Landbird Trends in National Parks of the North Coast and Cascades Network, 2005–12

Open-File Report 2014–1202

U.S. Department of the Interior
U.S. Geological Survey

Cover: Clark's Nutcracker (*Nucifraga columbiana*) in North Cascades National Park.
Photograph by Mandy Holmgren, The Institute for Bird Populations.

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Prepared in cooperation with the National Park Service and The Institute for Bird Populations

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U.S. Geological Survey
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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)

Datums

Vertical coordinate information is referenced to North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

Landbird Trends in National Parks of the North Coast and Cascades Network, 2005–12

By James F. Saracco[1], Amanda L. Holmgren[1], Robert L. Wilkerson[1], Rodney B. Siegel[1], Robert C. Kuntz, II[2], Kurt J. Jenkins[3], Patricia J. Happe[4], John R. Boetsch[5], and Mark H. Huff[5]

Abstract

National parks in the North Coast and Cascades Network (NCCN) can fulfill vital roles as refuges for bird species dependent on late-successional forest conditions and as reference sites for assessing the effects of land-use and land-cover changes on bird populations throughout the larger Pacific Northwest region. Additionally, long-term monitoring of landbirds throughout the NCCN provides information that can inform decisions about important management issues in the parks, including visitor impacts, fire management, and the effects of introduced species. In 2005, the NCCN began implementing a network-wide Landbird Monitoring Project as part of the NPS Inventory and Monitoring Program. In this report, we discuss 8-year trends (2005–12) of bird populations in the NCCN, based on a sampling framework of point counts established in three large wilderness parks (Mount Rainier, North Cascades, and Olympic National Parks), 7-year trends at Lewis and Clark National Historical Park (sampled in 2006, 2008, 2010, and 2012), and 5-year trends at San Juan Islands National Historical Park (sampled in 2007, 2009, and 2011). Our analysis encompasses a fairly short time span for this long-term monitoring program. The first 2 years of the time series (2005 and 2006) were implemented as part of a limited pilot study that included only a small subset of the transects. The subsequent 6 years (2007–12) represent just a single cycle through 5 years of alternating panels of transects in the large parks, with the first of five alternating panels revisited for the first time in 2012. Of 204 transects that comprise the six sampling panels in the large parks, only 68 (one-third) have thus been eligible for revisit surveys (34 during every year after 2005, and an additional 34 only in 2012) and can contribute to our current trend estimates. We therefore initiated the current analysis with a primary goal of testing our analytical procedures rather than detecting trends that might be strong enough to drive conservation or management decisions in the parks or elsewhere. We expect that aggregated trend detection results may change substantially over the next several years, as the number of transects with revisit histories triples and the spatial dispersion of transects contributing to trend estimates also improves greatly. In the meantime, caution should be exercised in interpreting the importance of trends, as individual years can have very large influences on the direction and magnitude of trends in a time series of such limited duration (and limited numbers of repeat visits at the small parks). Nevertheless, we estimated trends for 43 species at Mount Rainier National Park, 53 species at North Cascades National Park Complex, and 41 species at Olympic National Park. Of 137 park-species combinations (including combined-park analyses), we found 16 significant decreases (12 percent) and five significant increases (4 percent).

We identify several limitations of the current analytical framework for trend assessment but suggest that the overall sampling design is strong and amenable to analysis by more recently developed model-based methods. These could provide a more flexible framework for examining trends and other population parameters of interest, as well as testing hypotheses that relate the distribution and abundance of species to environmental covariates. A model-based approach would allow for modeling various components of the detection process and analyzing observations (detection process), population state (occupancy, population size, density), and change (trend, local extinction and colonization rates turnover) simultaneously. Finally, we also evaluate operational aspects of NCCN Landbird Monitoring Project, and conclude that our robust, multi-party partnership is successfully implementing the project as it was envisioned.

[1]The Institute for Bird Populations.

[2]North Cascades National Park Complex.

[3]U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center.

[4]National Park Service, Olympic National Park.

[5]National Park Service, North Coast and Cascades Network.

Introduction

National parks in the North Coast and Cascades Network (NCCN) can fulfill vital roles as both refuges for bird species dependent on late-successional forest conditions and as reference sites for assessing the effects of land-use and land-cover changes on bird populations throughout the larger Pacific Northwest region (Silsbee and Peterson, 1991; Siegel and others, 2012). These changes may result from regional processes such as land conversion and forest management, or from broader-scale phenomena such as global climate change. Monitoring population trends at 'control' sites in national parks is especially important because the parks are among the few sites in the United States where population trends resulting from large-scale regional or global change patterns are relatively unaffected by local changes in land use (Simons and others, 1999).

In 2007, the NCCN launched its Landbird Monitoring Project, which monitors population trends of dozens of bird species in three large wilderness parks and two smaller, historical parks that also comprise significant natural resources. Birds were selected for monitoring as they represent one of the key vital signs of all signs of park ecosystem health. Vital signs are selected physical, chemical, and biological elements and processes of park ecosystems that represent the overall condition of the park resources, known or hypothesized effects of stressors, or elements that have important human values (http://science.nature.nps.gov/im/monitor/docs/Monitoring_Brochure.pdf). Birds were selected not only out of concern for their population status, but also for the great interest they hold for the public, their distribution across nearly all portions of all parks, and the potential for monitoring dozens of species simultaneously across multiple parks with a single, integrated protocol.

From the outset, the NCCN Landbird Monitoring Project has served as a model for other resource monitoring efforts within the National Park Service (NPS). The NCCN landbird protocol (Siegel and others, 2007) was the first protocol approved in the NCCN and one of the first approved avian monitoring protocols in the NPS. A very similar protocol, patterned explicitly after the NCCN protocol, was later adopted and implemented by the Sierra Nevada Network (SIEN) (Siegel and others, 2010).Data from the North American Breeding Bird Survey (BBS) suggest that many landbird populations in Pacific Northwest coniferous forests have decreased in recent decades (Andelman and Stock, 1994a, 1994b; Sharp, 1996; Saab and Rich, 1997; Altman, 2000, 2005; Sauer and others, 2012). Sauer and others (2012) report that 35 percent of 164 species in the Northern Pacific Rainforest Bird Conservation Region significantly decreased between 1966 and 2011, while only 13 percent of the species significantly increased in the region over the same time period.

As climate change continues and likely accelerates in the coming decades, many bird species in the region are likely to be affected by changes in weather patterns, habitat structure and distribution, and phenology of food availability. Recent studies from elsewhere in the montane west suggest that birds dependent on high-elevation habitats may be particularly likely to be jeopardized by climate change (Gardali and others, 2012; Siegel and others, 2014), but also that effects may be complicated across montane regions, with some species undergoing range expansions and population increases and other species experiencing range contractions, population decreased, and possibly local extirpation. The NCCN Landbird Monitoring Project is poised to detect and describe many of these changes in bird populations within the parks.

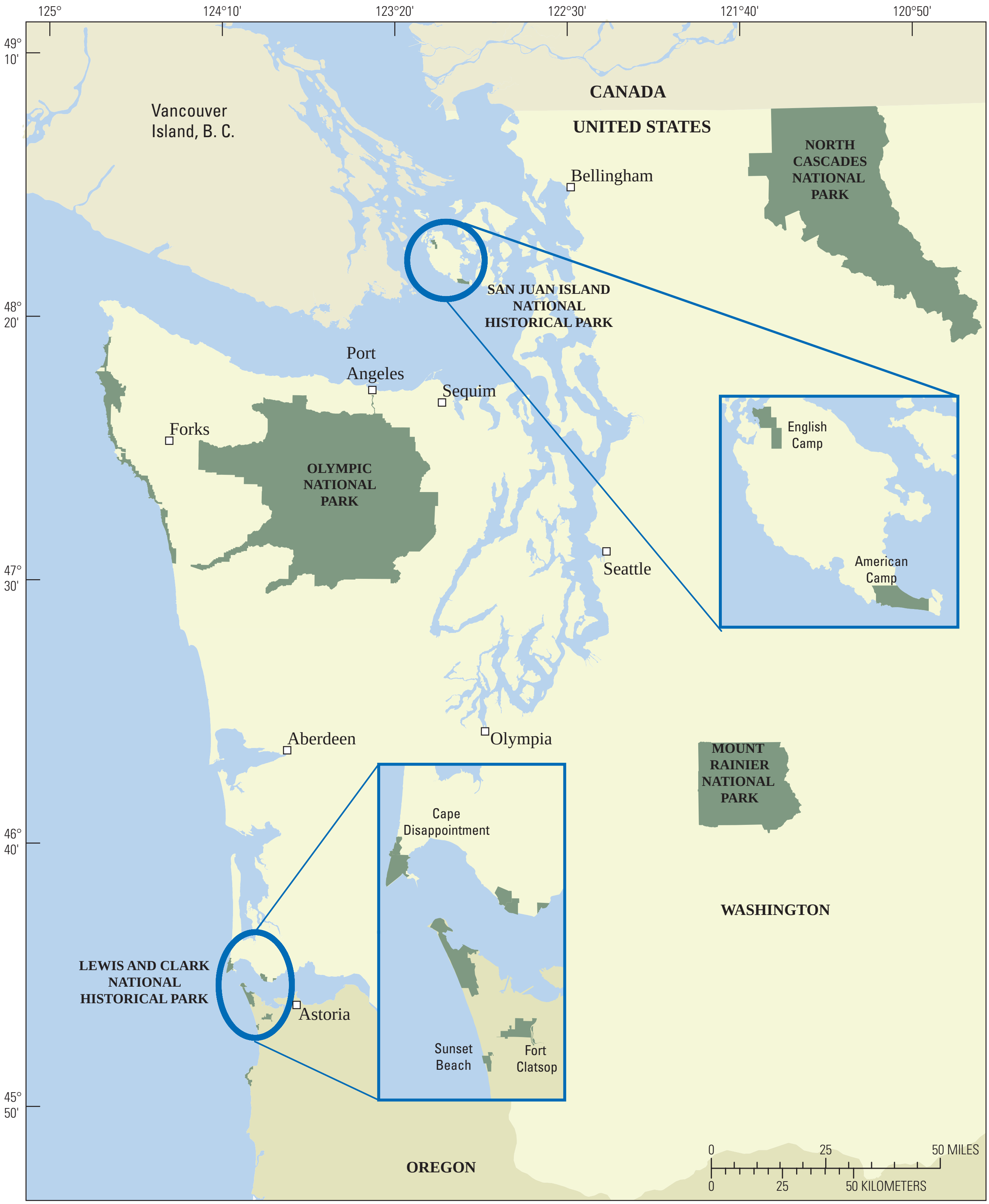
In addition to climate change, threats to bird populations breeding in Pacific Northwest coniferous forests include habitat loss and fragmentation, as well as altered forest structure resulting from varied forest management practices. Large tracts of low-elevation coniferous forest have been lost to residential and agricultural development since World War II (Bolsinger and Waddell, 1993). Landscapes managed for timber production are now often dominated by early- and mid-successional forest (Bunnell and others, 1997), may be highly fragmented, and can exhibit structural characteristics that can alter avian community structure and diminish bird diversity (Meslow and Wight, 1975; Hagar and others, 1995; Bunnell and others, 1997; Altman, 2005; Linden and others, 2012; Linden and Roloff, 2013; Yegorova and others, 2013). Pacific Northwest landbirds breeding in habitats other than coniferous forests face substantial threats as well. Species that breed in the subalpine and alpine zones, for example, may face ecological changes resulting from visitor impacts, among other issues. The NCCN protects and manages substantial high-elevation bird habitat; Oregon-Washington Partners in Flight identified monitoring birds in high-elevation areas throughout the Pacific Northwest as an important need and suggested that the NPS should be a key player in this monitoring (Altman and Bart, 2001). Additional threats face migratory landbirds that breed in the Pacific Northwest. For example, land-use changes or climate change on the wintering grounds and along migration routes may influence overwinter survival of migratory species.

The primary and secondary objectives of the NCCN Landbird Monitoring Project, respectively, are to (1) detect trends in the density of as many landbird species (including passerines, near passerines, and galliformes) as possible throughout accessible areas of five NCCN parks during the breeding season, and (2) to track changes in the breeding season distribution of landbird species in each park throughout accessible areas of the three large wilderness parks. In this report, we discuss 8-year trends (2005–12) of bird populations in the NCCN, based on a sampling framework of point counts established in three large wilderness parks (Mount Rainier, North Cascades, and Olympic National Parks), 7-year trends at Lewis and Clark National Historical Park (sampled in 2006, 2008, 2010, and 2012), and 5-year trends at San Juan Islands National Historical Park (sampled in 2007, 2009, and 2011). The secondary goal of the NCCN Landbird Monitoring Project, tracking changes in the breeding season distribution of landbird species, will be pursued in the coming years after a longer temporal span of data have been collected and new analytical methods are developed. An additional objective of this report is to evaluate the effectiveness of the Landbird Monitoring Project and identify any improvements that may be implemented.

Methods

Study Areas and Sampling Design

Bird surveys were conducted in three large wilderness parks (North Cascades [NOCA], Olympic [OLYM], and Mount Rainier [MORA] National Parks); and in two small parks (Lewis and Clark National Historical Park [LEWI] and San Juan Island National Historical Park [SAJH]; fig. 1). The three large parks span elevations from sea level to 4,400 m above sea level and contain large tracts of late-successional, coniferous forest on the Olympic Peninsula and the western slope of the Cascades Range, as well as areas dominated by subalpine and alpine plant communities. NOCA also includes substantial tracts of coniferous forest typical of the eastern side of the Cascades, which hosts a somewhat distinct avifauna (Altman, 2000). SAJH, in the rainshadow of the Olympic Mountains, includes small but important examples of coastal prairie and Garry Oak woodlands, plant communities that are fairly rare in western Washington (Atkinson and Sharpe, 1985), and hosts distinct bird communities (Lewis and Sharpe, 1987; Siegel and others, 2009e). LEWI includes lowland wetlands as well as coastal and upland forests, and extends our project's area of inference substantially southward. Because the three large parks of the NCCN are vastly larger and pose different logistical constraints than the smaller NCCN parks, we implemented two separate sampling schemes; one for the three large wilderness parks (MORA, OLYM, NOCA) and one for the two smaller parks (SAJH, LEWI).



Base map modified from National Park Service and US Geological Survey digital data, various scales. Coordinate Reference System: UTM Zone 10N, horizontal datum is North American Datum of 1983.

Figure 1. National Park Service units participating in the North Coast and Cascades Network Landbird Monitoring Project.

Large Park Sampling Scheme

Early efforts to conduct geographically extensive bird surveys in NCCN parks (Jenkins and others, 2000; Siegel and others, 2009a, 2009c, 2009d, and 2009e) explored logistical and safety challenges in monitoring bird populations across the NCCN's three large wilderness parks. Although we desired a sampling scheme that would approximate park-wide inference as closely as possible, some compromises had to be made because of constraints stemming from the parks' large size, limited road access, rugged terrain, frequent inclement weather, and associated safety considerations. At the three large parks, sampling for the long-term Landbird Monitoring Project was conducted along point-count transects using methods described in detail by Siegel and others (2007). For safety and logistical reasons, all transects emanated from a park trail (the vast majority of transects) or road (a small portion of the transects) (figs. 2–4). Although we limited the sampling frame (and inferences) to a buffer of approximately 1 km in either direction along trails and roads, a substantial portion of wilderness in each of the three large parks was available for sampling within that buffer. The 1-km buffer included 57 percent of the total land area at MORA, 31 percent at NOCA, and 39 percent at OLYM. Although the areas within the buffers could not perfectly represent the mix of habitats and environmental conditions across the entire landscapes of the parks, in all cases they included a broad diversity of habitats such that any bias introduced by this sampling design was deemed acceptably small relative to the safety and logistic benefits (Siegel and others, 2007).

