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Determinants of Threatened Sage Grouse in Northeastern Nevada

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We examined potential human determinants of observed declines in greater sage grouse (Centrocercus urophasianus) *populations in Elko County, Nevada. Although monitoring of sage grouse has occurred for decades, monitoring levels have not been consistent. This article contributes to the literature by normalizing grouse counts by the annual effort to count them, performing regression analyses to explain the resulting normalized data, and correcting for sample selectivity bias that arises from years when counts were not taken. Our findings provide some evidence that cattle-grazing contributes to a reduction in sage grouse populations, but this result should be interpreted with caution because our data do not include indications about the timing and precise nature of grazing practices. Annual variations in weather appear to be a major determinant after statistically controlling for human interactions with the landscape, suggesting that climate change is a key potential long-run threat to this species.*

Keywords population viability analysis, endangered species, sage grouse

Introduction

Biologists and game bird hunters have been concerned with the plight of the greater sage grouse (*Centrocercus urophasianus*) in western North America since the early 1900s. Biologists estimate that populations have declined by 69 to 99% from pre-European settlement to today (Deibert, 2004). Declines in the western States have averaged some 30% over the past decades (BLM, 2000). These estimates are based primarily on observations of habitat loss, with habitat fragmentation also having reduced the distribution of the species over time (Connelly, Knick, Schroeder, & Stiver, 2004).

After receiving petitions calling for sage grouse to be listed as threatened or endangered across its entire range, the U.S. Fish and Wildlife Service initiated a status review of the species in April 2004 (Deibert, 2004). Although Washington State declared it a threatened

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species in 1998 (Washington Department of Fish and Wildlife, 2000) and the State BLM office in Nevada designated it as "Sensitive" (Nevada Natural Heritage Program, 2004), the Fish and Wildlife Service determined that listing the sage grouse under the Endangered Species Act was not warranted at this time.[1] Federal listing would likely have resulted in significant restrictions on ranchers' use of public forage.

In Nevada, the governor formed a Sage Grouse Task Force to take a proactive approach to identifying range management options that might forestall a future listing or, at least, reduce the impact of a listing on the rural economy (Neel, 2001). During hearings in late 2000, views were expressed concerning factors that might negatively impact sage grouse in the State. These could be categorized as "pro-ranching" or "pro-conservation"—for or against grazing of domestic livestock on public lands. The debate was and continues to be political, mainly because there is little evidence concerning sage grouse populations in the State and the factors that affect them. The most definitive study to date, for example, concludes that, although sage grouse populations in Nevada are declining (at an annual rate of 1.41% over the period 1974–1985 and 2.53% thereafter), "current data sets are somewhat ambiguous and likely reflect erratic monitoring efforts … [so results] should be viewed cautiously" (Connelly et al., 2004, pp. 6–37). Reasons for the reported declines in Nevada are somewhat speculative, based primarily on evidence from field studies in other states.

Ranchers have their own views about sage grouse decline and its causes that are not easily ignored by politicians. Consider the 2002 results of a survey administered to all Nevada ranchers with public grazing allotments (see van Kooten, Thomsen, & Hobby, 2006; van Kooten, Thomsen, Hobby, & Eagle, 2006 for details). Responses to the following question are of particular relevance: "Do you think sage grouse populations are in decline?" (103 responded "yes," 97 "no," and 44 declared that they were uncertain whether population had declined). Those responding "yes" identified predation as the most important factor for declining sage grouse, followed by hunting and wildfire (Table 1). Most identified predation by ravens and coyotes as a particular problem. Of respondents who did not think grouse populations declined or did not know, 28 still indicated that predation was a major threat.

Table 1
Factors identified by respondents to the 2002 Nevada Ranch Survey as likely causes for declines in sage grouse populations (n = 103)

Factor	Respondents indicating this as a contributing factor[a]
Hunting	49 (8)
Wildfire	41 (16)
Loss of habitat due to invasive weeds	15 (2)
Over grazing	3 (0)
Range management policies	26 (4)
Increased number of predators of sage grouse & their eggs	97 (28)
Other	21 (1)

[a]Figures in parentheses indicate numbers of respondents who cited these reasons as contributing to decline in sage grouse even though they had indicated that they did not think grouse populations had declined or know if they had declined.

Ranchers were also asked whether "Wildlife species that are considered threatened or endangered are unaffected by livestock grazing." On average, most ranchers did not consider livestock grazing to be detrimental to sage grouse habitat. Under-utilization of range by domestic livestock, fire suppression, and poor range management practices were considered by 12 respondents to contribute to reduced sage grouse numbers.

