Original Article

Using Spatial Statistics and Point-Pattern Simulations to Assess the Spatial Dependency Between Greater Sage-Grouse and Anthropogenic Features

JEFFREY K. GILLAN,[1,2] *Department of Forest, Rangeland and Fire Sciences, University of Idaho, 709 Deakin Avenue, Moscow, ID 83844-9802, USA*

EVA K. STRAND, *Department of Forest, Rangeland and Fire Sciences, University of Idaho, 709 Deakin Avenue, Moscow, ID 83844-9802, USA*

JASON W. KARL, *New Mexico State University Las Cruces, NM 88003-8003, USA*

KERRY P. REESE, *Department of Fish and Wildlife Resources, University of Idaho, 709 Deakin Avenue, Moscow, ID 83844-9802, USA*

TAMARA LANINGA, *Department of Conservation Social Sciences, University of Idaho, 709 Deakin Avenue, Moscow, ID 83844-9802, USA*

ABSTRACT The greater sage-grouse (*Centrocercus urophasianus;* hereafter, sage-grouse), a candidate species for listing under the Endangered Species Act, has experienced population declines across its range in the sagebrush (*Artemisia* spp.) steppe ecosystems of western North America. One factor contributing to the loss of habitat is the expanding human population with associated development and infrastructure. Our objective was to use a spatial-statistical approach to assess the effect of roads, power transmission lines, and rural buildings on sage-grouse habitat use. We used the pair correlation function (PCF) spatial statistic to compare sage-grouse radiotelemetry locations in west-central Idaho, USA, to the locations of anthropogenic features to determine whether sage-grouse avoided these features, thus reducing available habitat. To determine significance, we compared empirical PCFs with Monte Carlo simulations that replicated the spatial autocorrelation of the sampled sage-grouse locations. We demonstrate the implications of selecting an appropriate null model for the spatial statistical analysis by comparing results using a spatially random and a clustered null model. Results indicated that sage-grouse avoided buildings by 150 m and power transmission lines by 600 m, because their PCFs were outside the bounds of a 95% significance envelope constructed from 1,000 iterations of a null model. Sage-grouse exhibited no detectable avoidance of major and minor roads. The methods used here are broadly applicable in conservation biology and wildlife management to evaluate spatial relationships between species occurrence and landscape features. Our results can directly inform planning of infrastructure and other development projects in or near sage-grouse habitat.

KEY WORDS *Centrocercus urophasianus*, Monte Carlo, pair correlation function, point pattern, Ripley's K, sage-grouse, spatial statistics.

The greater sage-grouse (*Centrocercus urophasianus;* hereafter, sage-grouse), a candidate species for listing under the Endangered Species Act of 1973 (ESA; U.S. Department of the Interior 2010), has experienced population declines across its range in the sagebrush (*Artemisia* spp.) steppe ecosystems of western North America (Connelly and Braun 1997, Connelly et al. 2004). Sage-grouse now occupy only 56% of their pre-settlement range, though they still occur in 11 western states and 2 Canadian provinces (Schroeder et al. 2004). The conservation status of this wide-ranging species could have a significant influence on public land policy regarding land use, energy and mineral development, transportation and communication corridors, and livestock grazing (Wambolt et al. 2002; US Bureau of Land Management 2004, 2011; Stiver et al. 2006, 2010), because two-thirds of remaining sagebrush lands (329,881 km^2) are publicly managed (Knick 2011). The remaining one-third of sagebrush lands (150,186 km^2) that are privately owned (Knick 2011) could be impacted if sage-grouse are listed under the ESA.

Causes for the species' decline have been attributed primarily to the removal and degradation of sagebrush-dominated lands essential for cover, nesting, and food (Connelly and Braun 1997, Braun 1998, Leonard et al. 2000, Connelly et al. 2004). Historically, conversion of sagebrush habitats to crop fields and livestock pastures was the primary driver of habitat reduction (Swenson et al. 1987, Beck and

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[1]*E-mail: jgillan@nmsu.edu*
[2]*New Mexico State University Las Cruces, NM 88003-8003, USA*

Mitchell 2000), but more recently wildfire, invasion of annual grasses, and infrastructure development have been responsible for habitat alteration in the sagebrush steppe biome (Knick et al. 2003, 2011; Connelly et al. 2004; Miller et al. 2011).

One factor contributing to current sage-grouse habitat threats is the continually expanding human population and footprint. From 1960 to 2000, the western United States was the fastest growing region of the country and during the 1990s grew at twice the national rate (Perry and Mackun 2001, Travis 2007). From 2000 to 2010, population growth in the region slowed only slightly and 3 of the 4 fastest growing states (NV, UT, and ID) were those with significant sage-grouse populations (Mackun and Wilson 2011). Development patterns spurred by increasing human populations have been characterized by extensive suburban development around major cities and rapid growth of exurban communities and "ranchettes" far removed from metropolitan centers (Brown et al. 2005, Hansen et al. 2005, Travis 2007). This type of growth consumes more land and fragments landscapes more significantly than concentrated urban development (Sullins et al. 2002, Connelly et al. 2004). Many ranches that were previously used for livestock production have been sold and subdivided into low-density housing (Knick et al. 2011). Associated infrastructure, including roads and power-lines, has also expanded on these landscapes (Leu et al. 2008, Leu and Hanser 2011). In some parts of the sage-grouse range, most notably Wyoming, USA, energy development has expanded (Walker et al. 2007, Naugle et al. 2011). Thousands of new natural gas wells have come on line in recent years and required the construction of roads, power lines, compressor stations, pipelines, and ponds (US Bureau of Land Management 2003).

