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ABUNDANCE OF THREE GRASSLAND SONGBIRDS IN AN AREA OF NATURAL GAS INFILL DRILLING IN ALBERTA, CANADA

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Abstract. Although grassland birds are the most severely declining habitat guild and energy development is a common land use in remaining grassland there is limited published literature on the effect of gas wells and associated infrastructure or activities on grassland bird populations. We examined our inventory and monitoring data from Canadian Forces Base Suffield National Wildlife Area for possible responses to the infill drilling. There was a low density (4 wells per 2.59 km^2) of gas wells during the inventory but infill drilling began in 1997. By the end of 2003 the number of wells had doubled in most of the area and increased 4 fold in some portions. Further drilling is proposed. The bird inventory took place in 1994 and 1995 and annual bird monitoring began in 2000. In analyzing existing count data for possible effects of shallow natural gas wells we focused our attention on three species. Sprague's Pipit (*Anthus spragueii*) and Baird's Sparrow (*Ammodramus bairdii*) show avoidance of non-native vegetation and are area sensitive. Savannah Sparrow (*Passerculus sandwichensis*) tolerates non-native grasses and uses small patches. We matched years with similar precipitation histories/habitat conditions but different well densities. Repeated measures testing found Sprague's Pipit and Baird's Sparrow decreased with increased well density while Savannah Sparrow increased. This is consistent with observed habitat effects of the industrial activity and known habitat preferences of these species. Mapping of territory boundaries in 2007 indicated pipit territories rarely crossed trails and usually did not contain non-native vegetation.

Key Words: Baird's Sparrow, crested wheatgrass, drilling, grassland, linear disturbance, natural gas, Savannah Sparrow, Sprague's Pipit.

ABUNDANCIA DE TRES ESPECIES DE AVES CANORAS DE PASTIZALES EN UN AREA DE EXTRACCIÓN DE GAS NATURAL EN ALBERTA, CANADA

Resumen. A pesar de que los pájaros de los pastizales son el grupo animal con los mayores índices de declinación poblacional en este hábitat y la explotación de recursos energéticos es el uso común de los pastizales existentes, hay un numero limitado de literatura científica en los efectos de los pozos de gas natural y la infraestructura o actividades asociadas a estos en estas poblaciones. Examinamos nuestro inventario y datos de monitoreo obtenidos en la base de las fuerzas armadas Canadienses en la reserva nacional de Suffield en busca de posibles respuestas al efecto de las perforación gasífera de relleno en esta área. Encontramos una baja densidad (4 pozos por cada 2.59 Km.) de pozos de gas durante nuestro inventario, pero las perforaciones en el área comenzaron en 1997. Para el año 2003 el número de pozos se había doblado en la mayoría de las áreas y se incremento hasta 4 veces en algunas porciones. Más perforaciones han sido propuestas. El inventario de pájaros tuvo lugar en los años 1994 y 1995 y el monitoreo anual de pájaros comenzó en el año 2000. Durante el análisis de los datos de conteo existentes para los posibles efectos de pozos relleno de gas natural enfocamos nuestra atención en tres especies. Sprague's Pipit (*Anthus spragueii*) y el gorrión de Baird evitan la vegetación no nativa y son sensibles a el tamaño del área. El gorrión de la Sabana (*Passerculus sandwichensis*) tolera pastos no nativos y usa pequeños terrenos. Comparamos los años con índices de precipitación y condiciones de hábitat similares pero con diferentes niveles en la concentración de pozos. La repetición de mediciones mostró que el Sprague's pipit y el gorrión de Baird se redujeron en número con el incremento de la densidad de los pozos mientras que el gorrión de la Sabana se incremento. Esto concuerda con los efectos observados en hábitats con actividad industrial y las preferencias de hábitat conocidas para estas especies. El mapeo de los territorios aledaños en el año 2007 indico que los territorios de pipit raramente cruzan caminos y usualmente no contienen vegetación no nativa.

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INTRODUCTION

Grassland birds as a group are declining more dramatically in North America than any other guild (Sauer et al. 2007). In western Canada declines appear to be steeper than current rates of breeding habitat loss. Although trends are better for most grassland bird species in areas of prairie Canada where grassland is more common, some species show similar or greater recent declines in core areas where native grasslands are still intact than they do in highly modified landscapes (Dale et al. 2005). These differential trends are not explained by productivity as demographic research in prairie Canada found similar or better nest success in large blocks of grassland than in small blocks for most species (Davis et al. 2006). We lack information on recruitment and over-winter survival. Degradation of intact habitat could have a stronger effect in areas of higher density and is one possible explanation for the observed trends. Conservation may depend on identifying detrimental land uses so that better management practices can be developed.

The extraction of oil, natural gas, and coal bed methane is a common activity in prairie Canada (see Fig. 10, p. 24 in Askins et al. 2007), yet there are few studies that have examined possible effects of this industry on birds in this or any biome. The few existing studies in open country have shown negative effects. Reduced numbers near, or avoidance of, wellheads, buildings, two-track trails, all terrain vehicle trails, low traffic dirt roads, and pipelines or seismic lines have been found for sagebrush obligate, tundra, and grassland songbirds (Ingelfinger and Anderson 2004, Ashenhurst and Hannon 2008, Linnen 2008), Lesser Prairie-chicken (Pitman et al. 2005), and Greater Sage-grouse (Holloran 2005, Walker et al. 2007, Doherty et al. 2008). Reduced nest initiation, nest success, or chick survival associated with energy infrastructure has also been demonstrated (Lyon and Anderson 2003, Aldridge and Boyce 2007).

