



Research Article

Energy Development Affects Populations of Sagebrush Songbirds in Wyoming

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ABSTRACT Oil and natural gas development in the Intermountain West region of North America has expanded over the last 2 decades, primarily within sagebrush dominated landscapes. Although the effects of energy development on high-profile game species such as the greater sage-grouse (*Centrocercus urophasianus*) have been documented, studies examining responses of non-game birds are lacking. Simultaneously, many songbirds that breed within sagebrush steppe habitats have shown range-wide population declines that are likely due to widespread habitat loss and alteration. We evaluated songbird abundance and species richness across gradients of oil and natural gas development intensity, as indexed by well density, at 3 energy fields (2 natural gas and 1 oil) in the Upper Green River Basin, Wyoming, USA during 2008–2009. While simultaneously accounting for important habitat attributes, increased well density was associated with significant decreases in Brewer's sparrow (*Spizella breweri*) and sage sparrow (*Amphispiza belli*) abundance, particularly in the Jonah natural gas field. Vesper sparrows (*Pooecetes gramineus*) were also negatively influenced by increased well density. Horned larks (*Eremophila alpestris*) increased with well density in the Pinedale Anticline natural gas field, and sage thrashers (*Oreoscoptes montanus*) showed no response to energy development. Species richness was not significantly affected by well density. Results suggest that regional declines of some songbird species, especially sagebrush-obligates, may be exacerbated by increased energy development. Understanding the specific mechanisms underlying responses to energy development is an important next step and will aid land managers in the development of effective mitigation and management strategies for the maintenance of stable bird communities in sagebrush habitat. © 2011 The Wildlife Society.

KEY WORDS avian abundance, Brewer's sparrow, natural gas, oil, sage sparrow, sage thrasher, shrubsteppe, species richness.

Habitat loss, fragmentation, and alteration due to anthropogenic activities are major factors contributing to wildlife population declines and biodiversity loss across a variety of ecosystems (Saunders et al. 1991, Wilcove et al. 1998). Rapid loss, fragmentation, and severe degradation of sagebrush (*Artemisia tridentata*) communities (Knick and Rotenberry 2000) have been primarily due to human activities including agricultural conversion (Braun et al. 1976, Vander Haegen et al. 2000) and livestock overgrazing (Beck and Mitchell 2000), invasive species such as cheatgrass (*Bromus tectorum*; Monsen and Shaw 2000, Rich et al. 2005), and altered fire regimes (Connelly and Braun 1997). Simultaneously, many wildlife species dependent on sagebrush have declined or been locally extirpated due to loss of historical habitat, behavioral avoidance of disturbance, increased predation risk, and decreased annual survival, reproductive success, and recruitment (Braun et al. 2002, Knick et al. 2003, Holloran 2005, Vander Haegen 2007).

Concurrent with increased anthropogenic land use in North American sagebrush habitats, shrubland and grassland bird populations have declined faster than other avian species groups (Paige and Ritter 1999, Knick et al. 2003). In particular, the Brewer's sparrow (*Spizella breweri*), sage sparrow (*Amphispiza belli*), and sage thrasher (*Oreoscoptes montanus*), 3 migratory passerine species considered sagebrush-obligates during the breeding season (Braun et al. 1976), have shown average annual declines in nationwide abundance between 1980 and 2007 of 1.5%, 0.2%, and 1.1%, respectively (Sauer et al. 2008). Indeed, species dependent on a single habitat type are usually more sensitive to anthropogenic habitat modifications than are generalists (Saab and Rich 1997). Although efforts to understand habitat relationships of non-game sagebrush birds have increased recently, we still know little about the impacts of specific types of habitat change on individual habitat use, reproductive success, and annual survival or how anthropogenic changes may interact with critical habitat components to influence populations.

Oil and natural gas development has expanded across the Intermountain West over the last 2 decades, primarily within sagebrush dominated landscapes (Knick et al. 2003). In Wyoming, for example, as of 2008 there were >2 million ha

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of producing oil and gas leases and >5.5 million ha authorized for production (U.S. Department of the Interior [USDI] 2009; Fig. 1). Energy development infrastructure such as drill pads, waste pits, access roads, and pipelines convert and fragment sagebrush habitats, often negatively impacting wildlife populations (Weller et al. 2002, Walker et al. 2007, Doherty et al. 2008, Sawyer et al. 2009, Holloran et al. 2010).

