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PASSERINE RESPONSE TO ROADS ASSOCIATED WITH NATURAL GAS EXTRACTION IN A SAGEBRUSH STEPPE HABITAT

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ABSTRACT.—Natural gas extraction and field development are pervasive throughout the sagebrush steppe of Wyoming. We conducted this study to determine how roads associated with natural gas extraction affect the distribution of breeding songbirds in sagebrush steppe habitat. The study encompassed dirt and paved roads in the Jonah Field II and Pinedale Anticline Project Area in Sublette County, Wyoming. Sites are dominated by Wyoming big sagebrush (*Artemisia tridentata*), and common passerines include sagebrush obligates: Brewer's Sparrows (*Spizella breweri*), Sage Sparrows (*Amphispiza belli*), and Sage Thrashers (*Oreoscoptes montanus*); and non-obligates: Horned Larks (*Eremophila alpestris*) and Vesper Sparrows (*Pooecetes gramineus*). Species relative density was measured using 50-m-radius point counts during spring 1999 and 2000. Four roads with low traffic volumes (700–10 vehicles per day) were surveyed and point counts were centered at variable distances from the road surface such that relative densities were measured 0–600 m from the road's edge. Density of sagebrush obligates, particularly Brewer's and Sage Sparrow, was reduced by 39%–60% within a 100-m buffer around dirt roads with low traffic volumes (700–10 vehicles per day). While a 39%–60% reduction in sagebrush obligates within 100 m of a single road may not be biologically significant, the density of roads created during natural gas development and extraction compounds the effect, and the area of impact can be substantial. Traffic volume alone may not sufficiently explain observed declines adjacent to roads, and sagebrush obligates may also be responding to edge effects, habitat fragmentation, and increases in other passerine species along road corridors. Therefore, declines may persist after traffic associated with extraction subsides and perhaps until roads are fully reclaimed.

Key words: oil development, natural gas development, roads, passerines, fragmentation, sagebrush, shrub steppe.

While the ecological effects of roads can be positive, such as in the indirect preservation of native grassland species in agriculturally developed areas (Bennett 1991, Lamont and Blyth 1992, Warner 1992, Straker 1998), many ecological impacts are negative. Increased mortality, animal behavior modification, habitat alteration, and spread of nonindigenous plants can all result from additional roads (Trombulak and Frissell 2000). Road impact affects an estimated 15%–20% of United States land area (Forman 2000).

The impact of roads with high traffic volumes (>10,000 vehicles per day) on breeding bird populations has been documented. In a Netherlands study of breeding bird density in deciduous and coniferous woodlands, 60% of species analyzed (26 of 43) showed evidence of decreased density adjacent to roads. Species-specific detectable zones, based on regression models, were between 40 m and 1500 m for roads with traffic volumes of 10,000 vehicles per day, and between 70 m and 2800 m where traffic volumes exceeded 60,000 vehicles. Traffic noise and its rate of attenuation were the best predictors of this pattern. Within 250 m of roadways, reductions in bird densities varied between 20% and 98% depending on species (Reijnen et al. 1995).

Studies of a breeding population of Willow Warblers (*Phylloscopus trochilus*) showed a 33% reduction in breeding male density within 200 m of a road with a traffic volume of 50,000 vehicles per day (Reijnen and Foppen 1994). Yearling males accounted for a larger proportion of territorial males within the road zone, suggesting that less fit individuals were relegated to this 200-m road zone. (Foppen and Reijnen 1994). Both productivity and population demographics from these studies suggest that habitat quality within these road zones is reduced and the area within the road zone may serve as a population sink for Willow Warblers (Foppen and Reijnen 1994, Reijnen and Foppen 1994).

In grassland communities adjacent to roads, breeding birds also showed similar reductions in densities. However, because noise attenuates

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more slowly in open habitats, reductions in breeding bird density were observed at greater distances from the road than in wooded habitats (van der Zannde et al. 1980, Reijnen et al. 1996).

Clearly, roads with high traffic volumes can impact breeding bird populations and habitat quality. However, little information is available on the impact low traffic volume (<700 vehicles per day) has on bird communities. New road construction in the United States is expected to be of this low-volume type, especially in rural areas and areas associated with resource extraction (National Research Council 1997, Trombulak and Frissell 2000). In Wyoming resource extraction is prevalent and mineral severance taxes are a major source of state revenue. In 2000 the assessed value of minerals extracted from Wyoming exceeded $4 billion and provided the state with $279 million in mineral severance taxes. The value of oil and gas alone exceeded 62% of the total value of minerals extracted from Wyoming (Department of Revenue 2001). While oil and gas extraction are a large source of revenue for Wyoming and an important domestic energy source, they often require intense road development. Our goal was to examine how roads associated with natural gas extraction in western Wyoming affect sagebrush steppe breeding bird distribution and species composition along roadways.