The sampling frame of potential transects started from points spaced every 50 m along maintained trails and roads in each park and extending perpendicularly away from the access routes. For transects emanating along trails, if off-trail travel was not possible, the transect was established directly on the trail. We used Geographic Information Systems (GIS) data to screen and eliminate potential starting points that were unusable because they were along roads in steep areas where off-road sampling would not be possible, paralleled shorelines of large lakes or reservoirs where one-half the points would be in open water or were located along roads that were too wide and/or busy with traffic to allow for safe or meaningful sampling. We used GIS data to classify the remaining transect starting points into low-, mid-, or high-elevation strata. For NOCA and OLYM, we defined low-elevation stratum as all potential transects with starting points less than 650 m above sea level; mid-elevation stratum as all potential transects with starting points between and including 650 and 1,350 m above sea level; and high-elevation stratum as all potential transects with starting points greater than 1,350 m above sea level. For MORA only, we adjusted the boundary between the low- and mid-elevation strata to 800 m, as virtually none of the park is less than 650 m above sea level, but otherwise defined the elevation strata in the same manner as for the other parks. The number of potential transect starting points (that is, the sampling frame or total available population units) for each park and elevation is presented in table 1.

Transects were selected based on an augmented serially alternating panel design (Urquhart and others, 1998). Based on this design we established one set, or panel, of transects to be surveyed annually (that is, the annual panel) and 5 sets of transects that will be revisited on a 5-year return interval (that is, the alternating panels). Each year we sampled the annual panel of transects and one of the five alternating panels. This design allowed for sampling a relatively large overall number of transects over the 5-year sampling cycle (providing better representation of diverse habitats and regions in each park), while providing substantial year-to-year continuity in the dataset by sampling transects in the annual panel every year (Breidt and Fuller, 1999; Urquhart and Kincaid, 1999; McDonald, 2003). Spatially dispersed, random sampling locations were selected as transect starting points using the Generalized Random-Tessellation Stratified (GRTS) sampling method (Stevens and Olsen, 1999, 2003, 2004) with reverse hierarchical ordering. The GRTS sampling method is well-suited for large-scale environmental monitoring programs, in part because it generally creates a spatially balanced sample while allowing for additional sample units to be added or subtracted without compromising the spatial balance (Stevens and Olsen, 2003, 2004). In NOCA and OLYM, we selected a total of 72 transects consisting of 12 transects in each of the six panels. Each panel was populated with four transects sampled from each elevation stratum. In MORA, because of the relatively small fraction of the park lying within the low-elevation stratum boundaries, we only sampled 60 transects total, consisting of 10 transects in each panel, with two, four, and four transects in low-, mid-, and high-elevation strata, respectively.

Each year, the sampling scheme included surveys of the annual panel as well as one of the alternating panels. During the first 2 years of protocol development (2005–06), we surveyed only the annual panel (Siegel and others, 2006, 2009b). Thereafter, we attempted to complete 24 transects at NOCA and OLYM and 20 at MORA each year, with sample effort in each park allocated evenly between the annual panel and one of the five alternating panels.

From selected starting points on trails or roads, transects extended perpendicularly in both directions with point count stations spaced 200 m apart. Observers followed a set of pre-defined decision rules for redirecting transects when cliffs, impassable streams, or other obstacles were encountered (Siegel and others, 2007). Where off-trail travel was impossible, transects were established on trails rather than along routes perpendicular to them. Depending on difficulty of travel and terrain, the number of points sampled along each transect ranged from 8 to 25. Because there was annual variability in the number of points sampled per transect, we based the trend analysis on the minimum number of points in which surveys were completed each year (generally the first 8–12 points of any transect). Avian detections made from points that were not sampled every year contributed to tabulations of species observed, but were not used in trend analysis.

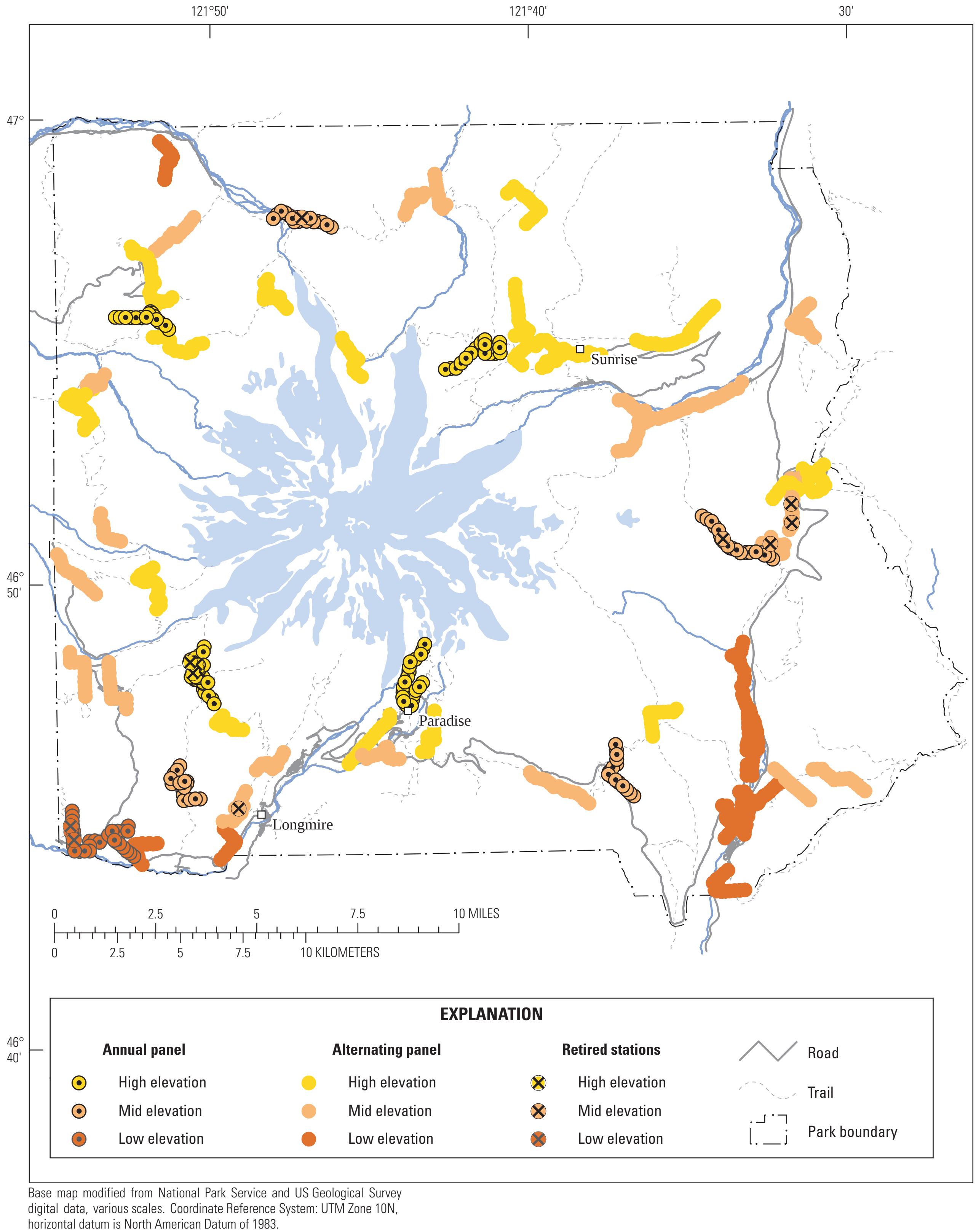
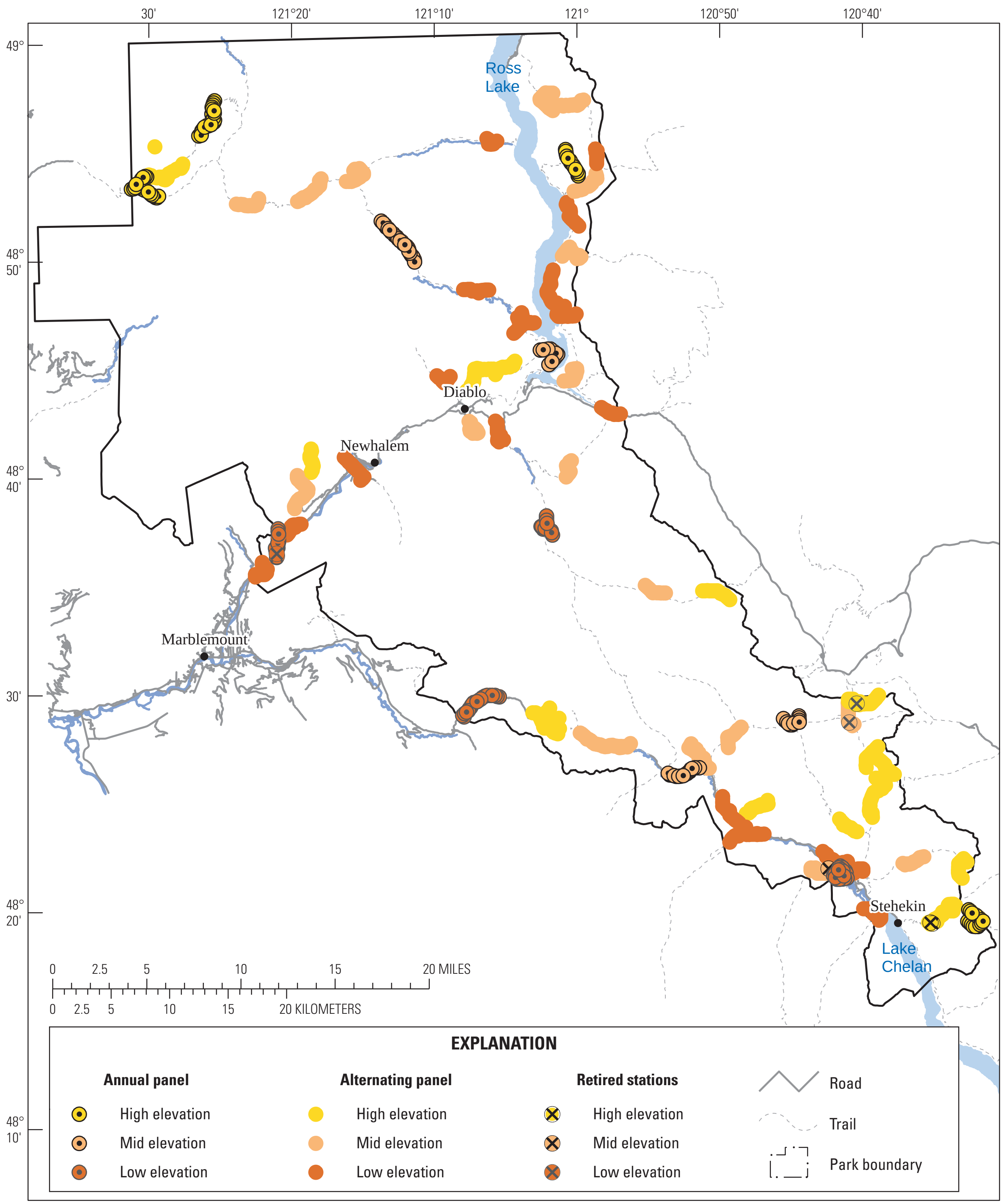
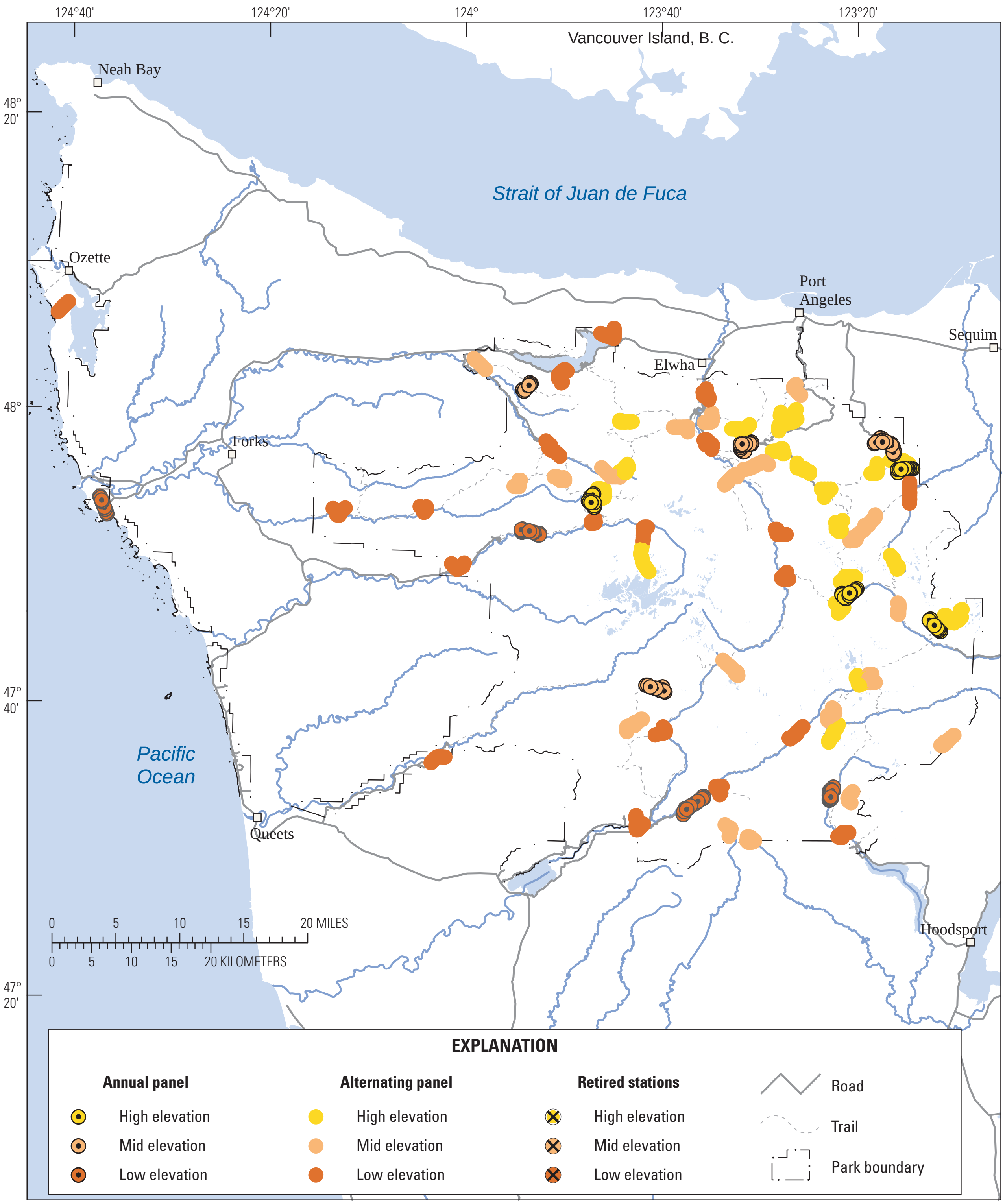


Figure 2. Approximate locations of transects established at Mount Rainier National Park, 2005–12. Each circular symbol represents a point-count station along a transect. Low-elevation stratum—all potential transects with starting points less than 800 m above sea level. Mid-elevation stratum—all potential transects with starting points between and including 800 and 1,350 m above sea level. High-elevation stratum—all potential transects with starting points greater than 1,350 m above sea level.



Base map modified from National Park Service and US Geological Survey digital data, various scales. Coordinate Reference System: UTM Zone 10N, horizontal datum is North American Datum of 1983.

Figure 3. Approximate locations of transects established at North Cascades National Park Complex, 2005–12. Each circular symbol represents a point-count station along a transect. Low-elevation stratum—all potential transects with starting points less than 800 m above sea level. Mid-elevation stratum—all potential transects with starting points between and including 800 and 1,350 m above sea level. High-elevation stratum—all potential transects with starting points greater than 1,350 m above sea level.



Base map modified from National Park Service and US Geological Survey digital data, various scales. Coordinate Reference System: UTM Zone 10N, horizontal datum is North American Datum of 1983.

Figure 4. Approximate locations of transects established at Olympic National Park, 2005–12. Each circular symbol represents a point-count station along a transect. Low-elevation stratum—all potential transects with starting points less than 800 m above sea level. Mid-elevation stratum—all potential transects with starting points between and including 800 and 1,350 m above sea level. High-elevation stratum—all potential transects with starting points greater than 1,350 m above sea level.

Table 1. Number of potential transect starting points (sampling frame) spaced at 50-meter intervals along trails or roads at the three large North Coast and Cascades Network parks within each elevation stratum.