Research focusing on effects of energy development on sagebrush birds has centered on the greater sage-grouse (*Centrocercus urophasianus*; Walker et al. 2007, Doherty et al. 2008, Holloran et al. 2010). Adverse effects of energy development on this high-profile game species are well-documented and include decreased recruitment to or abandonment of leks, avoidance of nesting near infrastructure, decreased nest and chick survival, and increased adult mortality due to increasing disease prevalence, vehicle collisions, and raptor predation (Naugle et al. 2011). Yet

studies examining responses of the rest of the sagebrush bird community to oil and natural gas development are lacking (Ingelfinger and Anderson 2004). Understanding how songbird populations may be impacted by anthropogenic disturbance, and how disturbance impacts may interact with critical habitat features, is an important step in developing effective recommendations for management strategies geared towards maintenance of stable sagebrush bird communities.

Our objective was to assess the relationship between energy development intensity in sagebrush habitat and songbird populations and avian community composition. Specifically, we evaluated the relative abundance and species richness of songbirds across gradients of oil and natural gas well density and habitat variation.

STUDY AREA

We conducted our study within sagebrush habitat coinciding with energy development in the Upper Green River Basin (42°60'N, 109°75'W) of southwestern Wyoming, USA (Fig. 1). Specifically, our 3 study areas were the northern portion of the Pinedale Anticline Project Area (PAPA) natural gas field, the Jonah natural gas field, and the northern portion of the Big Piney-LaBarge (LaBarge) oil field (Fig. 2). Located south of Pinedale, Wyoming, PAPA, and Jonah ranked among the most highly concentrated and productive natural gas fields in North America (USDI 2006, 2008). The LaBarge area was an aggregation of oil fields south of Big Piney, Wyoming. The Upper Green River Basin landscape was dominated by big sagebrush (*Artemisia tridentata* spp.) with a primarily native understory of grasses and forbs (Lyon and Anderson 2003). Yearly precipitation averaged 27.5 cm (Western Regional Climate Center 2010).

METHODS

Site Selection

To ensure sampling spanned a gradient of energy development intensity, we stratified each study area into 4 levels of development based on existing variation in well density: none (0 wells/km²), light (1–6 wells), moderate (7–15 wells), and heavy (>15 wells) development. Using aerial imagery and geographic well locations (Wyoming Geographic Information Science Center, Laramie, WY), we mapped well density in each energy field (Fig. 2) using ArcGIS 9.2 software, and randomly selected potential sampling sites within those strata.

Songbird habitats in sagebrush steppe have been characterized by measures of patch size, spatial homogeneity, and shrub attributes (Rotenberry and Wiens 1980; Wiens and Rotenberry 1981; Petersen and Best 1985a,b; Knopf et al. 1990). Therefore, we ground-truthed potential sampling sites to ensure they consisted of ≥20% shrub cover (Wiens and Rotenberry 1981, Chalfoun and Martin 2007), average shrub height ≥35 cm (Rich 1980; Petersen and Best 1985a,b), and average shrub crown vigor ≥50%

