



Summary and Evaluation of Landbird Monitoring in Grand Teton National Park, 2005-2008

Natural Resource Technical Report NPS/GRYN/NRTR—2012/622



ON THE COVER

American Pipit (*Anthus rubescens*)

Photograph by: Wolfgang Wander

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Executive Summary

Bird monitoring is one of the most widespread types of long-term monitoring in the United States. Birds are considered an indicator of ecosystem integrity because of their high body temperature, rapid metabolism, and high ecological position in most food webs. They are also useful indicators of habitat quality and quantity, as evidenced by numerous studies world-wide (e.g., Jansen and Robertson 2001).

This report presents results from the pilot phase (implemented only in Grand Teton National Park) of a long-term monitoring program for parks in the Greater Yellowstone Ecosystem. The focus of this report is to assess the effectiveness of the sampling design and methods to address the landbird monitoring objectives.

This pilot tested the methodology of distance sampling, which allows pooling of data across years to estimate the detection function, which can then be applied to annual data to produce annual density estimates (Buckland et al. 2001). Distance sampling can be used to simultaneously collect data to generate abundance estimates for multiple species and is usually efficient in a large-scale, multispecies setting. For landbird species that have a moderate to small number of detections per year, occupancy modeling can be used to estimate the percent area occupied of specific habitat types. Because distance sampling was the primary driver in determining the sampling design for the program, estimating occupancy required using the relatively novel approach of spatial rather than temporal replication (Mackenzie et al. 2005). In the case of Grand Teton National Park, this meant that each transect was considered a sampling unit and point counts within transects were treated as the replication, rather than conducting repeat visits over time.

Another objective of the monitoring program, quantifying bird community dynamics, was designed to yield habitat-specific data on species richness and turnover. Species richness is a useful state variable for conservation and management purposes because it provides a basis for evaluating community responses to management actions, natural disturbance, or changes to community structure such as the loss of a keystone species. Our analysis incorporated capture-recapture-based methodology to estimate detection rates and allowed the use of all data collected with no species being excluded due to small sample sizes.

With only four years of data, we generated reliable density estimates for 17 of 33 target species and species richness metrics for all five habitat types, including the little known alpine habitat. Additional years of data would allow the calculation of reliable density estimates for additional species, although it is unlikely that precise density estimates would ever be possible for rare species.

Our assessment of the sampling design used to date showed that estimates of density and species richness were successfully obtained and these data would be valuable to collect in the long term for trend analysis. Results from the data analysis also clearly demonstrate that given the current sampling regime, occupancy estimates are not sufficiently precise to be useful for evaluating status or trends (Gould et al. 2010).

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Introduction

Bird monitoring is one of the most widespread types of long-term monitoring in the United States. Birds are considered an indicator of ecosystem integrity because of their high body temperature, rapid metabolism, and high ecological position in most food webs. They are also useful indicators of habitat quality and quantity, as evidenced by numerous studies world-wide (e.g., Jansen and Robertson 2001); in fact, some studies suggest that bird reproduction rates vary with habitat quality, leading to higher densities in superior habitat (Bock and Jones 2004). Birds are charismatic and there is a high demand from the public for information on their status. For these reasons, landbirds were selected as a “Vital Sign” for the Greater Yellowstone Network (GRYN) of the NPS Inventory and Monitoring Program (Jean et al. 2005).

Between 2005 and 2008, GRYN conducted a pilot landbird monitoring project in Grand Teton National Park (NP) in collaboration with park staff. The overarching monitoring goal was to answer the following question: Are there observable changes in the native bird communities within each of five habitats of concern that would indicate a systematic decline in abundance or distribution within these habitats, suggesting that habitat quality may be changing? Specific monitoring objectives were as follows:

1. **To estimate the abundance (density) of birds in habitats of concern and changes in abundance over time.** Although abundance estimates can be generated for all species with sufficient data, our emphasis was primarily on species that have strong associations for either the particular habitat of concern or with environmental gradients within that habitat that would be information rich regarding the nature of observed changes. Changes in distribution and abundance frequently depend on environmental factors (Buckland et al. 2001) and thus are often used as indicators of environmental quality.
2. **To estimate the proportion of area occupied (or occupancy) as a measure of the distribution of birds in habitats of concern, and to estimate the changes in distribution over time.** Virtually all reliable estimators of abundance are based on a count statistic divided by an estimate of detection probability (Seber 1982, 1986). Unfortunately, obtaining estimates of detection probabilities can be expensive and time consuming (MacKenzie et al. 2002), especially for rare species. Frequently, the most difficult species for which to obtain reliable estimates of abundance are those species of the greatest concern. This limitation has been a primary motivation for the recent development of a canonical estimator of occupancy (MacKenzie et al. 2002) that is based on the presence or absence of a given species, taking into account the detection probability for that species, rather than on individuals as required for estimating abundance. Using this foundation, a suite of reliable and useful estimators for parameters such as the proportion of sites occupied and local extinction and colonization rates are possible for species for which estimates of abundance may not be feasible.
3. **To estimate community composition and associated parameters of birds in habitats of concern, with particular emphasis on distinguishing shifts in species with strong habitat associations or environmental gradients within habitats.** Protection of native species and their habitats is one of the primary challenges identified in the NPS Natural Resource Challenge (U.S.D.I. National Park Service 1999). Thus, monitoring the

composition of native communities of concern and the changes occurring within and among these communities is essential to meeting our Natural Resource Challenge.

4. **To estimate key parameters related to horizontal and vertical vegetation structure and plant species composition for which birds are likely to respond, and to estimate change in those parameters over time.** Previous studies have indicated that landbirds respond to vegetation structure; this objective is not intended to determine whether or not such a relationship exists. Rather, vegetation structure and species composition are considered essential information for interpreting trends in bird abundance, distribution, or species richness.

To summarize, objectives of the GRYN landbird monitoring program were to estimate the status and long-term trends in: (1) species-specific density; (2) occupancy as a measure of distribution; (3) community dynamics of birds in alpine, aspen, riparian willow, riparian cottonwood, and sage-steppe habitats during the breeding season; and (4) changes in vegetation structure or plant species composition that are important for landbirds. Vegetation data analysis was intended to improve the interpretation of results from the first three objectives. Stressors or threats to landbirds considered in developing the monitoring plan and sampling design for this program included climate change, land use change, invasive species, grazing, altered fire regimes, and visitor use. The focus on “habitats of concern” within Grand Teton NP was necessary due to the enormous variability in habitats within the park, and to provide habitat-specific results that would potentially allow park managers to respond to observed trends in landbird population dynamics.

Until recently, landbird monitoring traditionally relied on count indices in which observed individuals were used as a proxy for abundance; however, these methods make strong and often impractical assumptions regarding constant detection probabilities over space and time (Nichols et al. 2000). Norvell and others (2003) concluded that reliance on count indices to determine population trends was unsatisfactory because the assumption of constant proportionality is violated to an extent that it confounds trend analyses. In contrast, they (Norvell et al. 2003) reported that distance-sampling methods (Buckland et al. 2001) appeared to meet critical assumptions, were robust to assumption violations, accounted for differences in detectability, and were useful for detecting population trends. Landbird density estimates are now commonly obtained using distance sampling techniques described by Buckland and others (2001). Using this technique, estimation of density is possible for bird species detected on more than 60 occasions over the cumulative sampling period (i.e., multiple years). The robust methodology behind distance sampling allows pooling across years to estimate the detection function, which can then be applied to annual data to produce annual density estimates (Buckland et al. 2001). Distance sampling can be used to simultaneously collect data to generate abundance estimates for multiple species and is usually efficient in a large-scale, multispecies setting.