Anthropogenic features can impact ecological processes and wildlife behavior beyond the immediately affected area. Typically, lower biodiversity and more human-adapted species persist adjacent to ranchettes (Theobald et al. 1997; Maestas et al. 2001, 2003; Odell and Knight 2001). The introduction of non-native plant species is one cause because it can change the ecological composition of surrounding land, effectively degrading habitat (Hansen et al. 2005). Wildlife may also avoid anthropogenic features because of noise and the presence of domestic animals such as dogs and cats (Hansen et al. 2005). This type of avoidance behavior can fragment habitat, shrink total available habitat, and create dispersal barriers (Marzluff and Ewing 2001). By assuming that anthropogenic features have some effect on the surrounding land, a recent study by Knick et al. (2011) concluded that power lines have an ecological influence on 39% of all remaining sagebrush lands in the American West, highways influence 38% of remaining sagebrush lands, and urban development influences 18.6% of sagebrush lands. Also, <5% of the entire sage-grouse range is farther than 2.5 km from a mapped road (Knick et al. 2011).

Although sage-grouse cannot tolerate the outright removal of sagebrush (Braun et al. 1977, Connelly et al. 2000), the extent to which proximity to anthropogenic features can negatively influence sage-grouse or cause avoidance behavior is less understood. Some studies have observed negative associations of infrastructure on sage-grouse lek size and persistence (Braun 1986, Hall and Haney 1997, Harju et al. 2010, Holloran et al. 2010, Johnson et al. 2011) and also nest initiation rates (Lyon and Anderson 2003). Sage-grouse have been documented avoiding habitat adjacent to oil and gas wells and their associated infrastructure (Carpenter et al. 2010, Holloran et al. 2010). Sage-grouse are also thought to occur less often near power lines and major highways (Braun 1998, Hanser et al. 2011).

Most of the studies aimed at understanding sage-grouse habitat associations have not directly considered the clustered nature of sage-grouse populations and the impact of the resulting spatial autocorrelation of sage-grouse observations (only surveyed exception was Yost et al. 2008). Spatial autocorrelation refers to tendency of nearby observations to be more similar (positive autocorrelation) or less similar (negative autocorrelation) than distant observations (i.e., observations are not independent in space; Legendre and Fortin 1989, Legendre 1993). Almost all ecological data will exhibit some degree of autocorrelation as a result of processes (e.g., competition, succession, population genetics, predator–prey interactions), or underlying environmental patterns (e.g., vegetation, soils, topography, anthropogenic features; Legendre and Fortin 1989). Likewise, the species being sampled will often cluster because of habitat features or social structures within the population (Lieske and Bender 2009). Spatial autocorrelation inherent in ecological data by itself is not a problem; in fact, it is very useful for resource usage estimations that use interpolation techniques (Aarts et al. 2008).

Problems can arise when autocorrelated data are used in classical statistical models and significance testing that assumes independent samples (Legendre and Fortin 1989, Legendre et al. 1990, Fortin and Jacquez 2000). Spatial autocorrelation in sample data can reduce the effective sample size and the degrees of freedom for tests of statistical significance (Dale and Fortin 2002). As a consequence, results can be classified as significant when they are actually not (i.e., type I error; Dale and Fortin 2002, Klute et al. 2002, Lieske and Bender 2009). In logistic regression analysis, a popular modeling technique for species-habitat associations, spatially autocorrelated data can overestimate the effects of independent variables on the response (Klute et al. 2002, Dormann et al. 2007, Aarts et al. 2008, Lieske and Bender 2009). Similarly, "Monte Carlo" studies that compare observed data with many different computer-generated random permutations can also result in Type I errors if spatial autocorrelation of the observed data is not included in the null model (Fortin and Payette 2002).

Previous studies on sage-grouse habitat associations should not be disregarded and may be highly accurate if the parameters capture the spatial dependency inherent in the data. But frequently, non-environmental processes that cannot be modeled may be partly responsible for the species' distribution. Accordingly, all ecological studies should consider the potential of spatial autocorrelation in their data and how it might affect results.

Our objectives were to employ a spatial-statistical approach to determine whether sage-grouse in an isolated population in west-central Idaho, USA, were avoiding anthropogenic features (i.e., roads, power transmission lines, and rural buildings) and, if so, how far from the feature was the zone of influence. This study explicitly accounted for the spatial autocorrelation of sage-grouse observations to evaluate their association with anthropogenic features. This research incorporates spatial analysis techniques, including considerations for null model selection, that are broadly applicable for evaluating relationships between species occurrence and landscape features within the species' environment across large areas. The results can inform planning and decision making for rural development including infrastructure routes that minimize negative impacts to sage-grouse and their habitats.

