density estimates (e.g., Cimprich 2009, Mollon 2010).

Mollon's (2010) meta-analysis revealed that the majority of recent point count –based studies employed 5 or 10 minute count periods with no settling in period prior to initiating the count (Table 3). The BBS uses 3-minute count periods, while the IMBCR protocol dictates 6-minute count periods, during which each minute is tracked, with a 2-minute settling-in period prior to each count.

Table 3. Distribution of count lengths used in avian point count surveys.

Settling Down Period (minutes)	Point Count Length (minutes)	No. of studies
not stated	not stated	6
0	3	4
0	5	11
1	5	1
2	5	1
0	6	1
1	8	1
2	8	1
0	10	25
2	10	2
0	12	1
0	15	1
5	20	1

NEON plan: NEON will use the IMBCR protocol, which would allow counts to be subsetted, in order to be more directly comparable to the BBS, as well as any study that uses 5-minute count periods. In systems where birds are rich and abundant, this will require either a good timer and a well-designed datasheet or a mobile application that timestamps observations automatically, but that can be edited when necessary. Additional pilot efforts to evaluate this intensive method were initially recommended for complex, diverse habitats (e.g., Northeastern deciduous forest). If the method had been found to be too onerous in such habitats, the observer would conduct two consecutive 6 minute surveys, focusing on a few super-abundant or noisy species in the first survey, and the rest of the species in the second survey. In 2017, birds were successfully sampled using the IMBCR protocol at 42 of the 47 NEON terrestrial sites, spanning a diversity of ecosystems.

6.5 Logistics and Adaptability

The design for sampling breeding bird abundance and density presented herein is summarized in Box 7, with comparisons to the BBS and IMBCR sampling protocols. The NEON design is more intensive than the BBS, yet less so than the IMBCR due to spatial constraints.

Box 7. Comparison of point count sampling designs.

design parameters	BBS	IMBCR	proposed design
Count array	39.4 km route	100 ha grid	56 ha grid
Points per array	50	16	9
Point spacing	800 m	250 m	250 m
Count duration	3 minutes	6 minutes	6 minutes
Count radius	400 m	Unlimited	Unlimited
Distance measured	No	Yes	Yes
Repeat visits	No	No	At small sites
Sampling approach	roadsides	Random, spatially balanced, by land ownership	Random, spatially balanced, by vegetation type

6.5.1 Logistical Consideration of Proposed Design

If (a) a site were able to contain the full complement of 10 grids; (b) each grid was sampled only once per season; (c) points were 2 + 6 minutes long; (d) travel time between points was 10 minutes on average; (e) travel time between grids was 1 hour on average; and (f) 4 hours were available to sample each day of the season, then sampling for that site would take approximately 13 days for one observer to complete (Table 4).

Table 4. Summary of potential scheduling scheme for sampling birds. Note that not all sites will be able to include 15 sampling sites due to spatial limitations, and travel times will vary across sites due to area, vegetation, topography.

Number of cells	**10**
Area of cells (km^2)	0.56
Number of points/cell	9
Total points to sample/bout	90
Sampling time (h/point)	0.133
Total time/bout (h)	12
Travel time between cells (h)	9
Travel time between points	13
Travel time/bout (h)	22
Hours available per sampling day	4
Number sampling days/bout	9
Total points/year	90
Total bird observation h / year	12

6.6 Data Analysis

The specifics of the data analysis will be contingent on some of the design decisions made above, particularly with regard to which method will be used to adjust the count data to estimate densities. Some options include:

1. Use only raw indices of abundance
2. Estimate detection probability
    a. Distance sampling: program Distance 6.0 (Thomas et al. 2010)
    b. Removal sampling (Farnsworth et al. 2002)
3. Estimate density
    a. Use the unmarked R package (Chandler et al. 2011, Fiske and Chandler 2011), given the relative ease of incorporating covariates into density models (Royle et al. 2004, Sillett et al. 2012).
    b. Use the spsurvey R package (Kincaid and Olsen 2012) to estimate density, population size and its variance for each species at each site.
    c. The modified approach of Yamaura et al. (2012) allows for estimation of abundance and density and associated uncertainties for all species, regardless of the number of detections.