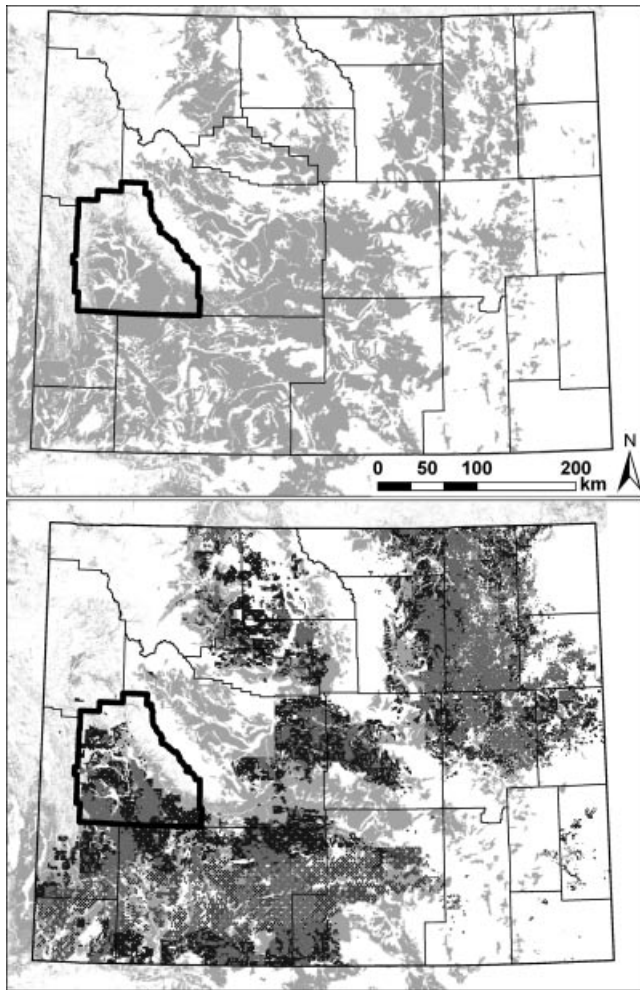


Figure 1. We examined sagebrush songbird population responses to energy development in Sublette County (outlined in bold), Wyoming, USA, 2008–2009. Top: Sagebrush habitats (light gray shading) are predominant throughout Wyoming (U.S. Geological Survey 2001). Bottom: Producing (medium gray) and authorized (dark gray) oil and natural gas leases (as of 2008; Wyoming Geographic Information Science Center 2009) show extensive overlap with sagebrush habitats across the state.

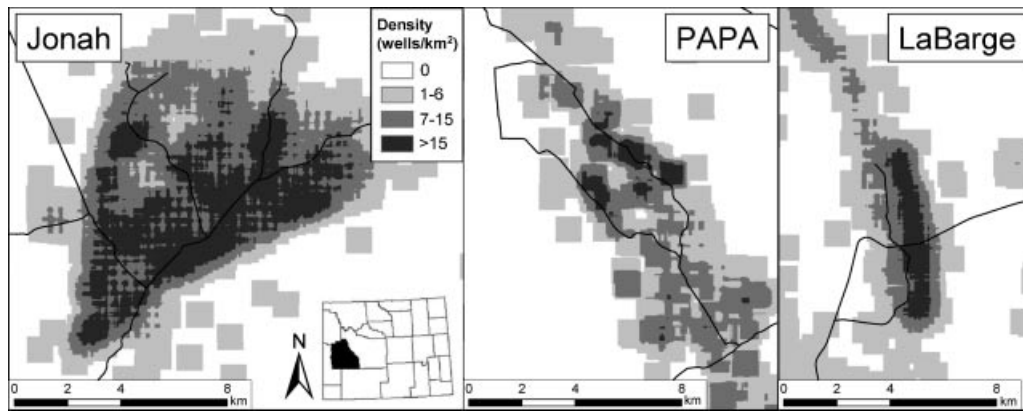


Figure 2. Three energy fields in Sublette County, Wyoming, USA (inset), that we used to examine the relationship between oil and natural gas development and sagebrush songbird abundance and richness, 2008–2009. We used 4 a priori categories of well density (wells/km²) to stratify point count sampling sites, represented by light to dark shading.

(Petersen and Best 1985a,b; Chalfoun and Martin 2009). Within each development strata at each study area, we chose the first 5 randomly selected sites that met these habitat criteria for placement of our point count clusters. Clusters consisted of 4 points in the shape of a square with 200-m spacing between points; if habitat minimums at points were not met, we adjusted points outward with a maximum spacing of 400 m. By selecting sites that met habitat minimums we sought to survey only potentially suitable nesting and foraging habitat within areas of differing energy development intensity.

Avian Abundance and Species Richness

We evaluated avian abundance and species richness using point count sampling (Reynolds et al. 1980) from May through July, 2008–2009. We surveyed 20 clusters per energy field (with 5 point count clusters in each of the 4 well density strata), for a total of 240 points. During each 10-min survey we recorded all birds seen or heard and distance to observer using digital rangefinders, taking care to avoid double-counting individuals. We recorded flyovers but excluded them from analyses. Surveys began at sunrise on mornings without rain or strong winds and were completed within 3 hr. We repeated surveys 3 times in 2008 and twice (due to persistent rain) in 2009, varying observer and time of visit among surveys. We surveyed the same sites in both years, except where creation or expansion of drilling infra-

structure encroached on 7 point count clusters (2 in PAPA and 5 in Jonah) in 2009, which required relocation of 10 survey points. In most cases, we moved just one point per cluster and reassessed well density for the cluster for that year. We could not resurvey 2 additional clusters in PAPA in 2009 because the entire cluster area was developed, and we excluded those clusters from analyses.

We used Program DISTANCE (Thomas et al. 2010) to fit detection-probability functions for species with sufficient detections at each study area. We pooled data across years, truncated the furthest 10% of distances, and fit detection functions for a uniform model with cosine expansions, a uniform model with simple polynomial expansions, and a half-normal model with hermite polynomial expansions (Somershoe et al. 2006, Thomas et al. 2010). We used Akaike's Information Criterion (Burnham and Anderson 2002) to select the model with the best relative fit and adjusted our relative abundance estimates using the model-generated detection probabilities (Table 1). However, the low-calculated detection probabilities for Brewer's sparrows (0.224–0.298) produced unrealistically high abundance estimates, based on minimum territory sizes of approximately 0.5 ha (Wiens et al. 1985, Chalfoun and Martin 2007). We therefore truncated the Brewer's sparrow data at 100 m rather than the furthest 10% of detections. We summarized adjusted detections for each species by cluster, averaged over the number of visits each year. We summarized species richness as the average number of breeding songbird species detected per cluster visit in each year.