Many grassland birds show negative responses to the types of habitat alteration associated with natural gas development such as increased linear development (roads trails and pipelines), fragmentation, and invasion by non-native plant species. Reduced numbers of several grassland songbirds near roads have been reported (Sutter et al. 2000, Koper and Schmiegelow 2006). A number of grassland birds show area sensitivity based on abundance and sometimes productivity in prairie Canada (Davis 2004, Davis et al. 2006). The replacement or invasion of native grassland by non-native plants is associated with reduced numbers of several grassland birds (Wilson and Belcher 1989, Sutter and Brigham 1998).

The Canadian Department of National Defence documented increased linear development and damage to native plant integrity on Canadian Forces Base Suffield (CFB Suffield) associated with drilling (Rowland 2008). The plant community integrity issues center on invasive, non-native crested wheatgrass (*Agropyron cristatum*) which was used to re-vegetate most wells and pipelines until the 1980s. The initial plantings, although small in extent were distributed throughout the area and the plants have had over 30 years to spread. Currently maintenance vehicles use trails on or adjacent to pipelines and visit both old and new wells on the same trip. This practice may potentially inoculate newer minimum disturbance wells and pipelines with crested wheatgrass. The species' high seed production is a factor in its success as an invader (Heidinga and Wilson 2002). Crested wheatgrass was detected up to the maximum sampling distance of 25 m from seeded pipelines at CFB Suffield (Henderson 2007).

Additional drilling is proposed within our study area making the examination of possible effects urgent. To quantify possible drilling effects we utilized existing counts of birds from a period with low well densities (inventory of 1994 and 1995) and counts from the same locations from years with similar precipitation history or habitat conditions after well densities had increased (monitoring data from 2004 or 2005).

We selected three species for investigation. Sprague's Pipit (*Anthus spragueii*) and Baird's Sparrow (*Ammodramus bairdii*) are endemic to the Northern Great Plains, are area sensitive (Davis 2004), display reduced numbers in areas near roads (Sutter et al. 2000), and in sites dominated by non-native plants (Wilson and Belcher 1989, Robbins and Dale 1999, Green et al. 2002). Both showed steeper declines on routes in high abundance areas than those in low abundance areas (Dale et al. 2005). The more widespread Savannah Sparrow (*Passerculus sandwichensis*) is not area sensitive in prairie Canada (Davis 2004), occurs in increased numbers near roads (Sutter et al. 2000), readily uses non-native plants (McMaster and Davis 2001) and shows better trends on routes where it is more common (Dale et al. 2005).

We hypothesized that Sprague's Pipit and Baird's Sparrow abundance would decrease and Savannah Sparrow's abundance increase with the additional linear disturbance and non-native vegetation associated with the drilling and maintenance of additional natural gas wells. To understand the observed responses of birds to habitat changes associated with natural gas drilling we made reference to 2007 observations of territory boundaries in relation to trails and the frequency and extent of occurrence of crested wheatgrass inside territories of two of the species (Sprague's Pipit and Savannah Sparrow). We hypothesized that Sprague's Pipit territories would rarely cross trails and be minimally associated with crested wheatgrass while Savannah Sparrow territories would be more associated with trails and crested wheatgrass.

METHODS

Study Area

Our study area is a 190-km^2 grassland block in the southeast corner of CFB Suffield, in southeastern Alberta, Canada (50°14'N, 110°37'W). The CFB Suffield block is one of the largest remaining areas (approximately 2690 km^2) in Prairie Canada where native grassland remains largely intact. CFB Suffield and surrounding grasslands has been rated as the most important area for grassland conservation in Canada (CEC and TNC 2005). The study area is grassland but varies from flat with little or no shrub to more hilly terrain including areas with moderate amounts of low shrub to large well-drained hills. The entire study area is part of a federal community pasture, stocked at similar conservative rates throughout the period of our study. The majority of our study area was designated as a National Wildlife Area (NWA) in June 2002. The NWA was the object of an inventory in 1994 and 1995 and supported virtually all grassland birds expected at this latitude (Dale et al. In Review). The inventory was conducted during a time when natural gas well density was uniformly 4 wells per square mile (wps, 1 mi^2 = 2.59 km^2). Additional wells were drilled between 1999 and late 2003 increasing well density to either 8 wps or 16 wps.

Six additional years of point-count data (2000–2005) were collected as part of a long-term monitoring program conducted by the Canadian Wildlife Service. During the course of the inventory and monitoring projects there was large variation in precipitation. The 30-year normal for the area is 329 mm (Meteorological Service of Canada 2004). The two inventory years had normal precipitation (within 10% of 30 year normal) and were preceded by normal or above normal conditions. Slightly dry conditions beginning in 1999 (10% less precipitation than the 30-year normal) developed into a serious drought in 2001 (50% less precipitation than normal) and extended into early spring 2002. Late spring 2002 saw higher than normal rainfall but then precipitation was normal for the region in 2003 and 2004. In 2005 precipitation was above the 30-year normal. No prescribed burns or wildfires took place on any count locations during the study period.