STUDY AREA

This study was conducted in the West Central Sage-grouse planning area in west-central Idaho, which included parts of Washington, Adams, Gem, and Payette counties (centered at 44°26′N, 116°38′W). The 374,700 ha planning area was established to conserve a small and isolated population of sage-grouse that was considered the most likely to be extirpated within the state (Idaho Sage-grouse Advisory Committee 2006). Exact population numbers are unknown but it was estimated that the population was significantly lower than in 1970 due to the abandonment of many leks (Idaho Sage-grouse Advisory Committee 2006, West Central Sage-grouse Local Working Group 2008). Currently, 14 leks are being monitored each year. The major potential threats to sage-grouse in this area were geographic isolation, private property development, wildfire, expansion of annual grasslands, and West Nile Virus (Idaho Sage-grouse Advisory Committee 2006).

The study area consisted primarily of rolling hills of sagebrush steppe and grassland vegetation. The shrub component was mainly xeric big sagebrush (*Artemisia tridentata* sp. *xericensis*), stiff sagebrush (*A. rigida*) and three-tip sagebrush (*A. tripartita*). Native perennial grasses included bluebunch wheatgrass (*Pseudoroegneria spicata*), Idaho fescue (*Festuca idahoensis*), Sandberg bluegrass (*Poa secunda*), and Thurber needlegrass (*Achnatherum thurberianum*). Elevations ranged from 630 m at the Snake River near Brownlee reservoir to >1,220 m at the southern boundary of Payette National Forest. The greatest proportion of the area and of occupied sage-grouse habitat lay between 760 m and 1,070 m in elevation (West Central Sage-grouse Local Working Group 2008). The climate was characterized by cold, wet winters and hot, dry summers. Mean annual precipitation was about 28 cm at lower elevations near the city of Weiser, Idaho, but increased quickly with elevation to >51 cm over much of the planning area. Seventy-five percent of the planning area was considered intact shrub and bunchgrass communities dominated by sagebrush species. Of the 25% that had been altered, 50% was due to invasive annual grasslands thought to have originated from contaminated wheat crops, 49% was in farmland, and only 1% was developed (West Central Sage-grouse Local Working Group 2008).

The study area was rural and had experienced slow human population growth compared with other regions of Idaho. The valley bottoms support irrigated farmland while the uplands were primarily used for livestock grazing. Most settlements, including the small towns of Midvale and Cambridge, occurred along the U.S. 95 highway corridor (Fig. 1). Land speculation and ranchette style housing, however, had become increasingly popular outside of city limits (Adams County, Idaho 2006, West Central Sage-grouse Local Working Group 2008).

METHODS

Sage-grouse Telemetry

We obtained sage-grouse location data from the Idaho Department of Fish and Game, who used radiotelemetry to locate sage-grouse in the study area from April 2005 to December 2007 (Gray 2009). Fourteen females and 44 males captured on 14 different leks were used in this study. To ensure a representative sample of the population, leks were selected to have a range of habitats, a mix of private and public lands, and geographic separation. Sage-grouse were monitored every 2–3 weeks from March through September and once per month from October through February. With this sampling method, bias from serially correlated individual sage-grouse should be small. Location coordinates were recorded using a Garmin (Olathe, Kansas, USA) 76CS Global Positioning System (GPS) where the bird was first seen, but 26 of the locations were obtained through triangulation to prevent flushing. Average accuracy of the GPS was 2–10 m, while the triangulation error could be up to 150 m. Four-hundred ninety-six locations, collected between the months of March and November across all years, were used for the analysis. We excluded the few locations obtained during the winter (Dec–Feb) because sage-grouse habitat use is greatly dependent on snow depth and topography and may not accurately reflect behavior toward anthropogenic features (Connelly et al. 2011). We treated all sage-grouse locations equally with no attempt to depict behavior based on sex, age, or lek of capture. Though it is likely that sage-grouse behavior is partially dependent on seasonal habitat requirements and sex (Patterson 1952; Gill and Glover 1965; Wallestad et al. 1975; Connelly et al. 1981, 1988, 2000, 2011; Gates 1985), we did not examine avoidance behavior distinguished by season or sex because of small sample sizes.

Anthropogenic Features

We compared sage-grouse locations with the mapped locations of major roads, minor roads, power transmission lines, and buildings within the study area (Fig. 1). Major roads were defined as any road receiving average daily traffic counts from the Idaho Transportation Department (2004*a*, *b*). The major roads could be paved or dirt and represented the most frequently used roads. Included in the major roads category was the only 2-lane highway in the study area, U.S.