Table 1. Detection probabilities for the 5 most common songbird species we detected at 3 energy fields in southwestern Wyoming, USA, 2008–2009, calculated using Program DISTANCE.

Species	Jonah	PAPA ^a	LaBarge
Brewer's sparrow	0.378	0.384	0.448
Sage sparrow	0.423	0.300	0.359
Sage thrasher	0.361	0.323	0.493
Vesper sparrow	0.432 ^b	0.432	0.565
Horned lark	0.508	0.555	0.581

^a Pinedale Anticline Project Area.

^b Detections at Jonah were insufficient (≤ 50 individuals) for estimation of vesper sparrow detection probabilities, so we assumed this value was similar to that of the adjacent energy field (PAPA).

Energy Development and Habitat Characteristics

We used well density as a proxy for energy development intensity. Using aerial imagery and geographic locations of wells, we calculated the number of well locations within a 1-km² area (564-m radius) around each point count center using ArcGIS 9.2 software and averaged these values to estimate well density for each cluster.

Because abundance of sagebrush songbirds is influenced by habitat characteristics at breeding sites, we quantified habitat variation at our sampling sites to control for habitat when

examining energy development effects. We measured habitat attributes within 5-m-radius circular plots (Martin et al. 1997; Chalfoun and Martin 2007, 2009) placed at 2 locations with randomly selected direction and distance up to 50 m from each point count center. We completed habitat measurements during a 3-week period beginning mid-July of each year, surveying half of each cluster in 2008 and the remainder in 2009. We quantified shrub cover using the line intercept method (Lucas and Seber 1977) along two 10-m transect lines oriented in the cardinal directions. For each intersected shrub we measured 1) height of the main crown (cm) and 2) percent crown vigor (proportion of the crown that was live). In each quadrant designated by the transect lines, we recorded total shrub density and the density of potential nest shrubs (PNS density), which we defined as shrubs with the proper quantitative and qualitative attributes to potentially accommodate a nest of a Brewer's sparrow (Chalfoun and Martin 2007, 2009), the most common species at our sites. We averaged habitat data collected at each point count cluster, combined across years, to obtain 1 value per cluster for each habitat variable.

Correlation analysis revealed significant positive relationships between many of our habitat variables (Table 2). For sparrows in sagebrush habitat, shrub vigor has merit as a proxy for increased insect food abundance and nest concealment, 2 critical resources for shrub-nesting birds (Rich 1980, Knopf et al. 1990, Wenninger and Inouye 2008). Shrub vigor is also important in identifying nest shrubs used by both Brewer's sparrows and sage sparrows (Petersen and Best 1985a,b). We therefore chose average shrub vigor as our habitat covariate for most species. For Brewer's sparrows, however, we used PNS density instead of shrub vigor, as PNS density influences nest site selection and reproductive success of Brewer's sparrows (Chalfoun and Martin 2007, 2009) and PNS density was correlated with most other habitat characteristics (Table 2). For horned larks (*Eremophila alpestris*), a ground-nesting species more associated with grasslands than shrublands (Beason 1995), we used shrub cover as our habitat covariate, as we anticipated that horned lark abundance would be inversely related to big sagebrush cover.

Statistical Analyses

After we checked abundance and species richness data for normality and homogeneity of variances, we analyzed abundance of each species and overall species richness across energy development gradients using repeated-measures general linear mixed models in SPSS 17 (SPSS Inc., Chicago,

Illinois). We treated year as a repeated measure on the experimental units (clusters), using cluster identification as a random effect to acknowledge the potential correlation in songbird abundance at locations across years. We included site as a fixed factor, and well density/km² as our covariate of interest. To account for habitat effects, we included a covariate representing habitat characteristics (PNS density for Brewer's sparrow, average shrub cover for horned larks, average shrub vigor for all others). Dependent variables were average species detections (adjusted) and average species richness per cluster per survey visit.