For landbird species that have a moderate to small number of detections per year, occupancy modeling can be used to estimate the percent area occupied of specific habitat types within Grand Teton NP (Bennetts et al., 2005 unpublished). Because distance sampling was the primary driver in determining the sampling design for the program, estimating occupancy required using the relatively novel approach of spatial rather than temporal replication (Mackenzie et al. 2005). In the case of Grand Teton NP, this meant that each transect was considered a sampling unit and

point counts within transects were treated as the replication, rather than conducting repeat visits over time.

The third objective of the monitoring program, quantifying bird community dynamics, was designed to yield habitat-specific data on species richness and turnover. Species richness is a useful state variable for conservation and management purposes because it provides a basis for evaluating community responses to management actions, natural disturbance, or changes to community structure such as the loss of a keystone species. Our analysis incorporated capture-recapture-based methodology to estimate detection rates and allowed the use of all data collected with no species being excluded due to small sample sizes.

In this report we present results from the pilot phase of a long-term monitoring program for parks in the Greater Yellowstone Ecosystem. The pilot phase was implemented only in Grand Teton National Park, while full implementation would involve expanding the protocol to Yellowstone National Park, and potentially Bighorn Canyon National Recreation Area. The focus of this report is to assess the effectiveness of the sampling design and methods at addressing the initial landbird monitoring objectives.

Study Area

Grand Teton National Park was established in 1929 and was expanded in 1950 to encompass 1,250 square km. It preserves a spectacular landscape rich with glaciated mountains, pristine lakes, and wildlife that attract nearly four million visitors per year.

Elevations within the park range from 1,950 m on the sagebrush-dominated valley floor to 4,197 m on the summit of the Grand Teton. Landbird monitoring occurred in five vegetation types: alpine and subalpine (the area above treeline and the area immediately below treeline), aspen, sage-steppe, riparian cottonwood, and riparian willow.

Climate in Grand Teton NP is semi-arid mountainous and characteristic of the central Rocky Mountains, with extended winters and short summers. Most precipitation occurs in winter; the first heavy snow of the year typically falls by November 1 and continues through March, although snow and frost can occur in any month. The average annual extreme high temperature is 34°C and average extreme low is -46°C. Average annual snowfall is 90 cm and average rainfall is 25 cm.

Methods

Surveys were conducted in Grand Teton NP, located in northwestern Wyoming.

Sampling Design

For sampling purposes, the park was stratified according to the five vegetation types of interest (Bennetts et al., 2005 unpublished) and 13-19 point transects were randomly distributed within each vegetation type (Figure 1). Sample sizes (i.e., the number of transects) were based on simulations in Program R (R Development Core Team 2008) and were chosen to allow a high likelihood of detecting a 20% decline in density over a 15-yr period for moderately abundant species (Paul Lukacs pers. comm. April 2008). This approach avoids convenience sampling and directly estimates detectability, thereby avoiding concerns expressed by Ellingson and Lukacs (2003) regarding the efficacy of some regional-scale landbird monitoring programs. The sample design emphasized density estimation as a priority over occupancy estimation, with the thought that a sufficient sample size for density estimation would also provide a sufficient sample size for occupancy estimation.

Point transects were approximately 1.0-2.85 km long and shaped as straight lines, L-shapes, or in a few cases, irregularly curved lines to avoid non-target habitats. Each transect contained 10-20 point count stations spaced 100-150 m apart. This number of points per transect was selected largely due to logistical concerns: a transect with 20 point counts was estimated as the amount of surveying that could be accomplished in a single morning within designated survey hours. The interval between points within transects represented a balance between survey efficiency and statistical independence. Intervals were 100 m in riparian habitat and 150 m in alpine, aspen, and sagebrush habitat. Points in riparian habitat were spaced closer together because transects in narrow linear habitats (e.g., some riparian habitats) can be problematic. Points along some transects in alpine habitat were more widely spaced because topographical features (e.g., boulders, cliffs, waterfalls) prohibited using the above guidelines.

The survey design violated the assumption of statistical independence among points because a single bird could be detected from multiple points; however, Buckland et al. (2001) considered such overlap of little practical consequence. Buckland (2006) simulated violations of independence among points with intervals of 100 m and found almost no bias associated with plot overlap and only mild underestimation of the standard error.

For occupancy estimation, the sampling design was based on spatial replicates (i.e., points within transects) that were not selected randomly and thus were expected to exhibit Markovian dependence in detection. Because birds reside in clusters and are highly mobile, cue detection on one point can translate to an increased probability of cue detection on an adjacent point. Hines and others (2009) recently developed occupancy models for data collected under this type of design. In their study, tiger tracks were recorded along a five km trail portioned into five one-km segments (akin to our point transects). The Markovian model for spatial dependence is directly applicable to this survey design that employs spatial replication in lieu of temporally replicated visits.