Bird Counts

We conducted bird surveys in 1994, 1995, and 2000-2005 as standard point counts (Hutto et al. 1986) and enumerated all birds seen and heard inside and outside of a 100-m-radius circle for five minutes. We paid special attention to multiple individuals singing or visible at the same time as these observations are the most helpful in determining total pair estimates.

Survey stations were located 500 m apart along transects spaced 1 km apart. Station spacing required that birds outside the 100-m-radius were only recorded within a 250-m-radius circle. Although the observers were already skilled at bird identification, we minimized observer differences through annual training and cross checks as recommended by Kepler and Scott (1981). We frequently verified our distance estimation by post count pacing in 1994 and 1995 and with a range finder thereafter.

We assigned observers (two in all years except 1995 when there were three) and adjusted visit order to control observer, time of day, and time of year bias. We used the total counts of estimated pairs within 250 m as the most reliable indication of the number of birds within the study area as several species had large territories that were not contained within the 100-m-radius circle. Most sites were visited in only one of the two inventory years. During monitoring we endeavored to visit all stations in every year, but in some years weather conditions or adjacent military exercises limited the number of stations that could be visited. Surveys were conducted between the latter half of May and early June in all years except for 1994 and 1995 where surveys were conducted as late as early July.

Well Density

We calculated year-specific well density at each of our bird sample points. We determined well density over an area the equivalent of one square mile by counting all wells within a 908 m radius of each sample site. Well location information was purchased from the geomatics company IHS Canada. We chose to express well density at the one square mile level for several reasons: aggregating the number of wells at this scale allows for comparisons to industry measures which are commonly expressed as wells per square mile; and, well density is a measure not just of disturbance in the immediate vicinity of the well but also of the associated trails, pipelines and anthropogenic changes in the surrounding landscape. Grassland bird habitat selection appears to be influenced by both micro-habitat within the territory and features of the surrounding habitat. Unpublished models of Sprague's Pipit and Baird's Sparrow have found predictive value for features at 800 or 1200 m (Environment Canada unpublished data) and occurrence models for other bird species in arid landscapes have found linear disturbance within 1 and 2 km to be an important predictor (Gutzwiller and Barrow 2003).

Selecting Samples

A before and after/control and impact approach was not possible because we were re-analyzing data collected for other purposes and additional drilling had taken place across the entire study area. In order to identify possible effects with just a before and after approach we sought to identify, minimize, or equalize possible sources of variation other than drilling. These were: soil, topography, fire, grazing, precipitation, associated habitat structure and observer.

Soil, topography, fire and grazing

We controlled for soil and topography as well as grazing and fire by matching sites in the before and after comparison. Soil and topography remain the same at a given location as does grazing because grazing patterns are sustained through time (Willms et al. 1988, Briske et al. 2008). Stocking rates and fire histories were comparable in the before and after periods (with any difference favoring the after period).

Precipitation

For grassland birds, detecting possible changes associated with increasing numbers of wells is complicated by substantial year-to-year variation in bird numbers (Wiens and Dyer 1975). Dramatic population variation likely relates to year-to-year fluctuation in precipitation and the associated variation in habitat structure and possibly productivity. Grassland birds have long been known to make habitat choices on the basis of habitat structure (Wiens 1969). Habitat structural measures such as canopy height and closure have been demonstrated to be strongly correlated with above-ground net primary productivity (ANPP) (Lane et al. 2000). In turn, the relationship between ANPP and precipitation was examined by Oesterheld et al. (2001) who reported r values of 0.58 and 0.60 for ANPP regression models based on current year precipitation and previous-year ANPP or previous-year precipitation respectively. The relationship between ANPP and precipitation, however, is not linear. Wet years can increase vegetative production more than dry years can reduce growth (Flanagan et al. 2002).

As standing and fallen dead grass (litter) result from the death and decay of vegetation, they are also related to precipitation. Epstein et al. (2002) examined the relationship between climate, ANPP, and decomposition. They suggest that grassland ecosystems are in fact in a steady state such that, with the exception of climatic extremes, the rate of decomposition is approximately equal to the rate of ANPP. Heitschmidt et al. (2005) studied the effects of drought on grass growth in mixed grass prairie in Montana. They found that two years post-drought, production had almost, but not fully, recovered. This would effectively mean that a two-year drought period would eliminate most litter which would then require two or more years to be replenished.

Clearly the relationship between bird numbers, precipitation, and habitat conditions is complex. In order to assess possible effects of anthropogenic activity this complexity must be accounted for by considering precipitation conditions in previous years as well as differences in species habitat preferences. In our case, where we sought to evaluate the impact of increased well density, it was critical we only compare bird numbers from years with species specific matched precipitation/vegetation condition histories.

Precipitation data for the five climate Environment Canada stations within 60 km of the study area were merged to generate local average precipitation by month for the period of 1992 through 2005. These local averages were then used to calculate current year (January through May), previous year, and two years previous totals.

In addition to their direct use, precipitation totals were used to calculate the Conserved Soil Moisture (CSM) index which is a weighted mean of spring precipitation and the precipitation from the previous two years (Williams and Robertson 1965). We previously (Wiens et al. 2008) identified which of these climatic measures were the best predictors at CFB Suffield for the occurrence of Baird's Sparrow (CSM) and Savannah Sparrow (precipitation from January to May of study year, previous year and two years previous) but found no ideal combination of precipitation variables or weightings for Sprague's Pipit. This was possibly because the species depends on litter, which takes several years to develop and may not be adequately described with combinations of precipitation variables that emphasize current year moisture (Wiens et al. 2008). Because an index of litter accumulation was available (Alberta Sustainable Resource Development 2007) for CFB Suffield we used this direct measure to identify year matches for Sprague's Pipit in place of indirect climatic proxies.