Policymakers must balance the views of ranchers against conservationists in designing appropriate range management strategies for the sage grouse's recovery. According to the conclusions from a sage grouse workshop in 2005, although evidence may suggest that sage grouse populations are declining, the hypothesis that numbers are non-declining cannot be rejected outright.[2] The implication for policy is that detractors of sage grouse conservation can with some legitimacy claim that there may be more birds than enumerated. The workshop concluded that greater effort is required to archive and analyze grouse data of all kinds as there is insufficient data available at this time.

The current article contributes to this debate and investigates the role that humans have on sage grouse populations in Nevada. We specifically consider whether there is evidence to indicate that ranchers' perceptions are correct. We use population data from northeastern Nevada for the period 1951 to 2001 to examine human factors that potentially affect sage grouse populations, while controlling for biological and climate factors. We estimate relationships between sage grouse numbers and factors that may impact grouse populations, focusing on the potential effects of hunting, grazing, re-vegetation and predator control, and efforts to measure grouse numbers—human factors that policy can impact. Because hunting success will decline in concert with declines in grouse numbers, we also investigate factors that contribute to hunting success and harvests to determine if this provides information about grouse populations and their determinants.

Potential Human Factors Affecting Sage Grouse Populations

Humans affect sage grouse populations through habitat manipulation (e.g., fire suppression, grazing of domestic livestock, and range re-vegetation), predator control programs, and hunting. In addition, there are extraneous factors that affect grouse numbers, most of which are climate or weather related. Our empirical analysis controls for these weather/climate variables; thus in this section we discuss only the human factors that might affect sage grouse. A more in-depth review of studies of factors affecting sage grouse is found in Connelly et al. (2004).

Habitat Modification and Loss

Sage grouse engage in a lek mating system. Birds congregate at a central location (known as a lek), where males seek to draw the attention of females for mating purposes. Counting birds at leks is considered the best means of estimating populations. Lekking occurs in open areas of 0.1 to 5 hectares in size, surrounded by sagebrush (*Artemisia* spp.). Nesting habitat is characterized by big sagebrush with 15% to 38% canopy cover and a grass and forb understory (Connelly, Wakkinen, Apa, & Reese, 1991; Gregg, Crawford, Drut, & DeLong, 1994; Sveum, Edge, & Crawford, 1998; Terres, 1991). The presence and quality of the sagebrush/grasses/forbs mosaic is critical to success of the sage grouse, with loss of good habitat thought to be a major contributor to reduced grouse numbers (Aldridge & Brigham, 2003). Grouse habitat is impacted by humans through their decisions concerning livestock grazing, fire suppression, and habitat modification (e.g., investments in range improvements) (Beck, Mitchell, & Maxfield, 2003).

The effects of cattle grazing on sage grouse are controversial. Some level of grazing may be acceptable or even beneficial, but, although there "is little direct experimental evidence linking grazing practices to sage grouse population levels, … indirect evidence suggests grazing by livestock or wild herbivores … may have negative impacts on sage grouse populations" (Connelly, Schroeder, Sands, & Braun, 2000, p. 974; Beck & Mitchell, 2000). Although "historic grazing practices had strong negative impacts on sage-grouse habitat, … research directly addressing the population-level impact of current livestock grazing practices on sage-grouse is lacking" (Crawford et al., 2004, p. 11). The presumption is that livestock grazing on public lands is detrimental to sage grouse, and conservation organizations have lobbied public land agencies to curtail domestic livestock grazing on key sage grouse habitat (Clifford, 2002). The BLM and Forest Service in Nevada have reduced grazing by nearly 540,000 AUMs, or by 33%, between 1981 and 2002. The timing, intensity and location of grazing, however, can be used as a range management tool for good or bad (Beck & Mitchell, 2000; Crawford et al., 2004; Pedersen, Connelly, Hendrickson, & Grant, 2003), although no data relating to these factors are available. We use data on cattle numbers and AUMs of grazing to determine if livestock are a contributing factor to habitat modification that results in reduced sage grouse numbers.

Humans also have some control over wildfire. If fires occur too infrequently and/or are too intense (D'Antonio & Vitousek, 1992; Pyne, 1997), land may be converted from perennial range (suitable habitat) to annual grassland, primarily cheatgrass (*Bromus tectorum*), that is considered detrimental to sage grouse. Intense infrequent fires can lead to more frequent occurrence of fire even with fire suppression if the range ecology has changed. Throughout the Intermountain West, the number of fires doubled and average fire size increased by 400% between 1988 and 1999 (Pyke, McArthur, Harrison, & Pellant, 2003). Although fire may rejuvenate and invigorate sagebrush, making it more palatable for grouse, it might also reduce habitat by controlling the sagebrush and favoring annual grasses. Lacking data on fire suppression expenses, we use annual area affected by fire as a proxy for human influence. We assume that sage grouse and their habitat are negatively correlated with wildfire area.

