Trends in Populations of Breeding Birds and Habitat Conditions in Riparian Areas along the Madison and Missouri Rivers, Montana 2004-2015

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EXECUTIVE SUMMARY

Long-term assessments of the distribution and abundance of populations are central to evaluating the potential effects of human activities on wildlife. Since 2004, the University of Montana (UM), with support from Northwestern Energy (formerly PPL Montana) and Bureau of Land Management (BLM), has monitored bird populations and riparian vegetation along over 500 miles of the Madison and Missouri Rivers. This program meets Northwestern Energy's Federal Energy Regulatory Commission (FERC) license requirements for hydroelectric operations on the river system by monitoring system-wide bird distributions and population trends as an indicator of wildlife habitat conditions, identifying critical habitats for wildlife based on spatial analysis of bird habitat use, measuring bird and vegetation responses to management efforts, and evaluating project benefits for wildlife to inform future project priorities within the system.

This report summarizes analyses of bird population and vegetation trends across four annual surveys events between 2004 and 2015, and provides recommendations for future efforts. To date, our monitoring efforts have resulted in 1,276 point-count surveys and detection of 23,723 individual birds of 139 species, including seven BLM Sensitive species, 16 Montana Species of Concern, and 14 species ranked as a continental priority by Partner's in Flight. For 33 of those bird species, we obtained sample sizes that were sufficient to generate precise annual estimates of density with the use of distance sampling methods.

We found statistically significant declines in densities of 11 bird species and increases in densities of six species across time. Declining species have a broad range of nesting and foraging requirements, and include both generalists and riparian specialists. Patterns we observed largely correspond to long-term trends documented across the region based on the North American Breeding Bird Survey (BBS; Sauer et al 2014). Such similarities suggest the drivers of population declines along the river system are likely operating across large spatial scales. We also documented significant changes in riparian habitat conditions since 2004, which are likely influencing habitat suitability for bird populations. Those changes include aging riparian forests, declining shrub cover, and increases in non-native plant species.

A review of bird data gathered since 2004 indicates that current monitoring effort (i.e. 1 visit to 223 sample points) is sufficient to generate precise estimates of density for many riparian species that occur along the Madison and Missouri Rivers of Montana. Those species include both common and uncommon species and species of significant management and conservation interest. Nonetheless, greater sampling effort is required to obtain more precise estimates of densities of rare species, which may be of greater management and conservation concern. Based on analyses of the tradeoff between sampling frequency and power to detect population changes, *we recommend conducting monitoring every other year to effectively monitor population trends of birds in this system*.

This program provides a direct measure of the status of wildlife within riparian areas across a large stretch of the Madison and Missouri Rivers, and is currently the only monitoring effort targeting riparian birds in Montana. Although monitoring spans over 10 years, our findings should be viewed cautiously, since inferences are based on surveys during only four years. Future monitoring will build on this dataset, providing a more complete picture of changes in wildlife populations over time.

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BACKGROUND

Riparian systems serve essential ecological functions and provide habitats for a disproportionately large number of plants and animals resulting in the highest known diversities of breeding birds in the western United States (Naiman and DeCamps 1997). Despite their limited spatial extent, riparian areas provide nesting habitats for the majority of Montana's bird species, including nearly half the state's Species of Concern (Montana Animal Species of Concern Report 2016). Because riparian areas are highly productive and often occur at low elevations, they are also highly impacted by human activities, such as agricultural and urban development, alteration of hydrologic functions due to irrigation and water diversion, and invasion by non-native species (Johnson 1992, Ringold et al. 2008).

Despite the importance of riparian areas to wildlife and major threats affecting them, there is little information on the status and trends of bird species that depend on riparian areas in Montana. Starting in 2004, the University of Montana, with support from Northwestern Energy (formerly PPL Montana) and the Bureau of Land Management (BLM), began monitoring bird populations along the Madison and Missouri Rivers, which encompass one of Montana's largest river corridors. This program meets Northwestern Energy's Federal Energy Regulatory Commission (FERC) license requirements for hydroelectric operations on the river system by monitoring system-wide bird distributions and population trends as an indicator of wildlife habitat conditions. Additionally, this program serves to identify critical habitats for wildlife based on analysis of bird habitat use, measures bird and vegetative responses to conservation efforts to evaluate project benefits for wildlife, and informs future conservation priorities within the area.

Preliminary analyses of bird population trends through 2012 showed significant declines for 14 of 27 species (52%) that were considered (Noson & Smucker 2013). Given those alarming patterns, the Northwestern Energy Wildlife Technical Advisory Committee sponsored a thorough re-analysis of bird population data following an additional year of monitoring in 2015. Moreover, they also requested an assessment of trends in riparian habitat conditions and other potential environmental drivers of trends in bird populations, and an evaluation of program design and tradeoffs between statistical power to detect trends and sampling effort. Such periodic reviews are an essential component of long-term monitoring efforts because they ensure that methods and sampling effort are appropriate and that objectives are being efficiently met.

Objectives

1. Complete a fourth survey of bird communities along the Madison and Missouri Rivers at sites that have been monitored since 2004, and assess the status and trends of riparian bird populations based on survey data gathered during four years between 2004 and 2015.
2. Complete a fourth survey of vegetation conditions at bird monitoring sites, and evaluate trends in riparian habitat conditions based on vegetation data gathered during four years between 2004 and 2015.
3. Evaluate the efficacy of future monitoring efforts across a range of program scenarios, including tradeoffs between effort, cost, and statistical power to detect trends of various magnitudes across a range of bird species.

Objective 1: Riparian Bird Population Status & Trends

Methods

Study Area & Design

In spring of 2004, monitoring plots were established along the Madison and upper Missouri Rivers in Montana between Varney Bridge (south of Ennis) to Fred Robinson Bridge (James Kipp Recreation Area; Figure 1). The river was stratified into three geographical sections: the Madison River (MAD), the Missouri River between Three Forks and Great Falls (MIS), and the Upper Missouri River Breaks National Monument (BRK). To select areas for long-term monitoring, patches of riparian vegetation along the river corridor were first delineated, and then a random sample of those patches were selected for sampling within each section. Survey points were then established within each selected patch by overlaying a 150 x 150 m grid (see Fletcher et al. 2005 for details). In total, 55 riparian patches were established, which included a total of 223 monitoring points. The number of points per riparian patch ranged from 2 to 8 depending on patch area, with an average of 4.1 (± 0.08 SE) points per patch. The sampled area covered over 500 miles of the river corridor and included a mix of public and private lands (55% private). In 2015, we increased sampling effort within the Upper Missouri Breaks National Monument by adding 24 additional patches, which included 74 sampling points. We also expanded the study area upstream to the headwaters of the Madison River near Hebgen Lake (HEB) by adding 4 new patches, which included 16 sampling points. New patches were not included in trend analyses summarized in this report.

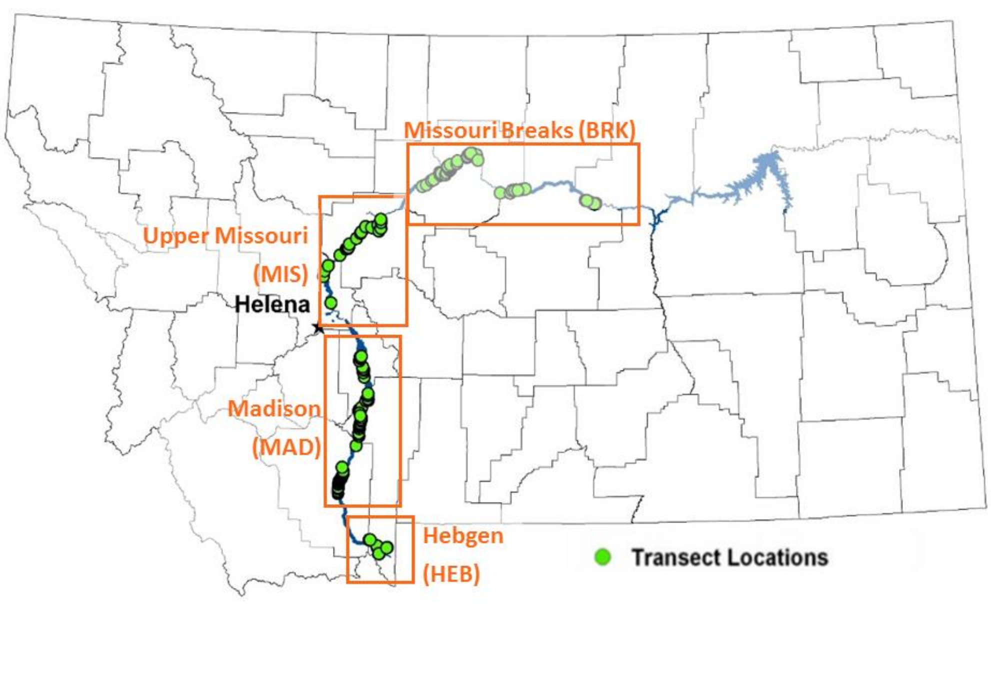

Figure 1. Long-term bird monitoring along the Madison and Missouri Rivers and location of geographical strata (Hebgen, Madison River, Upper Missouri River, and Upper Missouri River Breaks National Monument), Montana.

Bird Surveys

We used standard 10-minute point-counts and distance sampling to survey birds at all long-term monitoring points (Hutto et al. 1986, Buckland et al. 2001). We surveyed birds between sunrise and 5 hours after sunrise but not at times when wind velocity was high (≥ 20 km/hr) or during consistent precipitation. During surveys, observers recorded all birds seen or heard within a 50-m radius, how each individual was detected (song, visual, or call), sex of individuals, and estimated distances to birds from the center point. All distances were estimated to the nearest meter using a laser rangefinder. Species not observed within 50 m of points during surveys were also noted for the purpose of occupancy estimation.

In addition, we recorded all species detected incidentally outside of standard point-count surveys and while traveling between points. Those data were used for density estimation, but provide information on presence, species richness, and distribution of bird species not well surveyed during standard point counts, including rare species and species of conservation concern.

Analysis

Density Estimation

We used distance-sampling methods to estimate densities of various bird populations. Such methods use frequency histograms of distance data to model a detection function, which estimates detection probability and adjusts estimates of density for spatial and temporal variation in detection probability due to a range of factors. Distance sampling is based on the concept that the probability of detecting a focal object (e.g. a bird) decreases with increasing distance from the observer and also may vary with a range of spatial, temporal, or survey-related factors (Buckland et al. 2001).

We computed density estimates (no. of birds/ha.) of species and species groups at three spatial scales: patch, river section, and study area. Spatiotemporal replication within patches (but not at points) was sufficient to generate precise annual estimates of density. Here, we focus on species encountered at least 30 times across the study. Histograms of distance data of those species were all of suitable shape to fit detection functions. To compute estimates, we used the MRDS library in R (Laake et al. 2013, R Development Core Team 2013).

To estimate densities, we fit both simple detection functions with no covariates and more complex functions with covariates (Marques et al. 2007). Here, we consider both spatial and temporal covariates, and assume potential variation in detectability due to vegetation or other factors were linked to those factors. As covariates, we considered time-of-day (min. after local sunrise), time-of-year (Julian day), year, and river section (Madison, Upper Missouri, and Missouri Breaks). We fit models with all possible additive combinations of those covariates and used Akaike information criterion adjusted for small sample sizes (AIC_c) to rank models. To select final models, we assessed the shapes of detection functions, precision of parameter estimates, and goodness-of-fit of highly ranked models, and selected the best overall model for each species (Thomas et al. 2010). We considered uniform, half-normal (HN) and hazard-rate (HR) detection functions for models without covariates, and HN and HR functions for models with covariates. When fitting HN and HR functions, we considered models with up to 2 cosine or simple polynomial adjustment terms, and for uniform functions considered up to 2 hermite polynomial terms. We grouped data in 5 m bins, which in all cases effectively smoothed histograms. We did not right truncate encounter data because the small fixed radius used during counts (50 m) did not produce long-tailed distributions.

Trend Estimation

To estimate temporal trends in densities of each species and species group, and assess whether trends varied spatially among river sections, we used linear mixed-effects model (LMEM) of the following form:

$$y_{ijt} = (\beta_0 + b_{0i}) + \beta_1 x_{it} + \beta_2 x_{jt} + \beta_3 (x_{it} \times x_{jt}) + \varepsilon_{it}, \quad \varepsilon_{ijt} \sim N(0,\sigma_j^2) \quad \text{(eq. 1)}$$

where β_0 is an intercept for the population, b_{0i} is a vector of random intercepts for each patch, β_1 is a trend parameter for a fixed year effect, x_{it} indicates the year of each observation for the i^{th} patch centered at 0, β_2 estimates a fixed river section effect, x_{jt} indicates the river section of each observation for the j^{th} section, β_3 estimates an interaction term or whether the effect of year varies among sections, ε_{ijt} is an error term that has a normal distribution with a mean of zero and variance σ_j^2, which measures observation variance within each section, and y_{ijt} are estimates of density from each patch in each section and year. We log transformed density estimates before modeling to normalize distributions and so that parameter estimates equaled the relative or percent change in density per unit time.

We used the random effects and residual variance structures noted above after first assessing candidate models with other plausible structures and ranking them based on AIC_c. To assess variation in intercepts among river sections, for example, we assessed the efficacy of replacing b_{0i} in with a vector of random intercepts for section (b_{0j}) and a vector of random intercepts for patches nested within sections ($b_{0j(i)}$). To assess a simpler structure for observation error, we also assessed models that estimated one variance across all years. To assess covariance in observation error, we considered first-order autoregressive and compound symmetric structures. We used restricted maximum likelihood when assessing models with different random effects and variance structures and maximum likelihood to estimate fixed effects. We fit all models with the *nlme* library in R.

In addition to species-specific analyses, we also estimated densities and spatiotemporal trends in densities of three species groups: riparian-dependent and riparian-obligate species (Rich 2002, as listed in Appendix A), and all bird species combined. We categorized riparian-dependent as 60-90% of breeding restricted to riparian areas and riparian-obligate as >90% of breeding restricted to riparian areas throughout their range (Rich 2002). It is important to note that this is a conservative definition, since many species associated with deciduous forests, such as the Least Flycatcher, are found throughout forests in eastern North America, but are entirely restricted to riparian areas within Montana. We excluded raptors from these analyses because they are not effectively surveyed with point-count methods. We estimated densities at the scale of each riparian patch in each year, and used those estimates to assess trends across time and space with the LMEM procedure described above. In estimating densities of all species and species groups, we fit simple detection functions with no covariates and detection functions with river section and year fit as nominal potential covariates of detection probability. Analyses for species groups were run in DISTANCE software (Thomas et al. 2010).

Comparison with Regional Trends

To evaluate whether observed trends within the study area correspond to those at larger spatial scales throughout the western U.S., we compared our findings with results of the North American Breeding Bird Survey (BBS). BBS has monitored the status and trends of bird population in North America with the help of qualified volunteers for over forty years (Sauer et al 2014; http://www.mbr-pwrc.usgs.gov/bbs/specl14.html).

Species Richness

The richness or number of species in a given area at a given time is a useful metric for monitoring biodiversity dynamics (Gotelli and Colwell 2001). Regardless, because species are not detected perfectly during surveys, species that are present but undetected during sampling could bias estimates of species richness. Thus, to estimate species richness ($\widehat{N}$), we used observed species abundance distributions based on data we gathered during point counts and a bias-corrected version of the Chao 1 estimator (Chao 1984, Gotelli and Colwell 2011). The Chao1 estimator represents a universally valid lower bound of species richness that can be applied to any species abundance distribution and any sample size. In general, estimated lower bounds are close to species asymptotic richness if sample sizes are sufficiently large; a rough guideline for sufficiency is when the proportion of species detected once is <50% of the sample, which was the case with our dataset at 92% of samples at the patch level. The bias-corrected version of the Chao 1 estimator is as follows:

$$\widehat{N} = N_{obs} + \frac{f_1\,(f_1 - 1)}{2(f_2 + 1)} \quad (\text{eq. } 2)$$

where N_{obs} is the number of species observed, f_1 is the number of species observed once, and f_2 is the number of species observed twice in the sample.

We used point-count data from all points within each riparian patch to compute richness at the scale of patches. We considered data from 2004 and 2008, when points were visited twice, as separate samples of patches rather than summing detections across visits. To assess trends in richness across time, we used the same LMEM approach described above. We also computed species richness for the entire study area based on the Chao 1 estimator and 95% confidence intervals with use of EstimateS software (Colwell 2013).

Results

Survey Effort and Detections

We completed 1,276 point-count surveys across four years of monitoring (Table 1). Survey effort was highest in 2004 and 2008, when points were visited two times per year. One patch was not sampled in 2012, but otherwise we sampled each patch at least once during each of the four years.

Across all surveys, we recorded 23,723 individual birds and 118 species during standardized point-count surveys. We also observed an additional 21 bird species outside the standardized survey period or at distances >50 m, bringing the total number of species observed to 139, or 53% of species known to breed in Montana. The majority of species we observed were associated with riparian or wetland environments, including 24 species that are riparian obligates (>90% of breeding restricted to riparian areas), 18 species that are riparian-dependent (60-90% of breeding restricted to riparian areas), and 26 species associated with wetlands including waterfowl and other water birds (Rich 2002). We also documented numerous species of conservation concern, including 16 Montana Species of Concern (MTSOC), seven BLM Sensitive species, and 14 species ranked as a continental priority by Partner's in Flight (see Appendix A for complete list; Montana Animals of Concern Report 2016, Rosenberg et al. 2016).

Table 1. Annual sampling effort by sample patch for birds on the Madison and Missouri Rivers in Montana 2004-2015. Total effort includes repeated visits to sample points.

Year	Patches (no.)	Total Effort
2004	55	445 [a]
2008	55	412 [a]
2012	54	210
2015	82 [b]	295[b]

[a] Points were surveyed two times in 2004 and 2008, and once in 2012 and 2015.
[b] Total includes 28 new sample patches and 90 points established in 2015, which were included in annual estimates, but not in trend analyses.