METHODS

Study Area and Site Selection

We carried out this study along roads within 2 adjacent natural gas development areas in western Wyoming, the Pinedale Anticline Project Area (PAPA) and the Jonah Field II. The Jonah Field II is a developed natural gas field with a well density of 3 wells·km^{-2} (8 wells·miles^{-2}). PAPA, north of Jonah II, is a field in the beginning phase of natural gas development. It is located along the western edge of central Wyoming in Sublette County. The project area is bordered to the east by Highway 191 and to the west by the Green River. The town of Pinedale demarcates the project's northeastern boundary, and the Jonah Field II, approximately 56 km south of Pinedale, Wyoming, marks the project's southern boundary. The Pinedale Anticline Project Area encompasses 80,000 ha, 80% of which is under the jurisdiction of the Bureau of Land Management. Vegetation in both the Jonah Field II and PAPA is dominated by Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) with portions of basin big sagebrush (*Artemisia tridentata* ssp. *tridentata*) located throughout the bottoms of draws (PIC Technologies and Bureau of Land Management 1999, Bureau of Land Management 2000). Common passerines breeding in these areas include sagebrush obligates such as the Brewer's Sparrow (*Spizella breweri*), Sage Sparrow (*Amphispiza belli*), and Sage Thrasher (*Oreoscoptes montanus*), and grassland species such as the Horned Lark (*Eremophila alpestris*) and Vesper Sparrow (*Pooecetes gramineus*).

Traffic Volume

Traffic volume was measured with pneumatic axle counters. These counters consist of a counter connected to a 2-cm-diameter rubber hose that we stretched across the road and monitored daily throughout the breeding season (15 May–30 June). Since pneumatic counters count axles, not vehicles, dividing the total number of axles counted by 2 created an index of daily traffic volume (cars per day). Average daily traffic volume was calculated as the average of the total traffic volume throughout the breeding season.

Vegetation

To demonstrate that vegetation was comparable between distance classes, we characterized vegetation within each point count along line transects. Two 50-m tapes were extended in opposite directions from the point count's center and were oriented at a 45° angle to the road. Along each 50-m tape vegetation measurements were recorded along three 10-m intervals, namely, 10–20 m, 25–35 m, and 40–50 m, from the point count's center. We used the line-intercept method (Canfield 1941) to determine the percent canopy cover of live and dead sagebrush and live rabbitbrush (*Chrysothamnus* spp.). Height and species of each intercepted shrub were recorded and used to estimate average height of each shrub species within the point-count ($\sum_{i\text{-}n}$ (height $_i$ * length $_i$) / $\sum_{i\text{-}n}$ (Length $_i$)). Live and dead sagebrush density (plants·m^{-2}) was estimated using a 1-m-wide band transect taken along each of the six 10-m transect sections (James and Shugart

1970). We determined percent cover of grasses, forbs, litter, bare ground, lichen, cactus, cow dung, and total ground cover by class using a 20 cm × 50 cm Daubenmire frame (Daubenmire 1959). Cover classes were 0%–5%, 5%–25%, 25%–50%, 50%–75%, 75%–95%, and 95%–100%. Daubenmire frame samples were taken at 12 sites within each point count, 6 along each 50-m transect and centered at 12.5 m, 17.5 m, 27.5 m, 32.5 m, 42.5 m, and 47.5 m from the center. Total cover for each vegetation variable was calculated by averaging the 12 samples.

A density board (20 cm × 100 cm) was used to measure average vegetation density within each decimeter interval (10-cm), average maximum vegetation height, and an index of shrubbiness. Density board samples were recorded at the same 12 locations as Daubenmire frame samples. Percent vegetation density within each decimeter interval was estimated by walking 5 m away from the density board in a direction perpendicular to the transect and by recording percent of the density board covered by all forms of vegetation. Cover classes were the same as those used for the Daubenmire frame. Percent vegetation density within each decimeter interval was calculated by averaging the values obtained from the 12 density board samples. Maximum height of vegetation for each point count was the average maximum decimeter with vegetation cover. An index of shrubbiness was calculated as total vegetation density within the first 2 decimeters. Horizontal heterogeneity was measured as the between-sample variation in vertical structure and was indexed by using the coefficient of variation (CV) between the 12 samples of maximum height of vegetation recorded with the density board (CVMAXHT; Wiens and Rotenberry 1980). To correct for small sample bias, we used the following estimate of CV (Sokal and Braumann 1980):

$$CV = (1 + (1 / 4n)) (s * 100/Y_{bar})$$

Breeding Bird Distribution

Breeding bird distribution was surveyed along 4 roads and 1 pipeline right-of-way within the study area: Lumman Road, serving as the main access to the Jonah Field II; Mesa Road in the northern portion of PAPA; Oil Well Road, running north–south along northern PAPA; and Highway 351, which bisects southern PAPA and is a paved road between Highway 191 and Big Piney. We also surveyed bird distribution along a pipeline right-of-way. Vegetation within 8 m of pipelines is cleared and replanted with grass. Inclusion of a pipeline in this study provided a reference site with a surface disturbance similar to roads that lacked the associated traffic (Fig. 1). As topography can significantly influence vegetation structure in sagebrush steppe environments, we selected road sections for flat topography to limit variation in vegetation structure and floristic composition between distance classes. Within selected road sections, 8–14 transects were placed perpendicular to the road. Transects were located by randomly choosing a starting point for the 1st transect and then spacing transects at 300-m intervals.