Lastly, human investments in range improvements can impact the sagebrush ecosystem. Habitat conversion was pronounced during the 1950s and 1960s as sagebrush areas were converted to crested wheatgrass (*Agropyron cristatum*). Land converted in the BLM's Elko District amounted to 158,000 acres (ac) in the 1950s, 227,000 ac in the 1960s, 51,000 ac during the 1970s through 1990s, and a cumulative 512,000 ac by 2001. Planting of crested wheatgrass is thought to be detrimental to grouse survival (Braun & Beck, 1996; Connelly et al., 2000). We examine this proposition using data on area planted to crested wheatgrass as an explanatory variable in our regression analysis.

Predation

Predation is the largest source of mortality for sage grouse and occurs at every life stage. The major nest predators are the common raven (*Corvus corax*), ground squirrel (*Spermophilus* spp.), badger (*Taxidea taxus*), and coyote (*Canis latrans*), whereas the primary predators of adult grouse include golden eagle (*Aquila chrysaetos*), various types of hawk, weasel (*Mustela* spp.), coyote, and common raven (Schroeder & Baycack, 2001, p. 25). Humans can potentially affect grouse numbers by controlling predators. There is little information about the effects of predator control on sage grouse populations, but the data that do exist suggest it is a very effective management tool (Schroeder & Baycack, 2001). Predator control in Nevada occurred at intensive levels through the first half of the 20th century, but bait poisons and similar forms of predator control were prohibited from the mid-1970s on. Strychnine was used prior to 1973, primarily to target large mammals such as coyote, although the common raven, which was identified by ranchers as having a major negative impact on sage grouse, also fell victim to this method of control. We used a strychnine dummy variable and expenditures on predator control to test whether predators might contribute to declining sage grouse populations.

Harvests/Hunting

Hunting appears to have a negative effect on overall grouse populations, which suggests that it adds to mortality (Connelly, Reese, Garton, & Commons-Kemner, 2003; Johnson & Braun, 1999). However, because sage grouse are recognized as a game species, this might indicate that hunting simply shifts the cause of mortality—that hunting is compensatory. Compensatory mortality occurs when adult deaths are density dependent and not source dependent, so that perhaps only habitat loss, predation of nests and weather are sources of population decline. Connelly et al. (2000) suggested that harvests are additive and therefore recommend that, where hunting does occur, takes be limited to 10% of the population and that hunting cease when a particular population is below 300 breeding birds (p. 976). Using regression analysis, we tested whether hunting leads to additive or compensatory mortality.

Source and Analysis of Data for Northeastern Nevada

Population Data

The Nevada Department of Wildlife (NDOW) identifies some 1,362 leks statewide (although not all are active), and estimates that there are some 60,000 breeding birds (Neel, 2001, pp. 10–11).[3] However, the only population data that we could find consisted of lek data and reports of sightings by biologists (transect data).[4] Our data were compiled from handwritten forms found in filing cabinets in NDOW offices in Reno and entered in Excel spreadsheets by an NDOW biologist.[5] Compared to populations enumerated at leks, those enumerated along transects form a much more consistent set of observations over time. Population data for counties other than Elko County were considered to be too sparse and inconsistent to be of any use. We focused our analysis only on Elko County, although the lessons learned are applicable to other regions.

Lek data were only available from 1954 to 1985, with one additional observation from 1988 (Figure 1). For the 32 years, the average number of leks enumerated per year was 52.25 (=32.15 if missing years are treated as zeros) and the median was 9.5. Transect data were from 1951 through 2001, but "counts" varied from 0 (1992, 1993, 1996, 1997, 1998) to almost 300 (1968) (Figure 1).[6] Ignoring the 5 years when no effort was made to count (or collected data were not recorded/saved), the average number of transects counted per period was 51.78 (=45.81 if missing years are treated as zeros), and the median was 15.5. Clearly, population estimates in a given year depend on the effort expended to count birds.