We evaluated which, if any, of the increased wps years (2004, 2005) were appropriate climatic matches for the low wps years 1994 and 1995 for each study species. We initially assessed potential year matches manually. Because exact matches did not exist we utilized only those year matches which exhibited a reverse bias. For example, if wells were predicted to reduce abundance for a species we selected pairs of years such that the higher wps year would have climatic conditions associated with increased numbers. In this way if there was bias it decreased the size of observed changes making the test conservative. We confirmed our manual matching using agglomerative hierarchical clustering of years and precipitation variables as implemented in the cluster package for R (R Core Development Team 2007). In all cases we clustered the data using agglomerative hierarchical clustering first with complete linkage and then again with average dissimilarity evaluations to ensure consistency in the selection.

Observer

We compared abundance data for only those sites done in both the before and after periods by the principal observer or any observers who were not significantly different ($P > 0.05$) from the principal observer that year. We also examined the direction of any non-significant differences between observers to be certain our test was conservative (any differences in observers would lessen not increase the change in bird numbers between time periods).

Territorial Observations

Territories of Sprague's Pipit and Savannah Sparrow were delineated in the period 24 May to 28 July 2007. The territory mapping started as close to sunrise as possible. To locate the birds, we used existing location data from point counts and looked for generic habitat characteristics associated with the two species. When we heard a male singing, we walked towards him and marked the points where he was singing or calling using the boundary flush method as described by Reed (1985). We also marked where conflicts occurred between neighboring males. After we had a minimum of 20 locations, we used a handheld Global Positioning System to record each location (±4 m) and demarcated the perimeter of the territory.

Crested wheatgrass surveys took place within the same date range as territory observations. If there was crested wheatgrass visible within a delineated bird territory we recorded the locations of the edges of the patches or the individual clumps. The geo-referenced points were used to calculate the area of territories and extent of crested wheatgrass. Trails and well sites near or in the territories were also georeferenced. Trails, for the purpose of this study, did not include animal trails and were only counted if parallel vehicle tracks were observed. Not all trails observed were associated with energy development.

Mock territory mapping was conducted from 19 to 28 June, 2007. Mock territories for each species were established in areas where existing location data indicated the species was absent. As a further check we recorded birds present during vegetative mapping. A radius of 50 m was used for setting the boundaries of the mock territories. This incorporated an area of 0.78 ha, similar to the size of Savannah Sparrow territories and larger than the average pipit territory as found from territory mapping. Crested wheatgrass occurrence and extent was recorded in the same manner as in the bird territories.

Statistical Analyses

Matched Pairs

We used our matched year data and calculated a one-sided paired Wilcoxon Signed Rank Test for counts from each pair of years. This test is not dependent on assumptions of normality which are incompatible with count data. The species-specific hypotheses, of either increasing in response to well density or decreasing in response to well density, were tested. We calculated the Power and the Minimum Effect Size (MES) by importing the data into R and used the power t test function specifying the same alpha (0.05), variance (unequal variances), test type (paired), and as one-way rather than two-way (R Core Development Team 2007). The MES was calculated assuming power equaled 0.80.

Generalized Linear Model (GLM)

In cases where we found a significant difference in our paired analysis we fitted a GLM.

Where there were two sets of matching years we merged the data from both matched pairs into a single data set stratified by a categorical variable of climatic condition. Stratification was necessary to ensure that the validity of the estimated model, because the two sets of years were somewhat different climatically. From this data set we estimated a very simple Poisson regression model using R (R Core Development Team 2007) based on the formula (R syntax) *total count ~ well density + climatic condition*. Where only one year pair was available, climatic condition was not included and the formula was *total count ~ well density*.

To test each model we calculated the model's *P* value by subtracting the chi-square distribution function of the model's deviance from 1. In this case a large *P* value is desirable. To estimate predicted changes in abundance we followed precedent (Browner 2006) and used the slope of these models as implemented in the "effects" library for *R* (R Core Development Team 2007). We calculated the predicted abundance and 95 percentile confidence limits at three well densities and expressed the effect size of any change in density as the difference in abundance as a percent of the abundance at the lower well density.

Territory

For Sprague's Pipit and Savannah Sparrow we enumerated the number of territories that crossed two track trails or included crested wheatgrass. The difference in frequency of occurrence of crested wheatgrass between actual and mock territories was tested as the difference between two independent binomial proportions (Kachigan 1986) as a single-tailed test (Wagner 1992). The percent cover of crested wheatgrass within actual and mock territories was compared using a *t*-test assuming unequal variance.

RESULTS

Matched Sites

Clustering analysis to match years using litter showed that the only appropriate match for Sprague's Pipit repeated measures analyses was 1995 with 2005. There was no appropriate high wps match for 1994. Similarly, Baird's Sparrow matches, based on CSM, occurred between 1995 and 2005 with no matching pair for 1994. Although these matches were not exact 2005 was a more favorable year than 1995 in terms of habitat conditions and CSM. The best matches for Savannah Sparrow, (based on precipitation from current year, previous year, and two years previous) were 1994 with 2004 and 1995 with 2005. In both cases the year matches were such that the earlier year in the pair was more climatically suitable for Savannah Sparrow. The comparisons between matched years showed a non-significant 13% decline in Sprague's Pipit (power = 0.001, MES = 21%) and significant increases and decreases for Savannah Sparrow and Baird's Sparrow respectively (Table 1).