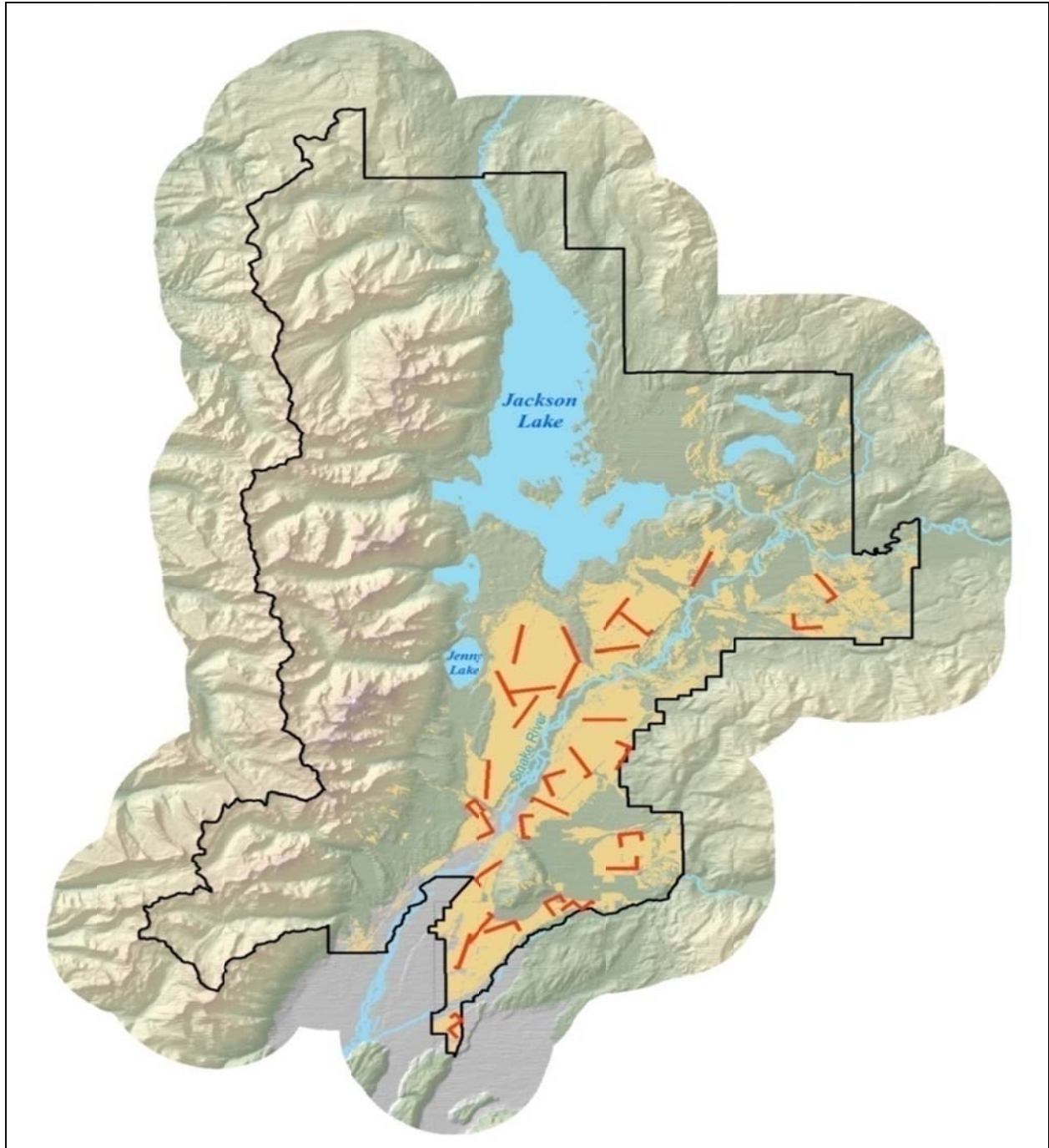


Figure 1. Map of point transects (in red) used for distance sampling within sage-steppe habitat (shown in yellow) in Grand Teton National Park, Wyoming.

For landbird community dynamics, data from point counts were collapsed to the transect level and transects were treated as the sampling unit. We analyzed community dynamics for each pair of successive years and for each habitat type by comparing the number of species observed per transect within each habitat across years using Program COMDYN 4.0 (Hines et al. 1999). COMDYN 4.0 allowed for sample sizes (number of transects) to vary among years and accounted for differences in detectability.

Field Methods

Surveys were performed at approximately the same time of year (Table 1) each year and were scheduled to occur when migratory species returned to the area for breeding. All surveys within a particular habitat were conducted over an approximately two-week period, thus the assumption that occupancy did not change during surveys was likely valid. Counts were conducted after the pre-dawn chorus and continued throughout the period during which bird activity and song is relatively constant (approximately 0630-1030 hours MST), when winds were <28 km/hr, and there was little or no precipitation.

Table 1. Approximate seasonal windows for conducting bird surveys in Grand Teton National Park, Wyoming in 2005-2008. Survey dates were sometimes altered according to weather and phenology patterns in an attempt to conduct surveys during the height of the breeding season.

Habitat	Start Date	End Date
Sage-steppe	15 May	12 June
Riparian cottonwood	2 June	23 June
Aspen	9 June	30 June
Riparian willow	9 June	30 June
Alpine	23 June	14 July

Distance sampling methodology was used to collect data for all three data analysis methods: density estimation, occupancy estimation, and community dynamics. Observers allowed a 60-second settling period after arriving at the point and then recorded all birds detected aurally or visually within 100 m for five minutes. Species, method of detection, and radial distance from the observer to first detection of an individual bird or flock were recorded for each detection. Distances were recorded using a rangefinder. All observers were experienced at bird identification and received specialized training by a park biologist (S. Wolff) prior to conducting surveys. In most cases, individual transect surveys were completed by one observer in a given year, but observers were not assigned the same transects in subsequent years.

Data Analysis

Distance sampling

We used Program Distance 6.0 (Thomas et al. 2010) to estimate the habitat-specific detection probability, expected cluster size, and the associated variances for each bird species of interest that had ≥ 60 detections cumulatively in 2005-2008 within a single vegetation type. Because very few species had 60 detections within a single year, we used global detection functions (developed using data pooled across years) in conjunction with detection data from each year to calculate annual species-specific density estimates. For comparison to density estimates obtained with global detection functions, we also calculated several density estimates with year-specific detection functions. As recommended by Buckland et al. (2001) we truncated the furthest 10% of

detections or as needed to eliminate excessive variation and avoid fitting extra adjustment terms to the tail of a detection function.

We fit the following five functions to the distribution of distances for each species to approximate the true detection function: uniform key function with a cosine series expansion, uniform key function with a simple polynomial series expansion, half-normal key function with a cosine series expansion, half-normal key function with a Hermite polynomial series expansion, and a hazard-rate key function with a simple polynomial series expansion. Although there are many possible models to evaluate, the above list is considered a useful suite of models for most datasets (Buckland et al. 2001, Thomas et al. 2010).

We used goodness-of-fit tests, Akaike's Information (Akaike 1973) corrected for small sample size (AICc), and model selection theory to select the most parsimonious detection function for each species/habitat combination. Area estimates for each of the five habitats were obtained using a Geographic Information System (GIS). Habitat-specific abundance estimates were calculated by applying habitat-specific density estimates to the park-wide area estimate for each habitat type.

Percent Area Occupied

Separately by year, vegetation type (habitat), and species, we estimated occupancy for several bird species with the largest sample sizes using program PRESENCE (Hines 2006). We considered three single-season models: one that ignored spatial autocorrelation among points for presence, and two that accounted for spatial correlation by estimating the probability of occurrence on a point count as a function of occurrence at the previous point count. The difference between the two spatial autocorrelation models was in how they treated the first survey point on a transect. One model treated the first survey point the same as the other points with an absence prior to their location. The other model allowed estimation of the "equilibrium" probability of occupancy using a combination of probabilities for previously occupied and unoccupied points, which essentially treated the first point as if it were a randomly selected point from the collection of points along the transect (Hines et al. 2009).

The spatial dependence models consisted of four parameters: occupancy at the transect level for transect t (ψ_t), occupancy at a point i given occupancy at the previous point j (θ_{ij}), occupancy at a given point i given presence on the transect t but absence at the previous point i ($\theta_{i|i-1}$), and probability of detection $p(.)$. The equilibrium probability of occupancy was a derived parameter based on the above four parameters. The standard model is one that considered no spatial correlation and estimated occupancy at the transect level and detection probability. Here, detection probability is the product of the probability that the species is present at the survey point and the probability it is detected given its presences at the point. Model selection was based on Akaike's Information Criterion (Akaike 1973) adjusted for small sample size, AIC.

Community Dynamics

We used program COMDYN 4.0 (Hines et al. 1999) to quantify changes in species diversity while incorporating detection probabilities. COMDYN is a set of programs developed for estimating community dynamics using count data from two time periods. This internet-based program uses a World Wide Web browser as the interface and conducts the analysis on a SUN workstation at the Patuxent Wildlife Research Center.

Our analysis of community dynamics focused on estimating species richness and its rate of change (λ), in addition to three community-level vital rates that drive changes in species richness over time: ϕ (the complement of local species extinction), γ (complement of species turnover), and β (estimated number of colonizing species). The estimator for species richness within COMDYN assumes there is heterogeneity in species detectability (P) (Table 2). This assumption is based on work by Boulinier et al. (1998), who applied closed population models to bird community data and found that by far, the most frequently selected model by program CAPTURE was model M_h , which assumes heterogeneity in the probability of detection among species. The jackknife estimator of M_h is robust and can therefore be used in most community sampling situations.

Program COMDYN incorporates the estimators described by Nichols and others (1998). A brief description of the community dynamics metrics we used is provided below, however, refer to Nichols et al. (1998) and Hines et al. (1999) for descriptions of how estimates are calculated. We defined local extinction probability as the probability that a species present in the community during sampling period i was not present in some later period j . Local species turnover between time periods i and j , where j is the more recent period, was defined as the probability that a species selected at random from the community at time j is a “new” species (i.e., it was not present in the community at time i). Number of local colonizing species was defined as the number of species not present in the local area at time i , but colonized the area between times i and j and were present at time j . Variance estimates for all community dynamics estimators were bootstrapped (Nichols et al. 1998).