The effort to count grouse populations fluctuated substantially over time due to budget constraints and priorities (Connelly et al., 2004). We divided (normalized) the lek (transect) populations enumerated in each year by the number of leks (transects) counted in that year to identify trends in bird populations. Without normalizing, the raw estimates of population are misleading as they would be sensitive to the actual number of leks and transects enumerated—sensitive to the effort made to count grouse. If normalized population trends downward, it would be evidence of declining bird numbers. We plotted annual

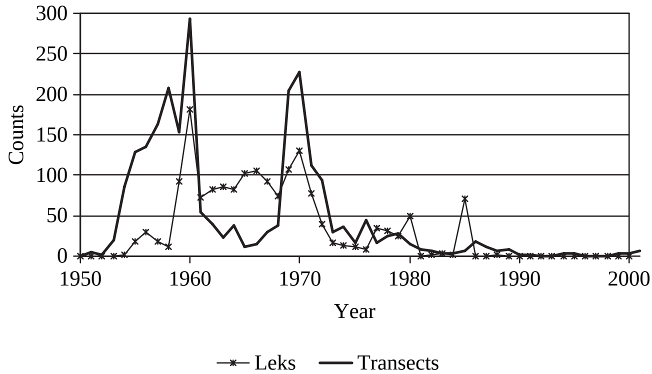

Figure 1. Effort to measure population in leks and along transects, Elko County, Nevada, 1951–2001.

population per unit of effort expended to count birds (Figure 2). The largest average number of grouse enumerated at any one time occurred in 1951, the first year for which data were available.[7] Five transects were enumerated in 1951 with an average of 56.4 birds per transect. Average population per count for 1951–2001 was 15.8, with the average higher for leks (20.99 birds per unit effort) than for transects (11.59).

Annual sage grouse populations obtained from lek and transect measurements were plotted (Figure 3). The respective mean annual populations for transects and leks were 510.6 (SD = 629.46) and 1141.0 (SD = 1045.24), while the mean of the annual populations counted by all methods was 1313.6 (SD = 1541.13).

Based on these data (Figures 2 and 3), but with particular reference to the per-effort counts (Figure 2), there does not appear to be a discernible decline in the sage grouse population. It appears that enumerated grouse numbers are simply a function of the effort made to count them, and any population decline can be attributed to a reduction in counting effort.

Harvests and Hunting Data

We obtained harvests by hunters from annual NDOW reports. Hunting data were available for the period from 1958 to 2000, except for 1963 (no reason given) and

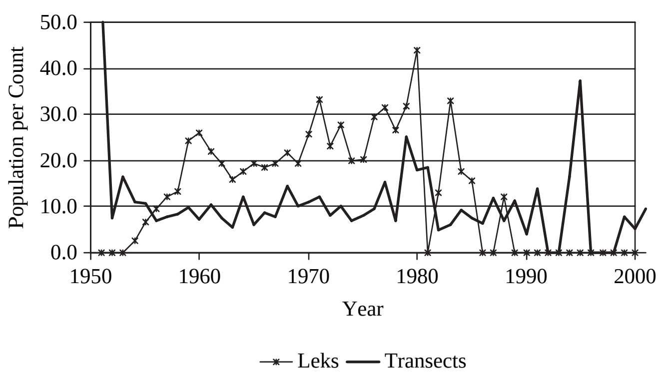

Figure 2. Annual sage grouse population per unit of effort in leks and transects, Elko County, Nevada, 1951–2001.

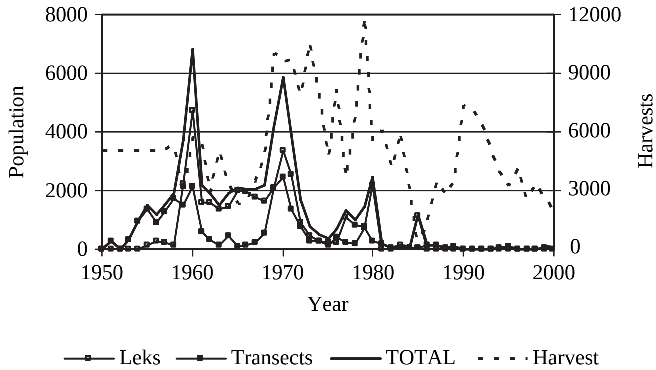

Figure 3. Sage grouse populations counted in leks and transects and total population (left scale), and annual harvests by hunters (right scale), Elko County, Nevada, 1951–2001.

1985 (when there was no hunting season). The average annual harvest over the period was 5,069 (SD = 2,683), substantially greater than the enumerated population of grouse. With rare exceptions (e.g., 1960), harvests exceeded enumerated populations (Figure 3).[8] This was not unexpected as information provided by hunters constituted a near total of all harvested birds, with maybe a few grouse taken illegally and some legal harvests not reported. In contrast, enumerated population constituted a sample that depends on counting effort. This underscores the importance of analyzing normalized count data.

Also available from NDOW annual reports were data on number of hunters and days spent hunting. Average annual take per hunter and per day spent hunting (replacing 1963 and 1985 with mean values) are plotted in Figure 4. There was a clearly discernible downward trend in harvests per day, and take per hunter appeared to be trending downward, with the exception of 1978–1979 when there were fewer hunters.