The GLM analysis was significant for Baird's Sparrow (n = 96, P = 0.22) and Savannah Sparrow (n = 144, P = 0.44). Well count was a significant variable for both (P = 0.004 and P = 0.005) and climate a non-significant variable (P = 0.51) for Savannah Sparrow. The effects of increased well densities are substantial for both sparrows (Table 2). Increasing well density from 4 to 8 wps brings about a 52% increase in Savannah Sparrow and a 35% decline in Baird's Sparrow. An increase from 8 to 16 wps is associated with a 130% upsurge in Savannah Sparrow and a decrease of 58% for Baird's Sparrow. Increasing well density from the 4 wps (density at the time of the inventory) to the proposed 16 wps would result in a decrease of 73% for Baird's Sparrow and an increase in Savannah Sparrow of 249%.

TABLE 1. Comparison of mean counts of three bird species for matched pairs of years.

Species Year match	*n*	X1[1]	SE1[2]	X2[3]	SE2[4]	*P*	δ[5] (%)
Sprague's Pipit							
1995/2005	48	1.60	0.12	1.40	0.12	0.11	– 13
Savannah Sparrow							
1994/2004	24	0.17	0.08	0.45	0.13	0.02	+ 172
1995/2005	48	0.10	0.04	0.69	0.10	<0.001	+ 583
Baird's Sparrow							
1995/2005	48	1.10	0.16	0.88	0.12	0.04	– 21

[1] Mean count of indicated pairs/ 250 m radius circle in first year of matched years shown in column 1.
[2] Standard error of the mean from first year of matched years.
[3] Mean indicated pairs/ 250 m radius circle in second year of matched years.
[4] Standard error of the mean from second year of matched years.
[5] Difference in counts between matched years expressed as a percent of the first year.

TABLE 2. ESTIMATED ABUNDANCE OF TWO GRASSLAND BIRD SPECIES AT SPECIFIED WELL DENSITIES AS PREDICTED BY POISSON GENERALIZED LINEAR MODELS.

Species	*n*	Well density [1]	Bird abundance [2]
Savannah Sparrow	144	4 in 2.59 km^2	0.16 / 0.25 / 0.38
		8 in 2.59 km^2	0.29 / 0.38 / 0.50
		16 in 2.59 km^2	0.47 / 0.87 / 1.62
Baird's Sparrow	96	4 in 2.59 km^2	1.03 / 1.33 / 1.73
		8 in 2.59 km^2	0.68 / 0.86 / 1.09
		16 in 2.59 km^2	0.17 / 0.36 / 0.76

[1] 2.59 km2 is equivalent to 1 square mile.
[2] Abundance (number of indicated pairs/250 m radius circle) is reported with 95 percentile confidence intervals and is formatted as: lower / estimate / upper.

TERRITORY AND CRESTED WHEATGRASS MAPPING

Sprague's Pipit territories crossed trails less frequently (5 of 46 territories) than did Savannah Sparrow (16 of 33 territories). Only 22% of Sprague's Pipit territories contained any measurable crested wheatgrass while 47% of Savannah Sparrow territories had some crested wheatgrass. The proportion of mock territories with crested wheatgrass was similar for Sprague's Pipit (47%) and Savannah Sparrow (55%). The difference in the presence of crested wheatgrass between mock and real territories for Sprague's Pipit was significant ($P = 0.03$) but there was no significant difference between mock and actual territories for Savannah Sparrow. The percent cover of crested wheatgrass inside Sprague's Pipit territories was very low (0.68%) and significantly different ($t = -2.32$, df = 29, $P = 0.03$) from the proportion in pipit mock territories (12.63%). Savannah Sparrows had a much higher percent cover of crested wheatgrass (12.59%) in their territories that was not significantly different ($t = 0.83$, df = 43, $P = 0.41$) from the cover in their mock territories (7.40%)

DISCUSSION

As predicted based on their habitat preferences, Sprague's Pipit and Baird's Sparrow abundance decreased and Savannah Sparrow abundance increased with well density in our before and after comparison and GLM analyses. Confidence intervals are wide for higher well densities as few of our matched sites had 16 wps. Sprague's Pipit territories rarely crossed trails, were significantly less likely to contain crested wheatgrass than were mock territories, and had a limited and significantly smaller extent of the invasive plant than in mock territories. Savannah Sparrow territories frequently crossed trails and the percent and area of occurrence of crested wheatgrass was similar to that of mock territories.

The advantage of matched sites is that differences in factors that could influence habitat structure, and thus counts, were controlled (soil, slope) or minimized (grazing, climatic/habitat conditions, observer) with the direction of difference favoring finding no effect. The matched year analysis using only sites that had been surveyed by the primary observer or observers with similar total counts resulted in very small sample sizes and thus low power. Using two observers in each year was a trade off as it increased our sample size and improved power but using multiple observers increased variance and decreased power (Diefenbach et al. 2003). In the case of Sprague's Pipit the calculated MES was substantially higher than the observed non-significant difference resulting in insufficient support to either accept or reject the hypothesis.