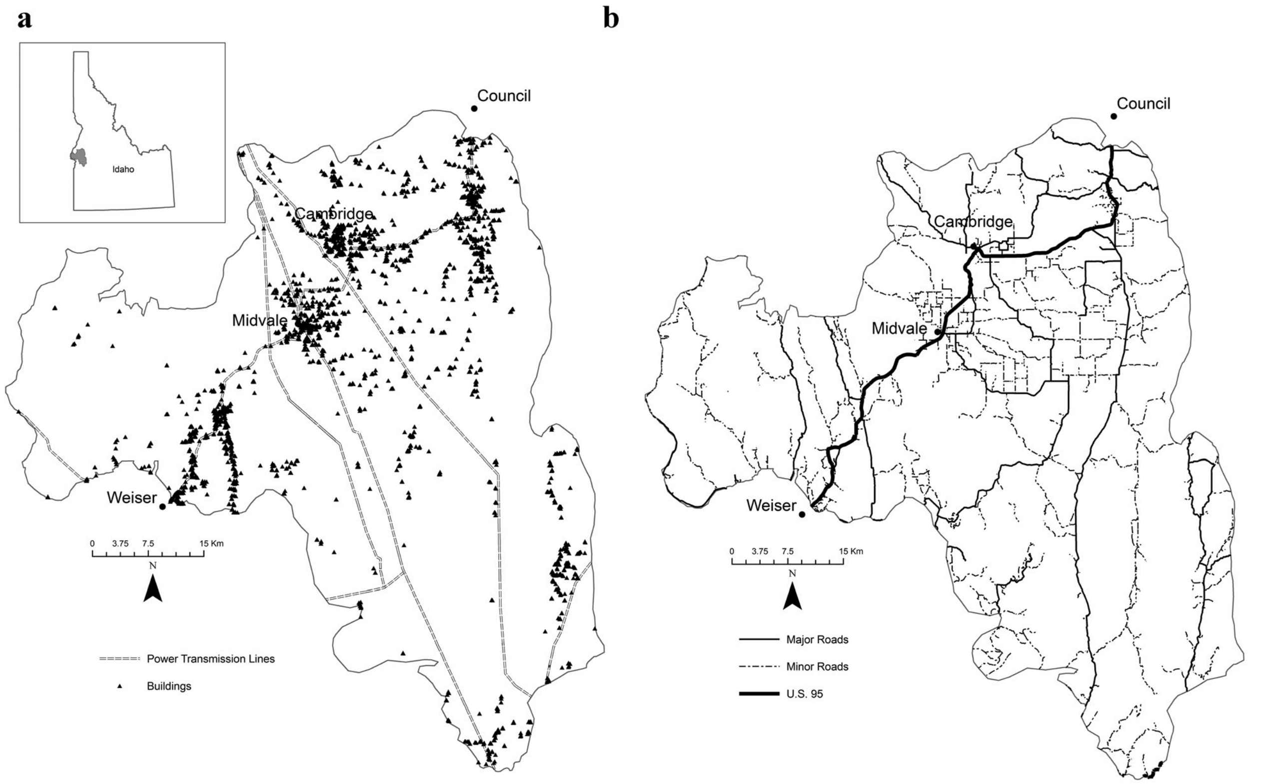

Figure 1. The west central sage-grouse planning area, Idaho, USA (Washington, Adams, Gem, and Payette counties) (a) power transmission lines and buildings, and (b) major and minor roads.

95. Minor roads consisted of all remaining mapped roads excluding 2-tracks. Mapped power lines included only the major transmission lines (>138 kV), and excluded the distribution lines (National Geographic Maps 2004, US Bureau of Land Management 2007). These transmission lines were usually supported by large structures, including the steel lattice (25 m ht) and steel H-frame (17 m ht). The buildings polygon layer included all structures in the study area and was created through digitizing (at a scale of 1:3,000) on aerial imagery from the National Agriculture Image Program (USDA-FSA-APFO 2004). Because the sage-grouse location data were collected 2005–2007, it is possible that some anthropogenic features were omitted or committed in the analysis.

For the analysis, we transformed each anthropogenic feature layer originally modeled as lines and polygons into point features. For linear features, we placed a point every 125 m, which was determined largely by computing limitations. The point frequency should not affect the results comparing the observed point pattern with the null model. For the buildings layer, a centroid point was placed in each polygon.

Analysis

To determine geographic relationships between sage-grouse locations and each of the anthropogenic feature types, we employed a multi-scale measure of spatial dependence for point patterns. We used the pair correlation function (PCF) to compare observed with expected number of anthropogenic feature points within concentric rings surrounding sage-grouse locations.

In the bivariate form, the PCF is defined (Stoyan and Stoyan 1994, Schurr et al. 2004):

$$\hat{g}_{12}(r) = \frac{1}{2\pi r} \frac{A^2}{n_1 n_2} \sum_{i=1}^{n_1} \sum_{j=1}^{n_2} w_{ij}^{-1} k_h(r - |x_i - y_i|)$$

where $\hat{g}_{12}(r)$ is the PCF at a specified radius, A is the total point-pattern area, and n_1 and n_2 are the number of sage-grouse points and anthropogenic feature points, respectively. The x_i are locations of sage-grouse points, y_i are the locations of anthropogenic feature points, and w_{ij} is a weighting function that accounts for edge effect bias created by unobservable anthropogenic feature points outside the study area. We used the "translation" edge correction described by Torquato (2002) and Pommerening and Stoyan (2006), which extrapolates the point-pattern spatial structure within the study area to infinitely outside the study area. This edge correction is also recommended for study areas with complex shapes (Baddeley and Turner 2005). The PCF looks at a neighborhood of points surrounding the specified radius and gives greater weight to points near the radius and less weight to points further away. This type of weighting is known as an Epanečnikov kernel and is specified by k_h, where h is the bandwidth parameter specifying the size of the radius neighborhood that will receive weighting. Points lying outside the bandwidth will not be considered in the calculation at that radius.