Table 2. Parameters describing changes in landbird community composition within focal habitats in Grand Teton National Park, Wyoming. Community dynamics parameters were estimated using program COMDYN 4.0 (Hines et al. 1999) and incorporated detection probabilities. Phi (estimated complement of extinction probability, or the proportion of sample 1 species still present in sample 2), gamma (estimated complement of species turnover, or the proportion of sample 2 species present in sample 1), lambda (estimated rate of change of species richness estimated as $N(2)/N(1)$), B (estimated local colonizing species, or the number of species not present in sample 1, but present in sample 2) and P (estimated species detection probability) are given.

Habitat and Year	Species Richness (SE)	PHI (SE)	GAMMA (SE)	LAMBDA (SE)	B (SE)	P
Aspen						
2005	98.89 (15.69)	n/a	n/a	n/a	n/a	0.61 (0.11)
2006	75.57 (9.00)	0.93 (0.0724)	1.0 (0.1176)	0.764(0.1720)	0.0 (6.35)	0.85 (0.08)
2007	101.07 (11.55)	1.00 (0.0968)	0.90 (0.0798)	1.34 (0.1752)	25.5 (14.02)	0.61 (0.07)
Alpine						
2005	51.44 (8.79)	n/a	n/a	n/a	n/a	0.45 (0.09)
2006	78.01 (10.94)	1.0 (0.16)	0.93 (0.13)	1.52 (0.35)	23.57 (13.07)	0.54 (0.08)
2007	42.79 (8.15)	0.71 (0.12)	1.0 (0.14)	0.55 (0.14)	0 (2.72)	0.84 (0.13)
2008	44.60 (7.9)	0.84 (0.10)	0.80 (0.11)	1.04 (0.22)	8.61 (8.68)	0.83 (0.11)
Sage						
2006	43.53 (8.42)	n/a	n/a	n/a	n/a	0.76 (0.12)
2007	51.43 (9.72)	1.0 (0.09)	0.82 (0.12)	1.18 (0.29)	7.90 (10.50)	0.76 (0.12)
2008	41.23 (1.84)	0.83 (0.09)	1.0 (0.07)	0.80 (0.14)	0.0 (2.58)	0.95 (0.40)
Riparian						
2005	78.45 (10.24)	n/a	n/a	n/a	n/a	0.79 (0.09)
2006	102.35 (12.30)	1.00 (0.10)	0.86 (0.11)	1.30 (0.20)	23.90 (15.70)	0.64 (0.08)
2007	84.26 (10.70)	0.84 (0.09)	0.98 (0.11)	0.82 (0.16)	0 (9.74)	0.81 (0.09)
2008	82.74 (9.41)	0.82 (0.08)	0.84 (0.09)	0.98 (0.16)	13.24 (11.83)	0.83 (0.08)
Willow						
2005	84.73 (8.11)	n/a	n/a	n/a	n/a	0.84 (0.07)
2006	83.42 (11.50)	0.85 (0.10)	0.8831 (0.0781)	0.98 (0.16)	11.44 (11.86)	0.74 (0.09)
2007	96.16 (13.36)	0.79 (0.10)	0.79 (0.10)	1.15 (0.22)	29.91 (15.92)	0.67 (0.10)
2008	76.18 (5.88)	0.89 (0.07)	1.00 (0.08)	0.79 (0.14)	0 (4.73)	0.91 (0.06)

Results

Each year between 2005 and 2008 a total of 45-73 point-transects were surveyed within target habitats in Grand Teton NP (Table 3). Sage-steppe and aspen habitats were not surveyed in 2005 and 2008, respectively due to budget constraints. The total number of transects surveyed per habitat during the four-year period ranged from 35 in aspen to 60 in riparian cottonwood.

Table 3. Number of point-transects surveyed for landbirds within the five target habitats in Grand Teton National Park, Wyoming.

Habitat	2005	2006	2007	2008	Total by Habitat
Sage-steppe	0	19	18	15	52
Aspen	8	13	14	0	35
Riparian cottonwood	14	15	16	15	60
Riparian willow	12	13	11	15	51
Alpine	11	13	12	13	49
Total by Year	45	73	71	58	

Density

We included density results for the 33 species considered habitat specialists in one of the five habitats of interest, although sample sizes were sufficient to estimate density for additional species. Sample sizes were adequate to estimate density and abundance for two or more years using species-specific global detection functions for 19 of 33 target species. For the remaining 14 species, either sample sizes were insufficient ($n = 8$) or the detection function increased with increasing distance rather than decreasing with distance ($n = 6$; Figure 2), which violates a key assumption of distance sampling. No density estimates were possible for the following species, which lacked detections near the point: Horned Lark (*Eremophila alpestris*), Sage Thrasher (*Oreoscoptes montanus*), Western Meadowlark (*Sturnella neglecta*), Clark's Nutcracker (*Nucifraga columbiana*), Rock Wren (*Salpinctes obsoletus*), and Western Wood Pewee (*Contopus sordidulus*).

Detection rates ranged from 0.21 for American Pipits (*Anthus rubescens*) in alpine habitat and 0.22 for Wilson's Warblers (*Wilsonia pusilla*) in riparian willow habitat to 0.74 for Brewer's Sparrows (*Spizella breweri*) in sage-steppe habitat (Table 3). Overall, density estimates were reasonable, with coefficients of variation $<30\%$ for all but two species (Wilson's Warbler and Green-tailed Towhee (*Pipilo chlorurus*)). Species and habitat-specific annual abundance estimates ranged from a low of 200 for Warbling Vireos (*Vireo gilvus*) in riparian cottonwood habitat in 2005 to a high of 16,595 for White-crowned Sparrows (*Zonotrichia leucophrys*) in alpine habitat in 2006 (Table 4).

Parameter estimates for 2008 based on year-specific detection functions frequently had smaller coefficients of variation than estimates for 2008 based on the global detection function (Table 4). In all but three cases, the abundance estimate from the year-specific model was contained in the 95% confidence interval for the estimate generated using the global detection function model.