[**Elevation stratum**: For NOCA and OLYM, low-elevation strata are defined as all potential transects with starting points less than 650 m above sea level; mid-elevation strata are defined as all potential transects with starting points between and including 650 and 1,350 m above sea level; high-elevation strata are defined as all potential transects with starting points greater than 1,350 m above sea level. For MORA only, the boundary between the low- and mid-elevation strata was adjusted to 800 m, but otherwise defined as the elevation strata in the same manner as for the other parks]

	Elevation stratum		
	Low	Mid	High
Mount Rainier National Park (MORA)	1,094	3,754	4,837
North Cascades National Park (NOCA)	4,000	5,112	2,079
Olympic National Park (OLYM)	9,771	6,872	3,972

Small Park Sampling Scheme

Because travel and logistics did not pose significant problems in the two smaller parks, we sampled bird populations from points distributed as a systematic grid (with a random starting point) covering each park area in its entirety (figs. 5–6). Grid points were 350 m apart, yielding 54 point count stations at SAJH (including 38 points at American Camp and 16 points at English Camp) and 71 point count stations at LEWI (including 29 points at Fort Clatsop, 5 points at Sunset Beach, and 37 points at Cape Disappointment). Nine additional points were initially established and surveyed at Cape Disappointment, but were later retired because of logistical concerns (fig. 5). Points at each small park were sampled every second year, alternating between the two parks each year. We sampled at LEWI during 4 years (2006, 2008, 2010, and 2012) and at SAJH during 3 years (2007, 2009, and 2011).

Data Collection

Once we began implementing the full sampling scheme in 2007 (after the 2005 and 2006 pilot years), crew size ranged from six to eight crew members each year, including one crew leader. Prior to collecting data each year, all crew members participated in a 3 week training session led by personnel from The Institute for Bird Populations and the National Park Service. This training included identification of all species by sight and sound, as well as the accurate estimation of distances of singing birds from the observers. Before collecting data, crew members were required to pass an examination testing their ability to identify park birds by sight and sound.

Data collection was timed to coincide with the peak of singing for most species. To avoid counting large numbers of still-migrating birds, the crew began collecting data no earlier than May 23 at NOCA and OLYM and no earlier than June 1 at MORA. The two small parks (LEWI and SAJH) were sampled during the last week of May or the first week of June. At all three of the large parks, crew members began sampling at low elevations early in the season and gradually moved upslope as the season progressed. All surveys were completed by July 31.

In concordance with other NPS bird monitoring protocols (Coonan and others, 2001; Peitz and others, 2002; Siegel and Wilkerson, 2005), we surveyed landbirds at points over a 5-minute period within two survey intervals (0–3 and 3–5 minutes). Beginning in 2011, a third 2-minute sampling interval was added to facilitate application of time-of-detection methods for accounting for imperfect detection (Alldredge and others, 2007a). However, we do not include those data in the analysis presented here (to maintain a consistent protocol over the entire study). We estimated distances to all birds (or groups of birds) encountered (Reynolds and others, 1980; Fancy, 1997; Nelson and Fancy, 1999; Rosenstock and others, 2002), except for a small number of individuals which were classified as 'flyovers' without any real connection to the habitat below them, to enable estimation and modeling of detection probability as a function of distance, and subsequent estimation of point-level avian densities (Buckland and others, 2001, 2004).

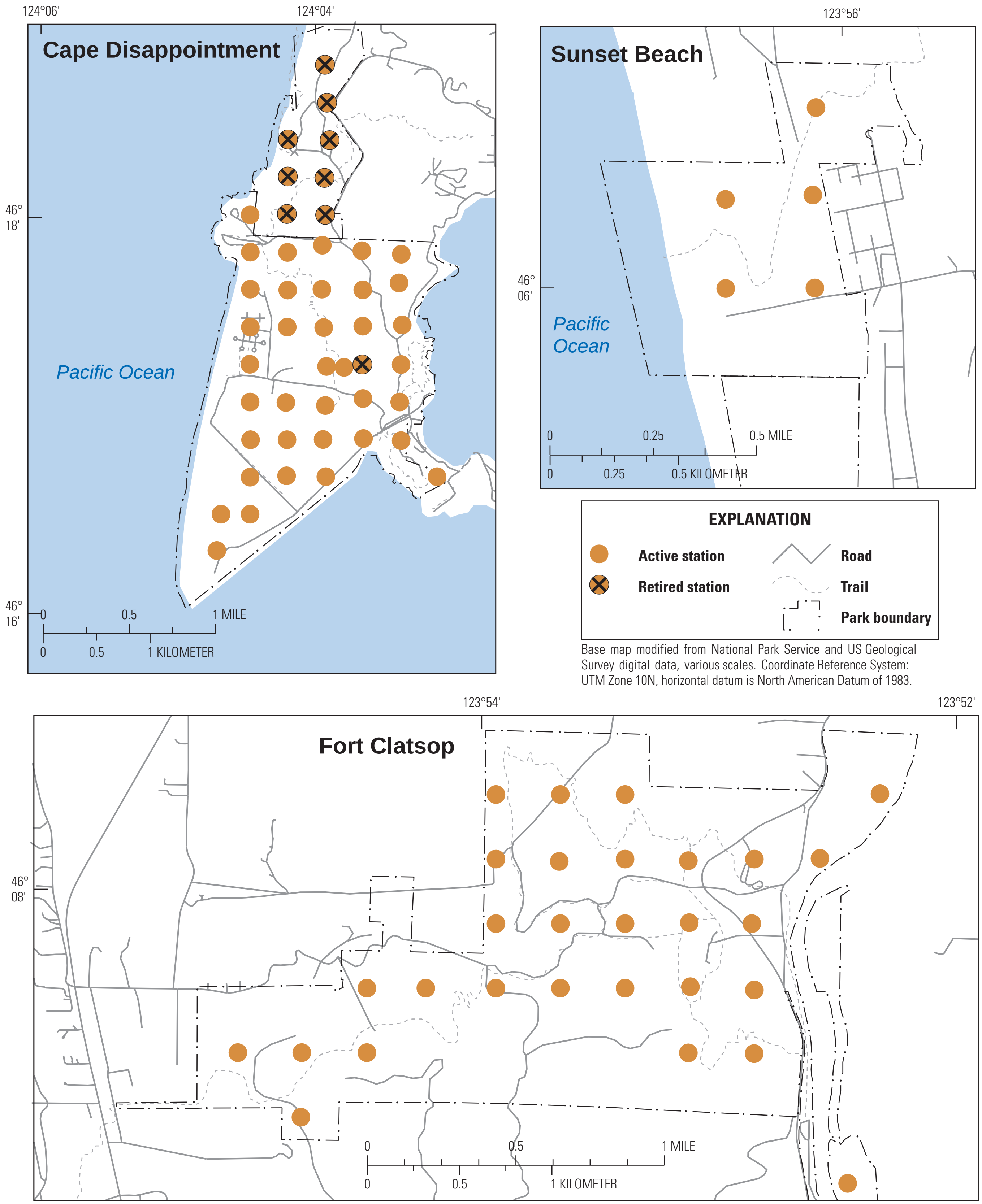


Figure 5. Locations of point-count stations surveyed at Lewis and Clark National Historical Park, 2005–12.

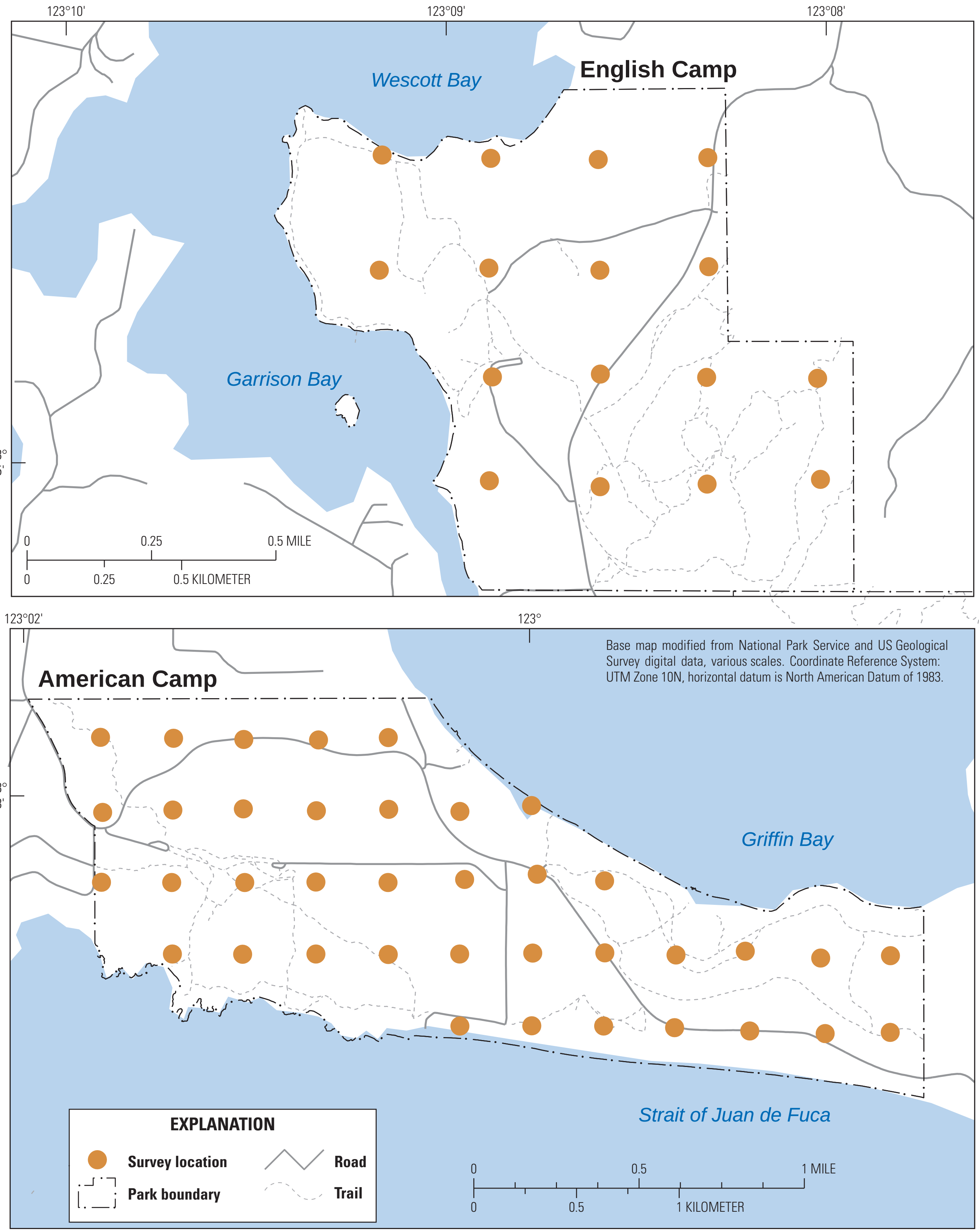


Figure 6. Locations of point count stations surveyed at San Juan Island National Historical Park, 2005–12.

Statistical Analysis

We wrote scripts in the statistical program R (R Development Core Team, 2012) to estimate distance-detectability functions and population trends following general guidelines provided in Siegel and others (2007). Detectability functions were estimated using the R package ‘Distance’ (Miller, 2012). For each species, we truncated 10 percent of observations that represented the largest detection distances to avoid complicating distance-detection functions, which would otherwise need to accommodate long tails in the data (Buckland and others, 2001; Thomas and others, 2010). We estimated distance-detection functions for species with greater than or equal to 75 detections (to meet minimum sample sizes requirements suggested by Buckland and others, 2001). Common and scientific names of all species analyzed are listed in appendix 1.

For each species, we considered up to 12 distance-detectability models (not all models were estimable for all species). These included conventional distance sampling (CDS) models, as well as models that allowed detection functions to vary by observer, by broad habitat class (sparse versus dense-canopied), or by observer and habitat class (additive model). For both the CDS and covariate models, we considered three key-function adjustment-term combinations suggested by Thomas and others (2010): half-normal key with cosine adjustment, half-normal key with Hermite adjustment, and hazard-rate key with simple polynomial adjustment. We compared models using Akaike’s Information Criterion (AIC) and AIC model weights (Burnham and Anderson, 2002). For some species-covariate model combinations (primarily for species with smaller sample sizes and models including observer effects), we had difficulty in estimating all model parameters (suggesting over-fitting), such that the mean detection probabilities were estimated with very low precision. Whenever coefficients of variation (CVs) on mean detection probability exceeded 100 percent, we excluded these models from further consideration (even if those models had lowest AIC). In addition, model convergence was not achieved for all species-model combinations. Based on the detection function from the best-performing model (lowest AIC with reasonable precision on mean detection probability estimates), we corrected point-level counts for variation in detection probability and then divided corrected counts by the actual sampling area at points (defined as a circle with radius equal to the longest detection distance after truncating the longest 10 percent of observations) to provide point density estimates for use in trend analyses.

Bird Population Trends in Large Parks

For the three large parks, we estimated 8-year trends using *BirdTrend* (Ver. 1.2; August 2013), a trend-analysis program developed by the TerraStat Consulting Group (see appendix 4 in Siegel and others, 2007) for use in the statistical software package R (R Development Core Team, 2012). *BirdTrend* evaluates linear trend in log+1-transformed mean point densities along each transect. In this report, we include the annual panel (sampled in all years, 2005–12) and data from one alternating panel (the only panel for which more than 1 year of sampling had been completed at the time of our analysis) sampled in 2007 and 2012.

The trend analysis method implemented in *BirdTrend* was closely linked to the availability of potential sampling points (that is, the sampling frame) in each of three elevation strata (see section, “Methods—Study Areas and Sampling Design—Large Parks Sampling Scheme, for detail). Trend estimation followed a hierarchical process, whereby first, for each species and park, slopes of the linear regressions of the log+1-transformed densities (adjusted through distance sampling to account for imperfect detection probability) on year (as a continuous covariate) were estimated for each of $i = 1,\ldots, n$ transects. By log-transforming the response variable, we made the density data less right-skewed (to better meet assumption of normally-distributed residuals), and the regression coefficient was easily interpretable as the approximate annual proportional change in density (Sokal and Rohlf, 1995). We did not include a particular transect in the analysis for a given species if the species was never detected on that transect; thus, n varied by species. The individual transect-level slopes, denoted here as y_i, were then averaged at the level of each of $j = 1,\ldots s = 3$ elevation strata (including transects from both the annual and alternating panel):

$$\bar{y}_j = \frac{\sum_{i=1}^{n_j} y_{ij}}{n_j} \tag{1}$$

Note that we diverge from the annotation of appendix 4 in Siegel and others (2007) here by indexing first at the transect (i), then at the strata (j) levels. Additionally, we do not include summation over variance groups (see below) in equation 1 to emphasize that variance group assignments do not enter into estimation of the mean stratum-level slope. Mean stratum-level slopes were then combined to provide an estimate of the mean park-level trend:

$$\bar{\bar{y}} = \frac{1}{N}\sum_{j=1}^{s} N_j \bar{y}_j \tag{2}$$

where

N is the total available population units (sampling frame), and

N_j is the number of available population units within each of the j strata (table 1).

Thus, the park-level trend was weighted by the availability of potential sampling points in each elevation stratum.

Estimation of variances of stratum-level and park-level mean trends required assigning each transect to a variance group (Siegel and others, 2007, appendix 6). Within each elevation stratum, we assumed that transects with similar numbers of sampled years had similar trend slope variance. Thus, for each stratum, we initially assigned all annual panel transects to a single variance group. Most (79 percent) transects in the annual panel were surveyed in all 8 years (the fewest number of years sampled for a transect in the annual panel was one transect at OLYM that was sampled in only 5 years). We initially assigned transects of the alternating panel for each elevation stratum to a second variance group. However, for many species, small sample sizes in some panel-stratum combinations precluded trend and trend-variance estimation with the initial variance group assignment, requiring combining variance groups or removing transects from the analysis for *BirdTrend* to provide estimates of trend variance and statistical tests of trend significance. Specifically, when a species was detected on only a single transect in a panel-elevation-stratum combination, it was assigned to the variance group of the other panel in the same elevation stratum. Although *BirdTrend* will provide mean trend and variance estimates if transects are reassigned to a variance group from another elevation stratum (because variance groups do not enter in to mean stratum- or park-level trend estimation; equations 1 and 2), tests of the statistical significance of trends were not possible in these cases in the current *BirdTrend* version. Thus, if a species was only encountered on a single transect in a particular elevation stratum, that transect was removed from the analysis.