Breeding bird density was surveyed between 15 May and the end of June 1999 and 2000 using 50-m fixed-radius point counts. We surveyed 2 roads during the 1999 field season: the Mesa and Lumman Roads (referred to hereafter as Mesa I and Lumman I sites). Along each road 8 transects were run perpendicular to the road, and transects were spaced 300 m apart. Points were spaced 250 m apart along these transects and were located at distances of 50 m, 150 m, 300 m, 400 m, and 550 m from the start of the natural vegetation. Road width ranged between 8 m and 11 m, and total width of disturbed area was 15–25 m wide. Points on adjacent transects had the opposite dispersion. For example, a road that ran east–west would have point counts located along transects oriented north–south with the 1st transects having points centered at 50, 300, and 550 m from the road disturbance to the north, and at 150 m and 400 m to the south, while at the next transect the locations would be reversed: 150 m and 400 m to the north, and 50, 300, and 550 m to the south. This dispersion provided 8 independent samples of breeding bird densities within each 100-m distance class. Distance classes ranged from 0–100 m, 100–200 m, 250–350 m, 350–450 m, and 500–600 m from the road disturbance for points located at 50 m, 150 m, 300 m, 400 m, and 550 m, respectively. During the 2000 field season, 2 additional roads (Oil Well Road and Highway 351), a pipeline, and additional sites along both the Mesa and Lumman Roads (referred to as Mesa II and Lumman II sites) were added to the

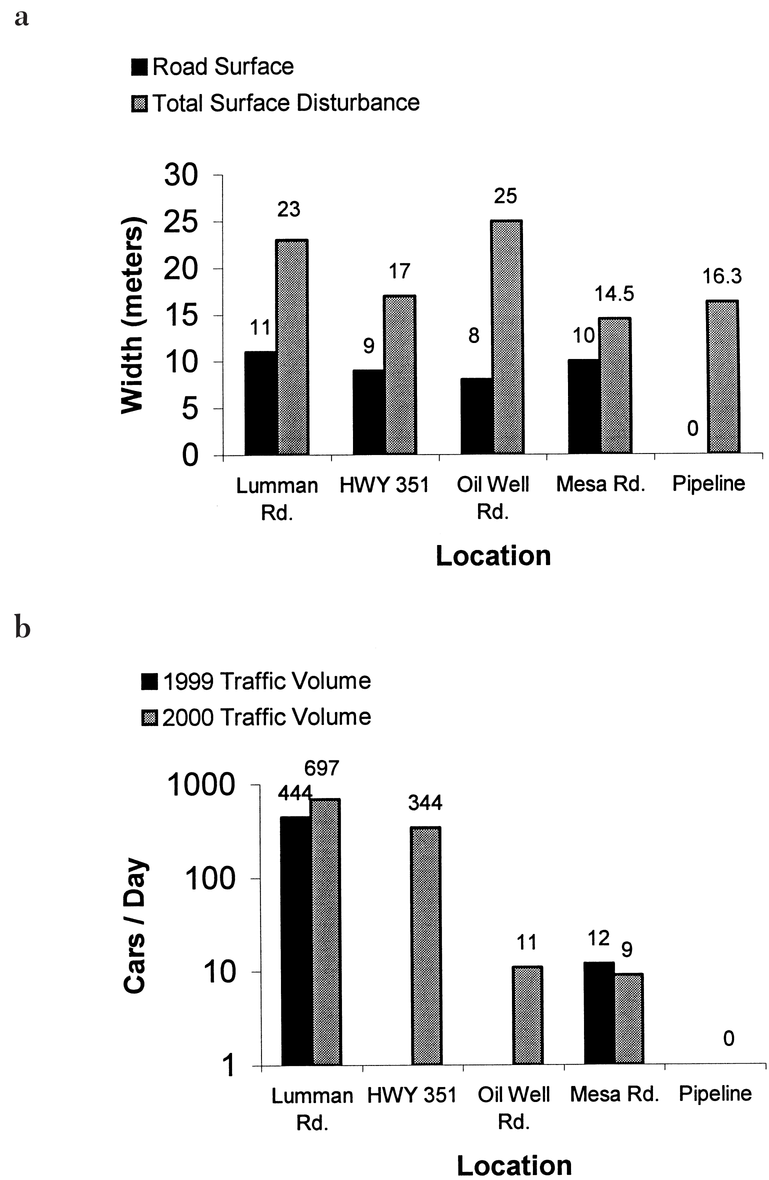

Fig. 1. Study area comparison of vegetation and traffic disturbance: (a) width of the maintained surface and extent of vegetation disturbance along roads, (b) daily traffic volume.