RESULTS

We conducted 1,184 point count surveys during 2008–2009. The most common species were, in order of abundance: Brewer's sparrow, horned lark, sage sparrow, vesper sparrow (*Poocetes gramineus*), and sage thrasher. These 5 species accounted for 95% of songbird detections. Detection probabilities ranged from 0.300 to 0.581 (Table 1). Other breeding songbird species included in species richness calculations were Brewer's blackbird (*Euphagus cyanocephalus*), green-tailed towhee (*Pipilo chlorurus*), loggerhead shrike (*Lanius ludovicianus*), western meadowlark (*Sturnella neglecta*), and white-crowned sparrow (*Zonotrichia leucophrys*).

Well density had negative effects on abundance of 3 of our most common species: Brewer's sparrow ($F_{1,52} = 5.247$, $P = 0.026$), sage sparrow ($F_{1,53} = 7.995$, $P = 0.007$), and vesper sparrow ($F_{1,53} = 3.055$, $P = 0.086$; Table 3). Because we observed significant site effects in abundance models for all 5 species and richness (Table 3), and because we were interested in which types of energy fields may influence bird populations most strongly, we further analyzed responses individually by site. Sage sparrows, sage thrashers, horned larks, and species richness lacked a significant year \times site interaction (Table 3); for these, we pooled data across years and analyzed site responses using general linear models.

Brewer's sparrow abundance decreased most steeply at the Jonah natural gas field ($\beta_{2008} = -0.311 \pm 0.102$, $P = 0.008$; $\beta_{2009} = -0.348 \pm 0.174$, $P = 0.063$; Table 4) with increasing well density; average decreases at all sites were greater in 2009 than in 2008 (Table 4, Fig. 3). For sage sparrow, the strongest declines also occurred at Jonah ($\beta = -0.294 \pm 0.070$, $P \leq 0.001$; Table 4), and the other 2 sites showed similar decreases, though not significant (Table 4, Fig. 3). Vesper sparrow abundance at PAPA decreased in response to increasing well densities

Table 2. Correlation matrix of habitat measurements we collected at 3 energy fields in southwestern Wyoming, USA, 2008–2009, averaged per point count cluster (1 cluster = 4 points). Data are 2-tailed Pearson correlation (r) and P -values; $n = 118$.

Habitat metric	PNS density ^a		Shrub height		Shrub cover		Shrub density	
	r	P	r	P	r	P	r	P
Shrub vigor	0.212	0.021	0.017	0.857	-0.166	0.072	0.147	0.112
PNS density ^a			0.305	0.001	0.619	≤ 0.001	0.553	≤ 0.001
Shrub height					0.149	0.106	0.258	0.005
Shrub cover							0.461	≤ 0.001

^a Potential nest shrub density.

Table 3. Between-subjects effects (top 3 lines) and within-subject contrasts (lower 3 lines) from repeated measures general linear mixed models examining effects of energy development density (wells/km²) on abundance of the 5 most common passerine species and species richness at 3 energy fields in southwestern Wyoming, USA, 2008–2009. *n* = 57 point count clusters for Brewer's sparrow and *n* = 58 for all other species and richness.

Variable	df	Brewer's sparrow		Sage sparrow		Sage thrasher		Vesper sparrow		Horned lark		Richness	
		F	P	F	P	F	P	F	P	F	P	F	P
Well density	1	5.247	0.026	7.995	0.007	0.144	0.706	3.055	0.086	0.795	0.377	0.430	0.515
Habitat ^a	1	2.437	0.125	1.786	0.187	1.059	0.308	0.682	0.413	0.030	0.864		
Site	2	38.871	≤0.001	6.953	0.002	7.722	≤0.001	36.175	≤0.001	19.78	≤0.001	12.663	≤0.001
Year	1	14.218	≤0.001	0.01	0.920	0.088	0.768	0.601	0.442	0.037	0.847	13.556	0.001
Year × Well Density	1	0.745	0.392	0.071	0.792	0.848	0.361	0.064	0.802	0.162	0.689	3.662	0.061
Year × Site	2	13.97	≤0.001	0.673	0.515	0.613	0.546	4.265	0.019	0.346	0.709	0.169	0.845

^a Potential nest shrub density for Brewer's sparrow, shrub cover for horned lark, and average shrub vigor for other species and richness.

($\beta_{2008} = -0.043 \pm 0.152$, $P = 0.407$; $\beta_{2009} = -0.141 \pm 0.331$, $P = 0.136$; Table 4), with mixed responses at LaBarge across years and consistently low detections at Jonah (Table 4, Fig. 3). We found increased horned lark abundance with increasing well density at PAPA ($\beta = 0.125 \pm 0.056$, $P = 0.031$; Table 4), but no significant responses at Jonah or LaBarge (Table 4, Fig. 3). Abundance of sage thrashers was unrelated to well density ($F_{1,53} = 0.144$, $P = 0.706$; Table 3), and direction of responses differed among study sites (Table 4, Fig. 3). Species richness at clusters was unrelated to increasing well density (Table 3, Fig. 3); this response was consistent among study sites (Table 4). Habitat covariates did not influence responses of any of the 5 species we evaluated (Table 3).