The PCF is a variation of Ripley's *K* (Ripley 1981), which measures spatial association within cumulative circles rather than rings. For this application, PCF is the preferred method because it is a more responsive analysis at multiple scales and can identify specific distances of avoidance or clustering. In a Ripley's *K* analysis, the results at larger distances are influenced by the shorter distances, which may obscure the spatial association at any given scale.

We computed the PCF function initially with $r = 150$ m, because this is the estimated largest possible location error associated with GPS and radio triangulation (Garmin 2011, Shepherd et al. 2011). We subsequently computed the PCF function every 150 m to a maximum of $r = 5$ km to assess the spatial relationship at different scales across the study area. We chose a bandwidth of 75 m because it was half the distance between PCF calculations, and because it provided enough smoothing to the PCF graph to aid in interpretation while not over-smoothing the results.

The empirical $\hat{g}_{12}(r)$ considers all the points of type 1 (sage-grouse) and calculates the intensity of points of type 2 (anthropogenic feature) surrounding it in a ring with a specified radius. The empirical value can then be compared with the expected number of points at the same radius, which is derived from a null PCF model constructed from Monte Carlo point simulations. A deviation between the empirical and expected curves suggests dependence between points of type 1 and 2. Empirical values larger than the expected curve at a given distance suggest that the 2-point types are clustering around each other at that scale. Smaller values than expected suggests the point types are exhibiting avoidance at that scale.

To test the significance of the spatial association between sage-grouse locations and anthropogenic features, we compared the empirical plot of $\hat{g}_{12}(r)$ to a null model constructed from 1,000 Monte Carlo simulations. We simulated point patterns designed to mimic the observed spatial pattern of sage-grouse habitat use. The map of sage-grouse telemetry points exhibited strong clustering (Fig. 2a). This strong spatial autocorrelation is a violation of sample independence (see Legendre and Fortin 1989), so a completely spatially random (CSR) null model or parametric statistical test is inappropriate. Therefore, the simulated points used in comparison with the spatially dependent data reflected the same intensity of clustering to prevent false positive findings of significance (Fig. 2b; Fortin and Payette 2002). We also ran the simulations using a CSR model for comparison purposes.

Computation of $\hat{g}_{12}(r)$ and the simulations were carried out using the Spatstat package (Baddeley and Turner 2005) in the statistics program R 2.10.1 (R Development Core Team 2009). Using the "Kppm" command in Spatstat, we fitted a homogenous Poisson cluster point process model to the sage-grouse data using the PCF function with the same parameters described previously. The simulated cluster patterns were realized following the Matern cluster process (see Moller and Waagepetersen 2003), which creates point patterns using 3 parameters: κ is the intensity of parent points generated through a Poisson process; μ is the average number of offspring points surrounding each parent point; and *R* is the radius of the cluster of offspring points centered