study. To concentrate sampling effort where the road effect was greatest, breeding bird densities along these additions were sampled only out to 200 m away from dirt roads and pipelines and out to 350 m from the paved highway. Ten transects were placed along each of these new road sites, providing 10 independent samples of bird density within each distance class (0–100 m and 100–200 m). Because Highway 351 was a paved state highway with greater traffic volumes and speeds than on dirt roads, points were located at 50 m, 150 m, and 300 m from the road surface along 14 transects, creating 14 independent samples of bird density within 3 distance classes (0–100 m, 100–200 m, and 250–350 m; Table 1).

TABLE 1. Description of survey locations, years surveyed, distance classes, and sample size in each distance class.

Location	Years surveyed	Distance classes	Samples size per class
Mesa 1	1999–2000	0–100 m, 100–200 m, 250–350 m, 300–400 m, 500–600 m	8
Lumman 1	1999–2000	0–100 m, 100–200 m, 250–350 m, 300–400 m, 500–600 m	8
Hwy 351	2000	0–100 m, 100–200 m, 250–350 m	14
Lumman 2	2000	0–100 m, 100–200 m	10
Mesa 2	2000	0–100 m, 100–200 m	10
Oil Well Road	2000	0–100 m, 100–200 m	10
Pipeline	2000	0–100 m, 100–200 m	10

Point centers were permanently marked with plastic-capped rebar stakes that we set below the height of the surrounding vegetation to reduce their attractiveness as perches and song posts. Birds were never observed using these stakes as perch sites or song posts. Because roads served as a natural 50-m boundary marker for points centered at 50 m from the road, we used 10 cm × 10 cm neon flags to mark the 50-m boundary of points located further than 50 m from the road.

Points were visited 3 times during each field season. We combined counts from 3 successive point visits to average the number of detections of individual species and sagebrush obligates (sum of Brewer's Sparrow, Sage Sparrow, and Sage Thrasher). Twenty counts were conducted per morning between 0430 and 0730 MST on rain-free mornings with wind speeds below 15 $km \cdot hr^{-1}$. Points were visited in the order in which they were located along transects. Upon reaching the end of a transect, the observer would continue counts on the adjacent transect. To ensure that stations were visited both early and late in the daily sampling period, observers surveyed points in reverse order on consecutive visits.

Each point count lasted for 5 minutes, with time beginning once the observer reached the 50-m boundary of the plot. Walking slowly towards the plot's center, the observer would record and map all birds detected by sight and sound. Birds that were flushed into the plot upon approach were not recorded unless they returned to the plot later in the survey. Flyovers were not counted.

Statistical Analysis

One-tailed t tests assuming unequal variance were used to compare relative breeding bird densities adjacent to roads (within 100 m) with those recorded at greater distances. Density of species compared in this analysis included Brewer's Sparrow, Horned Lark, and Sage Sparrow. To provide inference into the impact of roads on the guild of sagebrush obligates, we also extended analysis to include the sum of Brewer's Sparrow, Sage Sparrow, and Sage Thrasher detections, hereafter referred to as sagebrush obligates. Tests were considered significant at $\alpha = 0.05$. Because multiple tests of the same hypothesis were conducted, a Bonferroni correction was applied to the decision rule of each test to maintain a family error rate of 0.05 (critical $\alpha = 0.0125$). Vegetation characteristics were compared adjacent to and away from the road using 2-tailed t tests assuming unequal variance. We compared the following 17 vegetation variables with the greatest potential to influence species distribution: live and dead sagebrush density; live and dead sagebrush cover; percent cover of grass, forbs, litter, and total cover; live and dead sagebrush height; vegetation density in decimeters 10–40 cm; average maximum vegetation height; shrubbiness; and horizontal heterogeneity. Separate-variance t tests were employed for all t tests because the separate-variance approach is more conservative than the pooled-variance approach when sample sizes differ (Ramsey and Schafer 1997). We used the Mann-Whitney test to compare median values of horizontal structural heterogeneity (CVMAXHT) within and outside the 100-m road zone. The Mann-Whitney test provides greater power than *t* tests when the sample distribution is nonnormal and is recommended when comparing measures of heterogeneity based on correlation coefficients (Sokal and Braumann 1980). Because it is important to demonstrate the comparability of vegetation structure and cover between road adjacent sites and sites outside the road zone, we considered tests significant at $\alpha = 0.1$. Because multiple tests of the same hypothesis were conducted, a Bonferroni correction was applied to the decision rule of each test to maintain a family error rate of 0.1 (critical $\alpha = 0.0059$). Tests were performed for each study area (Pipeline, Oil Well Road, Mesa I, Mesa II, Lumman I, Lumman II, and Highway 351) and for the combined data from all dirt roads (Lumman I, Lumman II, Mesa I, Mesa II, and Oil Well Road).