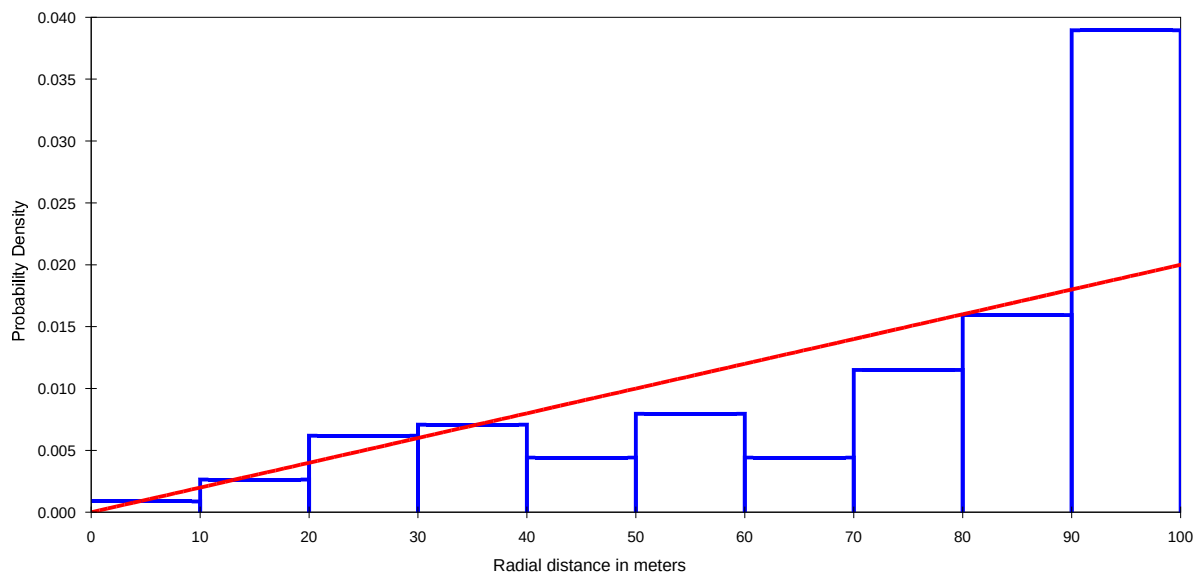
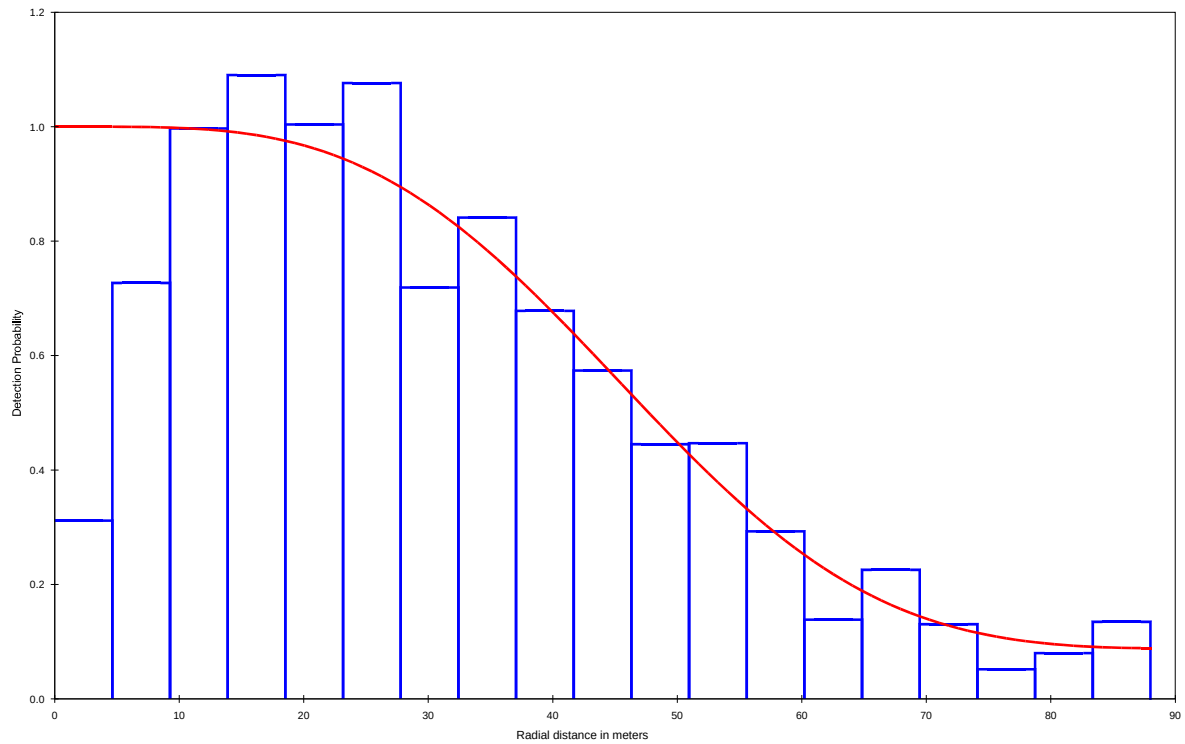


Figure 2. Detection probability (Y-axis) as a function of distance in meters (X-axis) for Yellow Warbler in riparian cottonwood habitat (top graph) and Clark's Nutcracker in alpine habitat (bottom graph). Note the increasing probability of detection with increasing distance for Clark's Nutcracker, which violates a fundamental assumption of distance sampling.

Table 4. Density and abundance estimates for habitat obligate bird species in Grand Teton National Park, Wyoming. Asterisk indicates a year-specific detection function was used rather than the global detection function. Not all habitats were surveyed in all years. P=detection probability. Key function and series expansion terms describe the top ranking global detection function model for each species.

Species	Habitat type	Year	Density	95% confidence interval for density	Coefficient of variation for density estimate	Abundance estimate	95% confidence interval for abundance	P	Key function for detection function	Series expansion term for detection function
Fox Sparrow	riparian willow	2006	0.41	0.28-0.61	20.4	3100	2083-4614	0.50	Uniform	Cosine
		2007	0.12	0.08-0.17	19.7	874	595-1283			
		2008	0.46	0.31-0.69	20.2	3519	2373-5219			
		2008*	0.37	0.29-0.49	13.5	2826	2165-3690	-	-	-
Lincoln's Sparrow	riparian willow	2005	0.64	0.38-1.09	27.3	4873	2877-8252	0.49	Uniform	Cosine
		2006	0.51	0.30-0.86	27.0	3864	2294-6507			
		2007	0.91	0.54-1.54	27.4	6875	4051-11669			
		2008	1.10	0.65-1.90	27.5	8356	4917-14202			
		2008*	0.88	0.66-1.17	14.5	6634	4986-8827	-	-	-
Song Sparrow	riparian willow	2005	0.59	0.48-0.72	10.3	4459	3634-5472	0.27	Uniform	Cosine
		2006	0.98	0.79-1.21	10.5	7400	6001-9125			
		2007	0.72	0.58-0.89	11.0	5421	4350-6756			
		2008	0.60	0.50-0.71	9.02	4501	3768-5378			
		2008*	0.39	0.29-0.52	14.9	2949	2196-3962	-	-	-

Table 4. Density and abundance estimates for habitat obligate bird species in Grand Teton National Park, Wyoming (*continued*).

Species	Habitat type	Year	Density	95% confidence interval for density	Coefficient of variation for density estimate	Abundance estimate	95% confidence interval for abundance	P	Key function for detection function	Series expansion term for detection function
Willow Flycatcher	riparian willow	2005	0.16	0.13-0.19	8.9	1211	1016-1442	0.27	Uniform	Cosine
		2006	0.25	0.21-0.30	9.9	1892	1556-2301			
		2007	0.22	0.18-0.26	9.7	1651	1363-2000			
		2008	0.30	0.24-0.36	9.6	2335	1850-2700			
		2008*	0.35	0.28-0.43	10.9	2635	2120-3275	-	-	-
Wilson's Warbler	riparian willow	2005	0.56	0.31-1.00	30.6	4200	2325-7587	0.22	hazard-rate	cosine
		2006	1.30	0.7-2.29	30.7	9566	5290-17299			
		2007	0.42	0.23-0.75	30.4	3159	1756-5681			
		2008	0.93	0.52-1.67	30.3	7016	3908-12596			
		2008*	0.42	0.29-0.61	18.4	3192	2212-4607	-	-	-

Table 4. Density and abundance estimates for habitat obligate bird species in Grand Teton National Park, Wyoming (*continued*).