Variances of stratum-level mean trends were estimated as:

$$Var(\bar{y}_j) = \frac{1}{n_j^2} \sum_{k=1}^{V_j} m_{jk} s_{jk}^2 \tag{3}$$

where

V_j is the number of variance groups in stratum *j*,

m_{jk} is the number of transects in stratum *j* and variance group *k*, and

s_{jk}^2 is the sample variance of slopes for variance group *k* in elevation stratum. *j*.

The right side of equation 3 reduces to s_j^2 / n_j whenever there is only a single variance group in elevation stratum *j* (because $m_{jk} = n_j$ in that case). Park-level variances were estimated as:

$$Var(\bar{\bar{y}}) = \frac{1}{N^2} \sum_{j=1}^{s} N_j^2 Var(\bar{y}_j). \tag{4}$$

Statistical significance of park-level trends was assessed by comparing the park-level mean trend (equation 2) divided by the standard error of this mean (that is, square-root of equation 4) to the t-distribution with degrees of freedom estimated using Satterthwaite's formula (Satterthwaite, 1946):

$$\frac{\left(\sum_{j=1}^{s} \frac{N_j \left(N_j - n_j \right)}{n_j} \times s_j^2 \right)^2}{\sum_{j=1}^{s} \left(\frac{N_j^2 \left(N_j - n_j \right)^2}{n_j^2 \left(n_j - 1 \right)} \times s_j^4 \right)} \tag{5}$$

If only a single transect occurs in an elevation stratum, the denominator of equation 5 cannot be calculated, and thus the degrees of freedom for the t-test cannot be estimated (hence, the need to remove the 'orphaned" transects from the analysis as described above).

For species that occurred on more than one transect in each of the three elevation strata at all three large parks, we also estimated a mean combined-park trend:

$$\bar{\bar{Y}} = \frac{1}{T} \sum_{p=1}^{3} T_p \bar{\bar{y}}_p \tag{6}$$

where

T is the total number of non-zero transects included for the species across parks,

T_p is the number of transects in park *p*, and

$\bar{\bar{y}}_p$ is the average trend for park *p* (based on equation 4).

The variance of this combined-park trend estimate was estimated as:

$$Var(\bar{\bar{Y}}) = \frac{1}{T^2} \sum_{p=1}^{3} T_p^2 Var(\bar{\bar{y}}_p). \tag{7}$$

Statistical significance was assessed by dividing the combined-park mean trend (eq. 6) by the standard error of this mean (that is, square-root of eq. 7) and comparing to the t-distribution with degrees of freedom estimated using Satterthwaite's formula as computed in a manner analogous to what was done for the park-level trends (eq. 5). For all trend analyses, we used two-tailed tests with $\alpha = 0.10$. We adopted this relatively liberal alpha level to increase the likelihood of early detection of real trends that might be of particular interest to managers and the lack of a substantial cost associated with false trend detection (Field and others, 2004).

Annual Bird Densities in Large Parks

In addition to estimating trends, we calculated mean transect-level annual densities (adjusted for imperfect detectability) for each park using the program *BirdTrendAnnualDensity* (ver. 1.1), based on data from all transects and all points sampled (regardless of whether detections were recorded or not). Specifically, for each of the 8 years, we estimated the park-level density as:

$$\bar{\bar{D}} = \frac{1}{N}\sum_{j=1}^{s} N_j \bar{D}_j \qquad (8)$$

where

$\bar{D}_j$ is the mean point-level density for each transect; calculated in the same way as for trend in equation 1, with the exception that all transects, not just those with detections, were used in the analysis.

The variance of equation 8 was calculated in a manner analogous to equation 3.

Bird Population Trends in Small Parks

For the two small parks, we estimated trends using a linear regression of the mean (log+1)-transformed point-level annual density on year. Trend was assessed based on the regression coefficient for the year effect and its associated t-statistic and *P*-value. As for the large-park analyses, we assigned significance based on a two-tailed test with $\alpha = 0.10$.

Results

Between 2005 and 2012, we completed 453 out of a possible 476 transect surveys (95 percent; table 2). Within these 453 transect surveys, 5,203 point surveys were conducted. We detected 51,612 individuals of 145 species, of which 61 species had enough observations (>75 after truncating 10 percent of the most distant observations) to model distance-detection functions and assess trends for one or more parks.

Table 2. Numbers of transects sampled for each of the three large parks in each panel, elevation stratum, and year.

[**National Park:** MORA, Mount Rainier; NOCA, North Cascades; OLYM, Olympic]

National Park	Elevation stratum	Number of transect surveys completed by year								
		[1]2005	[1]2006	2007	2008	2009	2010	2011	2012	Total
MORA	Low	2	2	4	4	4	4	4	4	28
	Mid	4	4	8	8	8	8	6	8	54
	High	4	4	8	8	8	7	3	8	50
	All	10	10	20	20	20	19	13	20	132
NOCA	Low	4	4	8	8	8	8	8	8	56
	Mid	4	4	7	7	8	8	8	8	54
	High	4	4	7	5	8	6	5	8	47
	All	12	12	22	20	24	22	21	24	157
OLYM	Low	4	4	8	8	8	8	8	8	56
	Mid	4	3	8	7	8	8	7	8	53
	High	4	4	7	8	8	8	8	8	55
	All	12	11	23	23	24	24	23	24	164
ALL	Low	10	10	20	20	20	20	20	20	140
	Mid	12	11	23	22	24	24	21	24	161
	High	12	12	22	21	24	21	16	24	152
	All	34	33	65	63	68	65	57	68	453

[1]Only the annual panel transects were surveyed in 2005 and 2006, during the protocol development phase of the project.

Modeling Detection Probability

We provide a summary of distance-detectability functions used in correcting count data collected on bird surveys in table 3. The sample radius (defined here as the distance containing 90 percent of observations) averaged 127 m and, as expected, was highly variable among species, ranging from a low of 29 m (Rufous Hummingbird) to a high of 340 m (Common Raven). Mean detection probability for the 61 species at a point during the 5-minute count was 0.368. Only about one-half of the species, most with greater than 500 detections, could support more complicated distance-detectability modeling (that is, those with observer effects included as covariates). On average, only about 7 of the 12 models could be fit with reasonable precision to be considered as candidates for correcting counts for imperfect detection. We provide histograms of distance-detection data and predicted detection probabilities based on best (lowest AIC) models with reasonable precision on mean detection probability estimates (SE<mean) in appendix 2 (online supplementary material). A feature common to many species was fewer-than-expected observations close to the observer (in two-dimensional distance), suggesting that birds either avoided or were flushed by (for example, on approach) observers, or that observers had difficulty in correctly assigning distances to nearby birds that may have been high overhead in tall trees or on steep slopes.

Table 3. Summary of numbers of detections used in distance-detectability models, sample radius (radial distance containing 90 percent of observations), mean detection probabilities (from best model), and detail of models used for correcting survey data for imperfect detection.

[Up to 12 models for 61 species with ≥75 detections (after removing the most distant 10 percent of detections) were considered. Species names are presented in standard taxonomic order (Chesser and others, 2013)]

Species	Number of detections	Sample radius (meter)	Mean detection probabilities		Model[1]			AIC model weight[2]	Number of models[3]
			P	Standard error	Key	Adjustment	Covariates		
Sooty Grouse	414	253	0.241	0.029	H-R	SP	Habitat	0.984	5
Band-tailed Pigeon	100	187	0.349	0.049	H-R	SP	CDS	0.391	6
Vaux's Swift	99	85	0.307	0.036	H-R	SP	CDS	0.373	6
Rufous Hummingbird	507	29	0.088	0.018	H-R	SP	CDS	0.705	6
Red-breasted Sapsucker	119	82	0.276	0.047	H-R	SP	CDS	0.782	3
Hairy Woodpecker	232	91	0.387	0.043	H-R	SP	Habitat	0.508	6
Northern Flicker	303	217	0.304	0.030	H-R	SP	Habitat	0.560	6
Pileated Woodpecker	110	307	0.276	0.057	H-R	SP	Habitat	0.575	5
Olive-sided Flycatcher	576	295	0.177	0.013	H-R	SP	Habitat	0.868	6
Western Wood-Pewee	206	128	0.499	0.041	H-R	SP	Hab. + Obs.	0.803	12
Hammond's Flycatcher	1,043	64	0.498	0.020	H-R	SP	Observer	0.526	11
Pacific-slope Flycatcher	1,934	75	0.531	0.015	H-R	SP	Observer	0.706	12
Cassin's Vireo	192	93	0.503	0.058	H-R	SP	CDS	0.417	6
Warbling Vireo	821	109	0.398	0.020	H-R	SP	Habitat	0.872	6
Gray Jay	419	134	0.235	0.012	H-N	C	CDS	0.289	6
Steller's Jay	314	126	0.386	0.027	H-N	C	CDS	0.319	6
Clark's Nutcracker	161	220	0.329	0.049	H-R	SP	CDS	0.345	6
American Crow	318	216	0.219	0.044	H-R	SP	CDS	0.661	6
Common Raven	159	340	0.159	0.047	H-R	SP	CDS	0.527	6
Mountain Chickadee	269	88	0.287	0.019	H-N	C	Habitat	0.252	4
Chestnut-backed Chickadee	2,465	46	0.524	0.082	H-R	SP	Observer	0.693	8
Red-breasted Nuthatch	1,645	148	0.329	0.071	H-R	SP	Observer	0.588	10
Brown Creeper	680	62	0.445	0.023	H-R	SP	CDS	0.706	6
House Wren	146	105	0.547	0.053	H-R	SP	Habitat	0.787	5
Pacific Wren	3,173	92	0.410	0.012	H-R	SP	Observer	0.506	11
Marsh Wren	79	72	0.337	0.047	H-N	C	CDS	0.276	6
Golden-crowned Kinglet	1,744	45	0.535	0.016	H-R	SP	Observer	1.000	10
Ruby-crowned Kinglet	92	136	0.182	0.036	H-R	SP	Habitat	0.767	5
Townsend's Solitaire	115	191	0.244	0.035	H-R	SP	CDS	0.705	6
Swainson's Thrush	2,021	107	0.412	0.014	H-R	SP	Hab. + Obs.	1.000	10
Hermit Thrush	1,551	206	0.286	0.011	H-R	SP	Hab. + Obs.	1.000	12

Table 3. Summary of numbers of detections used in distance-detectability models, sample radius (radial distance containing 90 percent of observations), mean detection probabilities (from best model), and detail of models used for correcting survey data for imperfect detection.—Continued

[Up to 12 models for 61 species with ≥75 detections (after removing the most distant 10 percent of detections) were considered. Species names are presented in standard taxonomic order (Chesser and others, 2013)]

Species	Number of detections	Sample radius (meter)	Mean detection probabilities		Model[1]			AIC model weight[2]	Number of models[3]
			P	Standard error	Key	Adjustment	Covariates		
American Robin	1,908	126	0.246	0.016	H-R	SP	CDS	0.999	6
Varied Thrush	3,337	200	0.352	0.008	H-R	SP	Hab. + Obs.	0.999	12
American Pipit	223	118	0.304	0.029	H-R	SP	CDS	0.465	6
Orange-crowned Warbler	255	92	0.457	0.038	H-N	C	CDS	0.304	5
Nashville Warbler	253	85	0.396	0.031	H-N	C	CDS	0.279	6
Yellow Warbler	645	81	0.376	0.346	H-R	SP	Observer	0.614	8
Yellow-rumped Warbler	1,108	91	0.522	0.016	H-R	SP	Hab. + Obs.	0.758	11
Black-throated Gray Warbler	309	90	0.530	0.041	H-R	SP	CDS	0.711	6
Townsend's Warbler	1,978	88	0.557	0.015	H-R	SP	Observer	0.527	12
Hermit Warbler	97	88	0.463	0.440	H-R	SP	Hab. + Obs.	0.733	7
MacGillivray's Warbler	407	86	0.397	0.277	H-R	SP	Hab. + Obs.	0.833	8
Common Yellowthroat	84	121	0.273	0.037	H-N	C	Habitat	0.360	6
Wilson's Warbler	550	86	0.484	0.092	H-R	SP	Hab. + Obs.	0.997	10
Western Tanager	1,139	118	0.421	0.015	H-R	SP	Hab. + Obs.	0.814	12
Spotted Towhee	219	95	0.635	0.050	H-R	SP	Habitat	0.489	7
Chipping Sparrow	423	106	0.307	0.018	H-N	C	Habitat	0.348	4
Savannah Sparrow	253	103	0.339	0.026	H-N	C	CDS	0.294	5
Fox Sparrow	167	206	0.190	0.025	H-R	SP	Habitat	0.747	6
Song Sparrow	401	112	0.278	0.059	H-N	C	Observer	0.263	12
White-crowned Sparrow	336	179	0.397	0.030	H-R	SP	Habitat	0.803	6
Dark-eyed Junco	3,823	92	0.208	0.013	H-R	SP	CDS	1.000	6
Black-headed Grosbeak	306	123	0.393	0.029	H-N	C	CDS	0.276	5
Red-winged Blackbird	154	218	0.181	0.046	H-R	SP	Habitat	0.552	6
Brown-headed Cowbird	271	88	0.436	0.034	H-R	SP	Habitat	0.895	6
Purple Finch	157	120	0.526	0.102	H-N	hermite	CDS	0.609	5
Cassin's Finch	126	106	0.444	0.057	H-R	SP	CDS	0.374	6
Red Crossbill	249	95	0.484	0.039	H-R	SP	CDS	0.520	6
Pine Siskin	1,584	84	0.423	0.015	H-R	SP	Hab. + Obs.	0.811	12
American Goldfinch	231	97	0.354	0.034	H-R	SP	Habitat	0.526	6
Evening Grosbeak	330	92	0.383	0.036	H-R	SP	Habitat	0.480	6

[1]Model used for the distance-detectability function. Key = key function (half-normal [H-N] or hazard rate [H-R]); Adjustment = adjustment terms (cosine [C], hermite [H], or simple polynomial[SP]); Covariate = covariates included in mean function of model, where CDS = conventional distance sampling (no covariates), habitat = dense or sparse, and Observer = observer identity.

[2]Akaike Information Criterion (AIC) model weight for model used for the distance-detectability function.

[3]Number of models included in candidate model set (maximum = 12; model set culled when precision on mean detection probability low [SE > mean]).

Bird Population Trends in Large Parks

We estimated trends for 43 species at MORA, 53 species at NOCA, and 41 species at OLYM (table 4). Of 137 park-species combinations, 12 significantly (P<0.10) decreased (9 percent) and 5 (4 percent) significantly increased. Annual density estimates for each species in each park are provided in appendix 3 (online supplementary material).

At MORA, two of 43 species (5 percent) significantly decreased and 0 species significantly increased (table 4). On average from 2005 to 2012, Pacific Wren decreased by about 1.6 percent per year and Golden-crowned Kinglet decreased by about 5.6 percent per year. Mean transect-level densities, however, suggested high annual variability and heterogeneous trends across the study period. For both species, abundance increased from 2005 to 2007, sharply decreased in 2008, recovered somewhat in 2009 (although not to peak pre-2008 levels), and tended to decrease thereafter (fig. 7).

At NOCA, five of 53 species (9 percent; table 3) significantly decreased. Significant decreases ranged from 1.4 to 2.2 percent per year for Red-breasted Sapsucker, Swainson's Thrush, and Hermit Thrush to greater than 3 percent per year for Golden-crowned Kinglet and Dark-eyed Junco. Two species (4 percent of those analyzed) significantly increased at NOCA—Gray Jay (increase of 1 percent per year) and Western Tanager (increase of 1.6 percent per year). Annual variation in densities for species with significant trends was high (fig. 8). As at MORA, species with decreasing trends actually tended to increase across the first 3 years of the study and decreased thereafter.