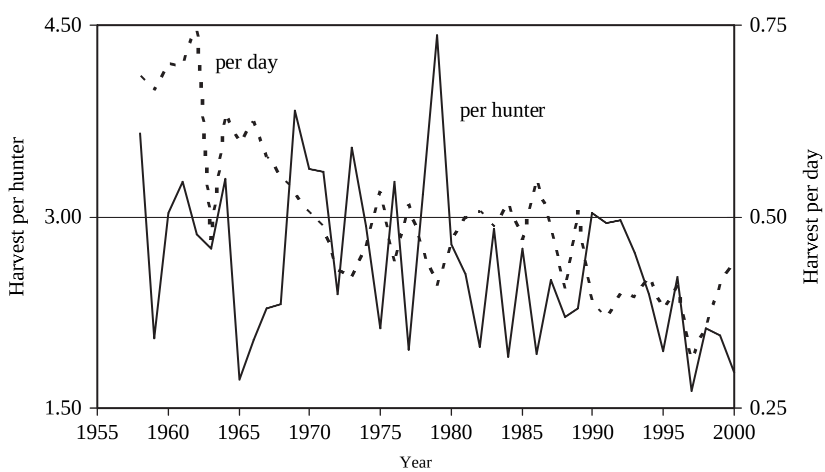

Figure 4. Hunting success: Annual harvests of sage grouse per hunter and per day spent hunting, Elko County, Nevada, 1958–2000.

Although our normalized population data do not enable us to discern a trend in grouse populations, the decline in hunter success serves as one indicator that sage grouse numbers might be falling over time. However, although hunter success may be a better indicator because hunting data are likely more reliable (although we cannot be entirely sure), such data may simply reflect declining returns to hunting effort for reasons unrelated to sage grouse population.

Miscellaneous Data

Annual real expenditures on predator control and use of strychnine in Nevada were obtained from files at the State Department of Agriculture's Predator Control Division in Reno. The former variable was deflated by the U.S. CPI (with 2000 = 100), whereas the latter was converted to a dummy variable that takes on a value of one in years when strychnine was used (otherwise zero).

Lacking basic annual data on key aspects of range management in Nevada, we used cattle numbers, AUMs of grazing made available by public land agencies, area affected by wildfire, and annual area planted predominantly to crested wheatgrass as proxy variables for the true effects that fire and range management have on habitat loss. State-level data on area affected by fire and AUMs of grazing on BLM land (accounting for the majority of public range land) were obtained from yearly BLM reports. Area planted (primarily) to crested wheatgrass for the Elko BLM District, which includes Elko County and some of the surrounding area, was obtained from the Elko BLM office. Total number of cattle in Elko County was available from the U.S. Department of Agriculture's website (www.usda.gov), whereas average monthly weather data on temperatures, snowfall, and precipitation were available for Elko Airport for the entire study period, with the exception of a gap in some of the data for the period 1952–1954. Summary information for all of the variables considered in the regression analyses is provided in Table 2.

Determinants of Enumerated Sage Grouse: Empirical Analysis

Regression Model

We determined the effect of human factors on the sage grouse population in Elko County, Nevada, while controlling for weather and other habitat factors.[9] If we consider only enumerated population, it would seem that, because the effort to count sage grouse varied from one year to the next (Figure 1), a Poisson count model with varying effort would be appropriate (Ramsey & Schafer, 2002, pp. 661–662). The count model was rejected because the number of counts in some years was substantial; the only variable that affected the enumerated population in a statistically significant fashion was effort. This was true whether separate equations for lek and transect populations were estimated, or whether we used a total population model with lek and transect effort included separately.[10] Instead, we regressed normalized populations—population per lek and population per transect—on potential explanatory variables.

Two problems arose. First, there were a number of years for which there were no observations because they were not recorded or no effort was made to monitor leks or "walk" transects, or both. In that case, it was appropriate to use a Heckman sample selectivity model in which there is a regression equation that is of primary interest and a