Species	Habitat type	Year	Density	95% confidence interval for density	Coefficient of variation for density estimate	Abundance estimate	95% confidence interval for abundance	P	Key function for detection function	Series expansion term for detection function
Yellow Warbler	riparian cotton-wood	2005	0.54	0.43-0.69	12.3	1818	1429-2313	0.62	uniform	cosine
		2006	1.32	0.99-1.76	14.5	4407	3303-5879			
		2007	1.58	1.21-2.08	13.8	5302	4037-6964			
		2008	0.92	0.72-1.17	12.5	3064	2397-3916			
		2008*	0.73	0.49-1.08	20.2	2434	1639-3616	-	-	-
Chipping Sparrow	riparian cotton-wood	2005	0.24	0.20-0.30	11.1	811	653-1009	0.33	half-normal	cosine
		2006	0.25	0.20-0.31	11.4	820	655-1026			
		2007	0.17	0.14-0.21	10.2	578	472-707			
		2008	0.28	0.22-0.35	11.3	926	741-1156			
		2008*	0.23	0.16-0.33	17.0	773	549-1087	-	-	-
Dusky Flycatcher	riparian cotton-wood	2005	0.09	0.07-0.13	17.7	312	221-440	0.48	half-normal	hermite polynomial
		2006	0.36	0.25-0.50	17.7	1189	842-1678			
		2007	0.46	0.32-0.65	17.8	1529	1082-2162			

Table 4. Density and abundance estimates for habitat obligate bird species in Grand Teton National Park, Wyoming (*continued*).

Species	Habitat type	Year	Density	95% confidence interval for density	Coefficient of variation for density estimate	Abundance estimate	95% confidence interval for abundance	P	Key function for detection function	Series expansion term for detection function
Dusky Flycatcher (cont.)		2008	0.54	0.38-0.77	18.3	1811	1268-2585			
		2008*	0.53	0.40-0.71	14.4	1786	1345-2371	-	-	-
House Wren	riparian cotton-wood	2005	0.28	0.24-0.34	8.9	950	797-1132	0.46	hazard-rate	cosine
		2006	0.51	0.42-0.62	9.7	1906	1409-2064			
		2007	0.55	0.45-0.66	9.5	1829	1517-2206			
		2008	0.62	0.51-0.75	9.9	2057	1691-2503			
		2008*	0.65	0.53-0.81	10.9	2181	1760-2704			
Warbling Vireo	riparian cotton-wood	2005	0.06	0.05-0.08	11.9	200	158-253	0.50	uniform	cosine
		2006	0.27	0.23-0.33	9.3	919	765-1104			
		2007	0.27	0.23-0.33	9.3	913	761-1095			
		2008	0.15	0.13-0.18	9.4	508	422-612			
		2008*	0.08	0.07-0.09	4.1	263	241-287			

Table 4. Density and abundance estimates for habitat obligate bird species in Grand Teton National Park, Wyoming (*continued*).

Species	Habitat type	Year	Density	95% confidence interval for density	Coefficient of variation for density estimate	Abundance estimate	95% confidence interval for abundance	P	Key function for detection function	Series expansion term for detection function
Dusky Flycatcher	aspen	2005	0.23	0.18-0.30	12.5	1020	794-1310	0.4	half-normal	hermite polynomial
		2006	0.35	0.28-0.44	10.9	1555	1256-1925			
		2007	0.43	0.35-0.53	10.9	1903	1537-2357			
Mountain Bluebird	aspen	2006	0.22	0.18-0.28	11.2	986	790-1231	0.54	hazard-rate	cosine
		2007	0.18	0.14-0.22	11.0	781	628-972			
Warbling Vireo	aspen	2005	0.54	0.44-0.69	10.8	2425	1932-3043	0.45	uniform	cosine
		2006	0.47	0.39-0.56	9.3	2061	1708-2486			
		2007	0.52	0.44-0.61	8.35	2283	1933-2695			
Brewer's Sparrow	sage-steppe	2006	0.70	0.53-0.87	12.5	14405	11202-18523	0.66	hazard-rate	simple polynomial
		2007	0.69	0.54-0.84	11.4	14060	11226-17608			
		2008	0.49	0.37-0.61	12.0	10032	7901-12739			
		2008*	0.56	0.42-0.76	14.9	11566	8629-15503	-		
Green-tailed Towhee	sage-steppe	2006	0.21	0.05-0.37	39.6	4206	1980-8934	0.54	uniform	cosine
		2007	0.086	0.02-0.15	38.8	1763	842-3695			

Table 4. Density and abundance estimates for habitat obligate bird species in Grand Teton National Park, Wyoming (*continued*).

Species	Habitat type	Year	Density	95% confidence interval for density	Coefficient of variation for density estimate	Abundance estimate	95% confidence interval for abundance	P	Key function for detection function	Series expansion term for detection function
Green-tailed Towhee (cont.)		2008	0.28	0.06-0.50	39.5	5715	2694-12125			
		2008*	0.24	0.19-0.31	12.5	4962	3863-6373	-	-	-
Vesper Sparrow	sage-steppe	2006	0.38	0.16-0.60	28.7	7828	4505-13601	0.74	half normal	cosine
		2007	0.50	0.47-0.53	28.1	10214	5941-17560			
		2008	0.68	0.29-1.07	29.0	13850	7926-24201			
		2008*	0.74	0.58-0.94	11.6	15129	11956-19145	-	-	-
American Pipit	alpine	2006	0.19	0.11-0.33	27.1	4150	2442-7053	0.21	uniform	cosine
		2007	0.316	0.19-0.53	26.7	6847	4062-11543			
		2008	0.34	0.21-0.57	25.3	7459	4531-12281			
		2008*	0.46	0.25-0.82	29.4	9885	5482-17825	-	-	-
Black Rosy Finch	alpine	2006	0.098	0.52-0.18	29.2	2122	1129-3988	0.28	uniform	cosine
		2007	0.244	0.15-0.39	23.6	5294	3314-8457			
		2008	0.104	0.06-0.17	24.8	2255	1364-3727			

Table 4. Density and abundance estimates for habitat obligate bird species in Grand Teton National Park, Wyoming (*continued*).

Species	Habitat type	Year	Density	95% confidence interval for density	Coefficient of variation for density estimate	Abundance estimate	95% confidence interval for abundance	P	Key function for detection function	Series expansion term for detection function
White-crowned Sparrow	alpine	2005	0.30	0.25-0.35	8.06	6428	5476-7544	0.38	uniform	cosine
		2006	0.76	0.61-0.96	11.2	16595	13209-20849			
		2007	0.61	0.47-0.08	12.5	13304	10269-17235			
		2008	0.56	0.46-0.69	10.0	12108	9884-14832			
		2008*	0.52	0.40-0.67	12.9	11254	8692-14569	-	-	-

Occupancy

Models that accommodated spatial correlation within transects were selected according to information criteria in the majority of cases, although in several cases data were insufficient for model convergence. Estimated occupancy was higher than the naïve estimates that relied simply on counting the proportion of transects on which the species was detected. Therefore, accounting for imperfect detectability using occupancy modeling was necessary.

The sampling design provided insufficient sample sizes to adequately estimate occupancy with reasonable precision for any of the species monitored; the most precise estimate of occupancy obtained was 0.4473-0.9767 for Mountain Bluebirds (*Sialia currucoides*). Because we deemed the occupancy estimates to be uninformative for any landbird species, only a limited number of example results are presented (Table 5). Refer to Gould et al. (2010) for additional details regarding occupancy estimation based on data collected in this study.

Table 5. Occupancy parameter estimates for bird species in Grand Teton National Park, Wyoming for those years in which the spatial dependence model was selected. Naïve estimates (assuming detection probability=1.0), estimated site occupancy (Psi), estimates of point occupancy Psi0 (previous point unoccupied) and Psi 1 (psi given the previous point was occupied), and the conditional probability of detection (p) are given. Cases in which the spatial-dependence models did not converge are not shown. Note large confidence intervals around occupancy estimates, which are attributed to small sample sizes.