DISCUSSION

Increased energy development intensity, as estimated by well density/km², was associated with decreased abundances of Brewer's sparrows, sage sparrows, and vesper sparrows. Declines were strongest for Brewer's sparrows and sage sparrows at the Jonah field, with an average decrease of 0.3 individuals per additional well/km² (Table 4). This translates to average losses of 2.5 individuals at clusters with densities of 8 wells/km² for both these sagebrush-obligates. Approved spacing of 16 well pads per 2.6-km² section at

Jonah (USDI 2006) readily yields these and higher well densities.

Sage thrashers did not respond significantly to increased well density in our study, despite sage thrashers being the largest-bodied species with the largest average territory size of those we studied. Sage thrashers have also shown a lack of response to other disturbances such as fire treatments (Castrale 1982, Knick and Rotenberry 2000), suggesting they may be less sensitive to habitat change. An alternative explanation is high annual site fidelity (Wiens and Rotenberry 1985, Knick and Rotenberry 2002), regardless of habitat changes, though this hypothesis requires explicit testing. If site fidelity is strong, population responses could take longer to detect due to turnover times of individuals creating a lag effect, which has been shown in greater sage-grouse population responses to energy development (Walker et al. 2007, Harju et al. 2010). Site fidelity within altered habitats, moreover, could reduce population size in the future if these habitats are of lower quality and result in lower fitness of remaining individuals.

We provide evidence that not all energy fields are created equal; significant site effects for all species evaluated suggest that characteristics of an energy development field may influence avian species responses. Effects were typically stronger in the Jonah and PAPA natural gas fields, developing energy fields that contained multiple disturbance sources, in contrast to the LaBarge oil field that had been

Table 4. Parameter estimates (β), standard errors (SE), and *P*-values for effects of well density (wells/km²) at 3 energy fields in southwestern Wyoming, USA, 2008–2009 on the abundance of the 5 most abundant passerine species and species richness by year and site from repeated measures general linear mixed models, or by site with years combined from general linear models.

Species	Year	Jonah			PAPA ^a			LaBarge		
		β	SE	<i>P</i>	β	SE	<i>P</i>	β	SE	<i>P</i>
Brewer's sparrow	2008	-0.311	0.102	0.008	-0.011	0.148	0.943	-0.017	0.097	0.865
	2009	-0.348	0.174	0.063	-0.147	0.133	0.286	-0.070	0.143	0.629
Sage sparrow		-0.294	0.07	≤0.001	-0.060	0.096	0.536	-0.144	0.094	0.134
Sage thrasher		0.057	0.053	0.296	-0.062	0.067	0.358	0.077	0.055	0.168
Vesper sparrow	2008	0.001 ^b	0.006	0.929	-0.043	0.051	0.407	-0.139	0.092	0.149
	2009	-0.012 ^b	0.009	0.183	-0.141	0.089	0.136	0.024	0.085	0.781
Horned lark		-0.024	0.151	0.739	0.125	0.056	0.031	0.005	0.068	0.937
Richness		-0.013	0.008	0.096	-0.002	0.008	0.816	-0.018	0.015	0.248

^a Pinedale Anticline Project Area.

^b Parameter estimates for vesper sparrow at Jonah based on very low numbers of detections (<20 individuals over 2 years).