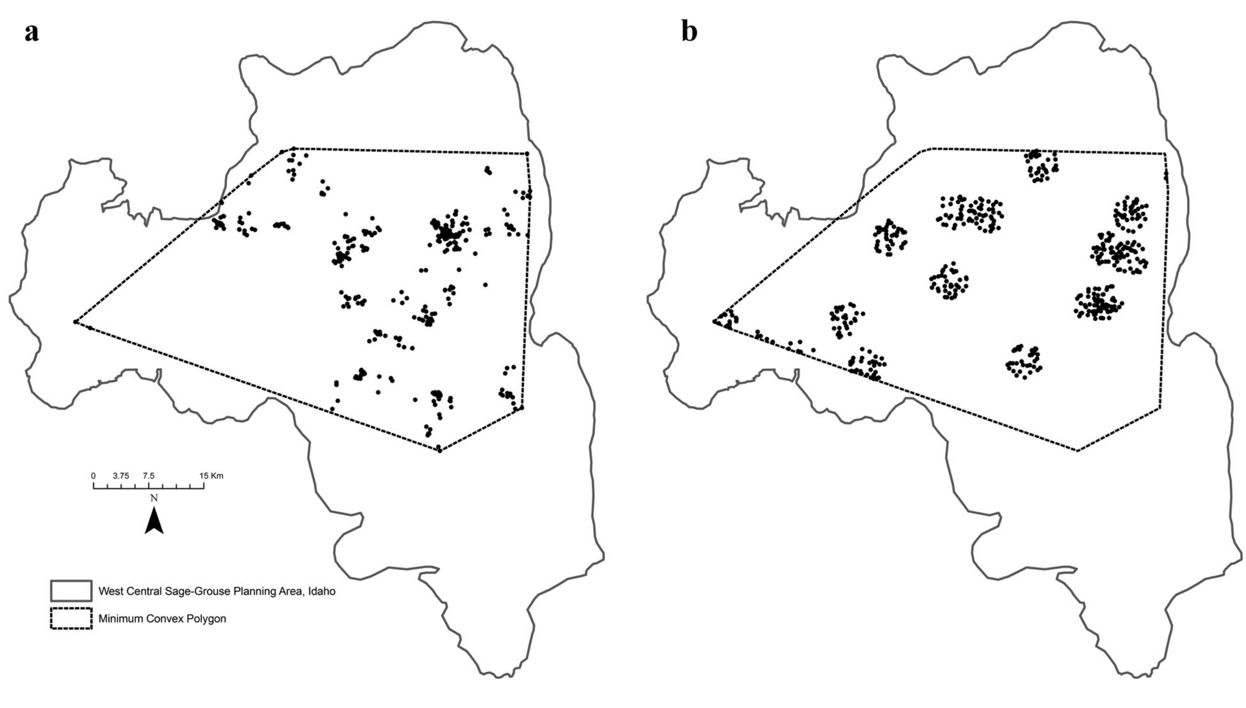

Figure 2. (a) Known sage-grouse locations in the west central sage-grouse planning area, Idaho, USA (Washington, Adams, Gem, and Payette counties) observed April 2005 to December 2007. The locations are bounded by a minimum convex polygon that served as the simulation boundary. (b) Example of a simulated cluster-point pattern created from a homogenous Poisson cluster-point process model. We used 1,000 realizations of the simulated cluster-point patterns as a null model to assess spatial dependency between observed sage-grouse locations and anthropogenic features.

on the parent point. The simulated points were allowed to occur only within available habitat, which we defined as a minimum convex polygon surrounding all of the sage-grouse locations. The Bureau of Land Management, Idaho, considers nearly all of the land within the minimum convex polygon to be sage-grouse habitat (US Bureau of Land Management 2009). Accordingly, simulated points were permitted to occur anywhere within the minimum convex polygon except in water bodies or towns. From the simulations, we created 95% significance envelopes for the clustered and CSR null models to illustrate the difference in statistically significant findings between the 2 simulation methods. For a given radius, values of $\hat{g}_{12}(r)$ outside of the clustered significance envelope were considered to be significantly different from random arrangements of points showing the same spatial dependence as the sage-grouse locations. This would indicate clustering around or avoidance of anthropogenic features by sage-grouse at those distances.

RESULTS

Fitting a homogenous Poisson cluster point process model to the sage-grouse data using the PCF function produced a clustered point pattern with $\kappa = 6.200333\text{e-}09$, $\mu = 47.51922$, and $R = 1{,}748$ m. The significance envelopes exhibited a typical funnel shape where PCF variability was greatest at near distances and shrinks at larger scales (Fig. 3). This was due to the fact that closer concentric rings have less total area and thus a greater opportunity for PCF variability. The funnel-shaped envelopes also tilted upward as scale increased. This is caused by the spatial clustering of the anthropogenic features we are testing. In the study area, there is more open space than there is developed space, so the simulated points were, on average, farther away from anthropogenic features than closer.

Selection of the null model proved to highly influence the statistical inference. The results indicated that observed sage-grouse exhibited avoidance of buildings by 150 m (Fig. 3a) because the PCF value at that distance was less than the clustered 95% significance envelope. The CSR null model produced a much narrower significance envelope, which equates to a much lower standard of statistical significance. The CSR null model indicated that sage-grouse were avoiding buildings by up to 3.45 km. At larger distances, the empirical PCF values were within the simulation significance envelope, which suggested no significant spatial relationship between sage-grouse and building locations.