A multivariate approach allowing inclusion of more sites could address some statistical power issues and is being pursued as part of a spatially explicit predictive exercise (Dale and Wiens In Preparation).

Observed declines in endemic species in this study are in agreement with the limited literature addressing energy effects on open country songbirds (Ingelfinger and Anderson 2004, Ashenhurst and Hannon 2008, Linnen 2008). However, we were unable to include before and after on-site controls because the entire study area underwent drilling. Therefore observed changes in numbers might simply be due to long-term population trends and unrelated to energy industry activities. To address this possibility, we examined regional trends for each species for the exact same time period and compared them to the direction and magnitude of observed changes in our disturbed study area. For the period of 1995 to 2005 the Breeding Bird Survey (Downes and Collins 2008) reported weak non-significant increases for Sprague's Pipit in Alberta. This suggests the non-significant decrease observed in our study is not simply due to a regional decline in the same time period. Baird's Sparrow did decline non-significantly in Alberta which is similar in direction to that observed in our study but of a lower magnitude (the BBS index for Alberta declined only 9% between 1995 and 2005 while matched pairs showed 21% decline). For Savannah Sparrow the BBS trends for 1995 to 2005 for Alberta show statistically significant decline ($P < 0.05$), the opposite to that seen in our study indicating our observed change is not explained by regional population level changes in the same time period.

The actual amount of habitat lost to wells, pipelines and trails is a very small percent of the landscape. The majority of the observed negative effect may be caused by altered reproductive behavior due to even brief disturbance by all terrain vehicles, trucks or pedestrians (Baydack and Hein 1987, McGowan and Simons 2006) similar to that associated with periodic well maintenance. It could also relate to indirect habitat loss as a result of: additional habitat being invaded by non-native species near linear development (Gelbard and Harrison 2003, Henderson 2007, Rowland 2008); reduced bird density near narrow linear disturbance (Miller et al. 1998, Ingelfinger and Anderson 2004, Bayne et al. 2005, Holmes and Guepel 2005, Machtans 2006); or area effects due to reluctance to cross narrow linear disturbances (Bayne et al. 2005, Machtans 2006).

Our 2007 observations, showing Sprague's Pipit is unlikely to cross trails and avoids including crested wheatgrass in its territories, are consistent with underlying causes such as indirect habitat loss and area effects. A study elsewhere in CFB Suffield found significant avoidance within 300 m and 400 m of oil wells and associated trails for Sprague's Pipit and Baird's Sparrow respectively while Savannah Sparrow showed a non-significant increase with proximity to trails (Linnen 2008). This supports our findings and suggests the observed changes may relate to linear development.

Two boreal studies more thoroughly quantified the impact that reluctance to cross narrow discontinuities such as we observed can have on breeding songbirds. A before-and-after study found Ovenbirds (*Seiurus aurocapilla*) were reluctant to cross 6-m wide seismic lines, shifted territories away from lines, and were reduced in abundance when seismic lines were added (Machtans 2006). The other study examined lines up to 8 m wide and found Ovenbirds largely confined themselves to one side of the line and, in practical terms, treated seismic lines as territory boundaries (Bayne et al. 2005). This constrained where Ovenbird territories could occur resulting in a 19% decline for each 1 km increase above 8.5 km of linear disturbance per km^2. This would be a species-specific rate of decline related to territory size and the distance to which lines are avoided. Sprague's Pipit has a wider range of documented territory sizes (0.3 to 2.2 ha; Robbins and Dale 1999) than that cited for Ovenbird (0.6 to 1 ha; Bayne et al. 2005).

Biologically, it would be surprising if a decline was not associated with drilling for the two endemic species given their area sensitivity (Davis 2004, Davis et al. 2006), reduced numbers near roads (Sutter et al. 2000), and intolerance of non-native species (Sutter and Brigham 1998, Davis and Duncan 1999, Robbins and Dale 1999, Green et al. 2002). The Sprague's Pipit territory observations, the increase in Savannah Sparrow numbers, and the measures of crested wheatgrass support the possibility that fragmentation and the spread of non-native species associated with drilling-related linear development is driving the changes in bird counts at Suffield. Because all other known sources of breeding ground variability are controlled for or would minimize effects, the evidence suggests increased natural gas drilling is a causal factor in the possible decline of Sprague's Pipit, significant decrease in Baird's Sparrow, and increase of Savannah Sparrow in the Suffield study area. Our data were originally collected for another purpose but our results indicate that focused and detailed studies are warranted to fully understand the magnitude and the mechanism of the effect the energy industry is having on grassland birds and their habitat.

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LITERATURE CITED

Alberta Sustainable Resource Development. 2007. Rangeland reference area monitoring program—annual summary. Lands Division, Alberta Sustainable Resource Development, Lethbridge.

Aldridge, C. L., and M. S. Boyce. 2007. Linking occurrence and fitness to persistence: a habitat-based approach for endangered Greater Sage-grouse. Ecological Applications 17:508–526.

Ashenhurst, A. R., and S. J. Hannon. 2008. Effects of seismic lines on the abundance of breeding birds in the Kendall Island Bird Sanctuary, Northwest Territories, Canada. Arctic 61:190–198.

Askins, R. A., F. Chávez-Ramírez, B. C. Dale, C. A. Haas, J. R. Herkert, F. L. Knopf, and P. D. Vickery. 2007. Conservation of grassland birds in North America: Understanding ecological process in different regions. Ornithological Monographs No. 64.