Population Status

We obtained estimates of density for 33 breeding bird species that together comprise approximately 25% of the breeding bird community we observed in the system. The majority of those species are associated with riparian environments during the breeding season; five are classified as riparian obligates, and 12 are classified as riparian dependent (Rich 2002). One obligate species, the Gray Catbird, is a Montana Species of Concern (MTSOC). Estimates of density by species pooled across patches and for each river section are presented in Table 2. Yellow Warbler was the most abundant species in the region with densities that averaged 10.28 birds per ha across years, followed by House Wren at 5.92 birds per ha. In contrast, abundance of some species were low, such as the Clay-colored Sparrow and Red-eyed Vireo with densities that averaged 0.07-0.08 birds per ha.

Densities of most species varied spatially, with significant differences among at least one river section for 20 of the 33 species we considered ($P < 0.05$; Table 3). For example, we estimated 2.49 Gray Catbirds per ha along the Madison and only 0.63 birds per ha in the Missouri Breaks (Table 2, Fig. 2). In contrast, densities of two riparian obligate species, Yellow-breasted Chat and Common Yellowthroat, were higher in the Missouri Breaks (0.62 and 0.39 birds per ha, respectively) than farther upstream where densities ranged from 0.03 - 0.10 birds per ha (Table 2, Fig. 4).

Average densities of all 107 bird species combined (excluding 12 species of raptors) were significantly higher along the Madison and upper Missouri Rivers than the Missouri Breaks. Similarly, densities of 14 riparian-obligate species (but not 15 dependent species) combined were also higher on average along the Madison and Upper Missouri than the Missouri Breaks (Fig. 5).

Table 2. Density estimates and degree of dependency on riparian environments (e.g. obligate, dependent, or generalist) of breeding bird species encountered along the Madison and Missouri Rivers, Montana. Sample sizes (*n*), estimated density per ha (*D*), and coefficients of variation (CV%) were pooled across all four survey years from 2004-2015.

				Madison		Upper Missouri		Missouri Breaks	
Species	***n***	***D***	**CV%**	***n***	***D***	***n***	***D***	***n***	***D***
Obligate									
Common Yellowthroat	174	0.18	14.7	25	0.07	13	0.03	137	0.39
Song Sparrow	538	0.90	10.6	168	0.90	261	1.20	231	0.85
Willow Flycatcher	113	0.18	20.4	59	0.30	53	0.32	2	0.01
Yellow-breasted Chat	229	0.30	16.1	5	0.08	7	0.10	218	0.62
Yellow Warbler	4083	10.28	4.5	1326	16.28	1567	11.46	1272	5.53
Dependent									
American Goldfinch	834	2.02	10.8	279	2.87	337	1.83	299	1.48
Black-capped Chickadee	315	1.48	30.3	99	1.37	148	1.92	82	0.85
Black-headed Grosbeak	229	0.37	15.8	72	0.80	107	0.33	54	0.12
Bullock's Oriole	563	1.08	10.9	181	1.51	170	0.75	248	1.02
Gray Catbird	710	1.98	7.9	266	2.49	362	3.26	100	0.63
House Wren	2722	5.92	4.6	623	5.75	942	6.22	1209	6.09
Lazuli Bunting	89	0.14	18.4	7	0.03	13	0.05	72	0.30
Red-eyed Vireo	51	0.08	26.5	5	0.02	6	0.06	40	0.10
Red-naped Sapsucker	79	0.16	18.3	55	0.31	22	0.16	3	0.03
Tree Swallow	1031	4.15	9.4	553	6.03	733	6.39	243	0.95
Warbling Vireo	209	0.27	16.7	99	0.58	62	0.18	49	0.11
Western Wood-Pewee	652	0.94	6.6	168	0.73	261	1.20	231	0.85
Generalist									
American Robin	1188	2.14	8.0	393	3.25	464	2.45	372	1.10
Black-billed Magpie	132	0.14	14.6	56	0.16	54	0.16	32	0.10
Brown-headed Cowbird	933	2.52	8.2	498	3.26	453	2.39	144	0.66
Clay-colored Sparrow	69	0.07	33.0	8	0.03	55	0.18	8	0.02
Cedar Waxwing	508	2.20	10.5	168	1.54	324	3.60	213	1.73
Common Nighthawk	48	0.12	32.5	14	0.08	15	0.09	42	0.24
Downy Woodpecker	193	0.45	12.9	21	0.29	83	0.61	91	0.36
Eastern Kingbird	414	0.64	9.2	125	0.62	156	0.63	171	0.64
European Starling	1127	2.35	10.3	410	2.45	623	2.74	475	1.83
House Finch	101	0.15	26.2	26	0.16	75	0.26	8	0.02
Least Flycatcher	1313	2.97	5.7	348	3.27	468	3.43	518	2.31
Mourning Dove	1001	1.09	5.4	197	0.75	387	1.16	478	1.19
Northern Flicker	368	0.41	7.1	81	0.33	115	0.42	188	0.43
Red-winged Blackbird	241	0.47	17.9	167	1.11	54	0.47	34	0.12
Spotted Towhee	183	0.24	15.3	14	0.05	10	0.04	162	0.53
Western Kingbird	233	0.49	19.0	13	0.06	82	0.29	187	0.94

Spatiotemporal Trends

Densities varied significantly (*P* ≤0.05) over time for 17 of the 33 bird species we considered (Appendix B1). For seven of these species, we also found evidence of spatial variation in population trends among river sections (Table 3, *P* < 0.040 for Year by Section interaction).

We found significant declines in densities of 11 species (Fig. 2). Declining species represented all nesting guilds (e.g. ground, shrub, tree, and cavity nesters), and included riparian obligate species such as the Song Sparrow and dependent species like the Gray Catbird, as well as more widespread, generalist species such as Mourning Dove and House Finch. The average annual trend for declining species was -1.7 ± 0.4%, and ranged from -0.6 ± 0.3% per year for Black-billed Magpie to -5.6 ± 0.6% per year for American Goldfinch (Appendix B1). Four species showed significantly steeper declines on the Madison than Missouri River, including the riparian obligate Song Sparrow, and the riparian dependent Red-naped Sapsucker, Western Wood-Pewee, and Warbling Vireo. In the case of Song Sparrow, for example, densities declined 5.2 ± 1.3% more per year along Madison River than along the upper Missouri River (Appendix B2).

Densities of six bird species increased significantly over time, including one riparian obligate species (Yellow Warbler), and two riparian-dependent species (House Wren and Black-capped Chickadee; Fig. 3). All of these species are relatively abundant and widespread in North America and four of them are among the most abundant species found in the study (e.g. Yellow Warbler, House Wren, Least Flycatcher, and American Robin; Appendix A). The average annual trend for increasing species was 1.9 ± 0.3% per year, and ranged from 1.3 ± 0.3%% for Yellow Warbler to 3.0 ± 0.5% per year for House Wren (Appendix B1).

We found no evidence of system-wide trends in densities of 16 of the 33 bird species we considered (Fig. 4). For three of those species, however, we found significant trends within one or more river sections as indicated by significant time by section interactions (i.e. Common Nighthawk, European Starling, and Willow Flycatcher). Densities of Willow Flycatcher, an obligate riparian species, for example, declined along the Madison River, but increased along the upper Missouri River (Appendix B2).

Table 3. Results from linear mixed-effects model test for year, section, and year x section interaction of bird species densities in riparian patches on the Madison and Missouri Rivers, Montana 2004-2015. Trend results and Western BBS results from 1968-2013 classified as Decline, Increase, or Varied.

	Year		Section		Year*Section			Western BBS
Common Name	***F***	***P***	***F***	***P***	***F***	***P***	**Trend**	**(1968-2013)**
Obligate								
Common Yellowthroat	0.68	0.41	8.12	0.00	0.20	0.82	-	-
Song Sparrow	6.18	0.01	0.52	0.60	9.51	<0.001	Decline	Decline
Willow Flycatcher	0.10	0.76	2.95	0.06	7.74	<0.001	Varied -	Decline
Yellow Warbler	18.86	<0.001	80.34	<0.001	15.99	<0.001	Increase	Decline
Yellow-breasted Chat	2.56	0.11	20.99	<0.001	1.03	0.36	-	Increase
Dependent								
American Goldfinch	60.78	<0.001	2.5	0.09	1.04	0.36	Decline	Decline
Black-capped Chickadee	16.68	<0.001	6.63	<0.001	2.09	0.13	Increase	Decline
Black-headed Grosbeak	0.24	0.62	16.25	<0.001	2.06	0.13	-	Increase
Bullock's Oriole	1.99	0.16	2.21	0.12	1.56	0.21	-	Decline
Gray Catbird	4.21	0.04	23.79	<0.001	1.62	0.20	Decline	Increase
House Wren	27.25	<0.001	0.03	0.97	1.27	0.28	Increase	Decline
Lazuli Bunting	0.47	0.49	12.68	<0.001	0.72	0.49	-	-
Red-eyed Vireo	0.39	0.53	3.11	0.05	1.41	0.25	-	Decline
Red-naped Sapsucker	6.96	0.01	9.34	<0.001	11.48	<0.001	Decline	Increase
Tree Swallow	1.69	0.20	42.06	<0.001	0.76	0.47	-	Decline
Warbling Vireo	15.5	<0.001	7.88	0.00	4.93	0.01	Decline	Increase
Western Wood-Pewee	4.83	0.03	1.59	0.21	8.01	<0.001	Decline	Decline
Generalist								
American Robin	4.91	0.03	25.52	<0.001	3.32	0.04	Increase	Decline
Black-billed Magpie	3.67	0.06	1.46	0.24	2.26	0.11	Increase	Decline
Brown-headed Cowbird	1.82	0.18	29.75	<0.001	0.60	0.55	-	Decline
Cedar Waxwing	4.00	0.05	2.92	0.06	0.32	0.73	Decline	-
Clay-colored Sparrow	0.51	0.48	1.95	0.15	1.52	0.22	-	Increase
Common Nighthawk	2.82	0.10	1.33	0.27	3.57	0.03	Varied	Decline
Downy Woodpecker	6.65	0.01	5.39	0.01	0.26	0.77	Decline	Decline
Eastern Kingbird	0.86	0.36	0.02	0.98	0.34	0.71	-	-
European Starling	0.51	0.48	0.90	0.41	5.01	0.01	Varied	Decline
House Finch	6.33	0.01	7.71	0.00	0.84	0.43	Decline	Decline
Least Flycatcher	8.06	0.01	0.83	0.44	0.03	0.97	Decline	Decline
Mourning Dove	27.00	<0.001	5.34	0.01	0.69	0.50	Decline	Decline
Northern Flicker	2.58	0.11	0.39	0.68	0.56	0.57	-	-
Red-winged Blackbird	20.09	<0.001	15.56	<0.001	11.07	<0.001	Increase	Decline
Spotted Towhee	1.54	0.22	17.72	<0.001	0.59	0.55	-	-
Western Kingbird	0.48	0.49	6.46	0.00	0.24	0.78	-	-

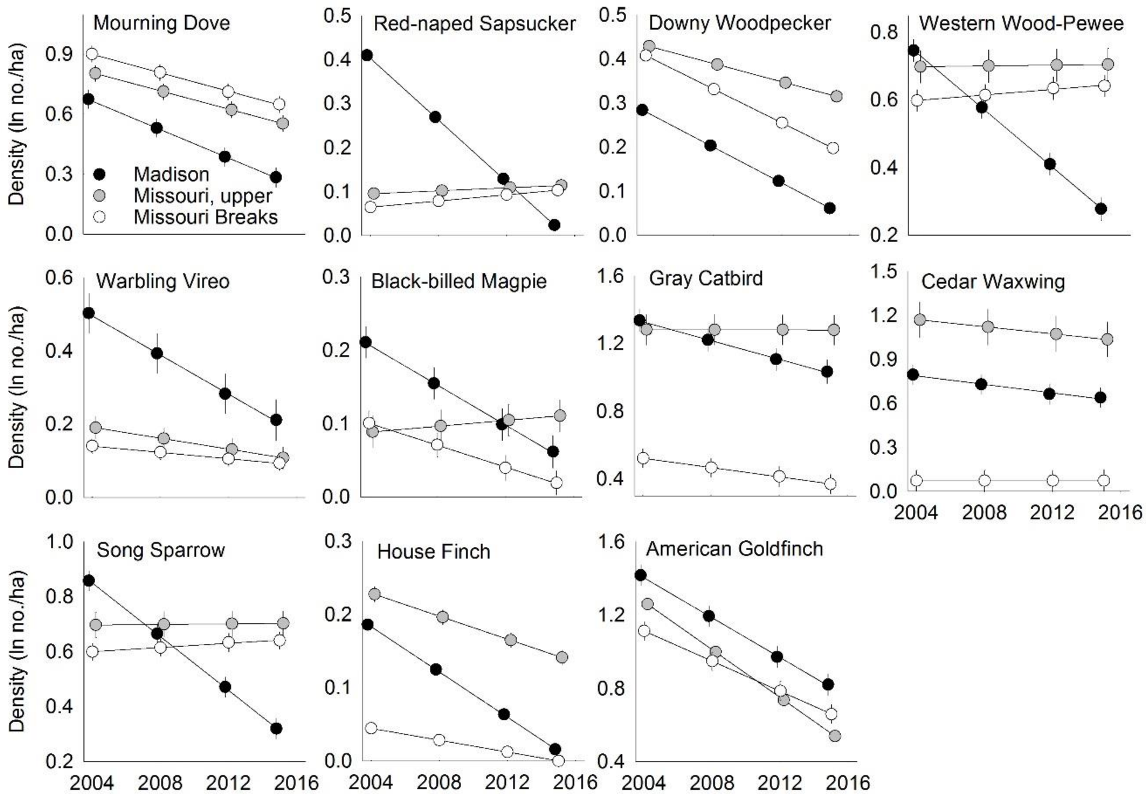

Figure 2. Spatiotemporal variation in densities (ln no./ha.) of 11 bird species with decreasing population trends along three sections of the Madison and Missouri Rivers, Montana 2004-2015. Estimates are predictions (± SE) from linear mixed-effects models that estimated trends across time. Note: scale of Y-axis varies among species.

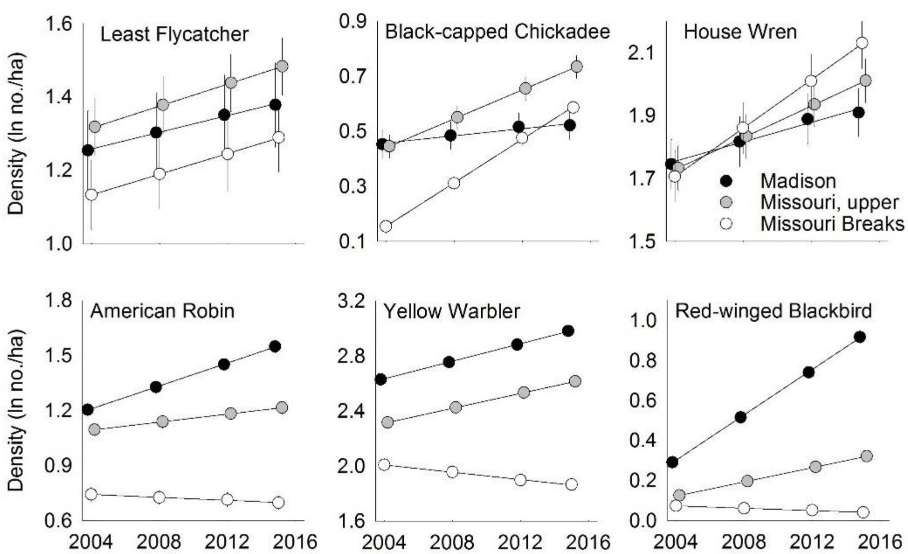

Figure 3. Spatiotemporal variation in densities (ln no./ha.) of six bird species with increasing population trends along three sections of the Madison and Missouri Rivers, Montana 2004-2015. Estimates are predictions (± SE) from linear mixed-effects models that estimated trends across time. Note: scale of Y-axis varies among species.

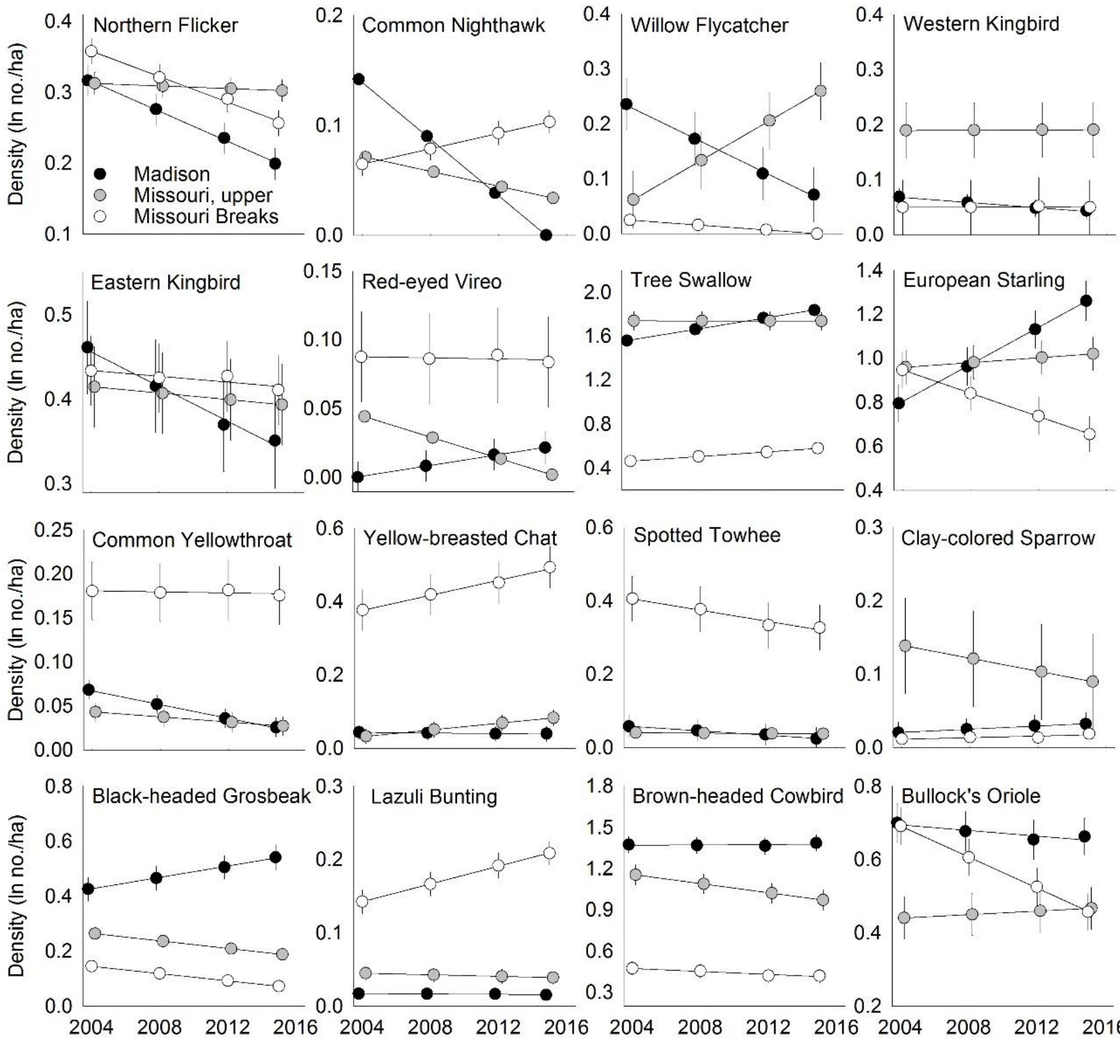

Figure 4. Spatiotemporal variation in densities (ln no./ha.) of 13 bird species with regionally variable or stable trends in populations across three sections of the Madison and Missouri Rivers, Montana 2004-2015. Estimates are predictions (± SE) from linear mixed-effects models that estimated trends across time. Note: scale of Y-axis varies among species.