Best practice for planning scientific studies includes identifying the statistical analyses intended as part of the design process (Gitzen et al. 2012), although NEON's goal is to identify a sampling design that will prove sufficiently robust for the greatest diversity of models. This flexibility is particularly important in light of the fact that all of the raw data derived from the TOS field sampling efforts will be provided to the community, to enable scientists to conduct analyses as they see fit.

An important caveat is that the design in its current form is intended to represent the ideal. These sampling designs are not going to be feasible at all sites, since weather and road conditions will prevent sampling at many sites during particular times of the year. The overarching goal of all sampling designs will be to be able to produce comparable estimates of abundance and diversity over time and space. This will require an iterative approach, in which the efficacy of the design is regularly evaluated at each site, given the data being collected. Moreover, new technologies and analytical methods are likely to emerge over the course of NEON, necessitating modifications to the design while maintaining the comparability and integrity of the data stream through time.

7 REFERENCES

Alldredge, M. W., K. Pacifici, T. R. Simons, and K. H. Pollock. 2008. A novel field evaluation of the effectiveness of distance and independent observer sampling to estimate aural avian detection probabilities. Journal of Applied Ecology 45:1349–1356.

Alldredge, M. W., K. H. Pollock, and T. R. Simons. 2007a. Time-of-detection method for estimating abundance from point-count surveys. The Auk 124:653–664.

Alldredge, M. W., K. H. Pollock, T. R. Simons, and D. H. Johnson. 2006. Estimating detection probabilities from multiple-observer point counts. The Auk 123:1172–1182.

Alldredge, M. W., T. R. Simons, and K. H. Pollock. 2007b. A field evaluation of distance measurement error in auditory avian point count surveys. Journal of Wildlife Management 71:2759–2766.

Anderson, S. H., D. Kelly, J. J. Ladley, S. Molloy, and J. Terry. 2011. Cascading effects of bird functional extinction reduce pollination and plant density. Science (New York, N.Y.) 331:1068–71.

Bart, J. 2005. Monitoring the abundance of bird populations. The Auk 122:15–25.

Bart, J., M. Hofschen, and B. G. Peterjohn. 1995. Reliability of the Breeding Bird Survey: effects of restricting surveys to roads. The Auk 112:758–761.

Bibby, C. J., N. D. Burgess, D. A. Hill, and S. Mustoe. 2000. Bird Census Techniques. Page 302. 2nd edition. Academic Press, London.

Blancher, P. J., K. V Rosenberg, A. O. Panjabi, B. Altman, J. Bart, C. J. Beardmore, D. Demarest, R. Dettmers, E. H. Dunn, W. Easton, W. C. Hunter, C. J. Ralph, T. D. Rich, C. M. Rustay, J. M. Ruth, and T. C. Will. 2007. Guide to the PIF Population Estimates Database. Version: North American Landbird Conservation Plan 2004. Partners in Flight Technical Publication No. 5. Page 26.

Blumstein, D. T., D. J. Mennill, P. Clemins, L. Girod, K. Yao, G. Patricelli, J. L. Deppe, A. H. Krakauer, C. Clark, K. a. Cortopassi, S. F. Hanser, B. McCowan, A. M. Ali, and A. N. G. Kirschel. 2011. Acoustic monitoring in terrestrial environments using microphone arrays: applications, technological considerations and prospectus. Journal of Applied Ecology 48:758–767.

Brewster, J. P., and T. R. Simons. 2009. Testing the importance of auditory detections in avian point counts. Journal of Field Ornithology 80:178–182.

Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers, and L. Thomas. 2001. Introduction to distance sampling: estimating abundance of biological populations. Page 448. Oxford University Press, USA, New York, NY.

Celis-Murillo, A., J. L. Deppe, and M. F. Allen. 2009. Using soundscape recordings to estimate bird species abundance, richness, and composition. Journal of Field Ornithology 80:64–78.

Chandler, R. B., J. A. Royle, and D. I. King. 2011. Inference about density and temporary emigration in unmarked populations. Ecology 92:1429–1435.

Cimprich, D. 2009. Effect of count duration on abundance estimates of Black-capped Vireos. Journal of Field Ornithology 80:94–100.

Claas, E. C., A. D. Osterhaus, R. van Beek, J. C. De Jong, G. F. Rimmelzwaan, D. A. Senne, S. Krauss, K. F. Shortridge, and R. G. Webster. 1998. Human influenza A H5N1 virus related to a highly pathogenic avian influenza virus. Lancet 351:472–7.