To investigate the influence of traffic on bird detectability, we measured traffic volume during counts. At each 5-minute point count, the number of cars (2 axles) and trucks (>2 axles) was recorded. The effect of traffic was investigated on a daily basis to isolate the influence of traffic on bird detectability. Simple linear regression was employed using the number of vehicles that passed during a count as a predictor of number of birds detected. Only 2000 field season data from the Lumman and Highway 351 sites were used since traffic volumes on other roads were so low that rarely more than 2 vehicles passed during an entire morning. Also, because the effect of noise on bird detectability should be greatest at sites adjacent to roads, analyses were restricted to point counts located 50 m from the road. This approach provided 9 independent estimates of traffic effect on bird detectablility. Slopes from these 9 regressions were pooled and a 1-sample *t* test was used to determine if the mean slope differed from 0.

RESULTS

Traffic Volume

Average daily traffic volume during the 1999 field season was 444 cars per day along Lumman Road and 12 cars per day on Mesa Road. During spring 2000, development activity increased in Jonah Field II and 2000 traffic volume averaged 697 cars per day on Lumman Road. Traffic volume on Mesa Road showed little change from the previous year (11 cars per day). Average daily traffic volume along the new study sites was 344 cars per day along Highway 351 and 9 cars per day along Oil Well Road. Vehicles were not present at the pipeline site (Fig. 1).

Lumman Road was the only road with enough traffic to discern temporal patterns in traffic volume, and those reflected workday and workweek schedules. Traffic peaked between 0430 and 0800 and thereafter remained fairly steady. On weekends traffic volumes dropped to 20% of the workweek volume. On weekdays between 0400 and 0730 traffic volume was 75 cars per hour. On the weekend traffic dropped to 15 cars per hour.

Vegetation

Vegetation at all study sites was dominated by Wyoming big sagebrush, with an average live sagebrush cover of 16.5% and an average height of 27 cm. Sagebrush cover and height were comparable between all study areas except Highway 351, where sagebrush cover and height were lower ($\text{mean}_{\text{cover}} = 11.5\%$, $s_{\bar{x}} = 0.65$; $\text{mean}_{\text{ht.}} = 20.8$ cm, $s_{\bar{x}} = 0.65$). Two-tailed *t* tests showed no statistical difference in vegetation structure, cover, or heterogeneity between distance classes (within and outside the 100-m road zones) for any of the individual study areas or for the combined data set of all dirt roads (Lumman I, Lumman II, Mesa I, Mesa II, and Oil Well Road). Similarity of vegetation within these 2 sections was corroborated by using discriminant analysis, which failed to classify stands into either road or non-road zones on the basis of measures of vegetation structure (Ingelfinger 2001).

Breeding Bird Abundance

Breeding bird abundance in 1999 was surveyed at 79 sites along Lumman and Mesa Roads (39 along Lumman Road, 40 along Mesa Road). Mean number of birds detected per point count was 2.97 ($s_{\bar{x}} = 0.20$) and 3.14 ($s_{\bar{x}} = 0.21$) for Lumman and Mesa Roads, respectively; means were not statistically different. Brewer's Sparrow was the most common species detected, accounting for over half of all detections. Sage Sparrows and Horned Larks each accounted for about 20% of detections, while Sage Thrashers and Vesper Sparrows each comprised less than 5% of detections. During the 2000 field season, point count means were lower than the previous season ($mean_{Lumman}$ = 2.20, $s_{\bar{x}}$ = 0.15; $mean_{Mesa}$ = 1.82, $s_{\bar{x}}$ = 0.16). While there was little change in relative species abundance, paired *t* tests showed that point count means declined by 35% (95% CI = 12%–40%, $P < 0.0000$) and 42% (95% CI = 27%–57%, $P < 0.0000$) at Lumman and Mesa Road sites, respectively.