Densities of all species combined did not vary significantly across time (*F* = 1.48, *P* = 0.23). However, densities of riparian-obligate and riparian-dependent species did vary significantly (*F* = 23.56, *P* <0.001 and *F* = 9.99, *P* = 0.002, respectively). Both species groups increased across time, but densities of riparian obligates increased at a somewhat greater rate (e.g., 1.5 ± 0.3% /yr. vs. 1.0 ± 0.3%/yr, Appendix B3). There was also evidence that temporal trends in densities of the two species groups varied spatially (Fig. 5). For example, riparian-obligate species increased by 2.1 ± 0.8% more per year along the upper Missouri River than the Missouri Breaks or Madison River (Appendix B3).

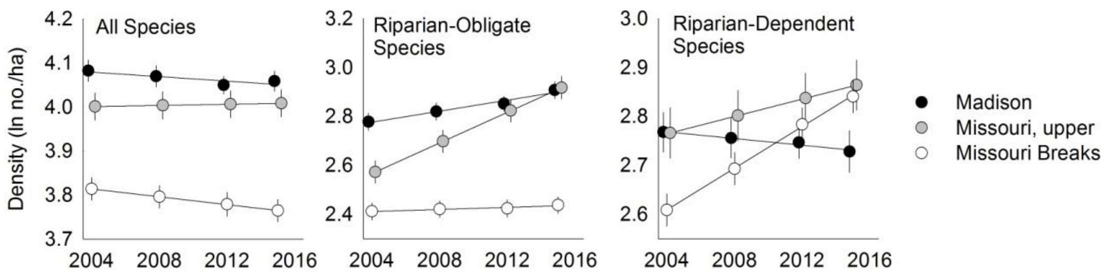

Figure 5. Spatiotemporal variation in densities (ln no./ha.) of 3 bird species groups along three sections of the Madison and Missouri Rivers, Montana 2004-2015. Estimates are predictions (± SE) from linear mixed-effects models that estimated trends across time**.** Note: scale of Y-axis varies among groups.

Comparison with Regional Trends

Of the 33 bird species we considered, BBS analyses showed that 20 declined and six increased significantly across the western United States since 1968 (Table 3). The majority of species (67%) for which our efforts indicated population declines along the Madison and Missouri Rivers also showed significant declines across broader spatial and temporal scales based on BBS analyses. For example, according to BBS, abundance of Willow Flycatcher has declined by 51%.

There were also important differences between trends we observed in the study area and long-term trends based on BBS data. For example, three species with negative trends in our study increased significantly across the west since 1968, including Red-naped Sapsucker, Warbling Vireo, and Gray Catbird. Additionally, three species with increasing trends in our study area declined at larger regional scales according to BBS, including Least Flycatcher, Yellow Warbler, and Red-winged Blackbird.

Species Richness

At the scale of riparian patches, estimated species richness ranged from 14.3 to 40.5 across all years of the study. Estimated richness was higher on average along the Madison River (28.0 ± 0.9) than along the upper Missouri (25.4 ± 0.8) or Missouri Breaks (23.9 ± 0.8; $F_{2,322}$ = 6.09, P = 0.0025, ANOVA). Despite spatial variation in species richness, there was no evidence that richness varied across time ($F_{1,322}$ = 0.093, P = 0.76, LMEM) or that the presence or magnitude of temporal trends varied among river sections ($F_{2,318}$ = 0.11, P = 0.90; for year × section interaction, Fig. 6).

Based on the observed abundance distribution and the 118 species we detected during point counts, we estimate that 129 species were present in riparian areas in the study area during the study period. An upper bound of a 95% confidence interval of estimated richness based on the Chao 1 estimator equaled 154.5 species.

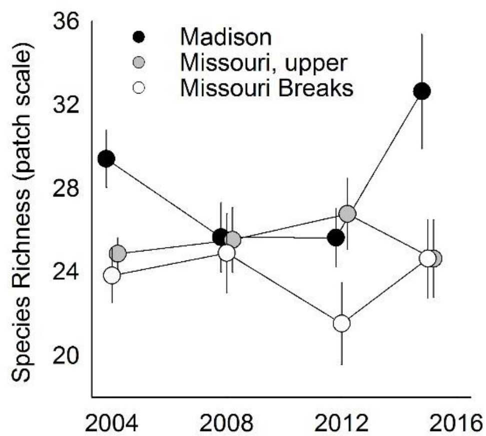

Figure 6. Spatiotemporal variation in estimated species richness along three sections of the Madison and Missouri Rivers, Montana 2004-2015. Points are estimates (± SE) based on the Chao 1 estimator**.**

Objective 2: Trends in Riparian Habitat Conditions

Methods

Study Area & Design

See Objective 1, "Study Area & Design".

Vegetation

At each point-count station, we measured vegetation within four sub-plots, one that was centered at points and three that were located 25 meters from the center point at directions of 0°, 120°, and 240° (Fig. 7; adapted from Martin et al. 1997). Within each sub-plot, we measured vegetation composition and structure at two scales: 5-m radius and 11.3-m radius circular plots.

Within each 5-m radius circular plot, we recorded ocular estimates of shrub species cover, shrub height, species cover of saplings (trees <8 cm diameter at breast height; DBH) and of non-native herbaceous species, and ground cover. We estimated grazing intensity based on the density of cow feces, which we classified as none, low, moderate, or high. In 2012 and 2015, we also measured sapling density of cottonwoods (*Populus* spp.) and of Russian Olive (*Elaeagnus angustifolia*) so as to monitor cottonwood recruitment and the spread of non-native Russian Olive.

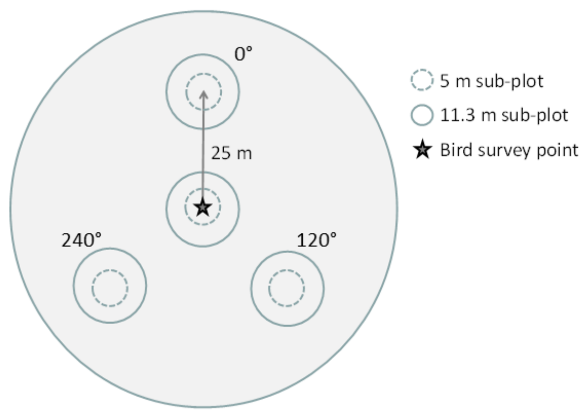

Figure 7. Vegetation sampling design showing locations of the 4 sample areas with 5-m and 11.3 m sub-plots.

Within each 11.3-m radius circular plot, we measured density of each tree species and of snags in three size classes: small (8-23 cm DBH), medium (23-38 cm DBH), and large (>38 cm DBH), and considered all woody plants with stems ≥8 cm DBH as trees. We measured tree canopy height using a clinometer.

Analysis

We combined several vegetation variables for analysis. We grouped all species of willow (*Salix* spp.) and cottonwood (*Populus* spp.). We calculated dominance of each individual tree species by multiplying basal area (m^2) of each size class by density (no./ha). We calculated maximum canopy height (m), as the height of the tallest canopy layer by combining shrub and tree height measures to generate a single continuous measure of vegetation height. We combined estimates of all species of herbaceous weed cover (%) into total weed cover.

To estimate trends in the structure and composition of vegetation and other habitat conditions (e.g., grazing), we considered a subset of variables (Appendix C2) and used the same modeling procedure described above for bird populations (see Objective 1, Analysis). That procedure involved using linear mixed-effects models with site-level random effects, and fitting year by river section interaction terms to evaluate spatial variation in trends (see eq. 1 above).

Results

Survey Effort

We completed 823 vegetation surveys at 55 patches across four years of monitoring (Table 4). One site was not sampled due to access issues in 2012, but otherwise we sampled all patches at least once during each monitoring year.

Table 4. Annual sampling effort for vegetation on the Madison and Missouri Rivers in Montana 2004-2015. Total effort is number of sample points with ≥3 vegetation plots recorded.

Year	Patches (no.)	Points (no.)
2004	55	223
2008	55	199
2012	54	197
2015	55	204

Riparian Habitat Conditions

We recorded a total of 11 tree species across the river system. Plains Cottonwood (*Populus deltoids*) and Narrowleaf Cottonwood (*Populus angustifolia*) were the most common trees, and occurred at 46% and 42% of sample points, respectively. Willows (*Salix* spp.) of tree size (≥8 cm DBH) occurred at 11% of points. Appendix C summarizes plant species we documented across all years.

We encountered 13 shrub species (or species groups), including seven species associated with wetland areas (facultative wetland plants, Lichvar 2014, Appendix C). Common Snowberry (*Symphoricarpus albus*) was the most common shrub and occurred at 70% of points, followed by willow (*Salix* spp.), which occurred at 49% of points. We rarely (3% of points) encountered upland shrub communities such as those dominated by sagebrush (*Artemesia* spp.).

We found invasive species of weeds at virtually all sample points that were represented by a total of 21 species or species groups (Appendix C). Canada Thistle (*Cirsium arvense*) was the most common weed and occurred at 73% of points we sampled, followed by Common Hound's Tongue (*Cynoglossum officinale*) and Leafy Spurge (*Euphorbia esula*) at 53% and 41% of points, respectively. Two tree species known to invade riparian habitats, Rocky Mountain Juniper (*Juniperus scopulorum*) and non-native Russian Olive (*Elaeagnus angustifolia*), occurred at 20% and 8% of points, respectively.

Rocky Mountain Juniper in the Upper Missouri (top) and Russian Olive in the Missouri Breaks (bottom)

Vegetation structure and composition varied geographically along the river system. Narrowleaf Cottonwood was dominant along the upper and middle sections of the system, and was largely replaced by Plains Cottonwood below Great Falls on the Missouri River (Fig. 8). Black Cottonwood (*Populus balsamifera*) occurred at low densities at only a few locations on the upper Missouri River near its headwaters. Distributions of other riparian-associated tree species varied as well. For example, Water Birch (*Betula occidentalis*) occurred commonly along the Madison River, whereas Box Elder (*Acer negundo*) and Green Ash (*Fraxinus pennsylvanica*) were located primarily along the lower portions of the Missouri River. Russian Olive was only found along the Missouri River, with the majority of observations in the Missouri Breaks, whereas Rocky Mountain Juniper was located primarily along the Madison and upper Missouri Rivers (Fig. 8). There was also an interesting geographic pattern in willow structure, with high shrub cover of willows along the Madison River, but very low cover starting near Helena on the Missouri River (Fig. 9). Of the three most commonly recorded herbaceous weeds, thistle species were found throughout the river system, whereas Common Houndstongue was most common along the Upper Missouri and Leafy Spurge was primarily in the Missouri Breaks (Fig. 9).

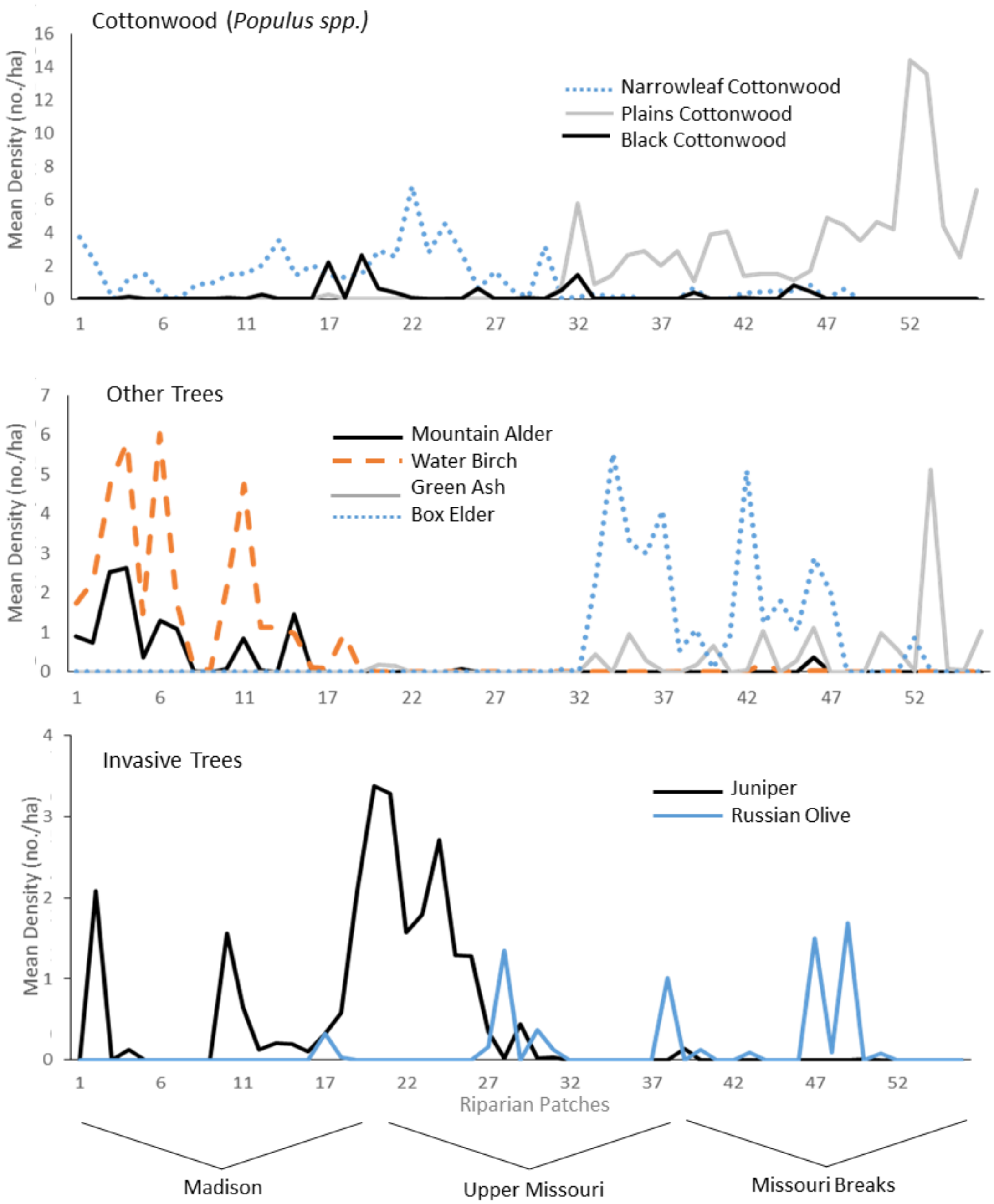

Figure 8. Geographic patterns in tree species composition in riparian patches along three sections of the Madison and Missouri Rivers in Montana, 2004-2015. Mean density (no./ha) of cottonwood trees (top), other riparian-associated trees (middle), and invasive trees (bottom).

Narrowleaf cottonwood with willow sub-canopy near Missouri River Headwaters (left) and Plains cottonwood with no sub-canopy below Missouri River Breaks (right).