Dettmers, R., D. A. Buehler, J. G. Bartlett, and N. A. Klaus. 1999. Influence of point count length and repeated visits on habitat model performance. Journal of Wildlife Management 63:815–823.

Dunn, E. H., B. L. Altman, J. Bart, C. J. Beardmore, H. Berlanga, P. J. Blancher, G. S. Butcher, D. W. Demarest, R. Dettmers, W. C. Hunter, E. E. Iñigo-Elias, A. O. Panjabi, D. N. Pashley, C. J. Ralph, T. D. Rich, K. V Rosenberg, C. M. Rustay, J. M. Ruth, and T. C. Will. 2005a. High Priority Needs for Range-wide Monitoring of North American Landbirds. Partners in Flight Tech. Ser. 2. Page 31.

Dunn, E. H., C. M. Francis, P. J. Blancher, S. R. Drennan, M. A. Howe, D. Lepage, C. S. Robbins, K. V Rosenberg, J. R. Sauer, and K. G. Smith. 2005b. Enhancing the scientific value of the Christmas Bird Count. The Auk 122:338–346.

Efford, M. G., and D. K. Dawson. 2009. Effect of distance-related heterogeneity on population size estimates from point counts. The Auk 126:100–111.

Fancy, S. G., and J. R. Sauer. 2000. Recommended methods for inventorying and monitoring landbirds in national parks. Page 13.

Farnsworth, G. L., J. D. Nichols, J. R. Sauer, S. G. Fancy, K. H. Pollock, S. A. Shriner, and T. R. Simons. 2005. Statistical approaches to the analysis of point count data: A little extra information can go a long way. Pages 736–743.

Farnsworth, G. L., K. H. Pollock, J. D. Nichols, T. R. Simons, J. E. Hines, and J. R. Sauer. 2002. A removal model for estimating detection probabilities from point-count surveys. The Auk 119:414–425.

Field, S. A., A. J. Tyre, and H. P. Possingham. 2002. Estimating bird species richness: How should repeat surveys be organized in time? Austral Ecology 27:624–629.

Fiske, I. J., and R. B. Chandler. 2011. unmarked: An R package for fitting hierarchical models of wildlife occurrence and abundance. Journal of Statistical Software 43:1–23.

Fuller, R., and D. Langslow. 1984. Estimating numbers of birds by point counts: how long should counts last? Bird Study 31:195–202.

Gardali, T., N. E. Seavy, R. T. DiGaudio, and L. a Comrack. 2012. A climate change vulnerability assessment of California's at-risk birds. PloS one 7:e29507.

Gitzen, R. A., J. J. Millspaugh, A. B. Cooper, and D. S. Licht (Eds.). 2012. Design and Analysis of Long-Term Ecological Studies. Page 600. Cambridge University Press, Cambridge, UK.

Grinnell, J. 1917. The niche-relationships of the California Thrasher. The Auk 34:427–433.

Handel, C. M., and M. N. Cady. 2004. Alaska Landbird Monitoring Survey: Protocol for Setting Up and Conducting Point Counts. USGS Alaska Science Center, Anchorage, AK, https://alaska.usgs.gov/science/biology/bpif/monitor/alms/ALMSprotocol_2004.pdf (accessed 17 April 2018).

Hanni, D. J., C. M. White, R. A. Sparks, J. A. Blakesley, G. J. Levandoski, and J. J. Birek. 2010. Field Protocol for Spatially Balanced Sampling of Landbird Populations. Page 34. Brighton, Colorado, USA.

Hansen, A. J. 2008. Birds, Fundamental Sentinel Units Tiger team report.

Hechinger, R. F., and K. D. Lafferty. 2005. Host diversity begets parasite diversity: bird final hosts and trematodes in snail intermediate hosts. Proceedings of the The Royal Society B: Biological sciences 272:1059–66.

Hurlbert, A. H., and Z. Liang. 2012. Spatiotemporal variation in avian migration phenology: citizen science reveals effects of climate change. PloS one 7:e31662.

Hutto, R. L., and J. S. Young. 2002. Regional landbird monitoring: perspectives from the Northern Rocky Mountains. Wildlife Society Bulletin 30:738–750.