Species	Habitat	Year	Parameter	Estimate	95% confidence interval
Chipping Sparrow	Aspen	2005	Psi (naïve)	0.2500	
			Psi (occupancy)	0.3385	0.0258-0.9080
			Psi 0	0.1121	0.0027-0.8542
			Psi 1	0.9126	0.4800-0.9916
			P	0.5443	0.2441-0.8154
		2006	Psi (naïve)	0.5385	
			Psi (occupancy)	0.9512	0.0000-1.0000
			Psi 0	0.0750	0.0065-0.5010
			Psi 1	0.7514	0.3000-0.9552
			P	0.4639	0.1405-0.8208
Dusky Flycatcher	Aspen	2005	Psi (naïve)	0.5000	
			Psi (occupancy)	0.6448	0.0706-0.9775
			Psi 0	0.0682	0.0028-0.6556
			Psi 1	0.9648	0.7425-0.9962
			P	0.5575	0.3829-0.7189
Mountain Bluebird	Aspen	2006	Psi (naïve)	0.7692	
			Psi (occupancy)	0.8536	0.4473-0.9767
			Psi 0	0.1962	0.1289-0.2870
			Psi 1	0.3889	0.2456-0.5543
			P	1.000	0.0000-1.0000
Wilson's Warbler	Riparian willow	2005	Psi (naïve)	0.5833	
			Psi (occupancy)	0.7574	0.0422-0.9955
			Psi 0	0.0742	0.0063-0.5054
			Psi 1	0.8205	0.3935-0.9699
			P	0.5238	0.2046-0.8247
Sage Thrasher	Sage steppe	2008	Psi (naïve)	0.6667	
			Psi (occupancy)	0.7373	0.3729-0.9298
			Psi 0	.1284	0.0553-0.2705
			Psi 1	0.7890	0.5967-0.9042
			P	0.9328	0.4251-0.9962

Community Dynamics

Bird species richness was highest for aspen and riparian cottonwood habitats and lowest in sage-steppe and alpine habitats (Figure 3). Trends in species richness over the four-year period were remarkably similar in riparian cottonwood and alpine habitats (Figure 4). During the three years of data collection in sage-steppe habitat, species richness changes mirrored those that occurred in aspen habitat and possibly willow, and were contrary to changes in cottonwood and alpine habitats.

Calculations of species richness were relatively straightforward to calculate and sample sizes were not a limitation.

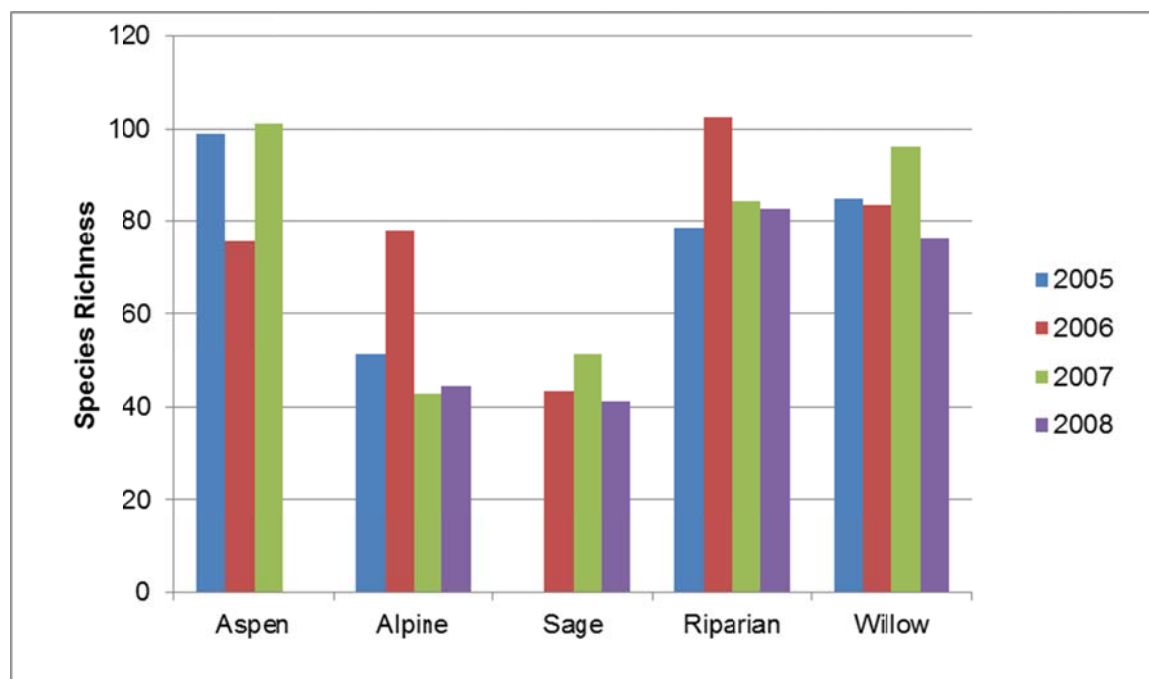


Figure 3. Species richness by habitat within Grand Teton National Park, Wyoming. Species richness estimates were calculated using COMDYN 4.0 (Hines et al. 1999) and account for differences in detection ability among species.

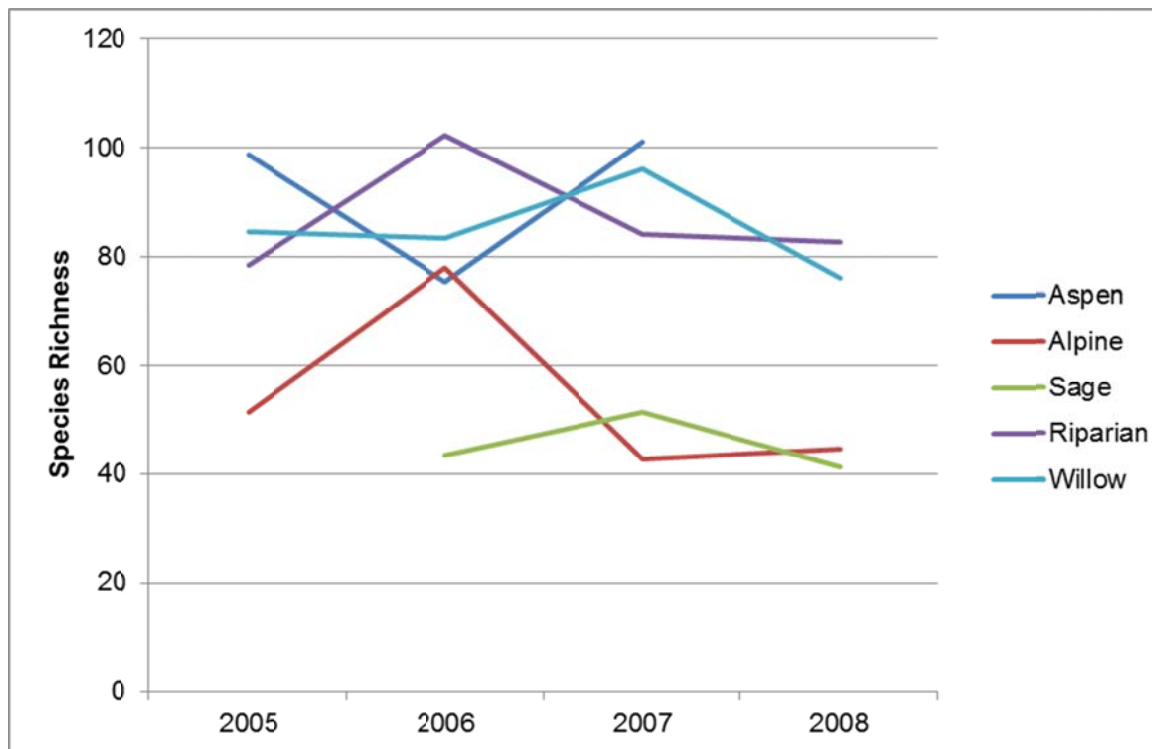


Figure 4. Species richness by year within Grand Teton National Park, Wyoming. Species richness estimates were calculated using COMDYN 4.0 (Hines et al. 1999) and account for differences in detection ability among species.