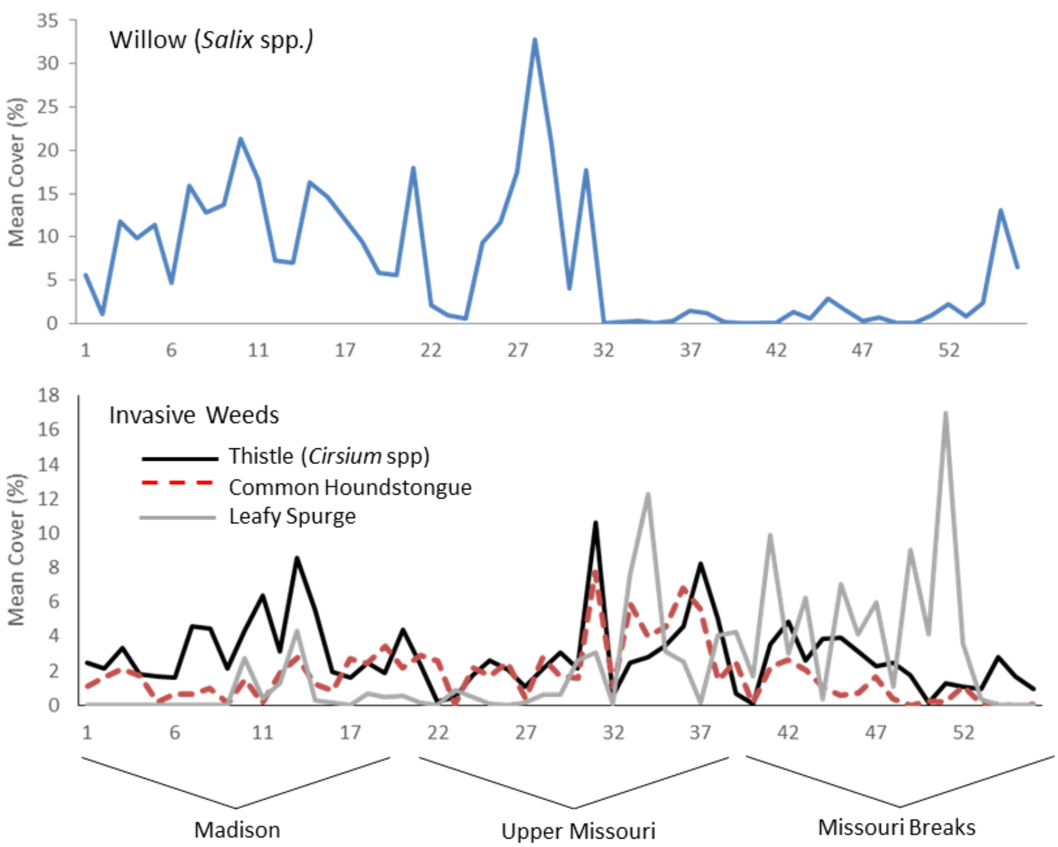

Figure 9. Geographic patterns in vegetation sampled in riparian patches along the Madison and Missouri Rivers in Montana, 2004-2015. Mean cover (%) of willow (*Salix* spp.) cover (top), and invasive species cover (bottom).

Trends in Riparian Conditions

We found significant changes in the majority (85%) of vegetation characteristics we monitored in riparian areas along the Madison and Missouri Rivers since 2004 (Table 5). Densities of all live trees combined increased across time, but densities of trees in the smallest size class declined, indicative of a maturing forest transitioning from small- to large-diameter trees (Fig. 10). We also found evidence of a decline in maximum canopy height across time, suggesting losses of taller trees and shrubs across the river system (Fig. 14). Appendix D summarizes trend estimates for all vegetation characteristics.

Snag densities also varied across time, with densities of small snags decreasing and densities of large snags increasing, particularly on the Madison River (Fig. 11). When monitoring began in 2004, densities of large snags were significantly lower on the Madison than the Missouri River, but by 2015, they were similar across the river system. That pattern matched trends for total snag dominance, which was largely stable along the Missouri River, but increased along the Madison River. Such results suggest a maturing riparian forest, particularly on the Madison River, with large trees dying during the monitoring period.

Vegetation composition changed significantly over time as well. Dominance of Cottonwood species and of two invasive tree species increased across the river system (Fig.12). Rocky Mountain Juniper increased along the Madison and Upper Missouri Rivers, while Russian Olive increased along the Missouri River. In contrast, dominance of willow trees declined considerably on all but the Madison River. Cover of all species of shrubs and saplings also declined significantly, including cover of willow shrubs and cottonwood saplings (Fig. 13). Declines in willow shrub cover were steepest on the Madison River and were estimated at a rate of -10.9 ± 1.3% per year (Appendix D). Sample sizes for Green Ash and Box Elder, which occur only locally along the Missouri Breaks, were too low to detect changes dominance.

Mature cottonwood and willow vegetation on Madison River, Montana.

Two measures of human disturbance, total herbaceous weed cover and livestock grazing intensity, showed significant declines over time throughout the river system (Fig. 14).

Table 5. Results from linear mixed-effects model testing for effects of Year, Section, and Year × Section interaction (MAD= Madison, MIS= upper Missouri, and BRK = Missouri Breaks), of bird species densities in riparian habitats on the Madison and Missouri Rivers, Montana 2004-2015.

	Year		Section		Year x Section			
Vegetation Measures	**F**	**P**	**F**	**P**	**F**	**P**	**Trend**	**Regional Differences**
Small tree density (no./ha)	43.44	<0.001	152.21	<0.001	1.21	0.300	Decline	BRK>MIS>MAD
Medium tree density (no./ha)	8.43	0.004	5.46	0.007	0.03	0.973	Increase	BRK>MIS>MAD
Large tree density (no./ha)	4.36	0.038	6.36	0.003	0.16	0.850	Increase	BRK>MIS>MAD
Populus spp. dominance (m^2/ha)	14.87	<0.001	9.91	<0.001	0.10	0.907	Increase	BRK>MIS>MAD
Salix spp. dominance (m^2/ha)	15.31	<0.001	2.34	0.106	4.93	0.008	Decline: MIS,BRK	
Green Ash dominance (m^2/ha)	0.65	0.423	4.39	0.017	0.15	0.859		BRK>MIS>MAD
Box Elder dominance (m^2/ha)	0.74	0.392	6.82	0.002	0.20	0.817		BRK>MIS>MAD
Juniper dominance (m^2/ha)	16.79	<0.001	8.39	0.001	5.16	0.007	Increase: BRK,MAD	BRK>MAD>MIS
Russian Olive dominance (m^2/ha)	7.32	0.008	0.82	0.447	2.63	0.075	Increase: MIS,BRK	
Small snag density (no./ha)	7.26	0.008	1.31	0.279	0.22	0.806	Decline	
Medium snag density (no./ha)	1.69	0.195	2.08	0.136	0.78	0.459		
Large tree density (no./ha)	3.82	0.052	2.05	0.139	2.53	0.083	Increase: MAD	
Total snag dominance (m^2/ha)	0.72	0.398	1.44	0.247	3.55	0.031	Increase: MAD	
Total shrub cover (%)	116.67	<0.001	3.60	0.034	0.70	0.500	Decline	MAD>MIS>BRK
Total sapling cover (%)	3.99	0.047	2.65	0.080	0.47	0.626	Decline	
Salix spp. cover (%)	75.95	<0.001	17.41	<0.001	11.14	<0.001	Decline	MAD>MIS>BRK
Populus spp. sapling cover (%)	6.71	0.010	0.49	0.616	0.11	0.893	Decline	
Max. canopy height (m)	37.15	<0.001	18.13	<0.001	0.07	0.929	Decline	BRK>MIS>MAD
Total weed cover (%)	16.86	<0.001	1.02	0.366	0.00	0.996	Decline	
Index of Grazing Intensity (0-3)	30.84	<0.001	0.74	0.482	0.01	0.988	Decline	

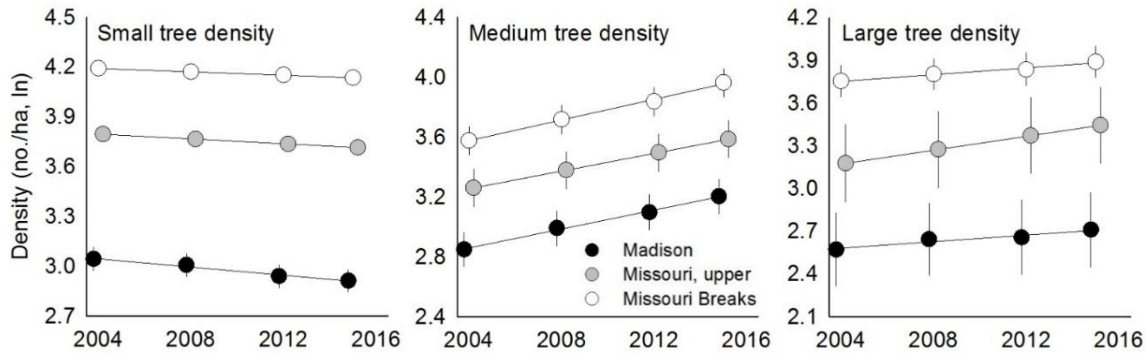

Figure 10. Trends in density of live trees (ln no./ha.) across time for three size classes (small=8-23 cm DBH, med.=23-38 cm DBH, and large=>38 cm DBH) along the Madison and Missouri Rivers, Montana 2004-2015. Estimates are predictions (± SE) from linear mixed-effects models that estimated trends across time.

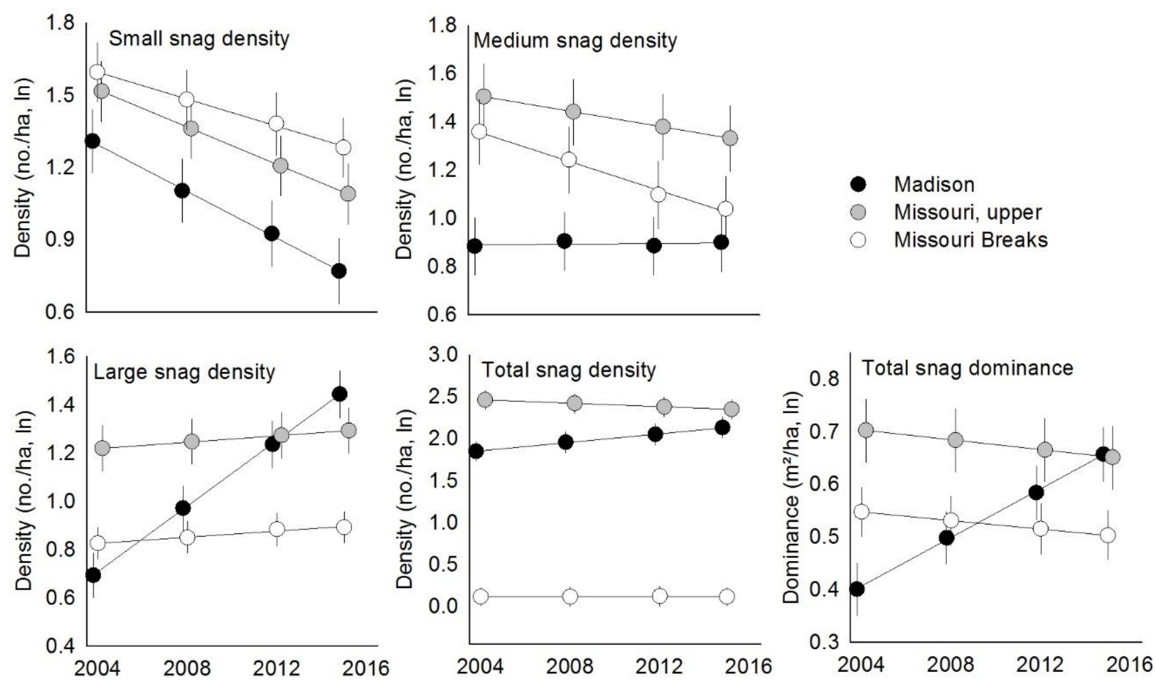

Figure 11. Trends in snag density (ln no./ha.) for 3 size classes (small=8-23 cm DBH, med=23-38 cm DBH, and large=>38 cm DBH), and total snag dominance (ln m^2/ha.) across time along the Madison and Missouri Rivers, Montana 2004-2015. Estimates are predictions (± SE) from linear mixed-effects models that estimated trends across time.

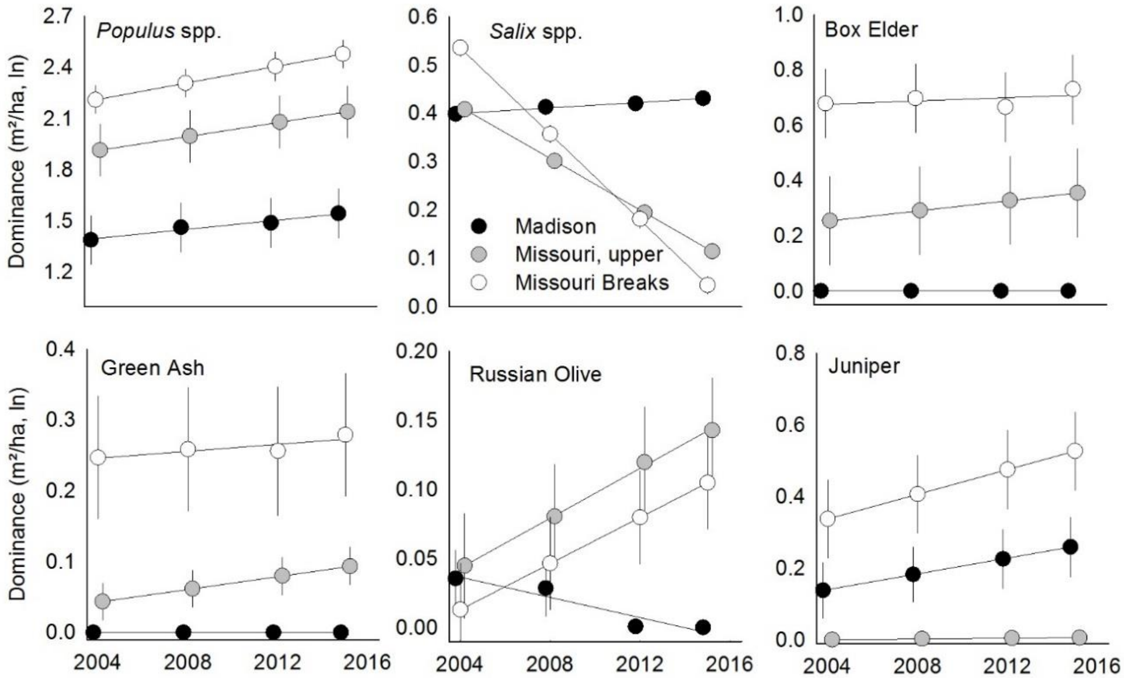

Figure 12. Trends in tree species dominance (ln m²/ha.) across time for 6 species (or genus) along the Madison and Missouri Rivers, Montana 2004-2015. Estimates are predictions (± SE) from linear mixed-effects models that estimated trends across time.

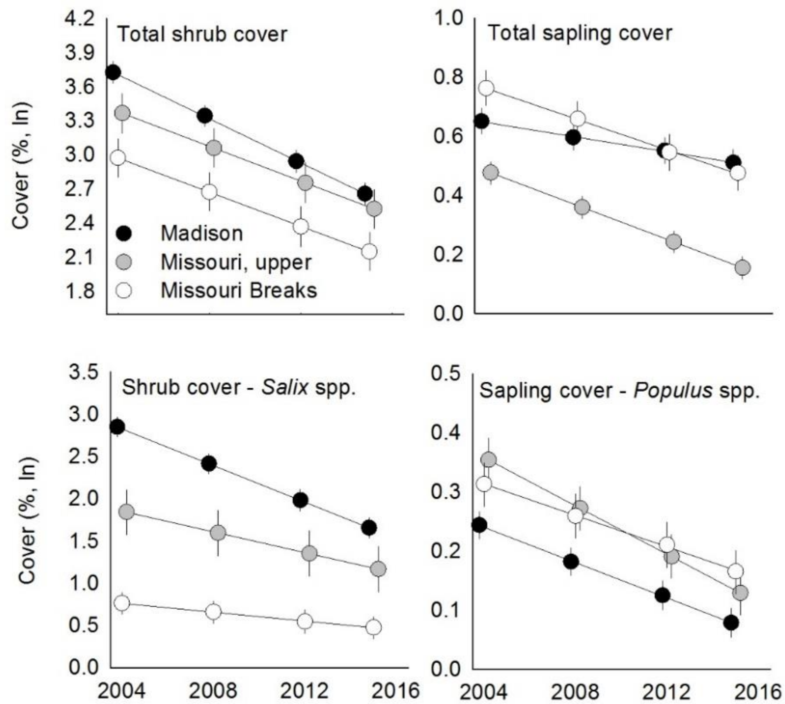

Figure 13. Trends in cover (ln %) across time for total shrubs and *Salix* spp shrubs, and total saplings and *Populus* spp. saplings, along the Madison and Missouri Rivers, Montana 2004-2015. Estimates are predictions (± SE) from linear mixed-effects models that estimated trends across time.

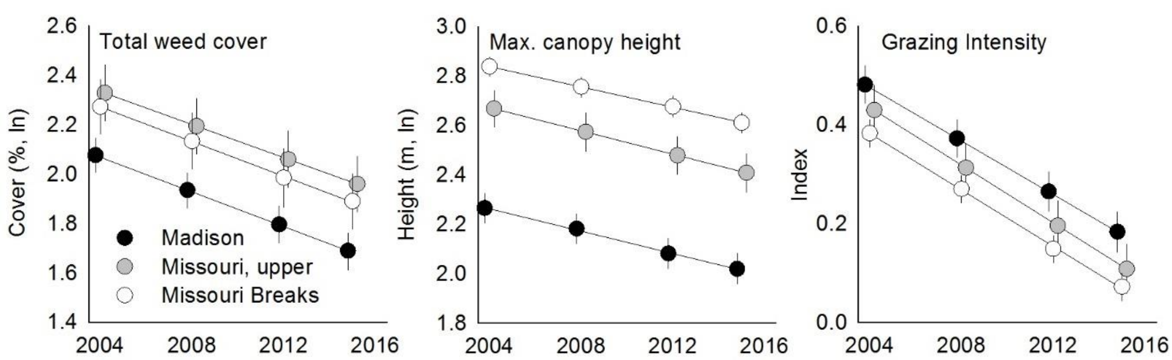

Figure 14. Trends across time for total weed cover (ln %), maximum canopy height (ln m.), and grazing intensity (ln index) along the Madison and Missouri Rivers, Montana 2004-2015. Estimates are predictions (± SE) from linear mixed-effects models that estimated trends across time.

Objective 3: Evaluation of Monitoring Effort

Determining the effort required to estimate population parameters, such as abundance, is an important consideration when designing a monitoring program (Gibbs et al. 1998, Bart et al. 2004). Without assessments to guide design and inform cost, effort expended on sampling may be inadequate to meet program objectives. The number of samples needed and frequency of sampling are often the most important considerations when designing monitoring programs because they greatly influence program cost. When the main goal is to derive annual estimates of abundance or density for a group of focal species, the number of samples required depends, in part, on the desired level of precision (Thomas et al. 2005). That is because our ability to detect temporal trends in density decrease as the precision of estimates decline. Conversely, the smaller the confidence interval and thus the higher precision, the greater our ability to detect trends, but more samples are needed to obtain higher precision.

