Hierarchical Modeling of Spatial Data to Estimate Abundance of Sage-Grouse in Nevada

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Abstract

Greater sage-grouse (*Centrocercus urophasianus*) are symbolic of western landscapes and an umbrella species indicative of sagebrush ecosystem health. The Nevada Department of Wildlife, and other state and federal agencies regularly monitor greater sage-grouse leks multiple times per season by visiting them, and counting the number of birds at each lek. Lek counts have provided important information on relative abundance and population trends across their range. Lek count data contain spatial information critical to understand greater sage-grouse ecology, and information required for examining and predicting future population trends. Statistical analyses capable of harnessing this information will improve sage grouse conservation and management. Our objective was to develop a hierarchical geostatistical model of sage grouse lek attendance across Nevada. We fit our model to a subsample of lek count data to show our ability to make state-wide inference on sage grouse abundance. We address spatial correlations among lek counts, reveal potential mechanistic drivers of lek dynamics, and account for statistical uncertainty. Our results indicate the importance of leveraging data to inform statistical uncertainty.

Background

- Greater sage-grouse (*Centrocercus urophasianus*) abundance has declined since the early 1930s, prompting discussions to list the species under the Endangered Species Act (Fig. 1).[1,2]
- Sage-grouse are an umbrella species indicative of sagebrush ecosystem health.[3,4,5]
- Sage-grouse are a cryptic species making them difficult to find, follow, and determine the exact number of birds on the landscape.[6]
- During the breeding season males gather and perform an elaborate "strutting" display for females on highly visible areas called leks.[7]
- The Nevada Department of Wildlife (NDOW), and other state and federal agencies, regularly monitor greater sage-grouse leks multiple times per season by visiting them and counting the number of birds at each lek.[7,8]
- Lek counts are used to develop population indices that estimate and predict population trends and size.[9,10] However observational uncertainty and count error make determining true sage-grouse abundance challenging.[6,7,10]
- Male lek attendance has had an annual long-term decline of 0.83% over their entire range since 1965, and Nevada sage-grouse populations have declined by by 50%.[2,5,7,11]
- In 2018, Nevada population data suggested that lek attendance was at a 5-year low and less than the long-term average.[8]

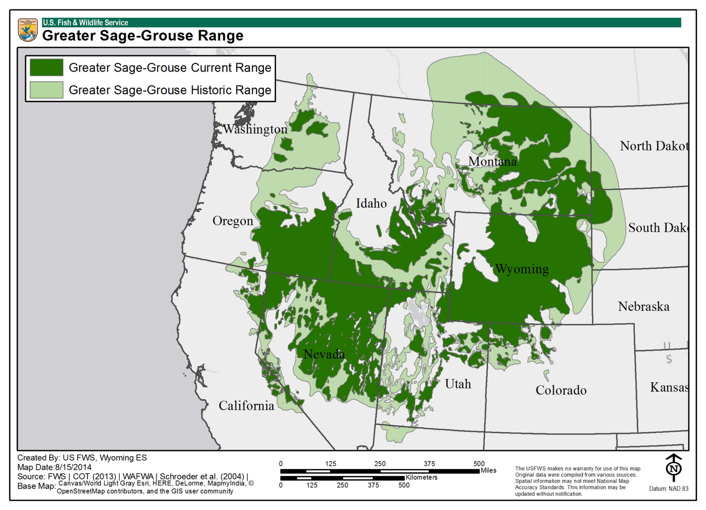

Figure 1. The historic and current range of Greater Sage-Grouse throughout the Intermountain West in North America.