Table 2
Summary description of available variables

Item	Years	Mean	Std. Dev.	Min	Max
Transects counted	46	51.8	71.3	1	293
Population in transects	46	502.0	644.2	8	2466
Population per transect	46	11.6	8.9	4	56.4
Number of leks counted	32	52.3	45.7	1	182
Population in leks	32	1166.6	1113.0	5	4708
Population per lek	32	21.0	8.6	2.5	43.9
Area affected by fire, Elko Co. (‘000s acres)	49	114.6	233.2	3.0	1383.1
Area revegetated (‘000s acres)	51	9.9	20.1	0	121.2
Number of cattle, Elko Co. (‘000s)	51	179.5	17.3	147	220
AUMs of grazing permitted in NV (millions)	51	2.0	0.6	1.14	3.20
Strychnine dummy (= 1 in years poison bait used)	51	0.4	0.5	0	1
Expenditure on predator control, NV ($2000 mil)	48	1.6	0.3	0.65	2.17
May precipitation, Elko (inches)	51	100.9	86.0	0	409
Annual snowfall, Elko (inches)	46	398.3	191.5	83	1008
Total annual precipitation, Elko (inches)	47	965.2	295.3	477	1834
Average monthly temperature, Elko (deg F × 10)	47	461.6	17.2	418.1	506.9
Minimum average monthly winter temperature, Elko (deg F × 10)	49	271.4	40.2	177.3	347.7
Harvest of sage grouse	42	5069.3	2715.7	0	11859
Number of hunters	42	1845.7	672.9	0	3296
Number of days of hunting	42	3938.2	1737.1	0	7660
Harvest per hunter	42	2.5	0.8	0	4.4
Harvest per hunter-day	42	1.3	0.5	0	2.5
% of harvest	42	38.0	13.2	0	58.98
% of hunters	42	32.2	10.6	0	47.36

selection equation (Greene, 2000, pp. 905–926). Let the equation that determines the sample selection be

$$z^*_j = \boldsymbol{\gamma}'_{\mathrm{j}} \boldsymbol{w}_{\mathrm{jt}} + u_{\mathrm{jt}}, \qquad j \in [\text{lek, transect, combined}], \tag{1}$$

and the equation of primary interest be

$$y_{\mathrm{jt}} = \boldsymbol{\beta}'_{\mathrm{j}} \boldsymbol{x}_{\mathrm{jt}} + e_{\mathrm{jt}}, \qquad j \in [\text{lek, transect, combined}]. \tag{2}$$

The dependent variable y_j refers to normalized population (population per count) for j (=leks, transects, combined), and is only observed when $z^*_j > 0$ (effort is made to count sage grouse); $\mathbf{x}_j$ are population-specific regressors (factors); $\boldsymbol{w}_j$ are regressors determining whether an effort is made to count grouse; and $e_j \sim N(0, \sigma)$, $u_j \sim N(0,1)$ and $corr(e_j, u_j) = \rho$. The marginal effect of the regressors on normalized population consists of the direct effect on the mean of y_j (namely $\boldsymbol{\beta}$) plus an indirect effect that makes its presence felt through the estimated Mill's inverse ratio (λ) derived from the sample selection equation (1). Failure to take into consideration years when grouse were not enumerated but information about the independent variables is nonetheless available results in sample selectivity bias, or a specification error from omitting λ in regression (2). We tested whether ρ is statistically different from zero; if not, OLS regression is adequate, but the coefficient estimates are more likely to be consistent if selectivity is taken into account.

The second problem was that the error terms in the two population equations were likely correlated. To take this into account and keep the statistical analysis simple, we combined the lek and transect data into a single regression, using a dummy variable to account for the difference between lek and transect counts.

Regression Results

In all cases, the results of a restricted version of a full model are presented, with a Wald χ^2 test used to determine if the restricted model is statistically different from the full model (Table 3). Because our interest was only on human factors, the only variables included in the full models but eliminated from the restricted regressions were weather variables (e.g., snowfall squared, snowfall multiplied by average monthly minimum temperature) and precipitation multiplied by re-vegetation area. All of the human factor variables were included in the final restricted regressions. The z-statistics on the estimated coefficients of dropped variables were all below 1.0. In addition, the lag of population was not included as an explanatory variable as it turned out to be statistically insignificant in all regression models and its use in the lek and transect (and combined) regression equations did not make sense since the lek- and transect-derived population series were highly irregular, with bird populations dependent on the effort to count them.

Likelihood ratio tests indicated that the selection and regression equations were independent (Table 3). Further evidence of this was provided by the high standard error on Mill's inverse ratio (λ). The results for both the regression and selection equations were valid. The selection equation results provided support for the trends observed in Figure 1. Over time there has been a statistically significant downward trend in effort to enumerate sage grouse, and this trend is greatest for leks. There was also weak evidence suggesting that the decision to count sage grouse was positively related to cattle numbers in the region, at least with respect to transects. Because NDOW relies on hunting data to model grouse populations, one expects effort to count grouse in the field (at leks or transects) to be inversely related to the number of hunters. The estimated coefficient on hunters in the selection model was negative in all three regressions (Table 3), but they were statistically insignificant.

For the "regression equation," we found that normalized population was higher for leks than for transects (i.e., on average more sage grouse were counted at a lek than along a transect, although this was not an unexpected result given that birds congregate at leks). There was some evidence that population per lek was higher if more effort was spent counting leks. However, this result did not carry over to the combined model (probably because effort is negatively correlated with population per unit of counting in the transect model, although the estimated coefficient is insignificant).