Baydack, R. K., and D. A. Hein. 1987. Tolerance of Sharp-tailed grouse to lek disturbance. Wildlife Society Bulletin 15:535–539.

Bayne, E. M., S. L. Van Wilgenburg, S. Boutin, and K. A. Hobson. 2005. Modeling and field-testing of Ovenbird (*Seiurus aurocapilla*) responses to boreal forest dissection by energy sector development at multiple spatial scales. Landscape Ecology 20:203–216.

Briske, D. D., J. D. Derner, J. R. Brown, S. D. Fuhlendorf, W. R. Teague, K. M. Havstad, R. L. Gillen, A. J. Ash, and W. D. Willms. 2008. Rotational grazing on rangelands: reconciliation of perception and experimental evidence. Rangeland Ecology and Management 61:3–17.

Browner, W. S. 2006. Publishing and presenting in clinical research, 2nd ed. Lippincott, Williams and Wilkins.

CEC and TNC. 2005. North American Central grasslands priority conservation areas: technical report and documentation. J. W. Karl and J. Hoth [eds.]. Commission for Environmental Cooperation and The Nature Conservancy. Montreal, Quebec.

Dale, B. C., M. Norton, C. Downes, and B. Collins. 2005. Monitoring as a means to focus research and conservation—The grassland bird monitoring example, pp. 485–495. *In* C. J. Ralph and T. D. Rich [eds.], Bird Conservation Implementation and Integration in the Americas: Proceedings of the Third International Partners in Flight Conference. 2002. U.S. Department of Agriculture, Forest Service General Technical Report PSW-GTR-191.

Dale, B. C., M. Norton, P. S. Taylor, and J. P. Goossen. In Review. Protecting a regional avifauna—topographic, habitat, and bird diversity in a prairie preserve. Canadian Field–Naturalist.

Dale, B. C., and T. S. Wiens. In Preparation. Using multi-year data to identify habitat for protection in a changing world.

Davis, S. K. 2004. Area sensitivity in grassland passerines: effects of patch size, patch shape, and vegetation structure on bird abundance and occurrence in southern Saskatchewan. Auk 121:1130–1145.

Davis, S. K., R. M. Brigham, T. L. Shaffer, and P. C. James. 2006. Mixed-grass prairie passerines exhibit weak and variable responses to patch size. Auk 123:807–821.

Davis, S. K., and D. C. Duncan. 1999. Grassland songbird occurrence in native and crested wheatgrass pastures of southern Saskatchewan. Studies in Avian Biology 19:211–218.

Diefenbach, D. R., D. W. Brauning, and J. A. Mattice. 2003. Variability in grassland bird counts related to observer differences and species detection rates. Auk 120:1168–1179.

Doherty, K. E., D. E. Naugle, B. L. Walker, and J. M. Graham. 2008. Greater Sage-grouse winter habitat selection and energy development. Journal of Wildlife Management 72:187–195.

Downes, C. M., and B. T. Collins. 2008. Canadian Bird Trends Web site (archived results for 1995–2005). Canadian Wildlife Service, Environment Canada, Gatineau, Quebec, K1A 0H3.

Epstein, H. E., I. C. Burke, and W. K. Lauenroth. 2002. Regional patterns of decomposition and primary production rates in the U.S. Great Plains. Ecology 83:320–327.

Flanagan, L. B., L. A. Wever, and P. J. Carlson. 2002. Seasonal and inter-annual variation in carbon dioxide exchange and carbon balance in a northern temperate grassland. Global Change Biology 8:599–615.

Gelbard, J. L., and J. Harrison. 2003. Roads as conduits for exotic plant invasions in a semiarid landscape. Conservation Biology 17:420–432.

Green, M. T., P. W. Lowther, S. L. Jones, S. K. Davis, and B. C. Dale. 2002. Baird's Sparrow (*Ammodramus bairdii*). *In* A. Poole and F. Gill [eds.], The Birds of North America, No. 638. The Birds of North America Inc., Philadelphia, PA.

Gutzwiller, K. J., and W. C. Barrow. 2003. Influences of roads and development on bird communities in protected Chihuahuan Desert landscapes. Biological Conservation 113:225–237.

Heidinga, L., and S. D. Wilson. 2002. The impact of an invading alien grass (*Agropyron cristatum*) on species turnover in native prairie. Diversity and Distributions 8:249–258.

Heitschmidt, R. K., K. D. Klement, and M. R. Haferkamp. 2005. Interactive effects of drought and grazing on northern Great Plains rangelands. Rangeland Ecology and Management 58:11–19.

Henderson, D. 2007. Crested wheatgrass invasion: influence of prevailing winds and grazing at CFB Suffield. Unpublished report. Environment Canada. Saskatoon, Saskatchewan, Canada.

Holloran, M. J. 2005. Greater Sage-grouse (*Centrocercus urophasianus*) population response to natural gas field development in western Wyoming. Ph.D. thesis, Dept. of Zoology and Physiology, University of Wyoming.

Holmes, A. L., and G. R. Guepel. 2005. Effects of trail width on the densities of four species of breeding birds in chaparral, pp. 610–612. *In* C. J. Ralph and T. D. Rich [eds.], Bird Conservation Implementation and Integration in the Americas: Proceedings of the Third International Partners in Flight Conference. 2002. U.S. Department of Agriculture, Forest Service General Technical Report PSW-GTR-191.