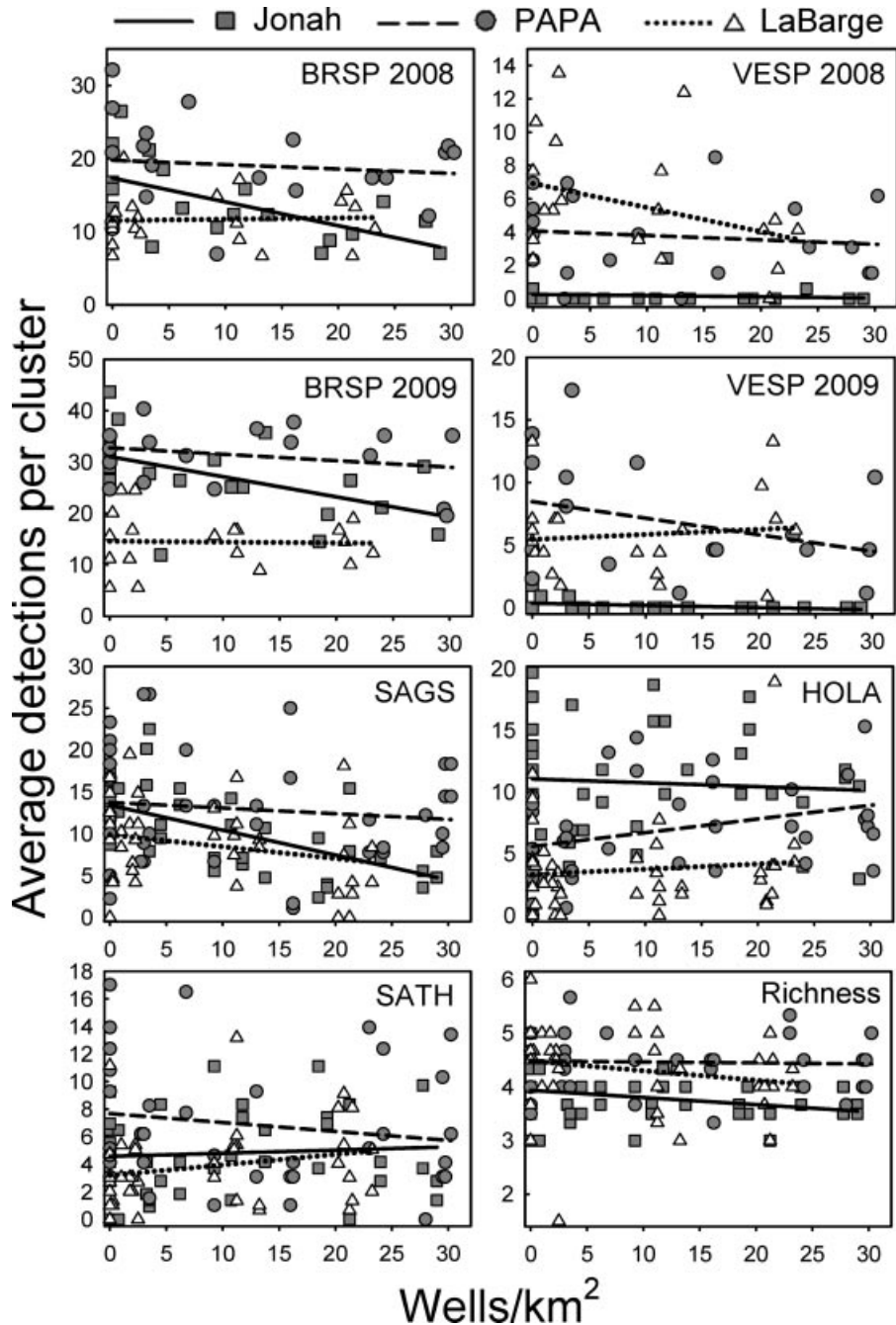


Figure 3. Relative abundance of Brewer's sparrow (BRSP), sage sparrow (SAGS), sage thrasher (SATH), horned lark (HOLA), and vesper sparrow (VESP), and passerine species richness in relation to well density at the Jonah (circles and solid lines), PAPA (squares and dashed lines), and LaBarge (triangles and dotted lines) energy fields, southwestern Wyoming, USA, 2008–2009. Open symbols designate oil fields, shaded symbols are natural gas fields. Data are average number of individuals or species detected per survey visit per cluster (sum of four 100-m radius point counts), adjusted for detection probabilities.

in production for several decades (McDonald 1976, Holloran 2005). Time since the initiation of development, spatial configuration of energy fields (Fig. 2), and higher human activity levels and drilling infrastructure presence may contribute to patterns of songbird abundance.

Human activity and vehicle traffic levels, for example, are highest on active drilling pads (Sawyer et al. 2009) and varied between our energy fields. On the growing PAPA and Jonah natural gas fields, manned drilling rigs were common on the landscape throughout the breeding season. In contrast, such

rigs were rare in LaBarge during our study. Likewise, traffic volume around an active well pad in the PAPA averaged 112 vehicles per day (Sawyer et al. 2009), and traffic on main haul roads in Jonah has exceeded 600 vehicles per day (Ingelfinger and Anderson 2004), whereas traffic at LaBarge rarely exceeded 5 vehicles per day during our study (M. Gilbert, University of Wyoming, personal observation).