Prospective power analysis can aid the efficiency of monitoring programs by providing an understanding of tradeoffs between sampling effort, cost, and the magnitude and probability of a trend that can be detected (Gerrodette 1987, Steidl et al. 1997). During power analysis, such design elements can be varied to determine a range of appropriate sampling strategies for meeting objectives (e.g., Gibbs et al. 1998, Flesch & Steidl 2006). In general, our ability to detect a trend is a function of the magnitude of the trend, variation around the trend line, and the amount of time or leverage over which the trend is assessed.

To guide the efficacy of future bird monitoring along the Madison and Missouri Rivers in Montana, we used data on encounter rates, densities, and observation error around trends from past years to assess the amount of effort required to estimate densities at varying levels of precision across a range species of various abundances. Based on those analyses, we determined which species can be effectively monitored across two different scenarios of effort. Additionally, we assessed tradeoffs between sampling effort and statistical power to detect trends of various magnitudes across a range of species with variable levels of observation error around trends from past years. This information will help inform future monitoring efforts.

Methods

Study Area & Design

See Objective 1, “Study Area & Design”.

Sample-size Estimation & Effort Allocation

We first assessed the influence of within-year sampling effort on precision of density estimates across a suite of species representing a range of encounter rates. Based on data gathered since 2004, we sought to determine the amount of effort in number of sample point visits (*K;* sampling effort as no. of points × no. of visits) needed to estimate density with use of distance-sampling methods. First, we calculated encounter rates as the total number of detections of a species divided by sampling effort. We excluded detections of birds that were flying over points and birds detected outside of the point-count period. The relationship between encounter rates and the number of samples required to estimate density is as follows:

$$K = \left(\frac{b}{\left\{ cv\left(\hat{D}\right) \right\}^2} \right) \times \left(\frac{K_0}{n_0} \right) \quad \text{(eq. 3)}$$

where $cv(\hat{D})$ is the desired coefficient of variation or level of precision for the estimate of density, and K_0/n_0 is the inverse of the encounter rate based on pilot data (Buckland et al. 2001). Note that *b* is a variance inflation parameter equaled to the number of detections (*n*) multiplied by the CV of the density estimate [$cv(\hat{D})$] that can be determined with point-count data. Although the value of *b* is often between 2 and 4 (Eberhardt 1978) and generally assumed to be 3 for planning purposes (Buckland et al. 2001), we estimated *b* to provide more precise estimates of sampling effort to guide future monitoring.

We used the *mrds* library in R (Laake et al. 2012, R Development Core Team 2013) to calculate density and $cv(\hat{D})$ for a subset of species with varying encounter rates. To estimate the relationship between encounter rates and sampling effort, we selected 18 species with at least 40 total detections across all years that represented the range of numbers of encounters. We used estimates of density and CV for those species from two years in which effort was lowest (2012; 210 points × 1 visit to each point) and highest (2004; 223 points × 2 visits to each point) across the study. Encounter rates varied from 0.01 to 3.5 detections per point per visit. We plotted encounter rates of all 18 species versus sampling effort at three levels of precision (10, 15, and 20% CV).

To assess the efficiency of various levels of sampling effort, we used estimates of sampling effort to determine the number of species for which estimates of density could be calculated at various levels of precision based on two scenarios of proposed effort. Those levels of sampling effort included one scenario based on two annual visits to all current monitoring points (Full Program; 223 monitoring points) and another with one visit to each point and thus half that effort (Reduced Program; 1 visit to each long-term monitoring point). We also considered the same sample of 18 species noted above because they were representative of the full range of encounter rates of species found in the region (e.g., 2-1297 encounters per year). We used predictions of survey effort based on expected encounter rates to determine the number of species for which densities could be estimated with CV equaled to 10%, 15% and 20%; 15% is often considered a good target for precision because it represents a reasonable tradeoff between lower values that are often expensive to obtain and greater values, which may only be appropriate for detecting large changes is population size. As an example, an increase in CV from 15% to 20% results in a 20% increase in the width of confidence intervals around density estimates (Fig. 15). Using these calculations, we were able to estimate the number of species for which density could be estimated with a CV of 10%, 15%, and 20% based on past results.

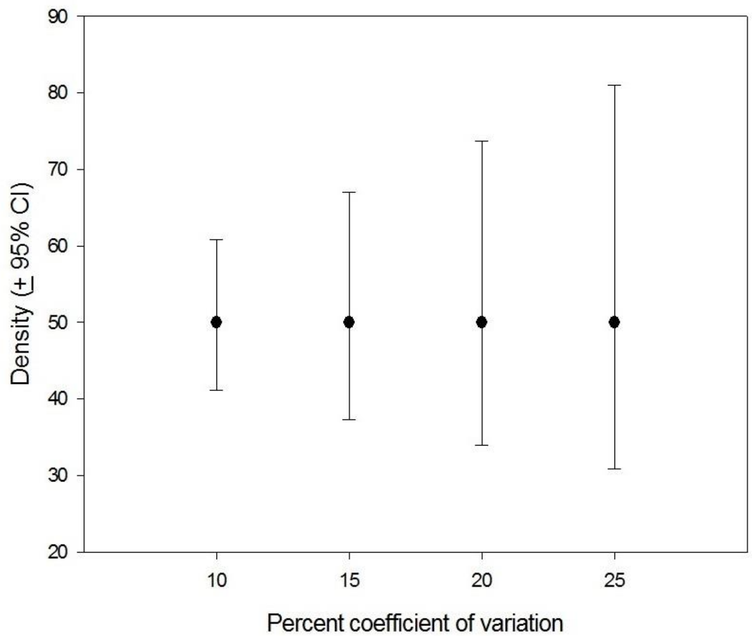

Figure 15. Effect of coefficient of variation (*CV*) on precision of density estimates for a hypothetical species with density of 0.5 birds/ha. Note that the lower confidence limit is smaller than upper confidence limit.

Power Analysis

To evaluate relationships between power, sample effort, effect size, and the duration of sampling on our ability to detect linear population trends across time, we estimated statistical power by varying each of these parameters and using estimates of variation around trends lines based on analyses reported here. We considered a time period of 25 years, sampling frequencies of every year to every four years, a Type-I error rate (α) of 0.05, and effect sizes varying from a 1 to 9% changes in density per year. To estimate variation around trends (e.g., observation error), we calculated the root mean squared error (RMSE) for a trend model for each species across time. RMSE measures variation between a trend line and the actual sample data used to fit the line and is therefore an appropriate measure of observation variance for estimating power to detect trends across time. We considered a total of nine species for these analyses, which represented the full range of variation of RMSE around trend lines (Table 1). To compute power, we used SAS 9.1; power analyses did not consider the precision of within-year estimates of parameters.

Results

Sample-size Estimation

Encounter rates (total detections/effort) were highest for Yellow Warbler, House Wren, and Least Flycatcher and lowest for Clay-colored Sparrow, Common Nighthawk, and Ovenbird (Table 6). For the 18 species for which we estimated density and coefficients of variation (*CV*), densities varied from 0.02 to 11.7 individuals/ha and *CV* averaged 0.25 ± 0.03 (± SE; range = 0.06-0.70) and was <0.19 for half the species evaluated, suggesting the current design is adequate for generating reasonably precise estimates of densities of many species. Nonetheless, *CV* averaged 0.07 ± 0.02 or 35% greater in 2012 than in 2004 when each point was surveyed two times during the season, and effort was 2.1-times greater overall ($t_{17} = 3.63$, $P = 0.002$, paired *t*-test).

As expected, there was a strong linear relationship between log encounter rates (e.g., no. of encounters per unit efforts in points × visits) and *CV*, with each doubling of encounter rates resulting in a 0.11 ± 0.01 (± SE) decrease in *CV* ($t_{34} = 10.83$, $P < 0.001$). On the untransformed scale, the relationship between encounter rates and *K* (e.g., effort in number of point visits required for various levels of precision) followed a strong negative exponential decay pattern (Fig. 16). For species encountered less that approximately 0.2 times per point count, effort required to estimate densities at high levels of precision (e.g., <15% CV) increased exponentially, whereas at lower precision that value increased to approximately 0.3 (Fig. 16). When both encounter rate per unit effort and estimated effort required to obtain estimates were log transformed to linearize distributions, there was a strong linear relationship with each 1% increase in encounter rates resulting in a 0.87 ± 0.076% decrease in required effort ($t_{34} = 11.36$, $P < 0.001$) after adjusting for the effects of year and species.

Based on the scenario of surveying each of the 223 long-term monitoring points once per year, we were able to estimate density with a precision of 15% *CV* for only 6 of 18 species. Increasing effort to two visits per stations per year, we estimate that densities of 50% of those species could be estimated at that level of precision (Table 7). Reducing precision to a *CV* of 20% increased estimates to 39% and 67% of species based on the reduced and full level of effort, respectively. In other words, we can estimate density with *CV* of ≤15% based on one visit to each sample point only for bird species with at least 0.5 detections per point count.

Table 6. Sample size requirements for estimating density of birds using distance sampling at 3 levels of precision (10, 15, and 20% CV). Data are from 2004, when there were 2 visits to each point, and 2012, when there was one visit per point. Species are listed in order of total encounters during the project.

Species	Year	Encounters (n)	Survey Effort (*K*)	Encounter Rate (n/*K*)	*D* (no./ha)	CV (*D*)	Scaling parameter ($n*CV^2$)	Est. *K* CV 10%	Est. *K* CV 15%	Est. *K* CV 20%
Yellow Warbler	2004	1297	445	2.92	9.64	0.06	5.0	171	76	43
	2012	736	210	3.51	11.70	0.08	4.8	138	61	34
House Wren	2004	832	445	1.87	5.42	0.06	3.2	171	76	43
	2012	402	210	1.91	5.46	0.07	2.0	103	46	26
Least Flycatcher	2004	484	445	1.09	2.84	0.09	3.9	360	160	90
	2012	246	210	1.17	4.12	0.11	3.1	263	117	66
American Robin	2004	448	210	2.13	1.94	0.10	4.2	196	87	49
	2012	221	210	1.05	2.44	0.15	4.8	460	204	115
Brown-headed Cowbird	2004	405	445	0.91	2.63	0.13	7.1	775	345	194
	2012	108	210	0.51	1.63	0.20	4.5	874	388	218
American Goldfinch	2004	390	210	1.86	2.77	0.14	7.6	409	182	102
	2012	139	210	0.66	1.12	0.16	3.5	524	233	131
Western Wood-Pewee	2004	245	445	0.55	1.10	0.09	1.8	329	146	82
	2012	89	210	0.42	0.84	0.14	1.9	435	194	109
Song Sparrow	2004	242	445	0.54	1.33	0.17	6.9	1271	565	318
	2012	60	210	0.29	0.66	0.22	2.9	1016	452	254
Eastern Kingbird	2004	183	445	0.41	0.70	0.14	3.7	910	404	227
	2012	57	210	0.27	0.55	0.21	2.6	944	419	236
Northern Flicker	2004	150	445	0.34	0.50	0.11	1.8	538	239	135
	2012	63	210	0.30	0.44	0.13	1.1	371	165	93
Red-winged Blackbird	2004	65	445	0.15	0.19	0.25	4.1	2826	1256	706
	2012	36	210	0.17	0.54	0.38	5.3	3080	1369	770

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Species	Year	Encounters (n)	Survey Effort (*K*)	Encounter Rate (n/*K*)	*D* (no./ha)	CV (*D*)	Scaling parameter ($n*CV^2$)	Est. *K*	Est. *K*	Est. *K*
Warbling Vireo	2004	104	445	0.23	0.35	0.19	3.9	1675	744	419
	2012	30	210	0.14	0.20	0.38	4.3	2985	1327	746
Downy Woodpecker	2004	82	445	0.18	0.64	0.18	2.8	1490	662	373
	2012	26	210	0.12	0.30	0.27	1.9	1508	670	377
Willow Flycatcher	2004	49	445	0.11	0.24	0.32	5.0	4500	2000	1125
	2012	23	210	0.11	0.23	0.43	4.2	3847	1710	962
Lazuli Bunting	2004	25	445	0.06	0.11	0.33	2.8	4935	2193	1234
	2012	12	210	0.06	0.11	0.32	1.2	2110	938	528
Clay-colored Sparrow	2004	25	445	0.06	0.08	0.57	8.1	14357	6381	3589
	2012	10	210	0.05	0.07	0.61	3.7	7712	3428	1928
Common Nighthawk	2004	10	210	0.05	0.06	0.37	1.4	2922	1299	730
	2012	2	210	0.01	0.02	0.70	1.0	10378	4613	2595
Ovenbird	2004	18	210	0.09	0.05	0.56	5.7	6633	2948	1658
	2012	7	210	0.03	0.04	0.57	2.3	6751	3001	1688

Table 7. Adequacy of two scenarios of sampling effort to generate estimates of density with 15% and 20% coefficients of variation (CV) using past survey data along the Madison and Missouri Rivers in Montana. Full effort is based 2 visits to the 223 monitoring points established in 2004 and reduced effort based on 1 visit to each point. Encounter rates are from pilot survey efforts and represent the average number of detections per point Species are listed in order of total encounters during the project.

Species	Encounter Rate	Encounters 2 Visits	Encounters 1 Visit	Est. K at CV 15%	CV ≤ 15% 2 Visits	CV ≤ 15% 1 Visit	Est. K at CV 20%	CV ≤ 20% 2 Visits	CV ≤ 20% 1 Visit
Yellow Warbler	2.915	1300	650	76	yes	yes	43	yes	yes
House Wren	1.87	834	417	76	yes	yes	43	yes	yes
Least Flycatcher	1.088	485	243	160	yes	yes	90	yes	yes
American Robin	2.133	951	476	87	yes	yes	49	yes	yes
Brown-headed Cowbird	0.91	406	203	345	yes		194	yes	
American Goldfinch	1.857	828	414	182	yes	yes	102	yes	yes
Western Wood-Pewee	0.551	246	123	146	yes	yes	82	yes	yes
Song Sparrow	0.544	243	121	565			318	yes	
Eastern Kingbird	0.411	183	92	404	yes		227	yes	
Northern Flicker	0.337	150	75	239	yes		135	yes	yes
Red-winged Blackbird	0.146	65	33	1256			706		
Warbling Vireo	0.234	104	52	744			419	yes	
Downy Woodpecker	0.184	82	41	662			373	yes	
Willow Flycatcher	0.11	49	25	2000			1125		
Lazuli Bunting	0.056	25	13	2193			1234		
Clay-colored Sparrow	0.056	25	13	6381			3589		
Common Nighthawk	0.01	4	2	4613			2595		
Ovenbird	0.033	15	7	3001			1688		

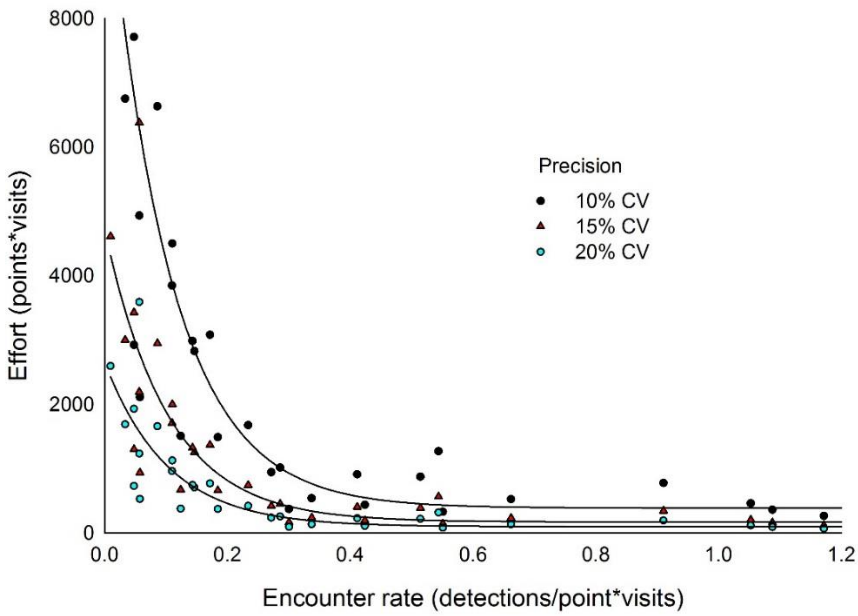

Figure 16. Relationship between encounter rate of birds and sampling effort required to estimate density at three levels of precision (10, 15, and 20% CV) based on distance sampling methods. Relationships were determined using density estimates, detection data, and effort from a sample of 18 bird species detected during 655 point counts*visits along the Madison and Missouri Rivers in 2004 and 2012. Prediction equations for each curve follow an exponential decay pattern and the x and y axes are truncated to better illustrate curves.

Power Analysis

Power simulations based on past efforts for nine species with variable levels of observation error around trend lines (RMSE = 0.14-0.62) indicated that detecting small annual changes (e.g., 1%) in population sizes of most species would be difficult even after sampling every year for the next 25 years (Appendix E). For species with RMSE less than ≈0.35, which included 22 of the 33 species for which we estimated trends, however, power to detect somewhat larger annual changes in population sizes of 3% is possible by sampling every year for the next 25 years. With regard to the frequency of effort, there was generally little gained by sampling every 3rd vs. 4th year despite the increase in effort, because differences in power between those scenarios were relatively small among species. Increasing effort to every two years, however, resulted in a substantial increase in power similar to sampling every year. Across all species we considered, a monitoring program based on sampling every other year was capable of detecting a 7% annual change in density with power of 0.8 after 25 years of effort, and 9% annual changes with power of 0.8 after ≈20 years of effort. For species with RMSE less than ≈0.35, effect sizes based on sampling every other year decreased to an ≈5% annual change with power of 0.8 after ≈20 years (Appendix E, 1-6).