Vegetation Structure and Composition

Standard operating procedures for vegetation data collection and analysis had not been finalized in the draft protocol (Bennetts et al. 2005 unpublished). Still, pilot data on vegetation structure and composition was collected throughout the four years of this pilot program. Habitat-specific methodologies were altered frequently in an attempt to maximize efficiency and data quality, but a formal evaluation of the data or methods used was not conducted. Vegetation data were not entered into an electronic database and were therefore not analyzed in our evaluation.

Discussion

Data collected through this pilot study provided valuable insights for future monitoring of landbirds in the Greater Yellowstone Ecosystem. Although the program was developed to maximize the amount of information gathered from a single survey per year, our results suggest that not all monitoring objectives can be met using the current sampling design. Vegetation data were collected, but because they were not collected consistently across years, we did not enter them into an electronic database and therefore they were not analyzed. Presumably these data could be analyzed at a future date.

Density

Distance sampling methodology worked well to produce reliable density estimates for 17 of the 33 target species. The number of target species having sufficient sample sizes to use the global detection function will increase over time, making it a valuable approach for a long-term monitoring program. In the future, density and abundance estimates can be generated for all species having sufficient sample sizes, rather than limiting the analysis to target species as we did here. Density estimates for most species were fairly precise even though sample sizes were moderate to minimal, which demonstrates the robustness and utility of distance sampling as a tool for long-term monitoring.

The number of species with no detections recorded near the point was problematic because a fundamental assumption of distance sampling is that all birds on the point are detected. Species-specific behaviors may make distance sampling inappropriate for some species. Additionally, efforts by the observers, such as approaching points in a manner that minimizes disturbance and counting birds near the center of the point that flush as the observer approaches, may improve detections near the point. In alpine habitat, which is particularly patchy, it is possible that transects fell outside of traditional habitat for a species, and therefore that species may have only been heard from a distance. Increasing the number of transects in alpine habitat may compensate for the patchiness of the vegetation and improve detection rates for some species.

A second issue noted with the detection functions for many species was heaping or rounding at particular distances from the points. Despite the use of range-finders by all field crew members, there was still a tendency to lump detections at certain distances (e.g., 50 m or 75 m). This issue can be overcome by additional training and checking data periodically throughout the field season. Aural estimation of distances from a point is known to be difficult (Alldredge et al. 2007) and underscores the importance of using experienced birders who have undergone recent training on distance sampling methods.

Occupancy Sampling

The low precision of landbird occupancy estimates was attributed to small sample sizes (i.e., small number of transects per habitat type). In some cases, only 12 or 13 transects were surveyed within a habitat type per year (Table 3). MacKenzie and Royle (2005) provided guidance for designing occupancy studies and suggested that when occupancy is low, expending considerable survey effort at relatively few sites may yield little information about occupancy (p) because most sites are unoccupied. For uncommon or rare species it is more efficient to survey more sampling units less intensively, while for a common species fewer sampling units should be surveyed more intensively.

Unless significant resources are added to the program to increase the number of transects monitored (along with potentially reducing the number of points per transect), it is not reasonable to expect estimates of occupancy from this program. If estimating occupancy is an important goal, the sampling design should be modified to increase the number of spatial or temporal sampling through an increase in sites or number of visits to each site. Calculations should be made to determine the optimal number of transects or points to survey for reliable estimates of occupancy (Mackenzie et al. 2005, Bailey et al. 2007) given the target species expected occupancy and detection rates.

Species Richness

The finding of highest species richness in aspen and riparian habitats was somewhat anticipated due to the assumed complexity of vegetation structure in these habitat types. Changes in relative species richness over time and examination of particular species presence or absence within a habitat can be used as a possible indication of habitat change.

Estimates of community dynamics were relatively simple to calculate and provided reliable estimates of multiple parameters related to community dynamics. The challenge in using species richness data is interpreting the data in light of climate change (Pederson et al. 2010) and the timing of surveys. The number of species observed in a habitat is highly influenced by the seasonal timing of the surveys. Warmer winters and springs have resulted for the most part in more precipitation falling as rain instead of snow, reduced snowpack, earlier snowmelt, earlier streamflow from snowmelt, an eight to ten day advance in the onset of spring on average across the West (Cayan et al. 2001).

With the current sampling design, multiple surveys are conducted per season; although this may need to be expanded further to ensure trends in species composition dynamics are tied to real changes in species richness and not simply changes in phenology. In 2008, landbird surveys were delayed in some habitats due to extensive snow cover lasting late into the season. Ecologically-based guidelines for when to initiate surveys in each habitat of interest are needed, rather than strict calendar dates. Additionally, it may be possible to use data on vegetation greenness as a covariate to better understand the influence of phenology on landbird populations. Changes in phenology can effectively be measured as a function of the Normalized Difference Vegetation Index (Zhang et al. 2003).

Monitoring species richness over time may provide valuable information regarding changes in vegetation and landbird habitat quality over time, and is useful detecting large-scale changes in habitat.

Conclusions

With only four years of data, we generated reliable density estimates for 17 of 33 target species and species richness metrics for all five habitat types, including the little known alpine habitat. Additional years of data would allow the calculation of reliable density estimates for additional species, although it is unlikely that precise density estimates would ever be possible for rare species. A benefit of the GRYN sampling approach using distance sampling is the ability to simultaneously monitor a large number of species from different guilds and in different habitats. The keen public interest in birds, the documented responsiveness of birds to climate change (Wather et al. 2002), and the ability to monitor the abundance of multiple species through one survey effort make landbirds a useful vital sign or indicator of ecological integrity in the Greater Yellowstone Ecosystem.

Our assessment of the sampling design used to date showed that estimates of density and species richness were successfully obtained and these data would be valuable to collect in the long-term for trend analysis. Results from the data analysis also clearly demonstrate that given the current sampling regime, occupancy estimates are not sufficiently precise to be useful for evaluating status or trends (Gould et al. 2010). Generally, if it is possible to estimate density or abundance, that is a preferred state variable to estimate rather than occupancy. Given the financial constraints of the program, we suggest that estimating occupancy for landbird species be dropped from the GRYN landbird program, provided that density estimation remains the primary objective.

Several actions can be taken to improve the GYRN landbird monitoring protocol. Our first recommendation is to narrow the monitoring objectives to include only estimation of status and trends in density and community dynamics, with increased attention on phenology and the timing of the surveys. A decision must be made regarding whether or not to continue to collect vegetation data, with the realization that time for entering and checking the data must be allowed. The addition of covariates such as observer, observer experience, vegetation characteristics, weather, and climate would likely improve density and community dynamics estimates, and their interpretation. Last, the development of ecologically-based guidelines for when to initiate surveys would help to minimize variance in parameter estimates caused by phenology. Another important step in revising the GRYN landbird monitoring program is completion of the entire protocol including standard operating procedures for the data management, data analysis, reporting, personnel, and operations sections of the protocol, prior to additional data collection.

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