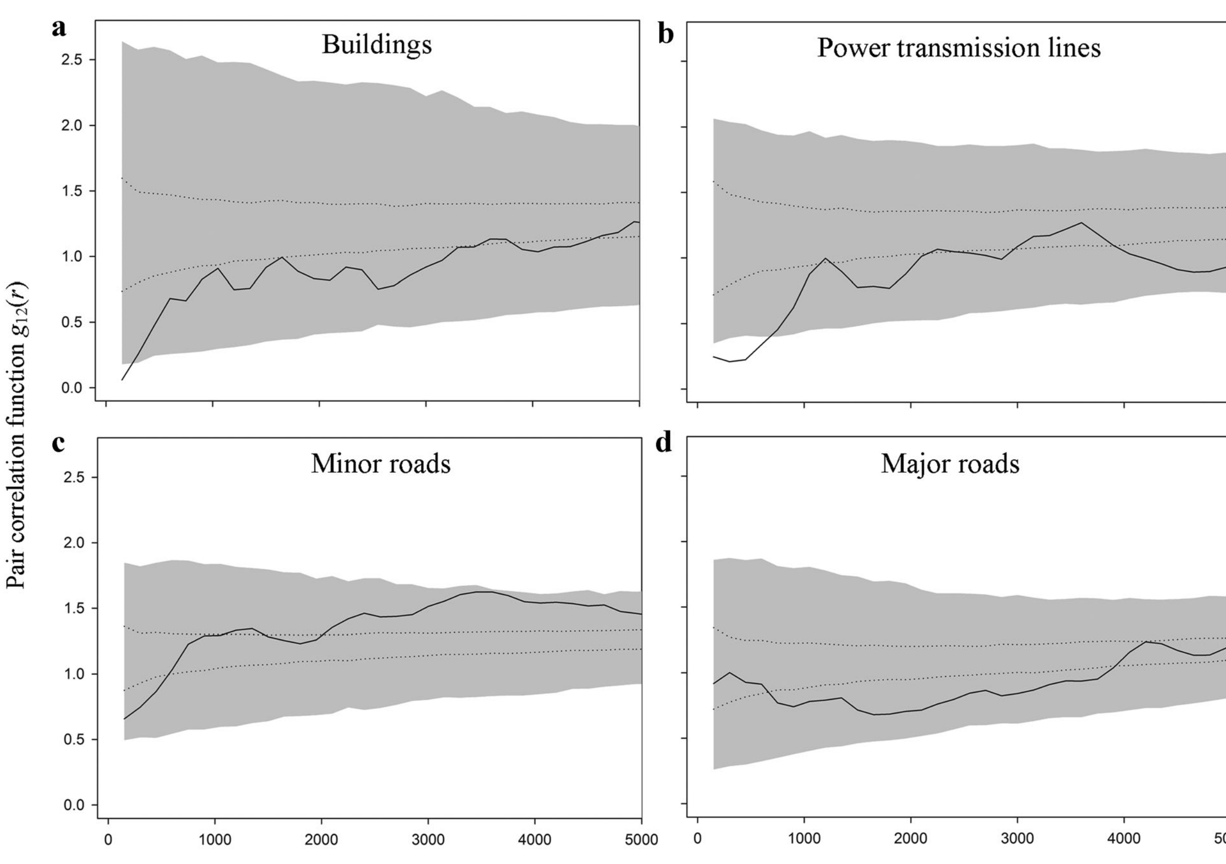

Figure 3. Bivariate pair correlation function, $\hat{g}_{12}(r)$, for greater sage-grouse locations and (a) buildings, (b) power transmission lines, (c) minor roads, and (d) major roads. Sage-grouse locations were collected April 2005 to December 2007. The empirical curve (solid line) is plotted against 2 95% significance envelopes: one determined from 1,000 clustered point-pattern simulations (shaded area); and one determined from 1,000 point patterns that were completely spatially random (dotted lines). This study occurred in the west central sage-grouse planning area, Idaho, USA (Washington, Adams, Gem, and Payette Counties).

Sage-grouse showed avoidance of power transmission lines up to distances of 600 m (Fig. 3b) because the PCF values at 150, 300, 450, and 600 m were less than the clustered significance envelope. At all other scales, the empirical PCF values were within the significance envelope, which suggested no significant spatial relationship. The CSR null model again showed that sage-grouse avoided the features at a greater distance of 1.05 km. At larger scales, the empirical curve dipped in and out of the CSR envelope.

Sage-grouse did not appear to avoid minor roads in the study area because the PCF empirical curve landed within the clustered null model significance envelope at all scales (Fig. 3c). The CSR null model showed that sage-grouse avoided minor roads by 450 m. At larger scales (3–4 km), the empirical curve was far above the CSR envelope and nearly left the bounds of the clustered model envelope. This suggests that, at these distances, there were far more sage-grouse near minor roads than was expected.

Sage-grouse also did not appear to avoid major roads in the study area because the PCF empirical curve landed within the clustered null-model significance envelope at all scales (Fig. 3d). There was agreement in the CSR null model up to 600 m, after which the empirical curve was below the envelope at all scales up to 3.9 km, which suggests avoidance at those distances.

DISCUSSION

This study showed that results from point-pattern simulations could vary greatly between those that incorporate spatial structure and those that employ a CSR method. The CSR null model produced significance envelopes much narrower than the clustered null model, thus setting a much lower standard for significance testing, which may lead to false positive results. This demonstrates the need to explicitly account for spatially dependent data in ecological studies, especially wildlife studies that have presence-only sampling.

Although an improvement over a CSR null model, the homogeneous clustered simulations were not a perfect representation of the observed data. The data appeared to exhibit non-stationary or an inhomogeneous cluster pattern probably caused by differences in seasonal habitat use. Sage-grouse aggregate during the spring lekking season and disperse when breeding has concluded. Analyzing and simulating the data by season and sex may produce improved null models but was not attempted due to small sample size.

Our results support Braun's conjecture (1998; personal communication) that sage-grouse avoid farms and ranch houses. However, he suggested that adult sage-grouse were avoiding occupied farms and ranches by 800 m, while hens with broods might come closer to seek out wet sites. Our study found avoidance up to 150 m, but we did not distinguish between occupied and unoccupied home sites, nor did we consider differences based on sex or season. Sage-grouse may show greater avoidance of occupied houses or farms because of the associated sounds such as human voices or motorized vehicles, or the presence of domestic animals such cats, dogs, horses, or other livestock.