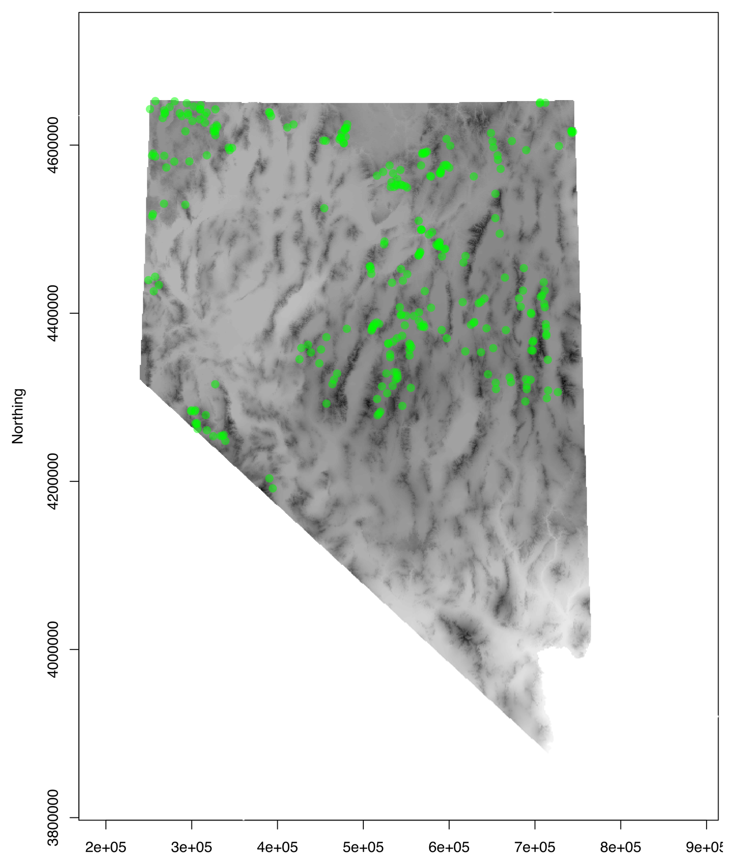

Figure 2. The GPS locations of 287 leks surveyed by the Nevada Department of Wildlife in April, 2018, NV USA. The gradient of green shows the overlap of lek locations, where darker greens represent more leks.

Data and Design

- We used lek count data collected by NDOW during peak breeding effort in April 2018 (Figure. 2).
- We used lek count data with only 4 replicate counts. excluded surveys with less than 4 replicate counts and cut off counts after 4 to standardize all leks.
- Lek counts were conducted in the state of Nevada using the protocol established by Connelly et al. (2003).
- We assessed the effect of elevation on lek dynamics. We used MCMC Gibbs sampling methods. We applied 2 chains of 50,000 MCMC iterations and assessed for convergence visually (Figure 5).

Model:

We used a geostatistical model with a Bayesian hierarchical framework to estimate abundance. We used the data model

$$y_{i,k} \sim \text{Poisson}(N_i),$$

where $y_{i,k}$ represents the observed number of sage-grouse obtained during lek counts at site $i = 1,\ldots,n$ for replicates $k = 1,\ldots,K$. We used a Poisson distribution because sage-grouse counts can either under- or over-represent the true number of birds present due to observational uncertainty.[12] We were interested in estimating the relationship between the true abundance and the expected count N_i at any site $i = 1,\ldots,n$. We describe our process model as

$$\log(N) \sim \text{Normal}(\boldsymbol{X\beta}, \sigma^2 R_{i,j}(\phi)),$$

$$R(\phi) = \exp\{-d_{i,j}/\phi\},$$

$$d_{i,j} = \sqrt{(\boldsymbol{s}_i - \boldsymbol{s}_j)'(\boldsymbol{s}_i - \boldsymbol{s}_j)},$$

We chose this process model due to conjugacy between log(N) and our parameters, and for the use of linear regression.[13] Our covariates are our intercept β_0 (the overall expected count) and β_1 (elevation). $R(\phi)$ is our exponential covariance function, where ϕ is the extent of the spatial correlation and σ^2 is our spatial variance parameter. Our distance matrix is represented by $d_{i,j}$, measuring the distance between all of our locations. We describe our prior model as

$$\boldsymbol{\beta} \sim \text{Normal}(\boldsymbol{\mu_\beta}, \boldsymbol{\Sigma}_\beta),$$