Hutto, R. L., S. M. Pletschet, and P. Hendricks. 1986. A fixed-radius point-count method for nonbreeding and breeding season use. Auk 103:593–602.

Ingelfinger, F., and S. Anderson. 2004. Passerine response to roads associated with natural gas extraction in a sagebrush steppe habitat. Western North American Naturalist 64:385–395.

Kachigan, S. K. 1986. Statistical Analysis. Radius Press. New York.

Kepler, C. B., and J. M. Scott. 1981. Reducing bird count variability by training observers. Studies in Avian Biology 6:366–371.

Koper, F., and F. K. A. Schmiegelow. 2006. Effects of habitat management for ducks on target and nontarget species. Journal of Wildlife Management 70:823–834.

Lane, D. R., D. P. Coffin, and W. K. Lauenroth. 2000. Changes in grassland canopy structure across a precipitation gradient. Journal of Vegetation Science 11:359–368.

Linnen, C. G. 2008. Effects of oil and gas development on grassland birds. Prepared for Petroleum Technology Alliance Canada.

Lyon, A. G., and S. H. Anderson. 2003. Potential gas development impacts on sage-grouse nest initiation and movement. Wildlife Society Bulletin 31:486–491.

Machtans, C. S. 2006. Songbird response to seismic lines in the western boreal forest: a manipulative experiment. Canadian Journal of Zoology 84:1421–1430.

McGowan, C. P., and T. R. Simons. 2006. Effects of human disturbance on the incubation behavior of American Oystercatchers. Wilson Bulletin 118:485–493.

McMaster, G., and S. Davis. 2001. An evaluation of Canada's Permanent Cover Program: habitat for grassland birds? Journal of Field Ornithology 72:195–210.

Meteorological Service of Canada. 2004. Canadian climate normals or averages 1971–2000. [Online.] <http://www.climate.weatheroffice.ec.gc.ca/climate normals/index.e.html> (19 September 2007).

Miller, S. G., R. L. Knight, and C. K. Miller. 1998. Influence of recreational trails on breeding bird communities. Ecological Applications 8:162–169.

Oesterheld, M., J. Loreti, M. Semmartin, and O. E. Sala. 2001. Inter-annual variation in primary production of semi-arid grassland related to previous-year production. Ursus 13:45–56.

Pitman, J. C., C. A. Hagen, R. J. Robel, T. M. Loughin, and R. D. Applegate. 2005. Location and success of Lesser Prairie-chicken nests in relation to vegetation and human disturbance. Journal of Wildlife Management 69:1259–1269.

R Core Development Team. 2007. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. [Online.] <http://www.R-project.org> (1 August 2008).

Reed, J. M. 1985. A comparison of the "flush" and spot-map methods for estimating the size of vesper sparrow territories. Journal of Field Ornithology 56:131–137.

Robbins, M. B., and B. C. Dale. 1999. Sprague's Pipit (*Anthus spragueii*). *In* A. Poole and F. Gill [eds.], The Birds of North America No. 439. The Birds of North America Inc., Philadelphia, PA.

Rowland, J. 2008. Ecosystem impacts of historical shallow gas wells within the CFB Suffield National Wildlife Area. Unpublished report, Department of National Defence. Ottawa, Ontario, Canada.

Sauer, J. R., J. E. Hines, and J. Fallon. 2007. The North American Breeding Bird Survey, Results and Analysis 1966–2006. Version 10.13.2007. [Online.] <http://www.pwrc.usgs.gov/> (26 May 2008).

Sutter, G. C., and M. Brigham. 1998. Avifaunal and habitat changes resulting from conversion of native prairie to crested wheat grass: patterns at songbird community and species levels. Canadian Journal of Zoology 76:869–875.

Sutter, G. C., S. K. Davis, and D. C. Duncan. 2000. Grassland songbird abundance along roads and trails in southern Saskatchewan. Journal of Field Ornithology 71:110–116.

Wagner, S. F. 1992. Introduction to statistics. HarperCollins College Outline Series, HarperCollins, NY.

Walker, B. L., D. E. Naugle, and K. E. Doherty. 2007. Greater Sage-grouse population response to energy development and habitat loss. Journal of Wildlife Management 71:2644–2654.

Wiens, J. 1969. An approach to the study of ecological relationships among grassland birds. Ornithological Monographs 8.

Wiens, J. A., and M. I. Dyer. 1975. Rangeland avifaunas: their composition, energetics, and role in the ecosystem, pp. 146–182. *In* D. R. Smith [ed.], Symposium on management of forest and range habitats for nongame birds U.S. Forest Service General Technical Report WO-l. Tucson, AZ.

Wiens, T. S., B. C. Dale, M. S. Boyce, and G. P. Kershaw. 2008. Three way k-fold cross-validation of resource selection functions. Ecological Modelling 212:244–255.

Williams, G. D. V., and G. W. Robertson. 1965. Estimating most probable wheat production from precipitation data. Canadian Journal of Plant Science 45:34–47.

Williams, W. D., J. F. Dormaar, and G. B. Schaalje. 1988. Stability of grazed patches on rough fescue grasslands. Journal of Range Management 41:503–508.

Wilson, S. D., and J. W. Belcher. 1989. Plant and bird communities of native prairie and introduced Eurasian vegetation in Manitoba, Canada. Conservation Biology 3:39–44.