CONCLUSIONS

Riparian Bird Populations & Habitat Conditions

Long-term assessments of the distribution and abundance of wildlife is central to evaluating the potential effects of anthropogenic stressors on animal populations (Thompson et al 1998, Pollock et al. 2002). This program provides a direct measure of the status of riparian-dependent wildlife populations across a large (500 mile) stretch of the Madison and Missouri Rivers in Montana, and is currently the only broad-scale monitoring effort that targets riparian birds in Montana. Based on four years of monitoring data that we gathered between 2004 and 2015 and 33 focal species that we consider here, our analyses show measurable declines for 11 species of birds, increases for 6 species, and trends that varied spatially for 3 other species. Collectively, those 33 species represent approximately 25% of the breeding landbird community in the region. Although abundances of other populations likely varied systematically in this system since 2004, those 33 focal species are those for which we could reliably estimate densities based on previous sampling effort and encounter rates. Moreover, we also found evidence of widespread systematic changes in the structure and composition of riparian vegetation across the system, which may explain some of those trends for bird populations.

Populations that declined have a broad range of nesting, foraging, and other habitat requirements, and included both generalist and riparian specialist species, such as the shrub-dependent Song Sparrow, forest-dwelling Western Wood-Peewee, and cavity-nesting Downy Woodpecker. Species that increased in abundance across time are all common in North America, and thus may not be as sensitive to changes in environmental conditions in this riversystem. For example, Red-winged Blackbirds, North America's most common breeding marsh bird, is a generalist that can breed in roadside ditches and agricultural lands, as well as cattail-dominated wetlands associated with poor hydraulic conditions (Yasukawa and Searcy 1995, Galatowitsch 1999). The only riparian obligate species that increased significantly was the Yellow Warbler, which is also the most abundant and widespread breeding bird species in this river system.

Yellow Warbler nestlings on Missouri River, Montana.

Our findings largely corresponded to long-term trends observed across the region by the North American Breeding Bird Survey (BBS) since 1968 (Sauer et al. 2014). Those similarities in trends suggest that the at least some of the drivers of population declines in our system are likely also occurring at larger spatial scales. Nonetheless, our results also included several important differences from regional BBS trends. For example, we found significant population declines of Gray Catbird, a Montana Species of Concern (MTSOC). This species is associated with high shrub densities that also declined significantly across the river system since 2004. However, according to BBS, Gray Catbirds have increased in the western U.S. due to increases in shrub cover associated with fire and forest clearing in other parts of the West (Smith et al 2011). Such differences show how large-scale monitoring of population trends, while critical for evaluating continental populations, may mask local changes in the status of populations of conservation concern.

We also examined trends in densities of all bird species combined, and of riparian-obligate and riparian-dependent bird species, and of species richness. Those analyses indicated only stable or increasing trends across the river -system. While these findings might be interpreted as showing overall bird community stability, it is important to understand that changes in abundances of the most common species, such as Yellow Warbler and House Wren), likely drove those patterns and masked declines of many less abundant species.

Generating efficient management responses to observed changes in bird communities and environmental conditions depends on understanding factors that are driving trends. Therefore, our next step will be to assess environmental conditions that explain spatiotemporal variation in densities of various bird populations in this system. We found significant changes in vegetation and other environmental conditions in riparian areas along the river since 2004, which are likely influencing habitat suitability for various bird populations (Fletcher & Hutto 2008). Such changes include aging riparian forests, declining shrub cover, and increases in non-native plant species that have been linked to large-scale modifications of the river system and its floodplain habitats over the past century for flood control, agriculture, and hydroelectric operations (Dixon et al. 2012). Other studies of riparian birds have found that bird communities are affected by land-use activities at multiple spatial scales, including local changes to vegetation structure associated with altered river flows and livestock grazing (Scott et al. 2003, Saab et al. 2005), and changes to surrounding landscapes due to agricultural conversion and urbanization (Tewksbury et al. 2002, Rodewald & Bakermans 2006). In addition, riparian bird populations are thought to be especially vulnerable to climate change due to their restricted breeding requirements and the sensitivity of riparian vegetation to climate-induced hydrologic changes (Huntley et al. 2006).

Although our efforts spanned a period of over 10 years, trend estimates we report are based on surveys from only four years of effort and thus should be viewed cautiously. This is because trends we report here could represent natural spatiotemporal variability in populations rather than deterministic changes in abundances. Continued monitoring will build on this dataset and provide more reliable assessments of population changes of wildlife and environmental conditions in riparian areas over time.

Evaluation of Monitoring Program

Ecological monitoring is built on a foundation of repeatedly measuring resources over time so that the presence, magnitude, and direction of trends can be detected in sufficient time to make informed management decisions (Thompson et al. 1998, Pollock et al 2002). Our review of bird observations gathered since 2004 indicate that the current monitoring effort (e.g., 1 visit to 223 sample points) is sufficient to generate precise estimates of densities of many common and uncommon species of breeding landbirds in riparian areas along the Madison and Missouri Rivers of Montana. This general finding is also corroborated by our analyses of population trends (Objective 1), which confirmed significant changes in densities of both common and uncommon species across time. Nonetheless, greater sampling effort is required to obtain more precise estimates for some uncommon and many rare species, which tend to be of greater management and conservation concern. For rare species and those of special concern, sampling could be increased to two times per year. Alternatively, more focused species-specific survey methods, such as those we employed for Yellow-billed Cuckoo (*Coccyzus americanus*) and Black-billed Cuckoo (*Coccyzus erythropthalmus*), could be implemented.

By assessing tradeoffs between sampling frequency and power to detect population changes, we found that increasing sampling frequency from every four years to every three years resulted in marginal gains in estimated power, whereas increasing effort to every two years resulted in substantial gains in power. Based on those findings, **we recommend sampling bird communities in this system every other year so as to more effectively monitor populations**. Importantly, our findings confirm the ability of this program to estimate biologically meaningful changes in densities of a relatively large number of breeding bird species, which include species that are common, uncommon, and of management and conservation interest.

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Appendix A. Total bird encounters, breeding habitat, and conservation status across long-term monitoring patches from 2004-2015.

Common Name	Total Abundance[a]	Breeding Habitat	MTSOC [b]	PIF SOC [c]	BLM Status
American Avocet	-	Wetland/Water			
American Crow	10				
American Goldfinch	715	Riparian Dependent			
American Kestrel	75				
American Redstart	28	Riparian Obligate			
American Robin	1,203				
American White Pelican	111	Wetland/Water	S3		
American Widgeon	2	Wetland/Water			
Bald Eagle	9	Riparian Obligate			SENSITIVE
Bank Swallow	25	Riparian Obligate		Declining	
Barn Swallow	8				
Belted Kingfisher	26	Riparian Obligate			
Black-billed Cuckoo	-	Riparian Dependent	S3	Yellow	
Black-billed Magpie	130				
Black-capped Chickadee	329	Riparian Dependent			
Black-headed Grosbeak	230	Riparian Dependent			
Blackpoll Warbler	2			Declining	
Blue-winged Teal	2	Wetland/Water			
Brewer's Blackbird	53			Declining	
Brewer's Sparrow	13		S3		SENSITIVE
Brown Thrasher	22				
Brown-headed Cowbird	1,007				
Bullock's Oriole	595	Riparian Obligate			
California Gull	83				
Canada Goose	12				
Caspian Tern	-	Wetland/Water	S2		
Cassin's Vireo	-				
Cedar Waxwing	630				
Chipping Sparrow	15				
Clark's Nutcracker	-		S3		
Clay-colored Sparrow	71				
Cliff Swallow	333				
Common Goldeneye	1	Riparian Obligate			
Common Grackle	223			Declining	
Common Loon	-	Wetland/Water	S3		SENSITIVE
Common Merganser	26	Riparian Obligate			
Common Nighthawk	63			Declining	

Common Raven	8				
Common Yellowthroat	175	Riparian Obligate			
Cooper's Hawk	9	Riparian Dependent			
Dark-eyed Junco	4				
Double-crested Cormorant	17				
Downy Woodpecker	193				
Dusky Flycatcher	4				
Eastern Kingbird	435	Riparian Dependent			
Eurasian Collared-Dove	8				
European Starling	1,393				
Evening Grosbeak	-		S3	Yellow	
Field Sparrow	-			Declining	
Fox Sparrow	3	Riparian Obligate			
Franklin's Gull	60	Wetland/Water	S3		SENSITIVE
Gadwall	5	Wetland/Water			
Gray Catbird	726	Riparian Obligate			
Great Blue Heron	36	Wetland/Water	S3		
Great Horned Owl	20				
Green-winged Teal	-	Wetland/Water			
Hairy Woodpecker	28				
Hooded Merganser	3	Riparian Obligate			
Horned Lark	-			Declining	
House Finch	107				
House Sparrow	8				
House Wren	2,774	Riparian Dependent			
Killdeer	7	Wetland/Water			
Lark Sparrow	28				
Lazuli Bunting	92	Riparian Dependent			
Least Flycatcher	1,334			Declining	
Lesser Scaup	1	Wetland/Water			
Lincoln's Sparrow	6	Riparian Obligate			
Long-billed Curlew	2		S3		SENSITIVE
Long-eared Owl	2	Riparian Dependent		Yellow	
MacGillivray's Warbler	4	Riparian Dependent			
Mallard	31	Wetland/Water			
Marbled Godwit	10	Wetland/Water			
Marsh Wren	30	Wetland/Water			
Mountain Bluebird	4				
Mountain Chickadee	1				
Mourning Dove	1,003				

Northern Bobwhite	-			Declining	
Northern Flicker	373				
Northern Harrier	2				
Northern Rough-winged Swallow	59	Wetland/Water			
Northern Waterthrush	17	Riparian Obligate			
Orchard Oriole	7	Riparian Obligate			
Osprey	8	Riparian Obligate			
Ovenbird	43	Riparian Obligate	S4		
Pileated Woodpecker	3		S3		
Pine Siskin	17			Declining	
Prairie Falcon	-				
Red Crossbill	2				
Red-breasted Nuthatch	10				
Red-eyed Vireo	51	Riparian Dependent			
Red-naped Sapsucker	79	Riparian Dependent			
Red-tailed Hawk	69				
Red-winged Blackbird	238	Wetland/Water			
Ring-billed Gull	5	Wetland/Water			
Ring-necked Duck	-	Wetland/Water			
Ring-necked Pheasant	34				
Rock Pigeon	20				
Rock Wren	-				
Ruby-crowned Kinglet	-				
Sage Thrasher	-		S3		SENSITIVE
Sandhill Crane	7	Wetland/Water			
Savannah Sparrow	9				
Say's Phoebe	-				
Sharp-shinned Hawk	2				
Song Sparrow	545	Riparian Obligate			
Sora	-	Wetland/Water			
Spotted Sandpiper	27	Wetland/Water			
Spotted Towhee	186				
Swainson's Hawk	5	Dependent			
Swainson's Thrush	30	Dependent			
Tennessee Warbler	-				
Tree Swallow	1,160	Riparian Dependent			
Trumpeter Swan	-	Wetland/Water	S3		SENSITIVE
Turkey Vulture	3				
Veery	36	Riparian Obligate	S3		
Vesper Sparrow	1				
Violet-green Swallow	204				

Warbling Vireo	209	Riparian Dependent			
Western Kingbird	278				
Western Meadowlark	35				
Western Screech-Owl	1	Riparian Obligate	S4		
Western Tanager	84				
Western Wood-Pewee	659	Riparian Dependent			
White-breasted Nuthatch	8				
White-crowned Sparrow	18				
White-throated Sparrow	1				
White-throated Swift	20				
Wild Turkey	2				
Willet	-	Wetland/Water			
Willow Flycatcher	114	Riparian Obligate			
Wilson's Snipe	5	Wetland/Water			
Wilson's Warbler	5	Riparian Obligate		Declining	
Wood Duck	1	Riparian Obligate			
Yellow Warbler	4,158	Riparian Obligate			
Yellow-breasted Chat	230	Riparian Obligate			
Yellow-headed Blackbird	5	Wetland/Water			
Yellow-rumped Warbler	14				
Yellow-throated Vireo	1	Riparian Dependent			

[a] No abundance reported for species detected outside of 50 m survey distance or 10 minute survey period.
[b] MTSOC- Montana Species of Concern, S1-high risk, S2-very limited, S3-Potential risk, S4-rare or potentially declining (Montana Animal Species of Concern Report 2016)
[c] PIF SOC- Partners in Flight Species of Conservation Concern, Red -highly vulnerable, Yellow - Range restricted or small population with major threats, Declining-Common birds in steep decline (Rosenberg 20

Appendix B. Estimates of trends in bird densities across the Madison and Missouri Rivers, 2004-2015.

B1. Estimates of annual trends (%) in bird species densities based on results of a simple linear mixed effects model without year x section interactions.

Species	Annual Trend (%)	*SE*	*t*	*P*
Obligate				
Common Yellowthroat	-0.2	0.2	-0.93	0.352
Song Sparrow	-1.3*	0.6	-2.34	0.020
Willow Flycatcher	0.2	0.4	0.57	0.573
Yellow Warbler	1.3*	0.4	3.28	0.001
Yellow-breasted Chat	0.5	0.3	1.64	0.104
Dependent				
American Goldfinch	-5.6*	0.7	-8.03	<0.001
Black-capped Chickadee	2.5*	0.6	4.03	<0.001
Black-headed Grosbeak	-0.2	0.4	-0.44	0.662
Bullock's Oriole	-0.8	0.6	-1.38	0.169
Gray Catbird	-1.3*	0.6	-2.10	0.038
House Wren	3.0*	0.5	5.72	<0.001
Lazuli Bunting	0.2	0.3	0.66	0.512
Red-eyed Vireo	-0.1	0.1	-0.62	0.534
Red-naped Sapsucker	-0.9*	0.4	-2.44	0.016
Tree Swallow	1.1	0.9	1.21	0.228
Warbling Vireo	-1.2*	0.3	-3.53	0.001
Western Wood-Pewee	-1.1*	0.5	-2.12	0.035
Generalist				
American Robin	1.1	0.6	2.00	0.047
Black-billed Magpie	-0.6*	0.3	-1.97	0.051
Brown-headed Cowbird	-0.8	0.6	-1.36	0.176
Cedar Waxwing	-1.9*	0.9	-2.07	0.040
Clay-colored Sparrow	-0.1	0.1	-0.72	0.471
Common Nighthawk	-0.4	0.3	-1.60	0.111
Downy Woodpecker	-1.6*	0.6	-2.56	0.011
Eastern Kingbird	-0.5	0.5	-0.88	0.378
European Starling	0.6	0.9	0.65	0.519
House Finch	-0.9*	0.4	-2.49	0.014
Least Flycatcher	1.4*	0.5	2.86	0.005
Mourning Dove	-2.7	0.5	-5.19	<0.001
Northern Flicker	-0.6	0.4	-1.61	0.108
Red-winged Blackbird	2.2*	0.5	4.20	<0.001
Spotted Towhee	-0.3	0.3	-1.18	0.240
Western Kingbird	-0.3	0.5	-0.63	0.531

* Significant ($P<0.05$) linear trend

B2. Estimates of trends in bird species density based on linear-mixed effects model with Section and Year x Section interaction terms. *Note*: estimates are only shown for species with significant ($P < 0.05$) Year x Section interaction, ANOVA.

	Year			Section						Year x Section					
				Missouri Breaks			Missouri, upper			Year x Missouri Breaks			Year x Missouri, upper		
Species	**Est.**	**SE**	***p***	**Est.**	**SE**	***p***	**Est.**	**SE**	***p***	**Est.**	**SE**	***p***	**Est.**	**SE**	***p***
American Robin	0.031	0.010	0.002	-0.661	0.090	<0.001	-0.222	0.088	0.014	-0.035	0.014	0.011	-0.020	0.013	0.134
Common Nighthawk	-0.013	0.004	0.004	0.017	0.026	0.523	-0.016	0.025	0.517	0.016	0.006	0.008	0.010	0.006	0.114
European Starling	0.042	0.016	0.008	-0.240	0.165	0.153	-0.044	0.161	0.785	-0.069	0.022	0.002	-0.037	0.021	0.085
Red-naped Sapsucker	-0.035	0.006	<0.001	-0.196	0.039	<0.001	-0.104	0.038	0.008	0.037	0.009	<0.001	0.037	0.009	<0.001
Red-winged Blackbird	0.056	0.009	<0.001	-0.556	0.078	<0.001	-0.385	0.076	<0.001	-0.059	0.013	<0.001	-0.038	0.012	0.002
Song Sparrow	-0.048	0.010	<0.001	0.039	0.090	0.667	0.118	0.088	0.183	0.052	0.013	<0.001	0.049	0.013	<0.001
Warbling Vireo	-0.028	0.006	<0.001	-0.230	0.068	0.001	-0.198	0.066	0.004	0.023	0.008	0.004	0.020	0.008	0.011
Western Wood-Pewee	-0.042	0.009	<0.001	0.115	0.088	0.196	0.196	0.086	0.026	0.046	0.013	<0.001	0.043	0.012	0.001
Willow Flycatcher	-0.016	0.006	0.016	-0.134	0.069	0.057	0.019	0.067	0.776	0.013	0.009	0.133	0.034	0.009	<0.001
Yellow Warbler	0.032	0.006	<0.001	-0.875	0.065	<0.001	-0.338	0.063	<0.001	-0.045	0.009	<0.001	-0.005	0.009	0.601

[a] Madison River set as reference section.

B3. Estimates of trends in bird density for combined species groups (all, riparian dependent, and riparian obligate) based on linear-mixed effects model with Section and Year x Section interaction.

	Year			Section [a]						Year x Section					
				Missouri Breaks			Missouri, upper			Year x Missouri Breaks			Year x Missouri, upper		
Species Group	**Est.**	**SE**	***p***	**Est.**	**SE**	***p***	**Est.**	**SE**	***p***	**Est.**	**SE**	***p***	**Est.**	**SE**	***p***
All Species	-0.003	0.003	0.329	-0.276	0.050	<0.001	-0.059	0.049	0.231	-0.001	0.005	0.783	0.004	0.004	0.382
Riparian Dependent	-0.003	0.005	0.567	-0.020	0.077	0.792	0.067	0.075	0.380	0.024	0.007	0.001	0.012	0.007	0.097
Riparian Obligate	0.011	0.006	0.068	-0.413	0.074	<0.001	-0.085	0.072	0.240	-0.008	0.008	0.308	0.021	0.008	0.009

[a] Madison River set as reference section.