$$\sigma^2 \sim \text{IG}(q, r),$$

$$\phi \sim \text{Gamma}(\gamma_1, \gamma_2)$$

Results

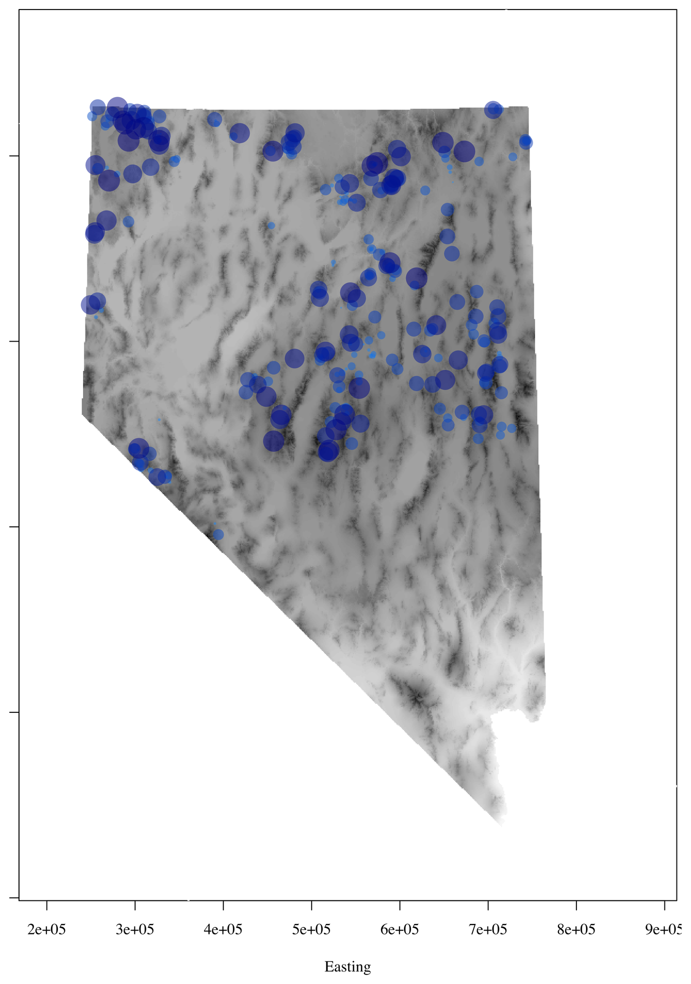

Figure 3. (left) Depicts the variation in lek count totals for each lek in the state of Nevada in April, 2018. Lighter blue and smaller points indicate lower count totals. Darker blue and larger points indicate higher count totals.

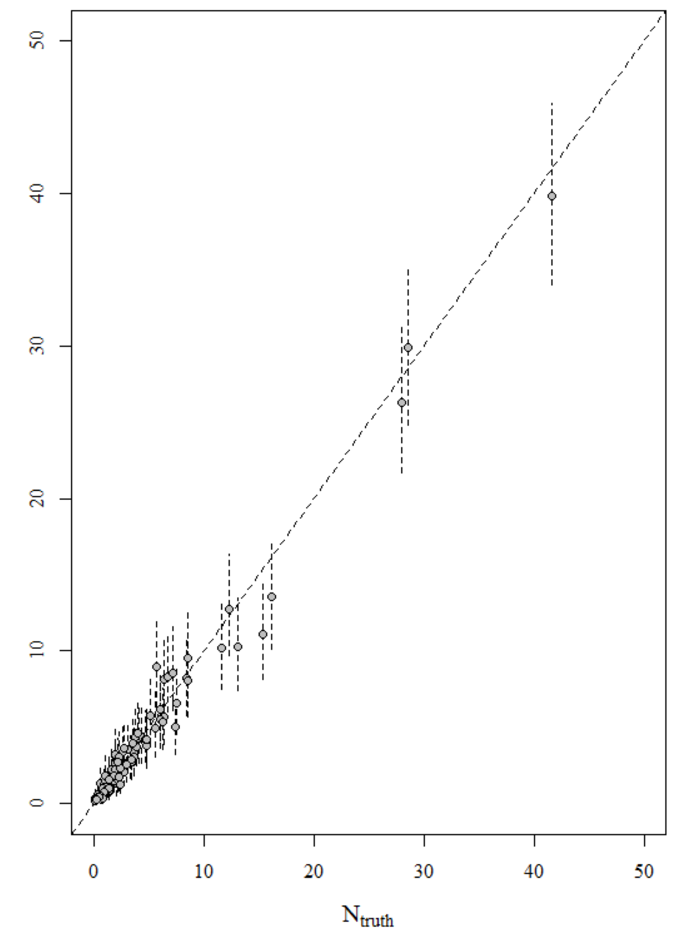

Figure 4. The correlation between simulated lek count data (x-axis) and predicted outcomes using the data generating model (y-axis), demonstrating that model parameters are identifiable.