Table 3
Heckman regression with sample selection, results for sage grouse populations in Elko County, Nevada, 1951–2001
(Dependent variable: Population per count)

	Transect Model		Lek Model		Combined Model	
Explanatory variable	Est. coeff.[a]	z-stat.	Est. coeff.[a]	z-stat.	Est. coeff.[a]	z-stat.
Regression equation						
Intercept	–258.1613**	–2.15	–41.2863	–0.45	–153.8399*	–1.79
Effort counting sage grouse	–0.0090	–0.50	0.0407*	1.84	–0.0001	–0.01
Lek dummy (=1 if lek, else 0)					13.0718***	10.47
Area affected by fire	0.0001	0.02	–0.0026	–0.33	0.0012	0.33
Area re-vegetated	–0.0088	–0.16	0.0500	1.30	0.0098	0.25
Number of cattle	–0.1515**	–2.31	0.0561	0.88	–0.0821	–1.68
Year strychnine used	–0.3334	–0.11	–4.0228	–1.37	–1.5518	–0.74
Sage grouse harvested	0.0005	1.17	0.0007**	2.43	0.0006**	2.19
May precipitation	0.0196	1.80	0.0358***	5.19	0.0295***	3.98
Annual snowfall	–0.0093	–1.18	–0.0152**	–2.45	–0.0141**	–2.46
Total annual precipitation	0.6357**	2.35	0.1009	0.52	0.3810**	1.99
Average monthly temperature	0.2431**	2.11	–0.0272	–0.35	0.1190	1.47
Minimum average monthly winter temperature	–0.0326	–0.97	–0.0094	–0.34	–0.0290	–1.17
Average monthly temperature × annual precipitation	–0.0005**	–2.08	0.0001	0.47	–0.0002	–1.38
Selection equation						
Intercept	37.2330	0.93	29.0052	0.99	11.1596	1.05
Year since 1950	–1.1784	–1.36	–0.4756	–1.52	–0.2759**	–2.04

(*Continued*)

Table 3
(Continued)

	Transect Model		Lek Model		Combined Model	
Explanatory variable	Est. coeff.[a]	z-stat.	Est. coeff.[a]	z-stat.	Est. coeff.[a]	z-stat.
Lek dummy (=1 if lek, else 0)					–3.6684**	–2.09
Number of cattle	0.1879*	1.67	–0.0599	–0.58	0.0226	0.56
Number of hunters	–0.0080	–1.30	–0.0009	–1.11	–0.0012	–1.35
Statistics						
ρ	0.1768	0.57[b]	0.1892	0.95[b]	0.0188	0.29[b]
σ	4.7073***	0.56[b]	2.8756***	0.41[b]	4.5736***	0.42[b]
λ	0.8322	2.69[b]	0.5440	2.75[b]	0.0862	1.31[b]
LR $\chi 2(1)$ test of independent equations ($\rho = 0$)	0.001		0.03		0.001	
Number of observations	40		40		79	
Censored observations	5		15		19	
Uncensored obs	35		25		60	
Wald $\chi 2$ (df)	26.04*** (12)		122.9*** (12)		169.95*** (13)	
Log likelihood	–109.0566		–67.25414		–188.5823	

[a]***denotes statistical significance at the 1% level or better, **significance at the 5% level or better, and *significance at the 10% level or better.
[b]Standard errors rather than z-statistics.

Of the factors under direct human control, there was weak evidence (from the transect model) suggesting that cattle grazing may have a negative impact on grouse populations, although the result did not appear in the lek regression or combined regression. Rather than postulating an inverse relationship between cattle and grouse numbers, it might simply be that biologists do not count transects where cattle are present.[11] Finally, the estimated coefficient on harvests was positive and statistically significant in the lek and combined regression models; but the estimated coefficient was so small that it can be considered negligible, suggesting that mortality is likely to be compensatory, contrary to recent thinking (Connelly et al., 2000, p. 976).

It is interesting that fire suppression, re-vegetation, and predator control (as measured by use of strychnine) were all statistically insignificant in explaining grouse populations. There was no evidence to support ranchers' contentions that predators are a major contributor to loss of sage grouse. Even actual expenditures on predator control were not correlated with grouse numbers (this variable was removed in the restricted version of the model). This result does not imply that the ranchers are wrong (because actual predator numbers were not used in the regressions as these were not available) (Table 1), but only that our particular analyses provided no support for the ranchers' position (see also Discussion section). Further investigation of the effect of predators certainly appears to be warranted, even if only for political reasons.