At Lumman I during the 1999 field season, sagebrush obligate and Brewer's Sparrow abundance was significantly lower, and Sage Sparrow abundance was marginally lower within 100 m of the road. Within the 100-m road zone, densities were reduced by 52% ($P = 0.0008$) for sagebrush obligates ($mean_{<100\ m}$ = 1.17, $s_{\bar{x}}$ = 0.25 vs. $mean_{>100\ m}$ = 2.41, $s_{\bar{x}}$ = 0.22), 49% ($P = 0.0045$) for Brewer's Sparrow ($mean_{<100\ m}$ = 0.79, $s_{\bar{x}}$ = 0.20 vs. $mean_{>100\ m}$ = 1.56, $s_{\bar{x}}$ = 0.17), and 52% ($P = 0.013$) for Sage Sparrows ($mean_{<100\ m}$ = 0.33, $s_{\bar{x}}$ = 0.11 vs. $mean_{>100\ m}$ = 0.69, $s_{\bar{x}}$ = 0.10) relative to densities outside this zone. Within the 100-m road zone along Mesa Road, where traffic volume was light, sagebrush obligate density declined by 40% ($mean_{<100\ m}$ = 1.42, $s_{\bar{x}}$ = 0.45 vs. $mean_{>100\ m}$ = 2.35, $s_{\bar{x}}$ = 0.20) and Sage Sparrow density declined by 49% ($mean_{<100\ m}$ = 0.38, $s_{\bar{x}}$ = 0.15 vs. $mean_{>100\ m}$ = 0.74, $s_{\bar{x}}$ = 0.11) relative to densities outside this zone. These declines were not statistically significant ($P = 0.045$ and $P = 0.034$, respectively).

Along the natural gas pipeline, comparisons of point count means showed no observable difference in breeding bird abundance between the 2 distance classes (0–100 m and 100–200 m). Sage Sparrow decline of 64% was not statistically significant ($P = 0.047$; $mean_{<100\ m}$ = 0.13, $s_{\bar{x}}$ = 0.05 vs. $mean_{>100\ m}$ = 0.37, $s_{\bar{x}}$ = 0.09), while Brewer's Sparrow density was slightly higher within the 100-m disturbance zone ($mean_{<100\ m}$ = 1.17, $s_{\bar{x}}$ = 0.17 vs. $mean_{>100\ m}$ = 0.93, $s_{\bar{x}}$ = 0.17). Similar comparisons of point count means along road sites illustrate a different trend. Along Oil Well Road sagebrush obligate and Brewer's Sparrow density declined by 50% ($P = 0.008$; $mean_{<100\ m}$ = 1.17, $s_{\bar{x}}$ = 0.14 vs. $mean_{>100\ m}$ = 2.33, $s_{\bar{x}}$ = 0.39) and 59% ($P = 0.012$; $mean_{<100\ m}$ = 0.63, $s_{\bar{x}}$ = 0.12 vs. $mean_{>100\ m}$ = 1.50, s = 0.31), respectively, within the 100-m zone. Along Mesa I site sagebrush obligates were reduced by 43% ($P = 0.0032$; $mean_{<100\ m}$ = 0.92, $s_{\bar{x}}$ = 0.18 vs. $mean_{>100\ m}$ = 1.62, $s_{\bar{x}}$ = 0.14) and Sage Sparrows by 76% ($P = 0.0012$; $mean_{<100\ m}$ = 0.13, $s_{\bar{x}}$ = 0.09 vs. $mean_{>100\ m}$ = 53, $s_{\bar{x}}$ = 0.08) within the 100-m road zone. Largest reductions within the 100-m road zone occurred at the Lumman I site. Within 100 m of this road, sagebrush obligates were reduced by 60% ($P < 0.0000$; $mean_{<100\ m}$ = 0.79, $s_{\bar{x}}$ = 0.15 vs. $mean_{>100\ m}$ = 1.96, $s_{\bar{x}}$ = 0.14), Brewer's Sparrows by 50% ($P = 0.0005$; $mean_{<100\ m}$ = 0.71, $s_{\bar{x}}$ = 0.13 vs. $mean_{>100\ m}$ = 1.41, s = 0.12), and Sage Sparrows by 76% ($P = 0.0006$; $mean_{<100\ m}$ = 0.08, $s_{\bar{x}}$ = 0.06 vs. $mean_{>100\ m}$ = 0.42, $s_{\bar{x}}$ = 0.08), relative to densities outside this zone.

While bird abundance declined within the 100-m road zone along all sites, declines were not always statistically significant. Along Highway 351, a paved road with an average daily traffic volume of 344 vehicles, there were no statistically significant differences in point count means for any species. Also, no statistical differences in means existed from Lumman II and Mesa II sites.

To provide an overall idea of how roads associated with natural gas development affect breeding bird distribution, we combined data from all dirt roads surveyed in 2000 and examined point count means for evidence of a road effect. Highway 351 was excluded from this analysis because it was a paved road with vegetation that was distinct from other surveyed sites. Within the 100-m zone sagebrush obligates are reduced by 39% ($P < 0.0000$; $mean_{<100\ m}$ = 1.09, $s_{\bar{x}}$ = 0.10 vs. $mean_{>100\ m}$ = 1.80, $s_{\bar{x}}$ = 0.08), Brewer's Sparrows by 36% ($P < 0.0000$; $mean_{<100\ m}$ = 0.83, $s_{\bar{x}}$ = 0.08 vs. $mean_{>100\ m}$ = 1.29, $s_{\bar{x}}$ = 0.08), and Sage Sparrows by 57% ($P < 0.0000$; $mean_{<100\ m}$ = 0.18, $s_{\bar{x}}$ = 0.04 vs. $mean_{>100\ m}$ = 0.42, $s_{\bar{x}}$ = 0.04), relative to areas outside the 100-m zone. The data also suggest that Horned Lark abundance may be slightly higher within the road zone (30% greater, $P = 0.023$ for 1-tailed *t* test for mean road zone > undisturbed zone; ($mean_{<100\ m}$ = 0.51, $s_{\bar{x}}$ = 0.08 vs. $mean_{>100\ m}$ = 0.36, $s_{\bar{x}}$ = 0.05).