Discussion

- This is the first study of its kind to use hierarchical spatial modeling to examine Greater Sage-grouse abundance.
- The limitations of our findings are a partial story, because we used a small sample of lek counts conducted in the state of Nevada in April, 2018.
- We found that elevation (β_1) had no effect on lek attendance. Therefore, elevation alone does a poor job of predicting sage-grouse abundance for April, 2018 in Nevada.
- We found our spatial dependence parameter (ϕ) to be near zero, this means that there is minimal spatial correlation between leks during April, 2018 in Nevada.[14]

Future directions:

- We will add a temporal component to make this into a spatio-temporal model.
- We will include additional covariates like precipitation and vegetation to allow us to examine multiple levels of uncertainty.[9] This will provide better insight to grouse population trends for managers. We can scale up this model to include multiple years to assess abundance trends of sage-grouse populations in the state of Nevada, as well as populations throughout the Intermountain West.
- If we can produce more accurate abundance estimates then we can determine the precise management needed to help this species and other threatened species from being listed under the Endangered Species Act.
- We hope to develop this model into a tool for managers who use count data to assess population trends of threatened species and allow them to make better informed decisions to support declining populations.

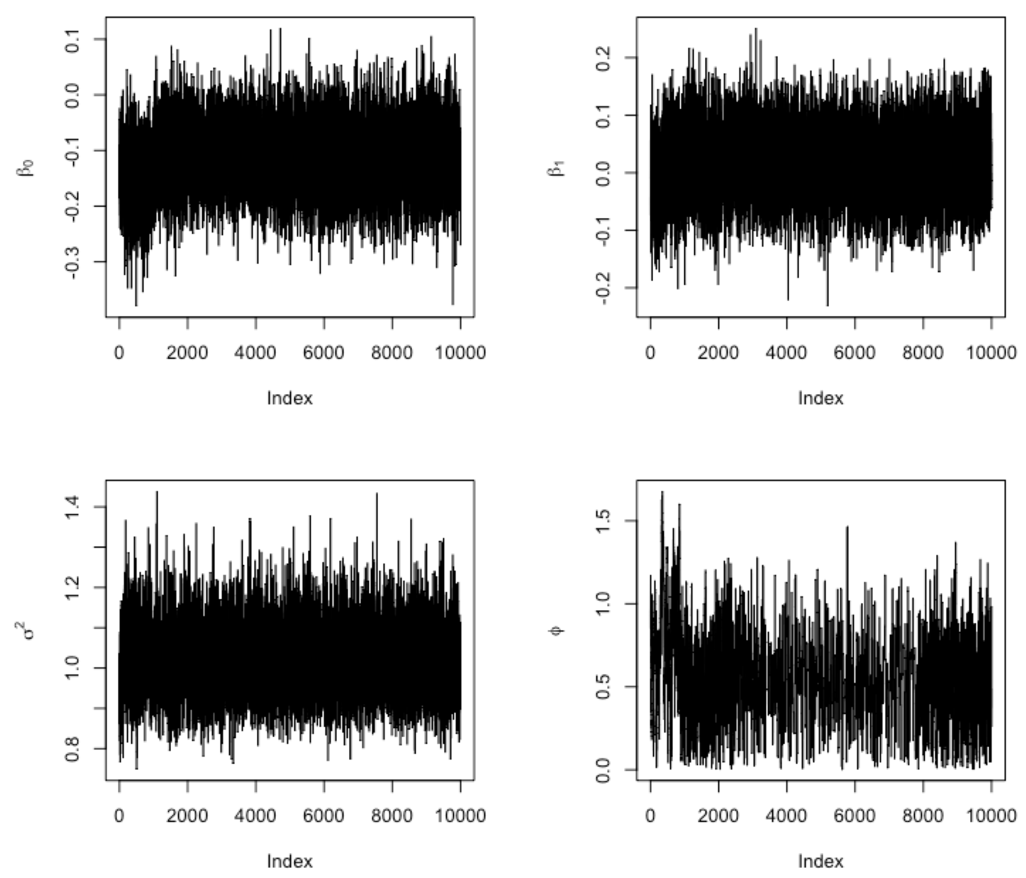

Figure 5. Trace plots used to determine convergence of the model's 4 parameters. Lek counts located top-left (β_0, median: -0.113, 95% CRI: -0.239, 0.008). Elevation located top-right (β_1, median: 0.016, 95% CRI: -0.105, 0.136). The variance parameter located bottom-left (σ^2, median: 1.015, 95% CRI: 0.863, 1.203). The spatial dependence parameter located bottom-right (ϕ, median: 0.552, 95% CRI: 0.052, 1.143).

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