Field age or spatial configuration may factor into response differences between the PAPA and Jonah natural gas fields. Development began on PAPA approximately 10 years ago

and the northern portion of the field was configured in a linear band of development (Fig. 2), primarily employing directional drilling technology with multiple wells drilled on a well pad (Sawyer et al. 2009). Approximately 30 km² of our 170-km² PAPA study area contained moderate to high well densities of ≥ 8 wells/km². The Jonah field, where species declines were steepest, was situated directly south of PAPA but was older, with development authorized in the late 1990s, and had a wide central area that was densely developed (Fig. 2), particularly where infill drilling occurred among existing wells (USDI 2006). As a result, nearly 70 km² of our 210-km² Jonah study area contained moderate to high well densities (≥ 8 wells/km²). Interestingly, overall abundance estimates for several species at the LaBarge field, the oldest of our study areas, were lower than at the other 2 sites (Fig. 3), suggesting that effects may compound over time at energy fields rather than showing patterns of acclimation or recovery after initial disturbances. The specific effects of such anthropogenic disturbance on wildlife are still unclear. Other studies have shown that mule deer (*Odocoileus hemionus*) avoidance of well pads on PAPA increased with higher levels of traffic (Sawyer et al. 2009), and greater noise at energy development facilities reduced passerine density and altered songbird community composition (Bayne et al. 2008, Francis et al. 2009). Even so, some species may show partial acclimation to human activity over time, thus long-term effects at the community level are unknown.

Our results corroborate those of other studies showing decreased occurrence and abundance of several grassland birds near oil and gas development edges and decreased sagebrush songbird density adjacent to natural gas development roads (Ingelfinger and Anderson 2004, Linnen 2008). Higher well densities result in a greater number and proportion of well pads, roads, and other anthropogenic infrastructure, which can intensify edge effects and may negatively impact songbirds via decreased nest success or altered species interactions (Fletcher 2005). Horned larks can be associated with disturbed vegetation communities (Knick and Rotenberry 2002), and the increased horned lark abundance we observed at PAPA, coupled with decreased sparrow populations, could signal a fundamental change in the bird assemblage of shrubsteppe habitats surrounding energy development.

Songbird population declines may be driven by increased nest predation risk as generalist predators become more abundant in human-altered areas (Chalfoun et al. 2002). Common ravens (*Corvus corax*) are widespread and effective nest predators (Andren 1994), and energy field encroachment upon undeveloped sagebrush areas appears to facilitate increases in breeding raven abundance (Bui et al. 2010). Increased raven numbers in sagebrush systems negatively affects nest survival of greater sage-grouse, another sagebrush obligate, particularly in areas with sparse shrub cover (Coates and Delehanty 2010). Data on the identification, abundance, and distribution of dominant nest predators in relation to energy development would shed light on nest predation as a potential mechanism for decreased sagebrush songbird abundance in energy fields.

Landscape-scale habitat alteration associated with energy development may also lead to songbird population declines via decreased food availability (Howe et al. 1996). Reduction of the amount of intact sagebrush habitat surrounding territories via conversion can limit foraging opportunities. Alternatively, if the condition of remaining sagebrush patches is altered, associated insect prey assemblages could decrease in abundance. Breeding songbirds rely heavily on such insect prey for their own maintenance and ability to provision young. We found no significant relationship between the habitat characteristics we measured and sagebrush obligate abundance, but this is likely an artifact of selecting our sampling locations above set minimums of shrub cover and vigor. That we found significant effects of energy development while simultaneously accounting for important microhabitat components suggests, moreover, that energy development independently affects non-game birds.

In conclusion, we documented a pattern of declining sagebrush songbird abundance with increasing well densities in energy development fields. An important next step is to examine the consequences of energy development for songbird demographic and population processes to clarify mechanisms for declines. Understanding patterns of population responses coupled with specific causes for declines will facilitate the development of effective management strategies for the maintenance of sagebrush bird communities.

MANAGEMENT IMPLICATIONS

Sagebrush-obligate songbirds are an important component of the biodiversity of the western United States and can serve as barometers of sagebrush ecosystem integrity due to their dependence on sagebrush and sensitivity to habitat alteration (Dobkin and Sauder 2004). The long-term impact of oil and natural gas development on songbirds in sagebrush habitat is unknown (Ingelfinger and Anderson 2004), but our data suggest that increasing energy development intensity will further exacerbate regional declines of sagebrush songbirds.

For oil and natural gas fields in early development stages, or expansions to existing fields such as the anticipated addition of 4,399 wells on up to 600 well pads in the PAPA (USDI 2008), it will be imperative for future studies to evaluate well placement configurations so as to assess their impacts on wildlife. Furthermore, explicit hypothesis tests focused on impacts to important limiting resources such as refugia from nest predation and food availability will be critical for determining underlying mechanisms through which energy development impacts songbirds and ultimately for developing appropriate mitigation strategies.

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LITERATURE CITED

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