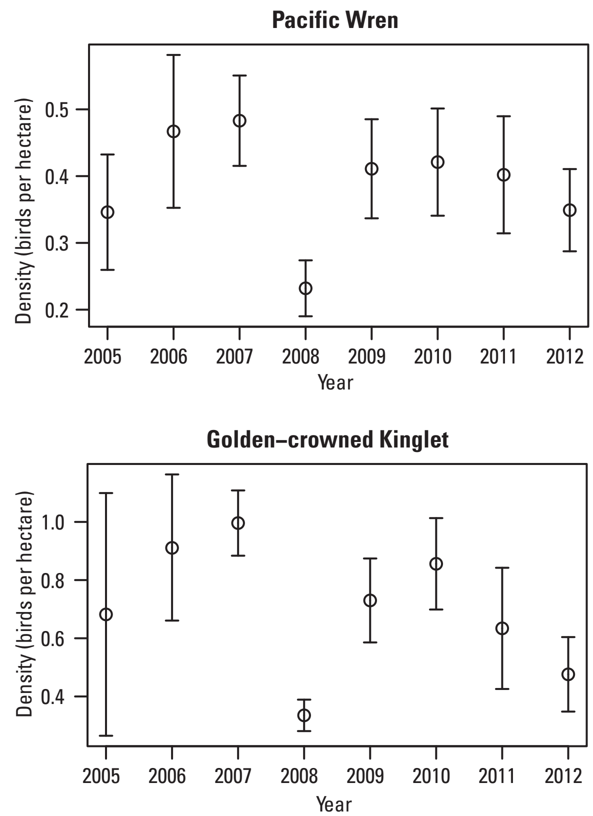


Figure 7. Annual mean point density estimates (±standard error) based on data from all points (that is, not just from transects with detections) for two species with significantly decreasing trends at Mount Rainier National Park.

Table 4. Trends (annual proportional change) for large parks in the North Coast and Cascades Network, 2005–12.

[Trends were estimated using the computer program BirdTrend (ver. 1.2), which bases park-level trends on mean transect-level trends, while accounting for unequal sampling among three elevation strata (see section, Methods—Statistical Analysis—Bird Population Trends in Large Parks, for detail). Species names are presented in standard taxonomic order (Chesser and others, 2013). Significant slopes (P < 0.10) are shown in **bold**]

Species	Park	Number of non-zero transects	Mean of slope	Variance of slope	df	t-stat	2-tailed *p*-value
Sooty Grouse	MORA	3	-0.00142	0.00000	2.00	-1.2305	0.3436
	NOCA	19	-0.00070	0.00000	15.48	-0.4753	0.6412
	OLYM	20	-0.00025	0.00000	15.18	-0.2307	0.8207
Band-tailed Pigeon	**OLYM**	**10**	**-0.00217**	**0.00000**	**3.02**	**-4.4860**	**0.0203**
Vaux's Swift	MORA	9	0.00656	0.00039	3.81	0.3319	0.7575
	NOCA	9	0.00633	0.00029	3.35	0.3710	0.7329
	OLYM	**7**	**-0.02402**	**0.00009**	**3.94**	**-2.4947**	**0.0681**
Rufous Hummingbird	MORA	10	-0.08639	0.00414	7.71	-1.3422	0.2177
	NOCA	16	-0.05031	0.00276	8.21	-0.9575	0.3657
	OLYM	14	-0.08106	0.00181	3.90	-1.9043	0.1314
Red-breasted Sapsucker	**NOCA**	**11**	**-0.01360**	**0.00004**	**9.00**	**-2.1754**	**0.0576**
	OLYM	**4**	**0.02191**	**0.00002**	**3.00**	**4.5255**	**0.0202**
Hairy Woodpecker	MORA	10	-0.00298	0.00001	2.76	-1.1628	0.3356
	NOCA	16	0.00205	0.00006	6.36	0.2703	0.7955
	OLYM	**13**	**-0.00969**	**0.00001**	**7.48**	**-2.5109**	**0.0383**
	Combined	39	-0.00316	0.00001	29.60	-0.9215	0.3642

Table 4. Trends (annual proportional change) for large parks in the North Coast and Cascades Network, 2005–12.—Continued

[Trends were estimated using the computer program BirdTrend (ver. 1.2), which bases park-level trends on mean transect-level trends, while accounting for unequal sampling among three elevation strata (see section, Methods—Statistical Analysis—Bird Population Trends in Large Parks, for detail). Species names are presented in standard taxonomic order (Chesser and others, 2013). Significant slopes (P < 0.10) are shown in **bold**]

Species	Park	Number of non-zero transects	Mean of slope	Variance of slope	df	t-stat	2-tailed *p*-value
Northern Flicker	MORA	8	-0.00079	0.00000	6.00	-1.1355	0.2995
	NOCA	14	-0.00290	0.00000	3.29	-1.9156	0.1431
	OLYM	17	0.00104	0.00000	5.58	1.1955	0.2802
Pileated Woodpecker	MORA	8	0.00071	0.00000	2.60	1.3084	0.2945
	NOCA	9	-0.00135	0.00000	4.13	-1.5680	0.1898
	OLYM	10	0.00017	0.00000	1.53	0.2069	0.8602
Olive-sided Flycatcher	MORA	11	0.00302	0.00001	3.22	0.8272	0.4650
	NOCA	18	-0.00441	0.00001	4.85	-1.5419	0.1855
	OLYM	14	-0.00028	0.00000	5.98	-0.1674	0.8726
Western Wood-pewee	NOCA	9	-0.00555	0.00001	6.36	-1.5716	0.1644
Hammond's Flycatcher	MORA	9	-0.00954	0.00025	3.84	-0.6081	0.5772
	NOCA	19	0.00687	0.00006	12.71	0.8576	0.4070
	OLYM	15	-0.00197	0.00012	2.34	-0.1817	0.8703
Pacific-slope Flycatcher	MORA	12	-0.01780	0.00014	4.63	-1.5063	0.1969
	NOCA	9	0.01592	0.00021	4.17	1.1015	0.3302
	OLYM	20	-0.01094	0.00012	12.04	-1.0137	0.3307
Cassin's Vireo	NOCA	16	0.00221	0.00001	8.73	0.8584	0.4136
Warbling Vireo	MORA	2	-0.00417	0.00006	1.00	-0.5246	0.6924
	NOCA	17	0.00893	0.00003	6.51	1.6058	0.1555
	OLYM	4	0.01376	0.00004	3.00	2.1645	0.1191
Gray Jay	MORA	19	0.00837	0.00002	2.02	1.8574	0.2029
	NOCA	**11**	**0.01004**	**0.00001**	**6.07**	**3.6104**	**0.0110**
	OLYM	**19**	**0.00531**	**0.00000**	**12.02**	**2.3857**	**0.0344**
Steller's Jay	MORA	8	-0.00003	0.00000	1.85	-0.0159	0.9888
	NOCA	17	-0.00065	0.00001	13.16	-0.2786	0.7849
	OLYM	11	0.00376	0.00001	8.04	1.2305	0.2533
Clark's Nutcracker	MORA	4	-0.01325	0.00009	3.00	-1.4293	0.2483
	NOCA	2	-0.00141	0.00000	1.00	-0.7408	0.5941
American Crow	**OLYM**	**6**	**-0.00198**	**0.00000**	**3.28**	**-4.7413**	**0.0145**
Common Raven	MORA	8	-0.00101	0.00000	3.44	-1.1267	0.3322
	NOCA	3	-0.00055	0.00000	2.00	-0.4401	0.7029
	OLYM	7	-0.00070	0.00000	4.95	-1.5971	0.1717
Mountain Chickadee	MORA	4	0.00401	0.00049	3.00	0.1810	0.8679
	NOCA	9	-0.04267	0.00073	1.01	-1.5829	0.3573
Chestnut-backed Chickadee	MORA	15	-0.01847	0.00018	3.45	-1.3675	0.2537
	NOCA	19	0.01175	0.00038	11.56	0.6027	0.5584
	OLYM	21	0.02574	0.00026	16.19	1.6056	0.1277
	Combined	55	0.00885	0.00010	43.62	0.9013	0.3724
Red-breasted Nuthatch	MORA	18	-0.00009	0.00000	2.11	-0.0494	0.9649
	NOCA	21	-0.00893	0.00002	9.08	-1.7965	0.1057
	OLYM	19	-0.00498	0.00001	10.38	-1.6414	0.1306
	Combined	**58**	**-0.00489**	**0.00000**	**39.84**	**-2.2913**	**0.0273**
Brown Creeper	MORA	15	-0.00295	0.00012	8.30	-0.2717	0.7925
	NOCA	17	0.00039	0.00004	10.60	0.0651	0.9493
	OLYM	18	0.00213	0.00003	13.41	0.3827	0.7080
	Combined	50	0.00002	0.00002	40.25	0.0037	0.9971

Table 4. Trends (annual proportional change) for large parks in the North Coast and Cascades Network, 2005–12.—Continued

[Trends were estimated using the computer program BirdTrend (ver. 1.2), which bases park-level trends on mean transect-level trends, while accounting for unequal sampling among three elevation strata (see section, Methods—Statistical Analysis—Bird Population Trends in Large Parks, for detail). Species names are presented in standard taxonomic order (Chesser and others, 2013). Significant slopes (P < 0.10) are shown in **bold**]

Species	Park	Number of non-zero transects	Mean of slope	Variance of slope	df	t-stat	2-tailed *p*-value
Pacific Wren	**MORA**	**18**	**-0.01627**	**0.00002**	**6.62**	**-3.9471**	**0.0062**
	NOCA	20	0.00588	0.00007	11.16	0.6833	0.5084
	OLYM	23	-0.02380	0.00019	9.94	-1.7422	0.1123
	Combined	**61**	**-0.01185**	**0.00004**	**28.97**	**-1.9756**	**0.0578**
Golden-crowned Kinglet	**MORA**	**17**	**-0.05610**	**0.00022**	**5.55**	**-3.7713**	**0.0107**
	NOCA	**22**	**-0.03335**	**0.00018**	**12.91**	**-2.4745**	**0.0280**
	OLYM	22	-0.02147	0.00041	15.41	-1.0659	0.3029
	Combined	**61**	**-0.03540**	**0.00009**	**33.18**	**-3.6601**	**0.0009**
Ruby-crowned Kinglet	NOCA	3	-0.02617	0.00023	2.00	-1.7209	0.2274
	OLYM	3	-0.01946	0.00005	2.00	-2.7589	0.1101
Townsend's Solitaire	MORA	3	-0.01151	0.00003	2.00	-2.0872	0.1721
	NOCA	12	-0.00135	0.00000	2.49	-0.8808	0.4551
	OLYM	8	0.00178	0.00000	2.38	1.7850	0.1956
Swainson's Thrush	MORA	4	0.00186	0.00000	1.01	1.4086	0.3909
	NOCA	**19**	**-0.02207**	**0.00006**	**12.07**	**-2.9748**	**0.0115**
	OLYM	7	-0.00877	0.00006	6.00	-1.1711	0.2859
Hermit Thrush	MORA	17	-0.01042	0.00002	1.02	-2.3628	0.2502
	NOCA	**14**	**-0.01532**	**0.00002**	**4.16**	**-3.7189**	**0.0191**
	OLYM	15	-0.00709	0.00002	12.04	-1.5108	0.1566
American Robin	MORA	16	-0.01388	0.00005	6.29	-1.9152	0.1017
	NOCA	22	-0.00887	0.00010	12.35	-0.8807	0.3953
	OLYM	**21**	**0.01281**	**0.00001**	**15.02**	**3.5292**	**0.0030**
	Combined	59	-0.00251	0.00002	51.53	-0.5671	0.5731
Varied Thrush	MORA	20	0.00476	0.00003	13.85	0.8944	0.3864
	NOCA	21	-0.00179	0.00001	15.42	-0.5335	0.6013
	OLYM	23	0.00148	0.00002	13.77	0.3323	0.7447
	Combined	64	0.00143	0.00001	44.13	0.5599	0.5784
American Pipit	MORA	4	-0.03823	0.00028	3.00	-2.2947	0.1055
	NOCA	3	-0.00500	0.00011	2.00	-0.4834	0.6766
	OLYM	2	-0.00445	0.00037	1.00	-0.2323	0.8547
Orange-crowned Warbler	NOCA	2	-0.00328	0.00000	1.00	-3.2342	0.1909
Nashville Warbler	NOCA	12	0.01122	0.00003	3.06	2.2225	0.1110
Yellow Warbler	MORA	2	-0.01460	0.00003	1.00	-2.5387	0.2389
	NOCA	14	-0.00797	0.00008	8.19	-0.8840	0.4019
Yellow-rumped Warbler	MORA	9	-0.00527	0.00006	1.29	-0.6848	0.5957
	NOCA	21	0.00985	0.00005	15.97	1.3488	0.1962
	OLYM	5	0.00013	0.00012	2.00	0.0114	0.9919
Black-throated Gray Warbler	MORA	3	-0.01911	0.00048	2.00	-0.8682	0.4768
	NOCA	12	0.00794	0.00007	8.81	0.9761	0.3550
	OLYM	4	0.01282	0.00013	3.00	1.1369	0.3382
Townsend's Warbler	MORA	12	-0.00531	0.00012	4.94	-0.4759	0.6544
	NOCA	21	0.00049	0.00011	11.16	0.0472	0.9632
	OLYM	13	0.00493	0.00001	7.79	1.3571	0.2127
	Combined	46	0.00023	0.00003	34.21	0.0412	0.9674
Hermit Warbler	MORA	3	-0.00445	0.00001	2.00	-1.3732	0.3034

Table 4. Trends (annual proportional change) for large parks in the North Coast and Cascades Network, 2005–12.—Continued

[Trends were estimated using the computer program BirdTrend (ver. 1.2), which bases park-level trends on mean transect-level trends, while accounting for unequal sampling among three elevation strata (see section, Methods—Statistical Analysis—Bird Population Trends in Large Parks, for detail). Species names are presented in standard taxonomic order (Chesser and others, 2013). Significant slopes ($P < 0.10$) are shown in **bold**]

Species	Park	Number of non-zero transects	Mean of slope	Variance of slope	df	t-stat	2-tailed *p*-value
MacGillivray's Warbler	MORA	4	-0.03951	0.00023	1.45	-2.5833	0.1680
	NOCA	14	-0.00837	0.00007	5.55	-0.9828	0.3666
	OLYM	4	0.00308	0.00001	3.00	1.2474	0.3008
Wilson's Warbler	MORA	4	-0.00788	0.00002	1.94	-1.6172	0.2508
	NOCA	11	0.01887	0.00008	4.15	2.0729	0.1043
	OLYM	6	0.01532	0.00008	5.00	1.6674	0.1563
Western Tanager	MORA	6	-0.00041	0.00004	1.03	-0.0673	0.9570
	NOCA	**18**	**0.01625**	**0.00006**	**4.85**	**2.1093**	**0.0904**
	OLYM	9	0.00688	0.00002	5.85	1.4807	0.1904
Spotted Towhee	NOCA	7	-0.00262	0.00001	4.88	-0.7521	0.4867
Chipping Sparrow	MORA	2	-0.01396	0.00001	1.00	-4.7789	0.1313
	NOCA	15	0.00323	0.00013	7.11	0.2872	0.7821
Fox Sparrow	MORA	4	-0.00692	0.00010	3.00	-0.6792	0.5457
	NOCA	5	0.00878	0.00006	4.00	1.1199	0.3254
Song Sparrow	MORA	2	-0.00441	0.00018	1.00	-0.3317	0.7961
	NOCA	9	-0.00734	0.00002	7.00	-1.5018	0.1769
	OLYM	5	0.01560	0.00029	4.00	0.9115	0.4136
White-crowned Sparrow	NOCA	4	0.00106	0.00000	3.00	0.5845	0.6000
	OLYM	3	0.00160	0.00002	2.00	0.3533	0.7576
Dark-eyed Junco	MORA	20	-0.02660	0.00038	4.49	-1.3693	0.2355
	NOCA	**22**	**-0.03257**	**0.00026**	**14.85**	**-2.0148**	**0.0624**
	OLYM	22	0.00380	0.00013	10.57	0.3339	0.7450
	Combined	**64**	**-0.01820**	**0.00008**	**58.35**	**-1.9974**	**0.0504**
Black-headed Grosbeak	MORA	2	0.00470	0.00001	1.00	1.9314	0.3041
	NOCA	12	0.00346	0.00002	9.82	0.7251	0.4853
	OLYM	2	-0.00749	0.00009	1.00	-0.7789	0.5787
Brown-headed Cowbird	NOCA	5	-0.00705	0.00008	2.08	-0.7779	0.5153
Purple Finch	NOCA	2	-0.00125	0.00001	1.00	-0.4833	0.7134
Cassin's Finch	MORA	4	0.00981	0.00014	3.00	0.8153	0.4746
	NOCA	5	0.01299	0.00003	1.45	2.4647	0.1781
Red Crossbill	MORA	11	-0.00256	0.00225	2.49	-0.0540	0.9609
	NOCA	13	0.03050	0.00036	4.68	1.6183	0.1705
	OLYM	**20**	**-0.03428**	**0.00013**	**12.77**	**-3.0093**	**0.0102**
	Combined	44	-0.00721	0.00020	16.86	-0.5123	0.6151
Pine Siskin	MORA	17	-0.01458	0.00045	12.96	-0.6863	0.5046
	NOCA	19	-0.00917	0.00031	8.93	-0.5185	0.6167
	OLYM	17	0.00698	0.00014	9.54	0.5811	0.5746
	Combined	53	-0.00573	0.00010	46.31	-0.5682	0.5726
American Goldfinch	NOCA	2	0.00793	0.00017	1.00	0.6075	0.6525
Evening Grosbeak	MORA	10	0.00670	0.00019	2.20	0.4920	0.6675
	NOCA	18	0.02529	0.00067	7.49	0.9791	0.3581
	OLYM	4	-0.01112	0.00024	1.04	-0.7225	0.5980