Species Composition

Along roads there was a shift in species composition, with an increase in Horned Lark abundance relative to sagebrush obligates. Within the 100-m road zone, Horned Larks accounted for 31% of detections and sagebrush obligates 66%. Outside the 100-m road zone, Horned Larks accounted for only 16% while sagebrush obligates increased to 81% of detections (Fig. 2).

Traffic Influence on Bird Detectability

The effect of noise was investigated on a daily basis for those roads where traffic volume was relatively high (>100 cars per day). The mean slope of regressions did not differ from zero ($\text{mean}_{\text{slope}} = 0.76$, $s_{\bar{x}} = 0.49$, $t = 1.58$, $n = 9$), suggesting that traffic noise did not affect the observer's ability to detect birds using a 50-m-radius point count.

DISCUSSION

Results from this study provide evidence that roads associated with natural gas development negatively impact sagebrush obligate passerines. Impacts are greatest along access roads where traffic volume is high. Density of sagebrush obligates declined by as much as 60% (95% CI = 40%–81%) within a 100-m buffer around these roads. Even along roads with light traffic volume (<12 cars per day), density of sagebrush obligates was reduced within the 100-m road zone.

Given that sagebrush obligate density is reduced along roads regardless of traffic volume, we might ask to what aspects of roads are sagebrush obligate species responding. Other studies illustrate that when traffic volume is greater than 10,000 vehicles daily, birds are responding to the disturbance created by traffic noise (Warner 1992, Foppen and Reijnen 1994, Reijnen and Foppen 1994). Along Lumman Road traffic volume is heavy and consistent enough that birds probably are responding to some aspect of traffic such as noise or dust.

However, traffic alone cannot explain the observed reductions in bird abundance along roads with light traffic volumes (<12 cars per day), and habitat fragmentation and avoidance of habitat edges may be influencing passerine distribution. Roads function as corridors for the spread of invasive plant species that over time can change vegetation characteristics and habitat quality. Roads also function as corridors for predators, including avian predators such as corvids. Within both PAPA and Jonah Fields, the Common Raven (*Corvus corax*), a common nest predator, frequently nested on

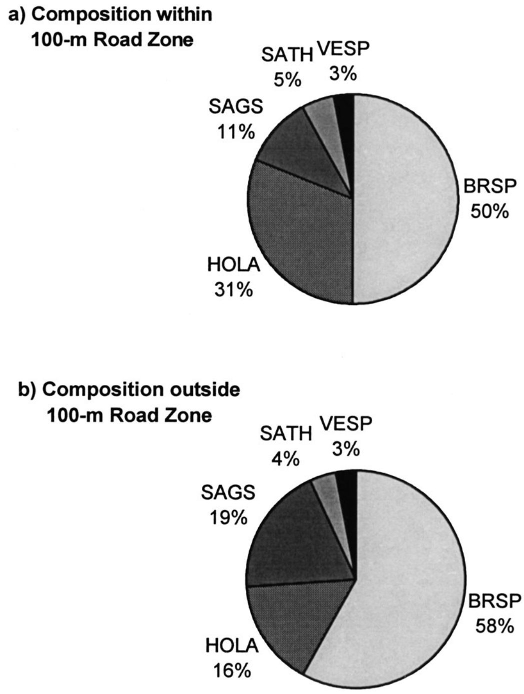

Fig. 2. Relative species abundance within (a) and outside (b) of the 100-m road zone for dirt roads surveyed during the 2000 field season ($n = 46$ within and $n = 88$ outside the 100-m road zone). BRSP = Brewer's Sparrow, HOLA = Horned Lark, SAGS = Sage Sparrow, SATH = Sage Thrasher, VESP = Vesper Sparrow.

well structures, and field development has likely increased the local raven population. Along the natural gas pipeline where traffic was absent, Sage Sparrow density was reduced by 64% within a 100-m buffer of the surface disturbance ($P = 0.047$). Although not statistically significant, there is some evidence that Sage Sparrows avoided edges created by surface disturbances. Sage Sparrows are area sensitive (Knick and Rotenberry 1995), and while roads created during natural gas extraction may not fragment the habitat to the extent found in forested regions, Sage Sparrows may select against edges created by road construction.