Our findings on sage-grouse and power transmission lines support other studies suggesting avoidance behavior. Braun (1998) concluded that sage-grouse infrequently use areas within 1 km of a power line, and Hanser et al. (2011) found there was less probability of sage-grouse pellet occurrence within 500 m of power lines. Power lines and transmission structures can serve as perches for avian predators in landscapes with few naturally tall structures (Ellis 1987, Connelly et al. 2004). Sage-grouse may also avoid traditional leks if perches or raptors are visible (Hall and Haney 1997). In California, USA, as distance to overhead power lines decreased, peak male lek attendance also decreased (Hall and Haney 1997). Other studies have found power lines to have a benign effect on sage-grouse. In a 10-year range-wide study, Johnson et al. (2011) found no negative effects of power lines on lek counts, but did report that lek trends were reduced when communication towers were nearby.

Though previous research has shown that sage-grouse may avoid major highways (Hanser et al. 2011), have lower lek attendance (Braun 1986, Johnson et al. 2011), and have lower nest initiation rates near roads (Lyon and Anderson 2003), our results show sage-grouse to be minimally affected by minor and major roads in our study area. There was only one 2-lane highway in the study area and most of the minor roads were composed of dirt or gravel and had infrequent traffic. Anecdotally, some sage-grouse actually lek directly on minor roads in the study area (Gray 2009), and perhaps roads provide an open area in the sagebrush where mating displays can be seen (Connelly et al. 1981, Gates 1985). At some scales for minor roads (3–4 km), more sage-grouse were near roads than was expected to almost a significant level. The reason this occurred is unknown. Sage-grouse may be attracted to riparian areas, agricultural fields, or water developments that are often near farms and ranches. In the summer, sage-grouse have been observed using riparian areas and crop fields, which provide a food source (Dunn and Braun 1986, Schroeder et al. 1999). Topography may be important because leks are often on gentle slopes or in valley bottoms (Rogers 1964), and sage-grouse may simply occupy lands that are popular for human settlements, including locations with roads.

Sage-grouse have been observed being influenced by energy infrastructure at greater distances compared with our results. In Alberta, Canada, sage-grouse avoided energy wells by up to 1.9 km during the winter (Carpenter et al. 2010). In Wyoming, yearling males established themselves less often than expected on leks within 3 km of producing wells and more often on leks farther than 3 km from producing wells (Holloran et al. 2010). Fewer yearling females nested within 950 m of infrastructure than was expected (Holloran et al. 2010). Yearling males and females reared within 1.65 km of a producing well pad or haul road had lower annual survival rates (Holloran et al. 2010). At 5 study sites in Wyoming, lek counts were negatively associated with the presence of producing wells within 800 m, 1.2, 1.6, and 4.8 km at each respective site (Harju et al. 2010). Two other study sites showed no reduced lek counts. In the Powder River Basin of Wyoming and Montana, USA, female sage-grouse in the winter were more likely to occupy habitats with no natural gas wells within 4 km^2 compared with the legal maximum density of 12.3 wells (Doherty et al. 2008).

Sage-grouse have distinct patterns of habitat use during different times of the year, which will likely affect their tolerance of anthropogenic features (Connelly et al. 2000, 2011). Lumping the seasons and sexes together possibly masked or coarsened the precision of some of the results. For example, during the late brood-rearing period (Jul–Sep), the diet of the chicks changes primarily to forbs and they will choose their habitat based on their availability (Patterson 1952). The hen and chicks may use irrigated crop fields, wet meadows, and riparian areas closer to anthropogenic features (Dunn and Braun 1986, Connelly et al. 1988). During the autumn as the forbs desiccate or are killed by frost, sage-grouse switch their diet back to sagebrush (Patterson 1952, Wallestad et al. 1975). A study in Colorado, USA, found that sage-grouse abandoned irrigated hay fields when the irrigation stopped or after the first frost (Gill and Glover 1965). Had the analysis been separated by season, we might have seen different habitat use between summer and autumn in relation to anthropogenic features.

MANAGEMENT IMPLICATIONS

Our results can directly inform land managers who are planning infrastructure and other development projects in or near sage-grouse habitat. We revealed a zone of influence around buildings and power lines that affects the occurrence of sage-grouse within their habitat. Our results indicate that anthropogenic features reduce the total amount of habitat available to the species by a factor larger than just the footprints of the features themselves. Planning and zoning commissions, utility companies, and other government entities can use these results to develop building regulations and plan infrastructure routes that are sensitive to sage-grouse populations and habitat. Specific actions that planning entities can take to protect greater sage-grouse populations and habitats in Idaho are to 1) identify goals for species and habitat protection in the county comprehensive plan, 2) incorporate the spatial data from this study and other studies on species of concern into county land use maps, and 3) develop zoning ordinances that encourage the implementation of 'on-the-ground' conservation actions by private landowners that minimize or mitigate the zone of influence from anthropogenic features (Haines et al. 2012).

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