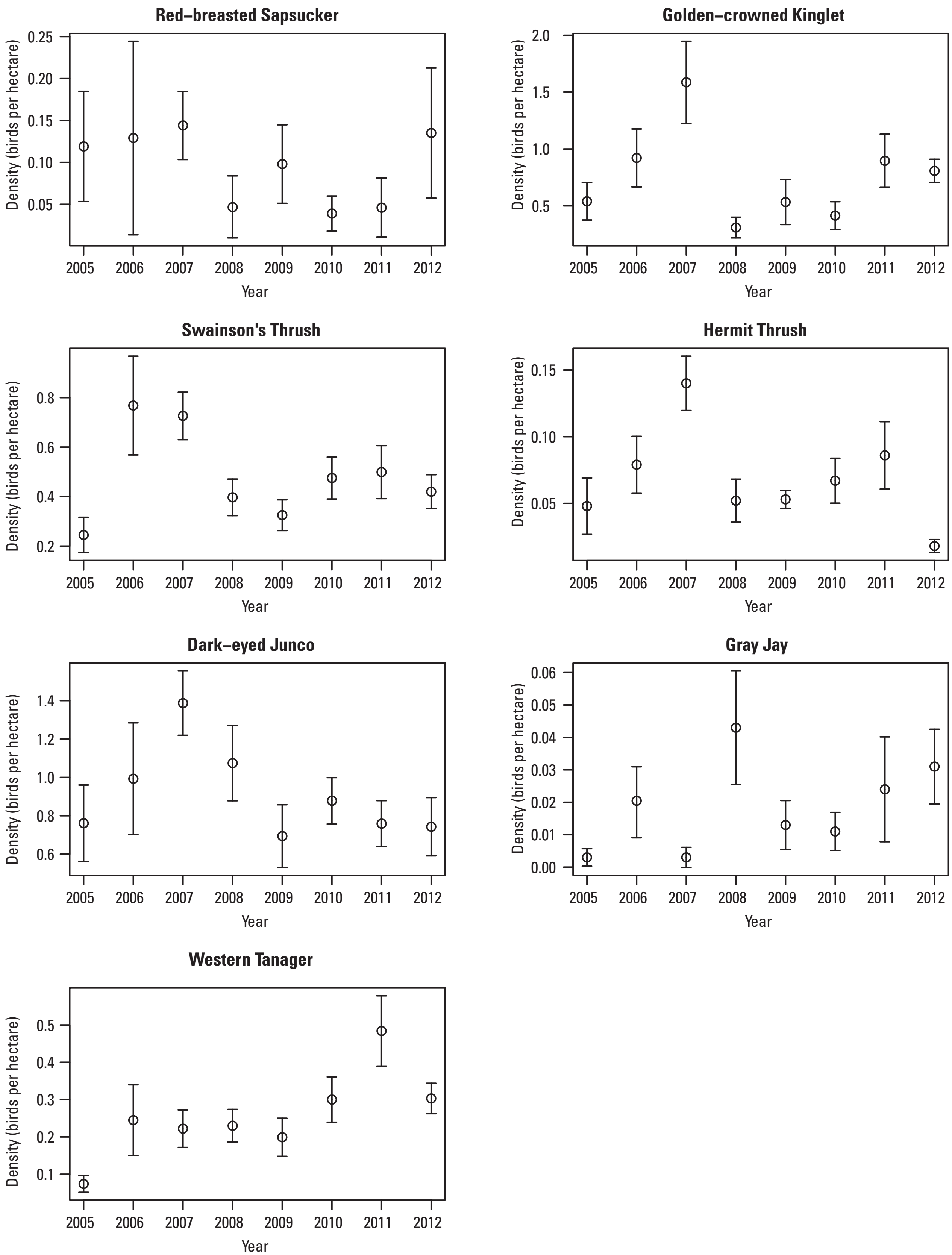


Figure 8. Annual mean point density estimates (±standard error) based on data from all points (that is, not just from transects with detections) for seven species with significant trends at North Cascades National Park. Five species significantly decreased (Red-breasted Sapsucker, Golden-crowned Kinglet, Swainson's Thrush, Hermit Thrush, and Dark-eyed Junco) and two species significantly increased (Gray Jay and Western Tanager).

Trends at OLYM were significant for 8 of 41 species (20 percent), 5 of which decreased (12 percent) and 3 of which increased (7 percent; table 3). Species with decreasing trends at OLYM included Band-tailed Pigeon (-0.2 percent per year), Vaux's Swift (-2.4 percent per year), Hairy Woodpecker (-1.0 percent per year), American Crow (-0.2 percent per year), and Red Crossbill (-3.4 percent per year). Species with increasing trends included Red-breasted Sapsucker (+2.2 percent per year), Gray Jay (+0.5 percent per year), and American Robin (+1.3 percent per year). Consistent with results from the other two parks, plots of annual density estimates showed high annual variation in density estimates (fig. 9).

Of 12 species for which we were able to estimate NCCN-wide trends (for example, pooling data across all three large parks), 4 species had significant negative trends (table 4). These included Red-breasted Nuthatch, Pacific Wren, Golden-crowned Kinglet, and Dark-eyed Junco. For Red-breasted Nuthatch, the trend appeared to be driven largely by low densities in the last 2 years of the time series, 2011 and 2012 (fig. 10). For the remaining three species, the time series was characterized by increasing densities during the first 3 years and lower abundance thereafter.

Bird Population Trends in Small Parks

We estimated trends for 45 species at LEWI and for 43 species at SAJH. Trends for 2006–12 were statistically significant for 6 of 45 (13 percent) species at LEWI (table 5). Three of these species decreased—Band-tailed Pigeon, Northern Flicker, and Olive-sided Flycatcher; and three species increased—Brown Creeper, Golden-crowned Kinglet, and Song Sparrow. At SAJH, 3 (7 percent) of the 43 species (Cassin's Vireo, Swainson's Thrush, and Townsend's Warbler) significantly decreased and none significantly increased (table 6).

Discussion

Avian Population Trends

In the first years of monitoring landbird populations in the NCCN, we detected several incipient trends in avian density. Our analyses revealed significant trends for multiple species at each of the parks. Most of the significant (P<0.10) trends in individual species were negative in direction (12 of 17 significant trends at large parks, all 4 significant trends in the combined large-park analysis, and 6 of 9 trends at small parks).

These preliminary indications of change, however, need to be interpreted with utmost caution at this early stage of the monitoring program. First, our analysis, based on data from 2005 to 2012, represents a fairly short-time span for this long-term monitoring project. The first 2 years of the time series (2005 and 2006) were implemented as part of a limited pilot study that included only the annual panel of transects. The subsequent 6 years (2007–12) represent just a single cycle through all five alternating panels, and repeat sampling of only one alternating panel. With such few years and repeat visits represented, random variability, particularly in the early or late-years of the series, may have strong stochastic effects of the estimated rates of change. Secondly, with trends across so many species-park combinations being tested independently, we are likely to obtain some statistically significant trends in instances where changes are not truly biologically significant, simply because of Type I error. In consideration of these constraints, it may be prudent, therefore, to focus attention on species with significant trends in the same direction in multiple parks or trends that are significant at the multi-park level, and view trends that are apparent in only one park as provisional.

At this relatively early juncture, the pervasive pattern of large inter-annual variation in the density estimates for individual species is noteworthy (appendix 3). Even among the relatively few species with statistically significant trends, annual density estimates often fluctuated greatly between years, with estimates occasionally changing by 50 percent or more in consecutive years (figs. 7–10).

Annual weather variation can drive fluctuations in populations of small birds (Crick, 1999), and this may be particularly true in montane environments where conditions related to snowpack can vary so greatly from year to year. Elsewhere in the montane west it has been demonstrated that winters with heavy snow accumulation may be associated with reduced breeding bird abundance in subalpine and upper montane forests (Raphael and White, 1984; Hejl and others, 1988; DeSante, 1990). In addition, late snowpack or late-season storms can delay initiation of breeding, resulting in fewer nesting attempts, and decreased overall reproductive success in these high-elevation habitats (Hahn and others, 2004; Pereyra, 2011; Mathewson and others, 2012). The persistence of spring snowpack (Smith and Anderson, 1985) or the incidence of late-spring storms (Whitmore and others, 1977; Morton, 2002) also may affect bird populations at mid elevations. In years with greater spring snowpack, there may be less snow-free substrate suitable for nests (for ground- or shrub-nesting species) and less plant material available with which to construct or line nests early in the season, factors that could delay nest-building or egg-laying (Smith and Andersen, 1985; Pereyra, 2011) and result in smaller clutches, fewer nesting attempts, or lower nest success (Verhulst and Nilsson, 2008; Pereyra, 2011).

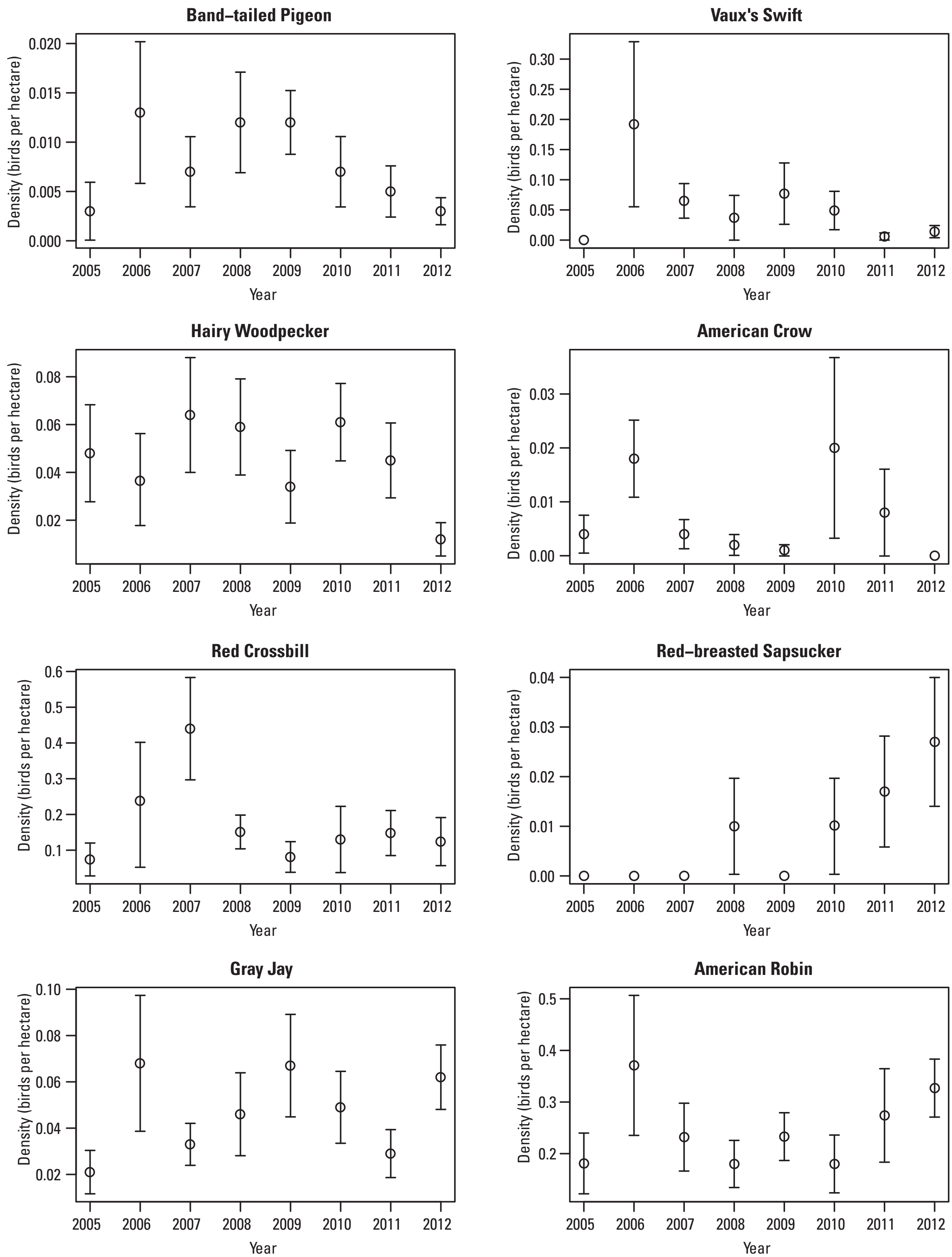


Figure 9. Annual mean point density estimates (±standard error) based on data from all points (that is, not just from transects with detections) for eight species with significant trends at Olympic National Park. Five species significantly decreased (Band-tailed Pigeon, Vaux's Swift, Hairy Woodpecker, American Crow, and Red Crossbill) and three species significantly increased (Red-breasted Sapsucker, Gray Jay, and American Robin).

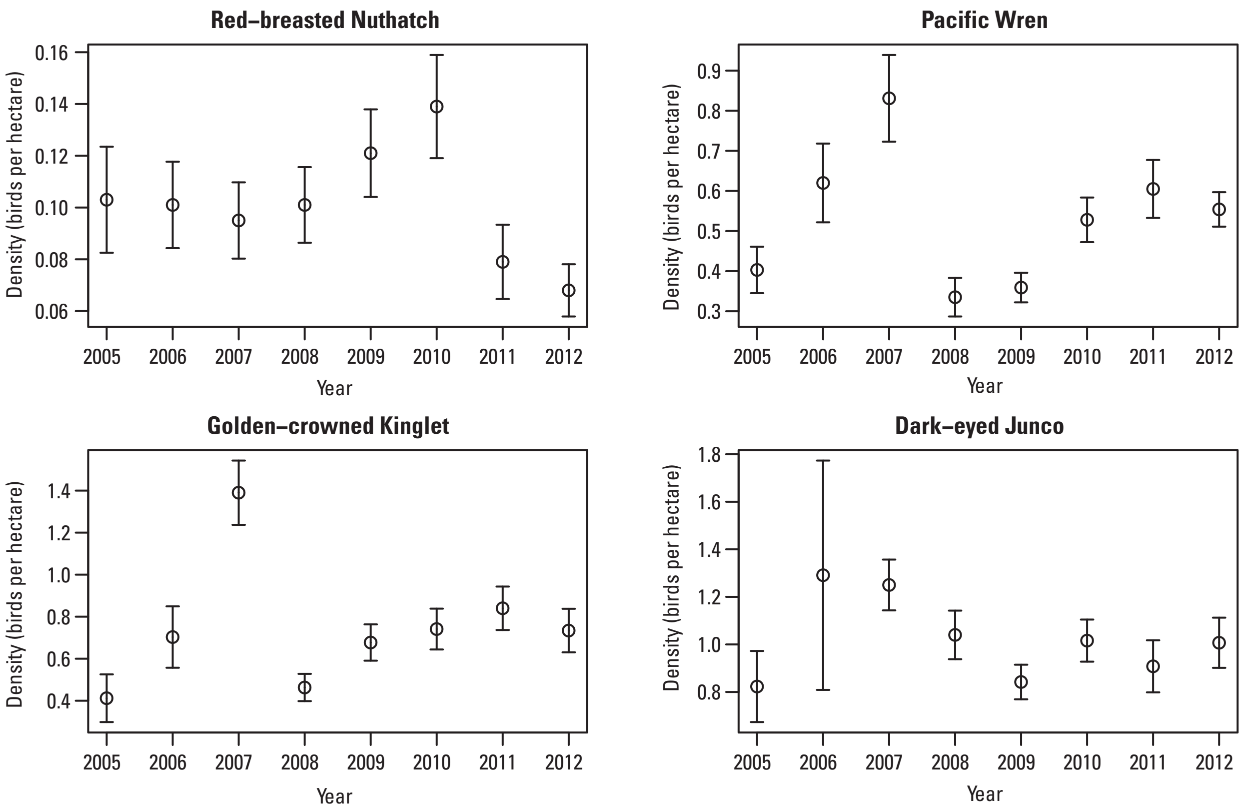


Figure 10. Annual mean point density estimates (±standard error) based on data from all points (that is, not just from transects with detections) for four species with significant trends across the three large wilderness parks of the North Coast and Cascades Network. Note that combined-park trends could only be calculated for 12 species that were detected in all elevation strata at all parks.