Johnson, D. H. 2008. In defense of indices: The case of bird surveys. Journal of Wildlife Management 72:857–868.

Jongsomjit, D., D. Stralberg, T. Gardali, L. Salas, and J. Wiens. 2012. Between a rock and a hard place: the impacts of climate change and housing development on breeding birds in California. Landscape Ecology 28:187–200.

Kao, R. H., C. M. Gibson, R. E. Gallery, C. L. Meier, D. T. Barnett, K. M. Docherty, K. K. Blevins, P. D. Travers, E. Azuaje, Y. P. Springer, K. M. Thibault, V. J. McKenzie, M. Keller, L. F. Alves, E. S. Hinckley, J. Parnell, and D. S. Schimel. 2012. NEON terrestrial field observations: designing continental-scale, standardized sampling. Ecosphere 3:115.

Keller, M., D. S. Schimel, W. W. Hargrove, and F. M. Hoffman. 2008. A continental strategy for the National Ecological Observatory Network. Frontiers in Ecology and the Environment 6:282–284.

Kincaid, T. M., and A. R. Olsen. 2012. spsurvey: Spatial Survey Design and Analysis. R package version 2.5.

LaDeau, S. L., A. M. Kilpatrick, and P. P. Marra. 2007. West Nile virus emergence and large-scale declines of North American bird populations. Nature 447:710–3.

Lee, D. C., and S. J. Marsden. 2008. Adjusting count period strategies to improve the accuracy of forest bird abundance estimates from point transect distance sampling surveys. Ibis 150:315–325.

Luther, D., J. Hilty, J. Weiss, C. Cornwall, M. Wipf, and G. Ballard. 2008. Assessing the impact of local habitat variables and landscape context on riparian birds in agricultural, urbanized, and native landscapes. Biodiversity and Conservation 17:1923–1935.

MacArthur, R. H. 1958. Population ecology of some warblers of northeastern coniferous forests. Ecology 39:599–619.

MacKenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Pollock, L. L. Bailey, and J. E. Hines. 2006. Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence. Page 344. Elsevier B.V., Burlington, Massachusetts, USA.

Matsuoka, S. M., E. M. Bayne, P. Sólymos, P. C. Fontaine, S. G. Cumming, F. K. A. Schmiegelow, and S. J. Song. 2012. Using binomial distance-sampling models to estimate the effective detection radius of point-count surveys across boreal Canada. The Auk 129:268–282.

McKenzie, V. J., and N. E. Goulet. 2010. Bird community composition linked to human West Nile virus cases along the Colorado Front Range. EcoHealth 7:439–47.

Mollon, A. 2010. The effect of point count duration on avian density estimates: a case study of distance sampling surveys of the avifauna of St. Lucia. Imperial College London.

National Audubon Society. 2002. The Christmas Bird Count historical results. http://www.audubon.org/bird/cbc.

Newbold, T., J. P. W. Scharlemann, S. H. M. Butchart, C. H. Sekercioglu, R. Alkemade, H. Booth, and D. W. Purves. 2012. Ecological traits affect the response of tropical forest bird species to land-use intensity. Proceedings of the Royal Society B: Biological Sciences 280:20122131–20122131.

Nichols, J. D., L. Thomas, and P. B. Conn. 2009. Inferences About Landbird Abundance from Count Data: Recent Advances and Future Directions. Pages 201–235 *in* D. L. Thomson, E. G. Cooch, and M. J. Conroy, editors. Modeling Demographic Processes In Marked Populations. Springer US, Boston, MA.

North American Bird Conservation Initiative (NABCI). 2000. North American Bird Conservation Initiative: bird conservation region descriptions. Washington, DC.

Nur, N., S. L. Jones, and G. R. Geupel. 1999. Statistical Guide to Data Analysis of Avian Monitoring Programs. Page 61. Washington, D.C.

O'Connor, R. J., E. H. Dunn, D. H. Johnson, S. L. Jones, D. Petit, K. H. Pollock, C. R. Smith, J. L. Trapp, and E. Welling. 2000. A programmatic review of the North American Breeding Bird Survey. Page 37.

Pacifici, K., T. R. Simons, and K. H. Pollock. 2008. Effects of vegetation and background noise on the detection process in auditory avian point-count surveys. The Auk 125:600–607.