Appendix C. Plant species encountered (number of sample points where detected) during riparian vegetation surveys from 2004-2015.

Common Name	Genus Species	Wetland Status[a]	2004	2008	2012	2015
Trees (>8cm DBH)						
Box Elder	*Acer negundo*		40	29	27	37
Mountain Alder	*Alnus incana.*	FACW	23	16	17	17
Water Birch	*Betula occidentalis*	FACW	31	35	25	37
Russian Olive	*Elaeagnus angustifolia*		13	13	20	20
Green Ash	*Fraxinus pennsylvanica*	FACW	13	15	15	20
Rocky Mountain Juniper	*Juniperus scopulorum*		44	33	37	48
Narrowleaf Cottonwood	*Populus angustifolia*	FACW	96	71	98	79
Black Cottonwood	*Populus balsamifera*	FACW	23	13	50	79
Plains Cottonwood	*Populus deltoides*	FAC	103	93	87	97
Choke Cherry	*Prunus viginiana*	FACU	1	4	4	9
Willow spp.	*Salix spp.*	FACW	57	88	43	35
Shrubs & Saplings (<8cm DBH)						
Box Elder	*Acer negundo*	FAC	1	14	5	4
Mountain Alder	*Alnus incana.*	FACW	7	9	11	4
Serviceberry	*Amelanchier alnifolia*	FACU	2	1	0	0
Silver sagebrush	*Artemesia cana*	FACU	4	0	0	3
Big Sagebrush	*Artemisia tridentata*		1	9	5	3
Water Birch	*Betula occidentalis*	FACW	6	19	21	11
Red-osier Dogwood	*Cornus sericea*	FACW	77	56	51	57
Russian Olive	*Elaeagnus angustifolia*		8	13	7	4
Green Ash	*Fraxinus pennsylvanica*	FACW	2	9	7	10
Rocky Mountain Juniper	*Juniperus scopulorum*		34	38	43	35
Common Juniper	*Juniperus communis*		12	7	15	9
Narrowleaf Cottonwood	*Populus angustifolia*	FACW	11	18	16	2
Black Cottonwood	*Populus balsamifera*	FACW	3	0	19	17
Plains Cottonwood	*Populus deltoides*	FAC	3	9	13	8
Choke Cherry	*Prunus viginiana*	FACU	15	19	16	17
Skunkbush Sumac	*Rhus trilobata*	FAC	31	13	26	44
Currant spp.	*Ribes spp.*	FAC	78	84	100	63
Rose spp.	*Rosa spp.*	FACU	117	103	116	94
Willow spp.	*Salix spp.*	FACW	123	100	107	87
Buffaloberry	*Shepherdia canendensis*	FACU	1	3	0	1
Common Snowberry	*Symphoricarpus albus*	FACU	159	151	142	133

[a] National Wetland Plant List: OBL-Obligate wetland (almost always occurs in wetlands), FACW-Facultative Wetland (Usually occur in wetlands), FAC-Facultative (Occur in wetlands and non-wetlands), FACU-Facultative upland (Usually occur in non-wetlands, Lichvar 2014)

.. Continued from previous page.

Common Name	Genus Species	2004	2008	2012	2015
Non-native & Invasive Herbaceous					
Yellow mustard	*Brassica* spp.	2	33	30	23
Cheat grass	*Bromus tectorum*	15	27	25	31
Shepherd's Purse	*Capsella bursa-pastoris*	-	-	-	14
Hoary Cress Whitetop	*Cardaria draba*	-	28	-	-
Knapweed species	*Centaurea* spp.	4	7	8	9
Canada Thistle	*Cirsium arvense*	136	151	161	155
Thistle spp.	*Cirsium* spp.	2	-	3	17
Common Hound's Tongue	*Cynoglossum officinale*	91	122	111	114
Leafy Spurge	*Euphorbia esula*	74	80	102	84
Bedstraw	*Galium* spp.	1	31	-	-
Pepperweed	*Lepidium latifolium*	4	1	2	6
Dalmation Toadflax	*Linaria dalmatica*	-	-	-	1
Common Toadflax	*Linaria vulgaris*	11	32	-	-
Reed Canary Grass	*Phalaris arundinacea*	4	1	-	1
Sulfur Cinquefoil	*Potentilla recta*	-	-	3	-
Tall Buttercup	*Ranunculus acris*	-	-	23	-
Sowthistle	*Sonchus arvensis*	1	-	9	1
Dandelion	*Taraxacum officinale*	2	47	63	*n/a*
Common Tansy	*Tanacetum vulgare*	3	8	9	-
Field Pennycress	*Thlaspi arvense*	1	-	-	-
Common Mullein	*Verbascum Thapsus*	13	13	18	18

Appendix D. Estimates of trends in vegetation measures based on linear-mixed effects model with Section and Year x Section interaction terms.

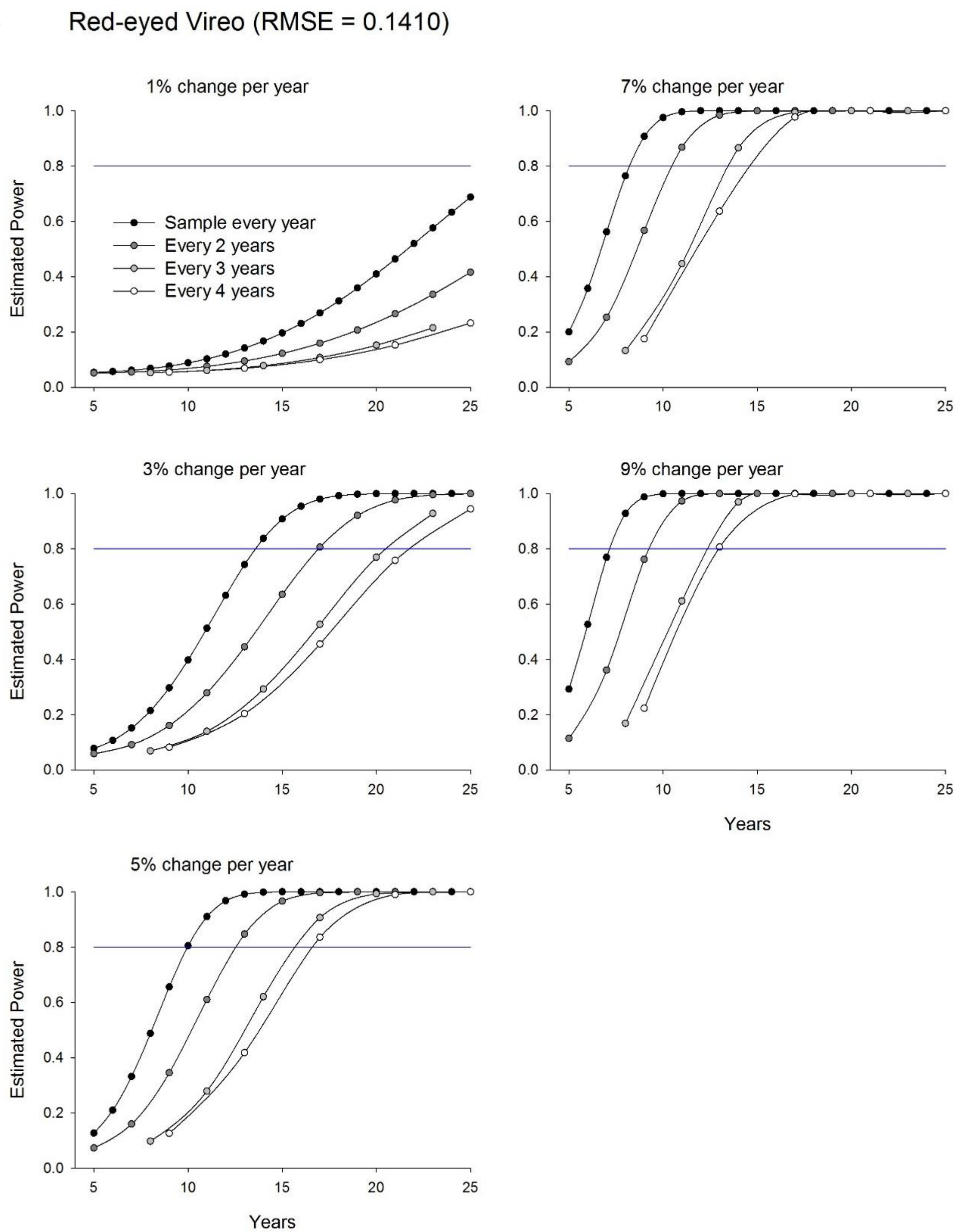
	Year			Section [a]						Year x Section					
				Missouri Breaks			Missouri, upper			Year x Missouri Breaks			Year x Missouri, upper		
Vegetation Measures	Est.	SE	p	Est.	SE	p	Est.	SE	p	Est.	SE	p	Est.	SE	p
Small tree density (no./ha)	-0.009	0.002	<0.001	1.169	0.067	<0.001	0.761	0.070	<0.001	0.004	0.003	0.123	0.002	0.003	0.487
Medium tree density (no./ha)	0.036	0.021	0.098	0.726	0.220	0.002	0.377	0.228	0.104	0.000	0.029	0.988	-0.006	0.030	0.838
Large tree density (no./ha)	0.018	0.016	0.258	1.150	0.322	0.001	0.641	0.334	0.060	-0.006	0.021	0.788	0.006	0.022	0.784
Max. canopy height (m)	-0.021	0.007	0.002	0.574	0.096	<0.001	0.387	0.100	<0.001	0.000	0.009	0.988	-0.003	0.009	0.754
Small snag density (no./ha)	-0.052	0.026	0.051	0.418	0.260	0.114	0.280	0.269	0.302	0.023	0.035	0.512	0.013	0.036	0.725
Medium snag density (no./ha)	0.005	0.021	0.806	0.280	0.240	0.249	0.502	0.248	0.048	-0.034	0.027	0.213	-0.021	0.028	0.466
Large snag density (no./ha)	0.069	0.024	0.004	-0.229	0.202	0.261	0.169	0.209	0.421	-0.063	0.031	0.046	-0.063	0.033	0.056
Total snag dominance (m^2/ha)	0.027	0.024	0.269	0.253	0.241	0.298	0.400	0.249	0.115	-0.052	0.032	0.114	-0.037	0.034	0.269
Populus spp. dominance (m^2/ha)	0.018	0.010	0.074	0.855	0.193	<0.001	0.538	0.200	0.009	0.006	0.014	0.669	0.002	0.014	0.889
Salix spp. dominance (m^2/ha)	0.004	0.012	0.751	-0.139	0.078	0.080	-0.163	0.080	0.046	-0.048	0.015	0.002	-0.030	0.016	0.059
Green Ash dominance (m^2/ha)	<0.001	0.006	1.000	0.264	0.094	0.007	0.070	0.097	0.477	0.003	0.008	0.716	0.005	0.008	0.587
Box Elder dominance (m^2/ha)	<0.001	0.010	1.000	0.705	0.192	0.001	0.307	0.199	0.130	0.005	0.014	0.738	0.009	0.014	0.525
Juniper dominance (m^2/ha)	0.011	0.004	0.007	-0.198	0.107	0.071	0.234	0.111	0.040	-0.011	0.005	0.053	0.006	0.006	0.282
Russian Olive dominance (m^2/ha)	-0.002	0.004	0.646	0.070	0.054	0.201	0.035	0.056	0.534	0.011	0.005	0.038	0.010	0.005	0.057
Total shrub cover (%)	-0.095	0.014	<0.001	-0.637	0.242	0.011	-0.252	0.251	0.318	0.020	0.019	0.275	0.019	0.019	0.335
Total sapling cover (%)	-0.014	0.016	0.394	-0.002	0.130	0.987	-0.263	0.135	0.057	0.004	0.021	0.857	-0.016	0.022	0.483
Salix spp. cover (%)	-0.109	0.013	<0.001	-1.617	0.277	<0.001	-0.741	0.287	0.013	0.083	0.017	<0.001	0.047	0.018	0.010
Populus spp. sapling cover (%)	-0.015	0.012	0.183	0.081	0.092	0.385	0.082	0.095	0.395	0.002	0.015	0.898	-0.005	0.016	0.752
Total weed cover (%)	-0.035	0.015	0.023	0.200	0.185	0.285	0.263	0.192	0.176	0.001	0.021	0.976	0.002	0.021	0.930
Index of Grazing Intensity (0-3)	-0.027	0.009	0.004	-0.105	0.086	0.229	-0.063	0.089	0.480	-0.001	0.013	0.930	-0.002	0.013	0.875

[a] Madison River set as reference section.

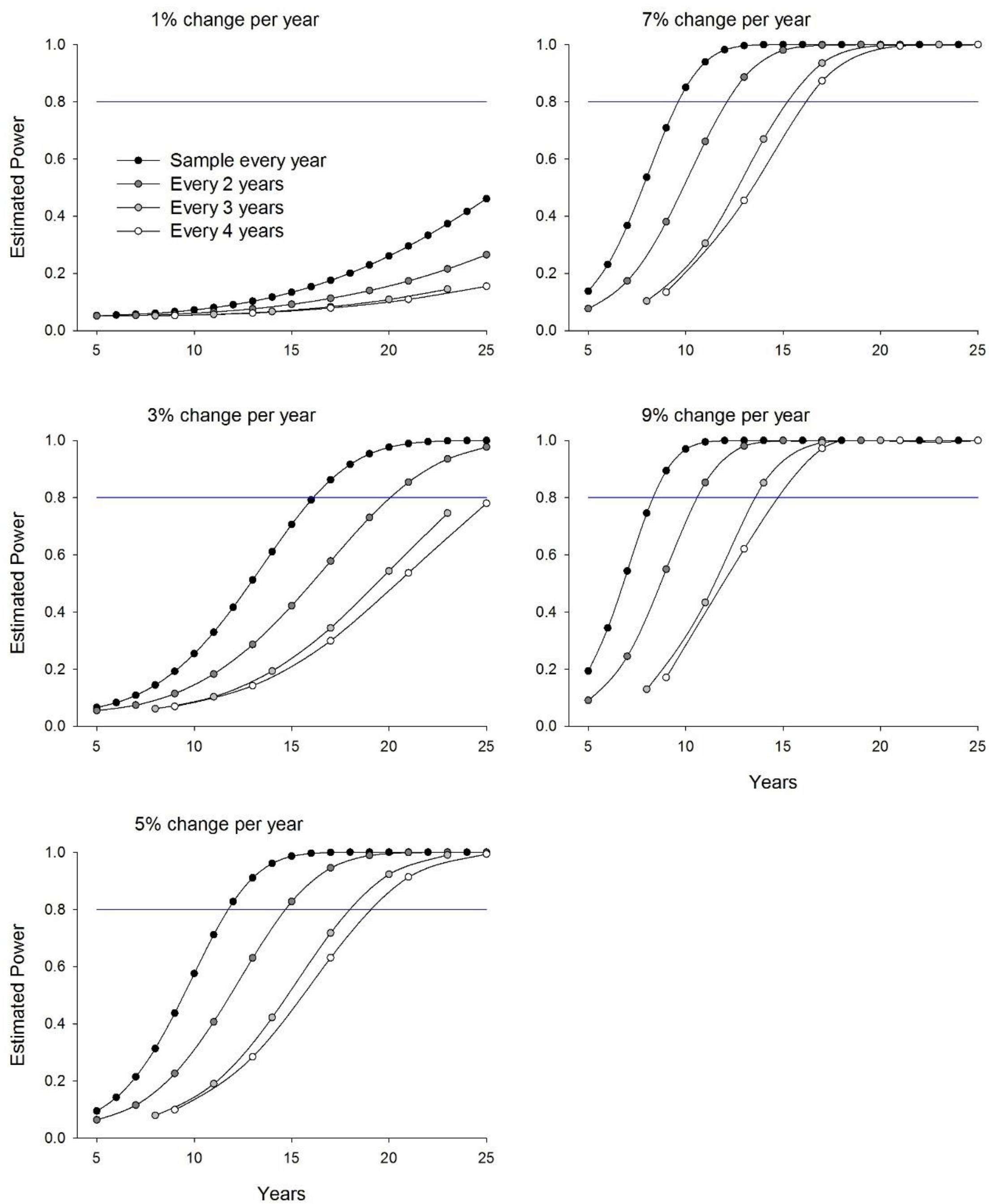
Appendix E. Power to detect linear trends in bird densities

Power to detect linear trends (1-9% annual change) in density of eight bird species based on survey frequency of 1-4 years for 25 years. Type-I error rate (α) was set at 0.05.