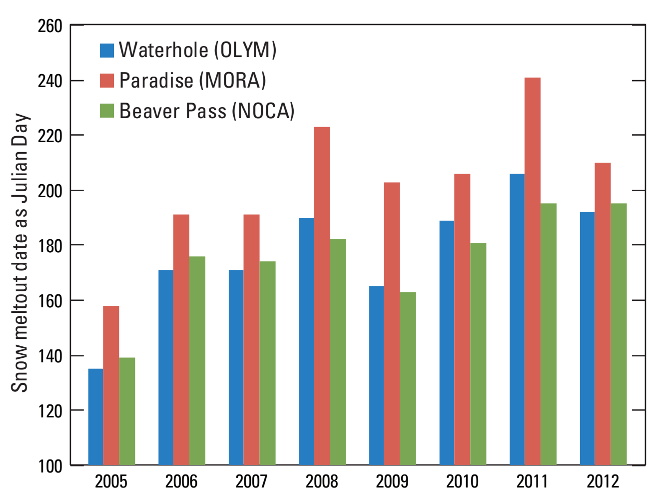


Figure 11. Annual snow meltout date (defined as ground surface albedo dropping below 30 percent) (Natural Resources Conservation Service, 2014) reported for individual snow telemetry ('SNOTEL') sites in each of the three large parks.

Table 5. Trends for Lewis and Clark National Historical Park sampled biennially.

[Trends are slope estimates from a linear regression of log+1-transformed mean point-level density estimates as a function of year and can be interpreted as annual proportional changes. Species names are presented in standard taxonomic order (Chesser and others, 2013). Significant slopes ($P < 0.10$) are shown in **bold**]

Species	Lewis and Clark National Historical Park (sampled in 2006, 2008, 2010, 2012)				
	Mean number of points	Mean density (birds per hectare)	Trend	Standard error	Slope (P)
Band-tailed Pigeon	**3.25**	**0.012**	**-0.003**	**0.001**	**0.060**
Rufous Hummingbird	5.50	3.310	-0.345	0.510	0.568
Red-breasted Sapsucker	0.25	0.005	-0.003	0.002	0.225
Hairy Woodpecker	1.50	0.020	0.007	0.004	0.266
Northern Flicker	**5.75**	**0.018**	**-0.003**	**0.001**	**0.036**
Pileated Woodpecker	1.50	0.003	0.000	0.001	0.612
Olive-sided Flycatcher	**10.75**	**0.038**	**-0.006**	**0.000**	**0.003**
Western Wood-Pewee	2.25	0.010	-0.004	0.001	0.105
Pacific-slope Flycatcher	38.75	0.826	0.028	0.079	0.757
Cassin's Vireo	0.25	0.003	0.001	0.001	0.742
Warbling Vireo	7.75	0.076	-0.016	0.009	0.204
Steller's Jay	8.00	0.071	-0.011	0.010	0.390
American Crow	30.00	0.184	-0.007	0.009	0.511
Common Raven	7.50	0.021	0.000	0.003	0.902
Chestnut-backed Chickadee	25.25	1.290	0.079	0.097	0.501
Red-breasted Nuthatch	5.25	0.041	0.003	0.004	0.552
Brown Creeper	**5.50**	**0.163**	**0.041**	**0.012**	**0.072**
Pacific Wren	43.00	0.867	0.024	0.105	0.841
Marsh Wren	9.25	0.495	0.021	0.017	0.352
Golden-crowned Kinglet	**20.25**	**0.923**	**0.205**	**0.059**	**0.074**
Swainson's Thrush	54.25	0.895	-0.011	0.067	0.884
American Robin	31.00	0.553	-0.007	0.012	0.631
Varied Thrush	2.00	0.007	0.000	0.001	0.777
Orange-crowned Warbler	14.75	0.236	0.008	0.010	0.521
Yellow Warbler	7.00	0.140	0.006	0.016	0.763
Yellow-rumped Warbler	0.75	0.010	-0.001	0.002	0.560
Black-throated Gray Warbler	9.25	0.123	0.017	0.020	0.493
Townsend's Warbler	4.75	0.068	-0.033	0.020	0.236
Hermit Warbler	10.75	0.219	0.046	0.041	0.382
MacGillivray's Warbler	0.50	0.005	-0.001	0.001	0.554
Common Yellowthroat	10.75	0.184	0.020	0.014	0.293
Wilson's Warbler	34.25	0.606	-0.005	0.028	0.883
Western Tanager	11.00	0.092	0.013	0.007	0.213
Spotted Towhee	3.25	0.030	0.005	0.002	0.115
Savannah Sparrow	2.00	0.032	-0.002	0.005	0.711
Song Sparrow	**28.25**	**0.503**	**0.063**	**0.015**	**0.051**
White-crowned Sparrow	11.75	0.069	0.002	0.002	0.479
Dark-eyed Junco	12.00	0.439	0.014	0.068	0.850
Black-headed Grosbeak	17.25	0.144	0.017	0.011	0.268
Red-winged Blackbird	9.25	0.061	0.006	0.005	0.359
Brown-headed Cowbird	12.25	0.223	0.027	0.013	0.180
Purple Finch	16.75	0.107	-0.004	0.005	0.531
Red Crossbill	0.75	0.009	-0.004	0.002	0.283
Pine Siskin	0.25	0.003	0.001	0.001	0.742
American Goldfinch	9.75	0.199	-0.002	0.016	0.927
Evening Grosbeak	0.50	0.053	0.032	0.018	0.225

Table 6. Trends for San Juan Island National Historical Park sampled biennially.

[Trends are slope estimates from a linear regression of log+1-transformed mean point-level density estimates as a function of year and can be interpreted as annual proportional changes. Species names are presented in standard taxonomic order (Chesser and others, 2013). Significant slopes ($P < 0.10$) are shown in **bold**]

Species	San Juan Island National Historical Park (sampled in 2007, 2009, 2011)				
	Mean number of points	Mean density (birds per hectare)	Trend	Standard error	Slope (*P*)
Band-tailed Pigeon	1.67	0.008	0.001	0.003	0.788
Rufous Hummingbird	7.00	5.842	0.797	0.460	0.333
Hairy Woodpecker	1.33	0.022	-0.002	0.001	0.333
Northern Flicker	4.67	0.020	0.001	0.001	0.551
Pileated Woodpecker	4.33	0.009	0.000	0.003	0.896
Olive-sided Flycatcher	5.33	0.023	-0.008	0.002	0.192
Hammond’s Flycatcher	0.33	0.007	0.000	0.006	1.000
Pacific-slope Flycatcher	21.00	0.594	-0.051	0.011	0.130
Cassin’s Vireo	**2.67**	**0.036**	**-0.017**	**0.002**	**0.073**
Warbling Vireo	8.00	0.129	-0.029	0.010	0.211
Steller’s Jay	0.33	0.003	0.000	0.003	1.000
American Crow	16.00	0.144	-0.017	0.030	0.667
Common Raven	5.33	0.022	0.005	0.003	0.333
Chestnut-backed Chickadee	14.00	0.796	-0.101	0.066	0.367
Red-breasted Nuthatch	16.67	0.165	-0.006	0.019	0.804
Brown Creeper	4.67	0.161	0.034	0.020	0.333
House Wren	19.67	0.305	0.059	0.033	0.324
Pacific Wren	9.00	0.205	-0.014	0.037	0.764
Golden-crowned Kinglet	5.67	0.355	0.090	0.089	0.497
Swainson’s Thrush	19.33	**0.275**	**-0.056**	**0.005**	**0.055**
American Robin	38.33	1.147	-0.053	0.157	0.793
Varied Thrush	4.00	0.017	0.010	0.002	0.115
Orange-crowned Warbler	23.00	0.442	0.011	0.007	0.333
Yellow Warbler	1.00	0.014	0.003	0.006	0.672
Yellow-rumped Warbler	5.00	0.057	0.019	0.008	0.247
Black-throated Gray Warbler	6.00	0.114	0.000	0.020	1.000
Townsend’s Warbler	**7.00**	**0.125**	**-0.020**	**0.003**	**0.084**
Common Yellowthroat	3.33	0.035	-0.016	0.012	0.401
Wilson’s Warbler	7.67	0.103	0.003	0.008	0.748
Western Tanager	5.00	0.036	-0.010	0.003	0.204
Spotted Towhee	22.00	0.326	0.016	0.052	0.805
Chipping Sparrow	1.67	0.031	0.010	0.007	0.379
Savannah Sparrow	17.00	0.748	0.025	0.061	0.758
Song Sparrow	12.33	0.173	0.011	0.007	0.364
White-crowned Sparrow	25.00	0.184	0.016	0.007	0.247
Dark-eyed Junco	10.67	0.502	0.042	0.044	0.512
Black-headed Grosbeak	3.33	0.036	0.005	0.003	0.333
Red-winged Blackbird	8.67	0.156	0.014	0.034	0.755
Brown-headed Cowbird	24.00	0.603	0.066	0.015	0.140
Purple Finch	13.33	0.130	0.029	0.012	0.255
Red Crossbill	0.67	0.009	0.000	0.004	1.000
Pine Siskin	6.67	0.173	-0.039	0.007	0.107
American Goldfinch	25.67	0.724	-0.057	0.073	0.582

One example of a possible weather-related signal is already apparent in the data collected to date: the winter of 2007–08 was a La Niña year with heavy snowpack in the Pacific Northwest (fig. 11), perhaps explaining why breeding populations of so many species, particularly resident species, were sharply reduced in 2008. However, the same pattern of sharply reduced breeding populations was not evident in 2011, which was a year with even heavier snowpack in the region (fig. 11), indicating that other factors could be involved. Elucidating the effects of climate fluctuations or climate change on NCCN bird populations is a complicated task that needs to test effects of multiple climate variables and account for climatic variation across the diverse conditions within each park. Such analyses will be important components of future analyses of this growing dataset.

As described above, we view trends of individual avian species identified within a single park as provisional, and place more weight on trends identified in multiple parks or for the three large parks combined. Hence, species with the greatest evidence of change were the Red-breasted Nuthatch, Pacific Wren, Golden-crowned Kinglet and Dark-eyed Junco, all decreasing, and the Gray Jay, increasing.

Despite high annual variation and short time-series duration, trends in the large parks tended to agree with recent BBS trends estimated at larger spatial scales. For example, correlation between 2001 and 2011 BBS trends for Washington State (Sauer and others, 2012) and trends from each of the three large parks for species shared between the two surveys was positive in each case (correlation coefficients for the three large parks ranged from 0.20 to 0.28 with *P*-values from 0.07 to 0.15), and comparisons of average trends between the Washington BBS and each of the large parks showed no overall differences in percent annual change (*P*-values from paired t-tests [each species representing a pair] all >0.4).

Despite overall similarities between regional trends and those at individual parks, it is worth noting that we detected trends in a variety of individual species-park combinations that were not evident in the regional BBS data. Furthermore, trends were not always consistent among parks. These findings may suggest evidence for regional-scale processes affecting bird populations as well as the need for continued monitoring at the scale of individual parks to understand factors affecting populations at finer spatial scales. However, an alternative interpretation is that they may provide a cautionary note about over-interpreting trend results from short-time series.

Although we were only able to estimate combined-park trends for 12 species, 4 of the 12 showed significant population decreases. Here, too, there was general agreement between the NCCN 2005–12 trends and BBS trends. For example, three of these four species (Pacific Wren, Golden-crowned Kinglet, and Dark-eyed Junco) showed significant 2001–11 BBS decreases for Washington State and for the larger Northern Pacific Rainforest region, while the fourth species (Red-breasted Nuthatch) showed non-significant 2001–11 BBS decreases for these regions (Sauer and others, 2012). Pacific Wren, Golden-crowned Kinglet, and Dark-eyed Junco also show longer term significant (1966–2012) BBS decreases at either (or both) the Washington or Northern Pacific Rainforest regions and at a continental scale (Sauer and others 2012, 2013). Although non-significant, the species with the largest-magnitude decreases for each of the three large parks of the NCCN was Rufous Hummingbird, a species that also shows severe short- and long-term regional decreases and is of overall high conservation concern (Partners in Flight, 2012; Watch List species; http://rmbo.org/pifassessment/Database.aspx). Among species at the small parks with significant decreases, Olive-sided Flycatcher (decreasing at LEWI) is also a species showing severe regional decreases, although decreases in this species were not evident at the large parks. Both Rufous Hummingbird and Olive-sided Flycatcher were recently ranked as ‘vulnerable’ in a comprehensive analysis of the population status of North American bird species (American Bird Conservancy, 2012), and both species are Partners in Flight (PIF) U.S.-Canada Watch List species (Partners in Flight Science Committee, 2012). The only other PIF Watch List species observed during our monitoring was Cassin’s Finch. We were able to estimate trends for this species in two of the large parks (MORA and NOCA); in both cases, we found no evidence of a significant trend.

Similarities in trends between the NCCN Landbird Monitoring Project and the BBS suggest that some factors driving trends are acting on populations at scales beyond the borders of individual parks. Climate change is an obvious example, and as more years of data are amassed, this project is likely to yield a rich source of information on the effects of annual weather variation on Pacific Northwest bird populations.

Limitations of the Analytical Approach

One of the primary goals of this first analysis of the NCCN landbird monitoring data was to implement and then evaluate the analytical methods prescribed in the protocol (Siegel and others, 2007). Our analytical approach to trend assessment for the large parks involved a multi-step process whereby (1) observations were corrected for imperfect detection based on distance-detectability functions, (2) mean transect-scale trends were estimated for each elevation stratum based on the corrected counts, and (3) trends were estimated at the park (or combined-park) scale based on the mean stratum-level trends and the relative size of the sampling frame in each elevation stratum. This analytical approach was tightly integrated with the sampling design and aimed to provide a relatively simple and effective approach for assessing trends. Similarities in trends between the BBS and our study suggest this approach was effective and robust to potential limitations or problems involved with its implementation. Nevertheless, there are limitations to the approach, and subsequent to its development (initiated 10 years ago), a variety of advances in the field of modeling detectability and trend have become available and could improve future analyses of these data. Here, we briefly discuss limitations of our analysis and offer suggestions for the future.

In regard to step 1 above, estimation of distance-detectability functions to correct raw count data (distance sampling) was a widely advocated means of correcting avian point count data for imperfect detection at the time the NCCN protocol was developed (Buckland and others, 2001, 2004). However, difficulties in meeting assumptions of the method in many avian point count surveys have since been widely acknowledged (for example, Alldredge and others, 2008; Johnson, 2008). The assumptions of perfect detectability at the point (that is, at distance = 0) and no movement prior to detection may be particularly problematic. We found fewer detections than expected close to observers for many species (histogram peaks at distance >0 in appendix 2), suggesting that we failed to meet one or both of these assumptions for many species. This pattern might reflect birds moving from the point as observers approached (and not returning to their original locations), reduced singing rates of birds close to observers (McShea and Rappole, 1997), or a tendency for overestimation of distances for birds at or close to the point (for example, because of difficulties in localizing sounds directly overhead). Accurate assignment of distances may be a difficult assumption to meet in studies of singing birds, for a variety of reasons, including levels of ambient noise, and the direction the vocalizing bird is facing (Alldredge and others, 2007b, 2008). Finally, heterogeneity in detection probability among observers probably was important for most species in our study, yet models including observer effects could only be supported for species with the largest sample sizes, presumably because of the large numbers of parameters that need to be estimated in those models. Methods that allow observers to be modeled as random effects would alleviate this problem (for example, see Schmidt and others, 2013). Overall, we feel that our distance-detectability modeling efforts likely improved inferences about trend over analyses of raw count data, which would have ignored heterogeneity in detection probability. However, it is unclear the degree to which inability to meet assumptions and model all sources of heterogeneity in detection probability may have affected results of the detectability or trend analyses.