Pavlacky, D. C., J. A. Blakesley, G. C. White, D. J. Hanni, and P. M. Lukacs. 2012. Hierarchical multi-scale occupancy estimation for monitoring wildlife populations. Journal of Wildlife Management 76:154–162.

Purcell, K. L., S. R. Mori, and M. K. Chase. 2005. Design considerations for examining trends in avian abundance using point counts: examples from oak woodlands. The Condor 107:305.

Ralph, C. J., S. Droege, and J. R. Sauer. 1995. Managing and Monitoring Birds Using Point Counts: Standards and Applications. Pages 161–168 *in* C. J. Ralph, J. R. Sauer, and S. Droege, editors. Monitoring bird populations by point counts. Gen. Tech. Rep. PSW-GTR-149. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA.

Ralph, C. J., T. E. Martin, G. R. Geupel, D. F. Desante, and P. Pyle. 1993. Handbook of Field Methods for Monitoring Landbirds. Gen. Tech. Rep. PSW-GTR-144-www. Page 41. Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture, Albany, CA.

Reidy, J. L., F. R. Thompson, and J. W. Bailey. 2011. Comparison of methods for estimating density of forest songbirds from point counts. Journal of Wildlife Management 75:558–568.

Rich, T. D., C. J. Beardmore, H. Berlanga, P. J. Blancher, M. S. W. Bradstreet, G. S. Butcher, D. W. Demarest, E. H. Dunn, W. C. Hunter, E. E. Iñigo-Elias, J. A. Kennedy, A. M. Martell, A. O. Panjabi, D. N. Pashley, K. V. Rosenberg, C. M. Rustay, J. S. Wendt, and T. C. Will. 2004. Partners in Flight North American Landbird Conservation Plan. Page 110. Ithaca, NY.

Riddle, J. D., K. H. Pollock, and T. R. Simons. 2010. An unreconciled double-observer method for estimating detection probability and abundance. The Auk 127:841–849.

Rosenstock, S. S., D. R. Anderson, K. M. Giesen, T. Leukering, and F. Carter. 2002. Landbird counting techniques: current practices and an alternative. The Auk 119:46–53.

Royle, J. A., D. K. Dawson, and S. Bates. 2004. Modeling abundance effects in distance sampling. Ecology 85:1591–1597.

Royle, J. A., and R. M. Dorazio. 2008. Hierarchical Modeling and Inference in Ecology: The Analysis of Data from Populations, Metapopulations and Communities. Page 444. Academic Press.

Saracco, J. F., D. F. Desante, and D. R. Kaschube. 2008. Assessing landbird monitoring programs and demographic causes of population trends. Journal of Wildlife Management 72:1665–1673.

Sauer, J. R., J. E. Fallon, and R. Johnson. 2003. Use of North American Breeding Bird Survey data to estimate population change for Bird Conservation Regions. Journal of Wildlife Management 67:372–389.

Sauer, J. R., J. E. Hines, J. E. Fallon, K. L. Pardieck, D. J. Ziolkowski, Jr., and W. A. Link. 2011. The North American Breeding Bird Survey 1966-2009. Version 3.23.2011. USGS Patuxent Wildlife Research Center, Laurel, MD, Laurel, MD.

Sauer, J. R., and W. A. Link. 2011. Analysis of the North American Breeding Bird Survey Using Hierarchical Models. The Auk 128:87–98.

Sauer, J. R., B. G. Peterjohn, and W. A. Link. 1994. Observer Differences in the North American Breeding Bird Survey. The Auk 111:50–62.

Schimel, D. S., M. Keller, S. Berukoff, R. H. Kao, H. L. Loescher, H. Powell, T. U. Kampe, D. J. P. Moore, and W. Gram. 2011. National Ecological Observatory Network 2011 Science Strategy: enabling continental-scale forecasting. Page 56.

Schmidt, K. A., S. A. Rush, and R. S. Ostfeld. 2008. Wood thrush nest success and post-fledging survival across a temporal pulse of small mammal abundance in an oak forest. Journal of Animal Ecology 77:830–7.

Sekercioglu, C. H. 2006. Increasing awareness of avian ecological function. Trends in ecology & evolution 21:464–71.

Shiu, H.-J., and P.-F. Lee. 2003. Assessing avian point-count duration and sample size using species accumulation functions. Zoological Studies 42:357–367.