In addition, road construction creates habitat for Horned Larks. Horned Larks are grassland species that are common along dirt roadways where they forage on windblown seeds that collect in the lee of gravel on dirt roads (Beason 1995). Within the 100-m road zone, Horned Larks accounted for 31% of bird detections, while beyond the 100-m zone they accounted for only 16%. This change in species composition is primarily the result of a decline in sagebrush obligate abundance within the 100-m zone; however, Horned Lark abundance was slightly higher within the 100-m road zone. Because Horned Larks foraging on roads and road margins were outside point count boundaries and not included in count totals, estimates of Horned Lark abundance along roads are conservative. Extensive studies of sagebrush steppe birds illustrate that competition rarely structures this avian community (Rotenberry 1980a, 1980b, Wiens and Rotenberry 1981). Negative interactions between sympatric species are rare in part because resources are seldom limiting and are not concentrated (Wiens 1974, 1977). However, the concentration of seed resources along dirt roads may create a foraging opportunity that Horned Larks defend. Of passerines in the study area, the Horned Lark is the 2nd largest, the Sage Thrasher being the largest. Horned Larks were repeatedly observed initiating aggressive interactions with Brewer's and Sage Sparrows along roads. Increased concentration of Horned Larks along roads may reduce the surrounding habitat's attractiveness to other sympatric species through either exploitative or interference competition. While evidence from this study does not support the competitive exclusion of sagebrush obligates by Horned Larks, the theory may warrant additional investigation.

At all study locations, regardless of traffic volume, sagebrush obligate bird density was reduced within the 100-m road zone. However, at 3 sites—Lumman II, Mesa II, and Highway 351—reductions were not statistically significant. At Lumman II and Mesa II, small sample size reduced the power of these analyses; reductions in breeding bird density of less than one-third were not statistically significant.

Along Highway 351 bird densities were less, but again reductions were not statistically significant. Three factors may contribute to this pattern. First, the road was paved. Although pavement allows for greater vehicle speeds, it eliminates the foraging opportunities for Horned Larks. Paved Highway 351 was the only site where Horned Larks were reduced within the road zone. Second, a barbed-wire fence ran the length of the highway. This fence, 1.3 m in height, ran parallel to the highway on both sides of the road. Located about 20 m from the road's edge, it split the point counts located within the 100-m road zone. Birds were often observed perching on and singing from this fence. If this elevated perch attracted birds or increased their detectability relative to other areas, the fence may have inflated detection totals within the 100-m road zone. Finally, Highway 351 was the most xeric area within the study and had the lowest sagebrush canopy cover and average height of any site. Point detections were lower here than at any other area, and the failure to detect significant declines could have been influenced by the overall paucity of birds within the area.

While a 50% reduction in sagebrush obligates within 100 m of a single road may not be biologically significant given the dominance of this vegetation type within the region, the density of roads created during natural gas development and extraction compounds the effect and the area of impact can be substantial. In the Record of Decision, signed in July 2000, the Bureau of Land Management approved the construction of 444 km of roads within the portion of PAPA under BLM jurisdiction (Bureau of Land Management 2000). If a conservative road width of 10 m is used, roads will cover over 0.7% of PAPA. If a 100-m buffer is extended around the roads, the impact will be over 14.6% of PAPA.

This study was conducted during the beginning phases of natural gas development, during which sagebrush vegetation was still fairly contiguous and unfragmented. As development continues, roads, pipelines, and well pads will perforate sagebrush habitats. Future studies should investigate how birds respond to these development changes. Of particular interest is how birds respond to habitat perforation and fragmentation and how species composition changes as roads create corridors that attract Horned Larks and nest predators to areas formerly dominated by sagebrush obligates.

The long-term impact of natural gas development on sagebrush obligate passerines is unclear. Based on this study, sagebrush obligate passerines are expected to decline within the study area. The magnitude of this decline will depend on the amount of road construction and on bird response to other development activities such as edges created by pipelines, habitat fragmentation, and perhaps increases in Horned Lark abundance.

While sagebrush obligate passerines will decline during natural gas development and extraction within PAPA, perhaps the more important issue relates to how quickly these populations will recover after the area is abandoned and reclaimed. Passerines are more flexible in their breeding requirements than many other bird species. This suggests that birds may quickly return to their former ranges after reclamation. However, population dynamics are not so simple. Natural gas extraction is expected to increase throughout Wyoming's sagebrush habitat. While population consequences of development of a single natural gas field may not be important, the development of multiple gas fields simultaneously could have important long-term population ramifications. Given the inability of sagebrush obligate passerines to expand their populations quickly (Wiens 1974, 1977), sagebrush obligate recovery may take decades after reclamation of the Pinedale Anticline Project Area. Given the inevitability of increased pressures of resource extraction on sagebrush ecosystems, understanding the large-scale implications for birds dependent on these systems is essential. Further monitoring seems advisable and may provide inference into how roads, even without significant traffic volumes, can impact bird communities.

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