Other potential issues with the current trend analysis involve steps 2 and 3 above–the trend estimation methods implemented in the *BirdTrend* software. First, in step 2, uncertainty in slope estimation at the transect-scale (that is, residual variation in year-specific density estimates from the transect-level trend models) never explicitly enters into variance estimation at the stratum, park-wide, or combined-park scales. Thus, transect-level slopes are considered known quantities with equal weight for all transects. For some species-park combinations, differences in slope variances among transects were accounted for by assigning transects with different numbers of years of sampling to different variance groups; however, for many species there were not enough transects with detections in a park to separate annual and alternating panels into separate variance groups. A second potential problem with our trend estimation method relates to the fact that many bird species that were encountered in multiple elevation strata were rare in one or more of those strata. As long as individual birds of those species were encountered on at least two transects in each stratum where they were encountered, overall trends could be estimated; however, these trend estimates may not be the best metrics of trend because stratum-weighting of the overall trend is based on the sampling frame, not the potential distribution of the species. Ideally, the weighting of trends would reflect both the distribution of the species and the distribution of potential sampling transects in each elevation stratum. An additional consequence of rarity of a species in a particular elevation stratum is that when the species was only encountered on a single transect in that stratum, data had to be discarded because lone transects could not be combined across elevation strata because of different sampling weights among strata. This situation occurred in at least one park for more than one-half of the species we considered. Finally, in the current version of *BirdTrend*, combined-park trend estimates were only possible for species detected in all elevation strata of all parks. This precluded our ability to provide combined-park trend estimates for more than one-half of the species found in all three parks.

Suggestions for an Alternative Analytical Framework

Despite these potential problems with the current analysis, the overall sampling design is strong and amenable to analysis by more recent methods that address these issues and provide a flexible framework for examining trends and other population parameters of interest, as well as testing hypotheses that relate the distribution and abundance of species to environmental covariates. These newer methods allow for modeling of various components of the detection process and analyzing observations (detection process), population state (occupancy, population size, density), and change (trend, local colonization and extinction rates, turnover) simultaneously (Nichols and others, 2009). Detection histories of individuals (informed mainly by the protocol with three intervals adopted in 2011) can be used within a time-of-detection closed-population framework to model population size (Alldredge and others, 2007a) or occupancy (Saracco and others, 2011) and detection probabilities. Changes in occupancy or population size also could be modeled with these detection histories based on methods developed for within-season repeated survey data (MacKenzie and others, 2003; Royle, 2004; Kéry and others, 2009). Even newer methods exploit open-population models that do not require multiple sampling intervals or within-season replication of counts (Dail and Madsen, 2011, 2013). All these techniques address a variety of limitations of the current analysis, including accounting for uncertainty in the detection and state processes simultaneously and at all spatial scales (from the individual transect to multiple parks), inclusion of random effects (for example, allowing for more efficient modeling of observer differences in detectability), allowing for the possibility of presence of birds at points with zero detections (that is, in the current analysis, zero counts are considered true zeros, while non-zero counts are corrected for imperfect detection), and providing a model-based, rather than a sampling-design based, approach to assessing trends. In addition, a model-based approach would allow incorporation of all data from all elevation strata, provide a flexible framework for modeling detection probabilities and population parameters as functions of covariates (including detection probability-distance relationships), and (with a Bayesian Markov chain Monte Carlo implementation) allow summaries of trend (or other parameter) at multiple scales of interest. An example of such an analysis for a point-count based monitoring project (with replicated within-season counts) in a national park is provided by Schmidt and others (2013).

Evaluating Operational Aspects of the North Coast and Cascades Network Landbird Monitoring Project

Aside from the limitations of the current analytical framework described above, the implementation of the NCCN Landbird Monitoring Project has largely proceeded as intended and has been highly successful from an operational perspective. Despite occasional difficulties with transects being inaccessible because of late-lingering snowpack, washed out bridges, or other causes, the crew has successfully surveyed an average of 95 percent of the intended transects each year since monitoring began in 2005, with at least 90 percent of the intended transects surveyed in any particular year except for 2011 (table 2). During that year, a combination of heavy snowpack, frequent summer rain, and multiple crew members who were unable to pass the certification exam resulted in only 57 of the 68 intended transects (84 percent) being surveyed. Across all years of monitoring, the transect surveys that are missed most often tend to be those that require high-elevation travel to access or survey— generally because such travel is impeded by snow until late in the survey season during some years. Nevertheless, during 3 of the 8 years analyzed here (2005–12), 100 percent of the intended transects were surveyed, and in 2013, the crew again was able to survey all 68 transects.

Sampling Frequency and Intensity

The present multi-year analysis provides an opportunity to reflect on the project's sample design, particularly whether cost-saving reductions in sampling frequency or intensity might be warranted. In anticipation of possible budget shortfalls, several options for structuring such reductions have been considered in the past. Below we discuss briefly the tradeoffs involved with each option.

1. Discontinue monitoring in one or more of the three large parks. Elimination of a large park from the sampling frame would allow reduction of the seven-person field crew (comprised of a crew leader and six interns) by two interns. This would reduce costs associated with multiple project components, including data collection, data-quality assurance, and to a lesser degree, data analysis and reporting, but in all cases, the savings would be less than two-sevenths of the overall cost of the project component, because of efficiencies currently realized through an economy of scale. For example, the remaining four interns would still require supervision by a full-time crew leader, who currently trains and supervises six interns. Additionally, extending inference to all three large parks–which vary considerably in their habitats and bird community composition–was a fundamental objective in the development of the NCCN Landbird Monitoring Project, and has frequently been identified as one of its important strengths.

2. Discontinue monitoring of the alternating panels of transects. Elimination of the alternative panels of transects would likely allow reduction of the crew by three interns and reduce costs associated with project components, including data collection, data-quality assurance, and to a lesser degree, data analysis and reporting. Cost savings would be greater than those realized by eliminating one large park, since three, rather than two, crew positions could be eliminated and the amount of data collected in the large parks would be reduced by one-half, rather than one-third. The primary disadvantage to this approach would be the loss of much of the program's ability to assess spatial heterogeneity in the dataset, because the alternating panels represent four-fifths of the total pool of transects. Even though the overall sampling frame would not be reduced if data collection were scaled back to just the annual panel of transects, the capacity of those transects to represent landbird dynamics across the extensive and diverse landscapes of the parks would be greatly reduced.

3. Discontinuing monitoring of the annual panel of transects. Elimination of the annual panel of transects would reap similar cost-savings as elimination of the alternating panels of transects, but would largely preserve the program's ability to assess population dynamics across the diversity of the park landscapes, because four-fifths of the transects would be retained. The major disadvantage of this approach is that it would make it difficult, if not impossible, to separate spatial variation from temporal variation in bird densities, as our analysis reveals a high degree of annual variability in NCCN bird populations. In addition to complicating assessment of spatial and temporal variability, elimination of the annual panel would make it more difficult or impossible to assess and describe relationships between annual weather patterns and bird populations in the NCCN. In an era of increasing concern over the effects of climate change, sacrificing inference about the effects of weather (and by extension, climate) seems like a high price to pay.

4. Periodically skip a year of monitoring, perhaps coinciding with the production of each 5-year synthesis report. Periodically skipping a year of data collection may be the best way to reduce costs without undermining the integrity of the sample design or sacrificing important programmatic goals. Particularly if the skipped years coincide with the production of each 5-year report, the cost-savings in data collection, analysis, and reporting may free up needed funds for those reporting efforts. However, this approach also has drawbacks. Cost savings would only be approximately one-fifth of the current program costs (excluding production of the 5-year reports), and those savings would be realized only every 5 years, with no savings in the annual costs in the years when data collection is implemented. Additionally, skipping a year of data collection could result in difficulties restarting the efforts after the skipped year, particularly if staff members are reassigned to other duties during the interim and/or if field personnel who might otherwise return opt to leave the project permanently during the off year.

Considering the cost-cutting options together, we believe that option 4, periodically skipping a year of data collection, is the most tractable. However, we suggest that final decisions on the matter be delayed, as efforts are currently underway to develop and assess an alternative analytical framework for the NCCN Landbird Monitoring Program, and the increased analytical flexibility of the new approach may suggest other options for reducing data-collection effort and expenses.

Safety

Despite working largely off-trail, the NCCN landbird monitoring crew has never had a serious project-related injury. Nevertheless, we are continually reviewing and refining our safety procedures. Throughout the 8 years of our study, crews submitted a detailed itinerary for each trip to the park dispatch center and checked in twice daily over radios while in the field. More recently, the crew also started completing and submitting forms before each trip that identify the potential risk involved and indicate what is being done to mitigate those risks. In addition to these safety procedures, in 2013 the crew also attended a 2-day Operational Leadership Training and received training in ice axe usage and snow travel training, both provided by the NPS. This extra training was considered very helpful and will continue in future years.

Successful Collaboration

As a network-wide project implemented with a single field crew, the Landbird Monitoring Project requires close coordination among five national park units. Additionally, the project has been implemented every year through a cooperative agreement with a non-governmental organization, The Institute for Bird Populations, and also frequently relies on consultation with staff at USGS- Forest and Rangeland Ecosystem Science Center. By all accounts, this multi-party partnership has been highly successful, and has consistently produced data and reports on time and within budget constraints.

Optimal Crew Size

The project has been implemented over the years with a crew size ranging from six to eight surveyors, including one crew leader. Although the work nominally requires six people, a seven-person crew seems to be the optimal size, providing one fully trained backup person if needed in case of minor injuries (for example, sprained ankle) or another crew member's inability to pass the bird identification exam.

Data-Sharing and Dissemination

The project dataset has been requested by and provided to multiple independent researchers. Besides being posted online in the usual NPS locations, the project partners also have created a website (http://www.birdpop.net/nccn/) that describes the project and provides access to data and reports. The data and metadata represent a valuable asset, the value of which will only increase over time, especially given the context provided in the annual reports, field season crew lead summaries, and annual quality assurance documentation provided in the certification reports.

Training and Mentoring Young Biologists

An ancillary benefit of having implemented landbird monitoring for NCCN has been that a cadre of five to seven field biologist interns has been trained in bird survey techniques and wilderness safety every year. Of the 36 interns who participated in monitoring for at least 1 year between 2005 and 2012, many have continued on to graduate studies and/or careers in the biological sciences or natural resource management.

Conclusions

The NCCN Landbird Monitoring Project is still in the early years of its implementation, with only one-third of its 204 transects having been eligible for re-survey prior to this analysis. The project is being implemented successfully at the operational level, and is already yielding preliminary findings that hint at the increasing value of the data and results in years to come as the remaining transects are re-visited and more years are added to the overall time series. Particular strengths of the project include its ability to monitor trends of dozens of species simultaneously, its broad area of inference across reasonably accessible areas (including much of the backcountry) of the large parks, and the integration of operations, analyses, and inference across multiple Network parks. The largest challenge now facing the project is the need to transition to a more modern, flexible analytical framework incorporating a model-based approach that will allow for modeling and analyzing observations (detection process), population state (occupancy, population size, density), and change (trend, survival, recruitment, turnover) simultaneously. A model-based approach should provide more flexibility to make adjustments for missed or reduced sampling effort, better ability to identify range or habitat shifts in response to climate change, and an enhanced capacity to test hypotheses about the effects of weather and habitat on temporal and spatial variation in bird populations.

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Appendix 1. Common and Scientific Names of Species Used in Trend Analysis

[Species names are presented in standard taxonomic order (Chesser and others, 2013)]

Species	Scientific name
Sooty Grouse	*Dendragapus fuliginosus*
Band-tailed Pigeon	*Patagioenas fasciata*
Vaux's Swift	*Chaetura vauxi*
Rufous Hummingbird	*Selasphorus rufus*
Red-breasted Sapsucker	*Sphyrapicus ruber*
Hairy Woodpecker	*Picoides villosus*
Northern Flicker	*Colaptes auratus*
Pileated Woodpecker	*Dryocopus pileatus*
Olive-sided Flycatcher	*Contopus cooperi*
Western Wood-Pewee	*Contopus sordidulus*
Hammond's Flycatcher	*Empidonax hammondii*
Pacific-slope Flycatcher	*Empidonax difficilis*
Cassin's Vireo	*Vireo cassinii*
Warbling Vireo	*Vireo gilvus*
Gray Jay	*Perisoreus canadensis*
Steller's Jay	*Cyanocitta stelleri*
Clark's Nutcracker	*Nucifraga columbiana*
American Crow	*Corvus brachyrhynchos*
Common Raven	*Corvus corax*
Mountain Chickadee	*Poecile gambeli*
Chestnut-backed Chickadee	*Poecile rufescens*
Red-breasted Nuthatch	*Sitta canadensis*
Brown Creeper	*Certhia americana*
House Wren	*Troglodytes aedon*
Pacific Wren	*Troglodytes pacificus*
Marsh Wren	*Cistothorus palustris*
Golden-crowned Kinglet	*Regulus satrapa*
Ruby-crowned Kinglet	*Regulus calendula*
Townsend's Solitaire	*Myadestes townsendi*
Swainson's Thrush	*Catharus ustulatus*
Hermit Thrush	*Catharus guttatus*

Species	Scientific name
American Robin	*Turdus migratorius*
Varied Thrush	*Ixoreus naevius*
American Pipit	*Anthus rubescens*
Orange-crowned Warbler	*Oreothlypis celata*
Nashville Warbler	*Oreothlypis ruficapilla*
Yellow Warbler	*Setophaga petechia*
Yellow-rumped Warbler	*Setophaga coronata*
Black-throated Gray Warbler	*Setophaga nigrescens*
Townsend's Warbler	*Setophaga townsendi*
Hermit Warbler	*Setophaga occidentalis*
MacGillivray's Warbler	*Geothlypis tolmiei*
Common Yellowthroat	*Geothlypis trichas*
Wilson's Warbler	*Cardellina pusilla*
Western Tanager	*Piranga ludoviciana*
Spotted Towhee	*Pipilo maculatus*
Chipping Sparrow	*Spizella passerina*
Savannah Sparrow	*Passerculus sandwichensis*
Fox Sparrow	*Passerella iliaca*
Song Sparrow	*Melospiza melodia*
White-crowned Sparrow	*Zonotrichia leucophrys*
Dark-eyed Junco	*Junco hyemalis*
Black-headed Grosbeak	*Pheucticus melanocephalus*
Red-winged Blackbird	*Agelaius phoeniceus*
Brown-headed Cowbird	*Molothrus ater*
Purple Finch	*Haemorhous purpureus*
Cassin's Finch	*Haemorhous cassinii*
Red Crossbill	*Loxia curvirostra*
Pine Siskin	*Spinus pinus*
American Goldfinch	*Spinus tristis*
Evening Grosbeak	*Coccothraustes vespertinus*

Appendix 2. Distance-Detection Histograms and Predicted Detection Probabilities

The appendix contains histograms of distance-detection data and predicted detection probabilities used to correct count data for imperfect detection for 61 bird species with at least 75 detections at point count stations in national parks of the North Coast and Cascades Network from 2005 to 2012. Appendix 2 in .PDF format can be downloaded from http://pubs.usgs.gov/of/2014/1202/.

Appendix 3. Annual Density Estimates

The appendix contains graphs showing annual mean point density estimates from 2005 to 2012 for 56 bird species with sufficient data to estimate trends in at least one of three large national parks of the North Coast and Cascades Network. Estimates are also shown for the three national parks combined. Appendix 3 in .PDF format can be downloaded from http://pubs.usgs.gov/of/2014/1202/.

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For more information concerning the research in this report, contact the
Director, Forest and Rangeland Ecosystem Science Center
U.S. Geological Survey
9777 NW 9th St., Suite 400
Corvallis, Oregon 97330
http://fresc.usgs.gov

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