Siegel, R. B., D. F. Desante, and M. P. Nott. 2001. Using Point Counts to Establish Conservation Priorities: How Many Visits Are Optimal? Journal of Field Ornithology 72:228–235.

Siegel, R. B., R. L. Wilkerson, K. J. Jenkins, R. C. Kuntz II, J. R. Boetsch, J. P. Schaberl, and P. J. Happe. 2007. Landbird Monitoring Protocol for National Parks in the North Coast and Cascades Network: U.S. Geological Survey Techniques and Methods 2-A6. Page 200.

Sillett, T. S., R. B. Chandler, J. A. Royle, M. Kery, and S. A. Morrison. 2012. Hierarchical distance sampling models to estimate population size and habitat-specific abundance of an island endemic. Ecological Applications 22:1997–2006.

Simons, T. R., M. W. Alldredge, K. H. Pollock, and J. M. Wettroth. 2007. Experimental analysis of the auditory detection process on avian point counts. The Auk 124:986.

Smith, W. P., D. J. Twedt, P. B. Hamel, R. P. Ford, D. A. Wiedenfeld, and R. J. Cooper. 1997. Increasing point-count duration increases standard error. Journal of Field Ornithology 69:450–456.

Sólymos, P., S. M. Matsuoka, E. M. Bayne, S. R. Lele, P. Fontaine, S. G. Cumming, D. Stralberg, F. K. A. Schmiegelow, and S. J. Song. 2013. Calibrating indices of avian density from non-standardized survey data: making the most of a messy situation. Methods in Ecology and Evolution 4:1047–1058.

Stevens, D. L., and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99:262–278.

Stralberg, D., D. Jongsomjit, C. A. Howell, M. A. Snyder, J. D. Alexander, J. A. Wiens, and T. L. Root. 2009. Re-Shuffling of Species with Climate Disruption : A No- Analog Future for California Birds ? 4.

Sullivan, B. L., C. L. Wood, M. J. Iliff, R. E. Bonney, D. Fink, and S. Kelling. 2009. eBird: A citizen-based bird observation network in the biological sciences. Biological Conservation 142:2282–2292.

Theobald, D. M., D. L. Stevens, D. White, N. S. Urquhart, A. R. Olsen, and J. B. Norman. 2007. Using GIS to generate spatially balanced random survey designs for natural resource applications. Environmental Management 40:134–46.

Thomas, L., S. T. Buckland, E. a Rexstad, J. L. Laake, S. Strindberg, S. L. Hedley, J. R. Bishop, T. A. Marques, and K. P. Burnham. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. Journal of Applied Ecology 47:5–14.

Thomas, L., and K. Martin. 1996. The importance of analysis method for Breeding Bird Survey population trend estimates. Conservation Biology 10:479–490.

Thompson, W. L. 2002. Towards reliable bird surveys: accounting for individuals present but not detected. The Auk 119:18–25.

Tingley, M. W., M. S. Koo, C. Moritz, A. C. Rush, and S. R. Beissinger. 2012. The push and pull of climate change causes heterogeneous shifts in avian elevational ranges. Global Change Biology 18:3279–3290.

U.S. North American Bird Conservation Initiative Monitoring Subcommittee. 2007. Opportunities for Improving Avian Monitoring. Page 50.

Vergara, P. M., J. E. Jiménez, and R. P. Schlatter. 2010. Effective point-count duration for estimating bird species' richness in Chilean forests. Zoological Studies 49:381–391.

Verner, J. 1988. Optimizing the duration of point counts for monitoring trends in bird populations. Res. Note PSW-395. Page 4. Berkeley, CA.

Welsh, A. H., D. B. Lindenmayer, and C. F. Donnelly. 2013. Fitting and interpreting occupancy models. PloS one 8:e52015.

White, C. M., N. J. Van Lanen, D. C. Pavlacky, J. A. Blakesley, R. Sparks, J. Fogg, M. McLaren, J. Birek, and D. J. Hanni. 2012. Integrated Monitoring in Bird Conservation Regions (IMBCR): 2011 Annual Report. Page 113. Brighton, Colorado, USA.

Yamaura, Y., J. A. Royle, N. Shimada, S. Asanuma, T. Sato, H. Taki, and S. Makino. 2012. Biodiversity of man-made open habitats in an underused country: a class of multispecies abundance models for count data. Biodiversity and Conservation 21:1365–1380.