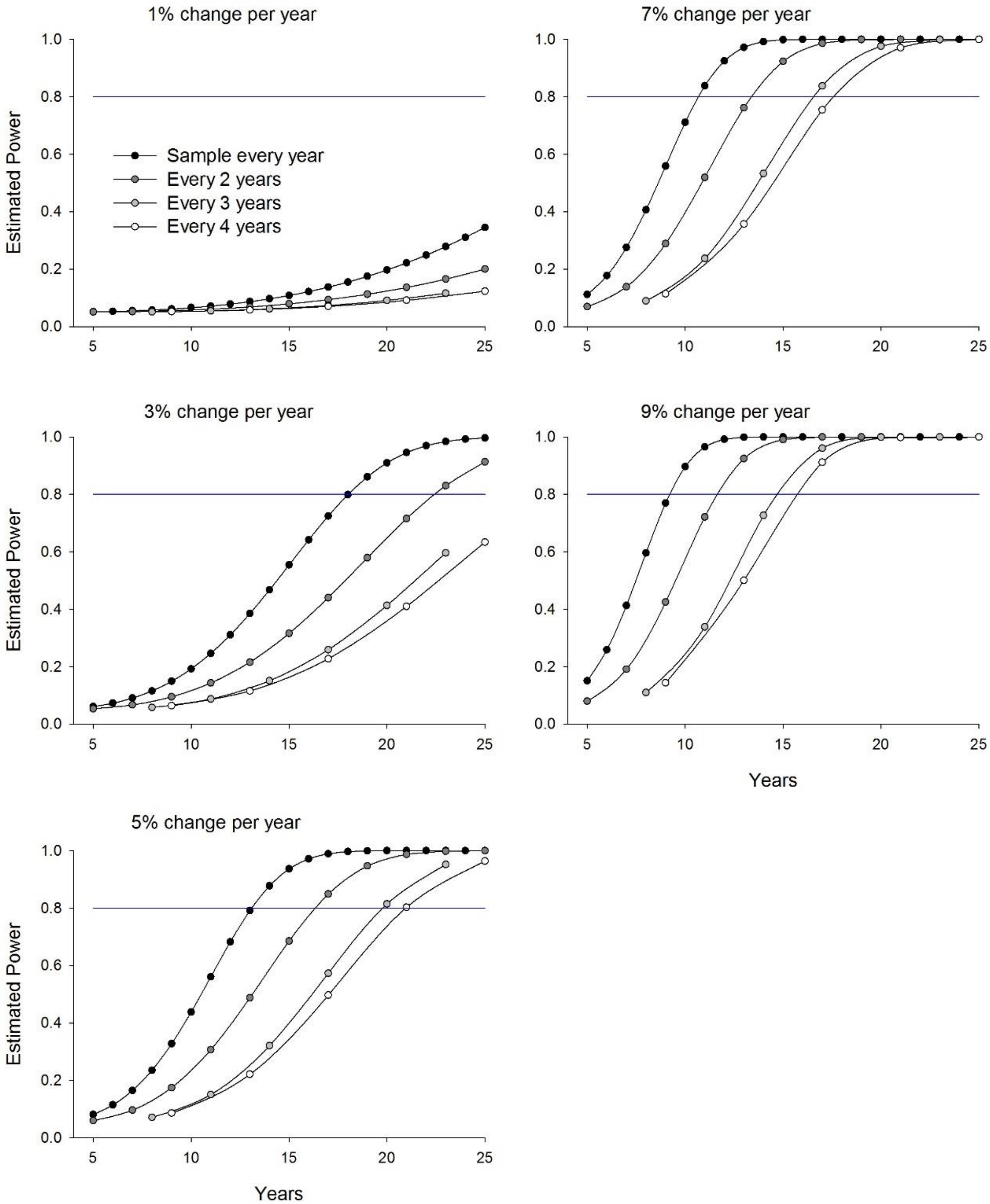
E-1



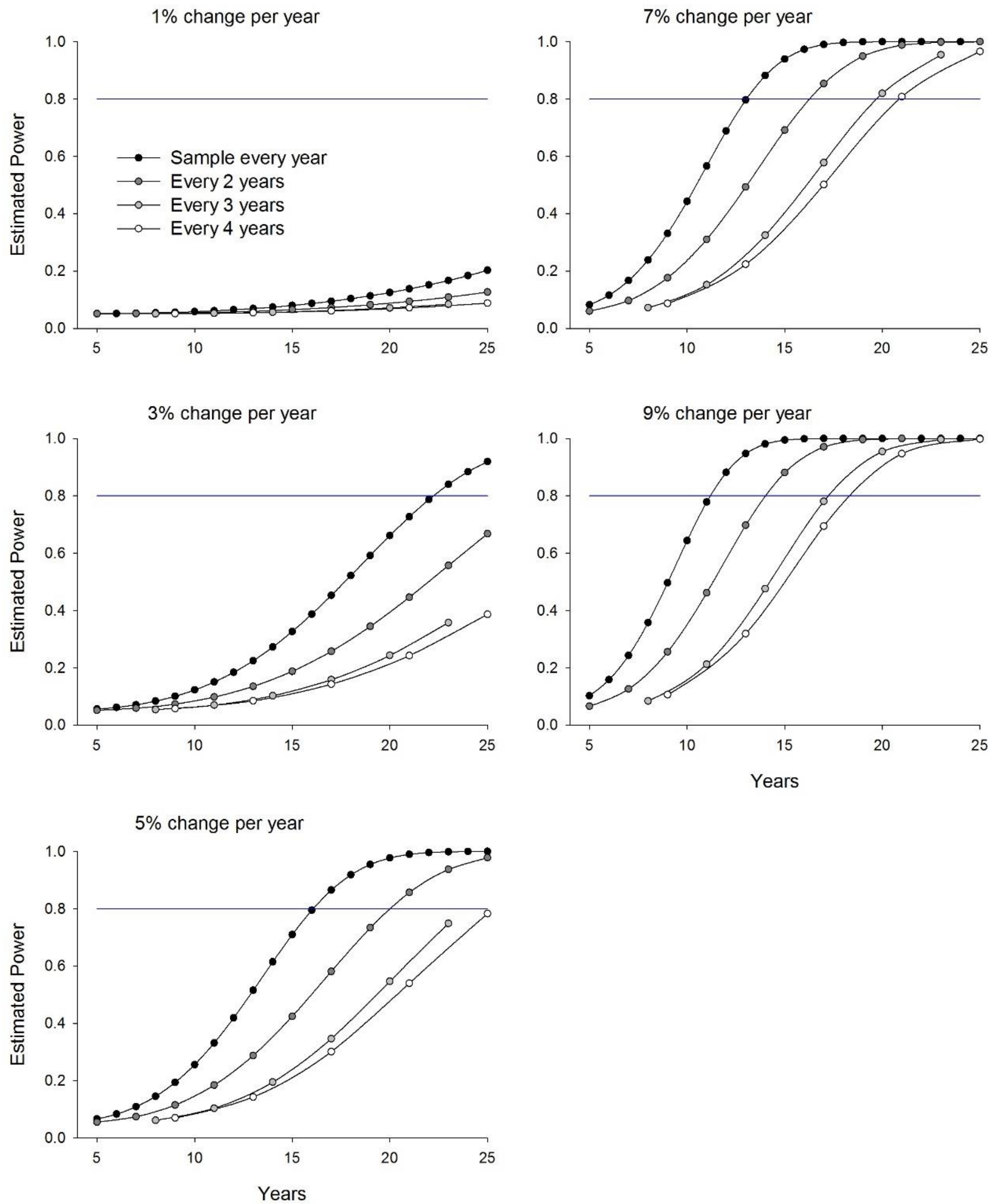
E-2 Willow Flycatcher (RMSE = 0.1856)



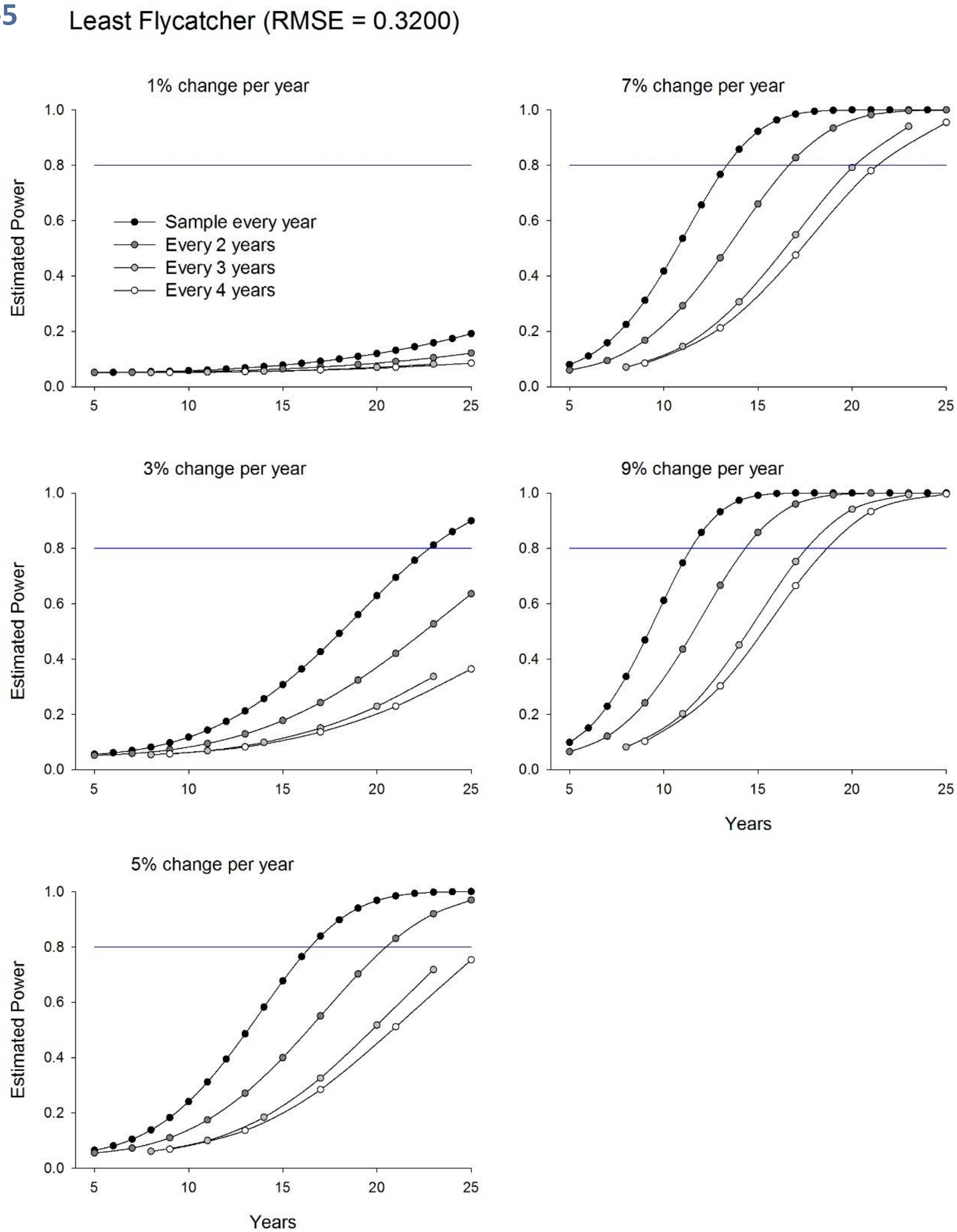
E-3 Yellow Warbler (RMSE = 0.2216)



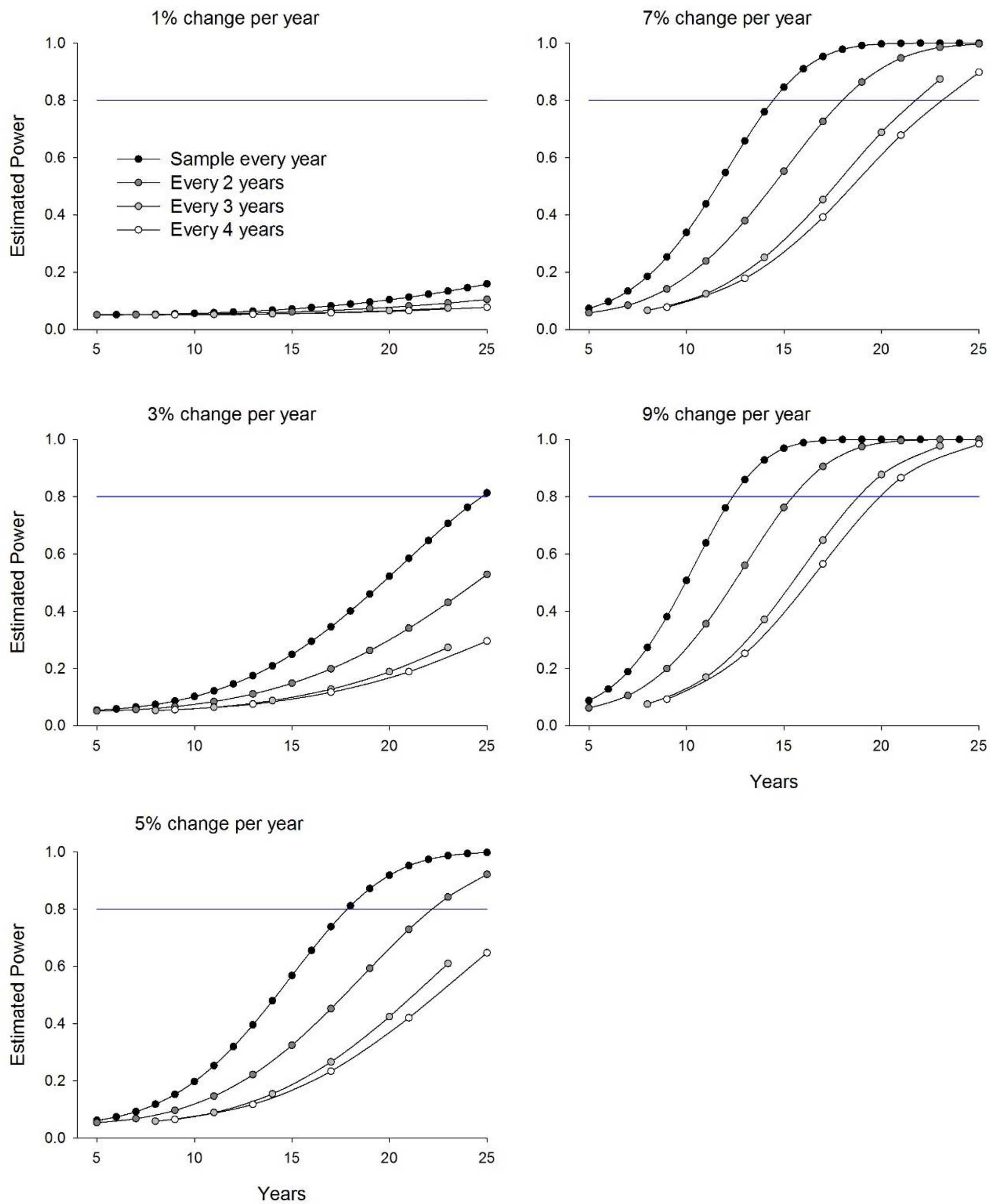
E-4 Song Sparrow (RMSE = 0.3081)



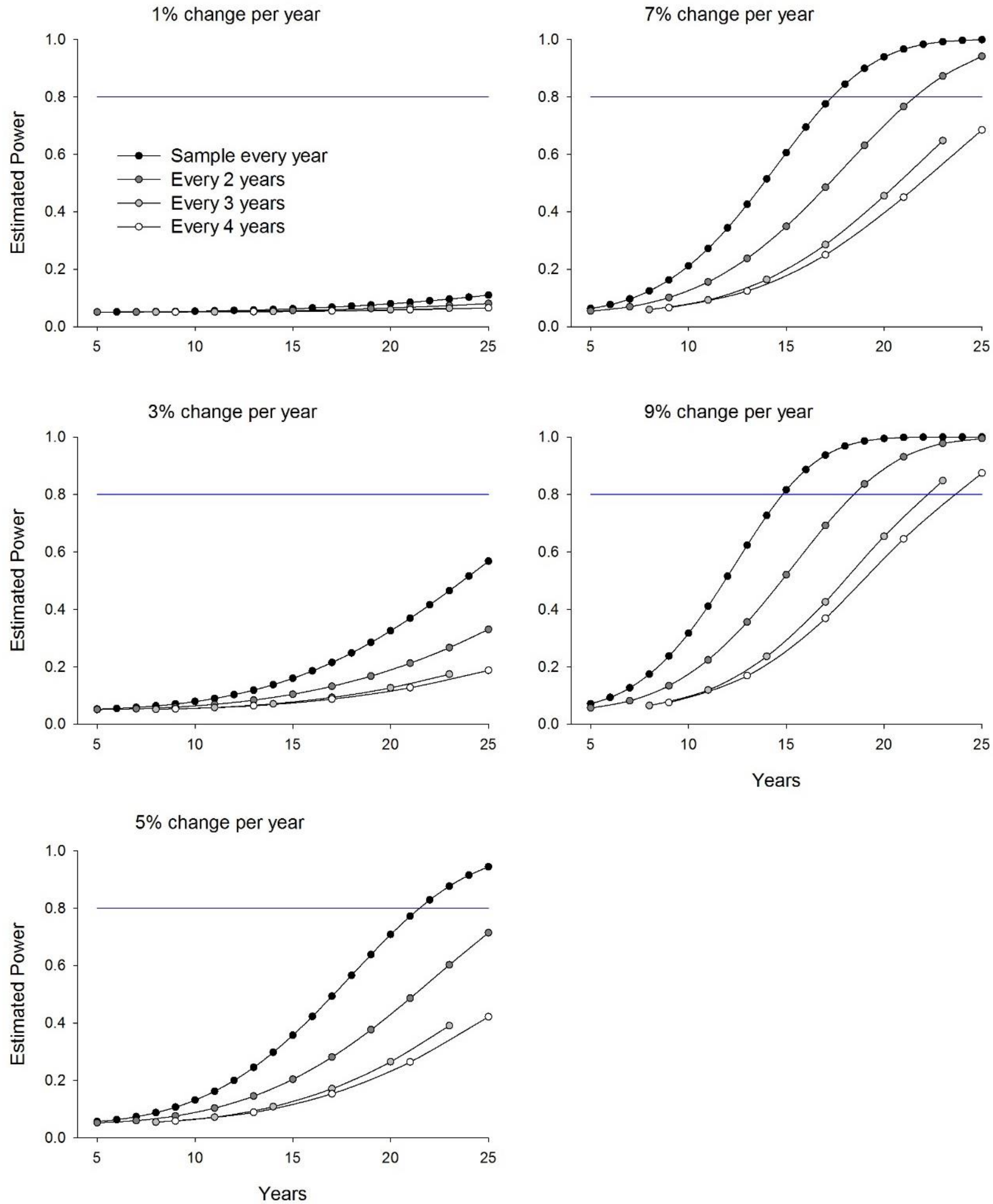
E-5


Least Flycatcher (RMSE = 0.3200)
1% change per year
7% change per year
3% change per year
9% change per year
5% change per year
Estimated Power
Years
Sample every year
Every 2 years
Every 3 years
Every 4 years
0.0
0.2
0.4
0.6
0.8
1.0
5
10
15
20
25

E-6 Gray Catbird (RMSE = 0.3636)



E-7 European Starling (RMSE = 0.4866)



E-8 Black-capped Chickadee (RMSE = 0.6177)