APPENDIX A INITIAL CONFIGURATION OF NEON SITES

Table A1. Number of bird grids by site, 2018 (may have been reduced from the original number of plots established). Sites that are too small to accommodate 5 or more grids are indicated by 'NA' in the Number of Grids column.

Domain ID	Domain Name	Site ID	Site Name	Number of Grids	Number of Points
D01	Northeast	BART	Bartlett Experimental Forest	9	81
D01	Northeast	HARV	Harvard Forest	10	90
D02	Mid-Atlantic	SERC	Smithsonian Environmental Research Center	NA	24
D02	Mid-Atlantic	BLAN	Blandy Experimental Farm	NA	11
D02	Mid-Atlantic	SCBI	Smithsonian Conservation Biology Institute	NA	24
D03	Southeast	DSNY	Disney Wilderness Preserve	9	81
D03	Southeast	JERC	Jones Ecological Research Center	9	81
D03	Southeast	OSBS	Ordway-Swisher Biological Station	10	90
D04	Atlantic Neotropical	GUAN	Guanica Forest	9	81
D04	Atlantic Neotropical	LAJA	Lajas Experimental Station	NA	16
D05	Great Lakes	STEI	Steigerwaldt Land Services	10	90
D05	Great Lakes	TREE	Treehaven	NA	17
D05	Great Lakes	UNDE	UNDERC	9	81
D06	Prairie Peninsula	KONZ	Konza Prairie Biological Station	10	90
D06	Prairie Peninsula	UKFS	The University of Kansas Field Station	5	45
D06	Prairie Peninsula	KONA	Konza Prairie Biological Station	NA	15
D07	Appalachians & Cumberland Plateau	GRSM	Great Smoky Mountains National Park, Twin Creeks	10	90
D07	Appalachians & Cumberland Plateau	MLBS	Mountain Lake Biological Station	8	72
D07	Appalachians & Cumberland Plateau	ORNL	Oak Ridge	10	90
D08	Ozarks Complex	LENO	Choctaw National Wildlife Refuge, Lenoir Landing	NA	23
D08	Ozarks Complex	DELA	Dead Lake	NA	15
D08	Ozarks Complex	TALL	Talladega National Forest	10	90
D09	Northern Plains	DCFS	Dakota Coteau Field School	NA	20
D09	Northern Plains	NOGP	Northern Great Plains Research Laboratory	NA	20
D09	Northern Plains	WOOD	Woodworth	9	81
D10	Central Plains	STER	North Sterling, Co	NA	9
D10	Central Plains	CPER	Central Plains Experimental Range	10	90

D10	Central Plains	RMNP	Rocky Mountain National Park, CASTNET	10	90
D11	Southern Plains	CLBJ	LBJ National Grassland	9	81
D11	Southern Plains	OAES	Klemme Range Research Station	7	63
D12	Northern Rockies	YELL	Yellowstone Northern Range (Frog Rock)	NA	NA
D13	Southern Rockies & Colorado Plateau	NIWO	Niwot Ridge Mountain Research Station	6	54
D13	Southern Rockies & Colorado Plateau	MOAB	Moab	7	63
D14	Desert Southwest	JORN	Jornada LTER	10	90
D14	Desert Southwest	SRER	Santa Rita Experimental Range	10	90
D15	Great Basin	ONAQ	Onaqui	6	54
D16	Pacific Northwest	ABBY	Abby Road	NA	20
D16	Pacific Northwest	WREF	Wind River Experimental Forest	10	90
D17	Pacific Southwest	SJER	San Joaquin	10	90
D17	Pacific Southwest	SOAP	Soaoroot Saddle	NA	16
D17	Pacific Southwest	TEAK	Lower Teakettle	10	90
D18	Tundra	BARR	Barrow Environmental Observatory	7	63
D18	Tundra	TOOL	Toolik Lake	NA	20
D19	Taiga	DEJU	Delta Junction	9	81
D19	Taiga	BONA	Caribou - Poker Creeks Reseaarch Watershed	10	90
D19	Taiga	HEAL	Healy	9	81
D20	Pacific Tropical	PUUM	Pu'u Maka'ala Natural Area Reserve	NA	20