Remaining explanatory factors were weather-related. Sage grouse numbers increase with higher May precipitation, higher annual precipitation, lower annual snowfall, higher average monthly temperatures, and higher minimum temperatures in the winter months, although the latter result was statistically insignificant. The results for average monthly temperature and annual precipitation were moderated somewhat, as indicated by the coefficient on the cross product of these variables. These results were expected from the literature (Neel, 2001).

Although humans clearly have some impact on sage grouse, it is difficult to identify and appears to be swamped by weather factors (Table 3). Humans do impact sage grouse indirectly through, for example, activities that cause climate change. But climate change is a global issue beyond the control of range management policy.

Sage Grouse Harvests and Hunter Success

Sage grouse continue to be a hunted species in Nevada. If grouse are truly in decline one would expect harvests to decline, controlling for number of hunters and length of season. One would also expect hunting success as measured by harvests per hunter and per hunter-day to be falling over time. It is difficult to determine if there is a discernable trend in harvests (Figure 3), while it appears that hunting success declines over time (Figure 4).

We examined whether there was a statistically significant decline in sage grouse harvests and hunter success over time. Further, what effect did rangeland policy decisions have on harvests and hunter success? In particular, our interest was to determine if re-vegetation, cattle grazing, effort to control predators, number of hunters, and number of days of hunting affect hunting success and harvests of grouse. We employed seemingly unrelated regression (SUR) because the error terms in the equations for total harvests, harvests per hunter and harvests per hunter-day were likely correlated; by taking this into account, estimated coefficients were more efficient. The SUR regression results are reported in Table 4.

We only used regressors that come under the direct control of policymakers—number of hunters, length of season (measured by hunter-days),[12] area re-vegetated, cattle grazed,

Table 4

Seemingly unrelated regression results for sage grouse hunting success and harvests in Elko County, Nevada, 1951–2001[a]

Explanatory variable	Harvest per hunter	Harvest per day of hunting	Harvest
Intercept	5.9096***(5.17)	3.9571***(5.83)	4019.71(1.43)
Year since 1950	–0.0342**(–2.53)	–0.0270***(–3.36)	–79.5347**(–2.40)
Number of hunter-days	–0.0002(–1.15)	–0.0003***(–2.88)	0.4149(0.93)
Number of hunters	0.0016***(3.20)	0.0011***(3.84)	2.7751**(2.29)
Area re-vegetated	0.0114***(2.73)	0.0053**(2.15)	6.0377(0.59)
Number of cattle	–0.0237***(–4.46)	–0.0148***(–4.79)	–17.1311(–1.31)
Year strychnine used (=1, else 0)	–0.7368***(–2.56)	–0.3067*(–1.79)	–966.0973(–1.37)
Number of observations	42	42	42
χ^2 (6)	83.51***	106.87***	226.10***
R^2	0.665	0.718	0.843

[a]Estimated regression coefficients with z-statistics provided in parentheses: ***denotes statistical significance at the 1% level or better, **significance at the 5% level or better, and *significance at the 10% level or better.

and predator control effort. Enumerated (lek plus transect) grouse population and population lagged one period were left out of the regressions because it is unlikely that wildlife managers access these data in deciding how many permits to issue and length of season.[13]

All regressors were statistically significant at the 10% level or better in all three regression equations, except for hunter-days in the harvest per hunter and harvest equations and the re-vegetation, cattle, and strychnine variables in the harvest equation. Goodness-of-fit tests indicated that our regressors explained a high degree of the variation in all dependent variables.

The most important result was that harvests and hunting success declined over time. This is perhaps the strongest statistical evidence available for the view that sage grouse numbers are indeed declining. Further, the evidence suggested that, upon controlling for other variables including time, cattle grazing reduces hunting success. This provides indirect evidence that cattle grazing may negatively impact sage grouse, supporting the result found for the transect model (Table 3). However, further research is required to establish this causal link as hunters may simply avoid cattle-grazed habitats, and this shows up in lower success rates.

Hunter success was also lower during years that strychnine was used to control predators. This provides some evidence against the hypothesis that a decrease in the control of predators contributed to declining sage grouse populations. This accords with the finding that the strychnine dummy variable (as well as expenditures on predator control) was a statistically insignificant factor in explaining enumerated sage grouse.

Hunter success was positively correlated with re-vegetation efforts. Re-vegetation did not seem to affect grouse populations (Table 3), so its role is unclear. Perhaps more grouse congregate on areas that have been re-vegetated (at least during hunting season), making it easier for hunters to find them. This warrants further investigation.

Finally, an increase in the number of hunters increased harvests as expected. However, an increase in hunters also increased the success rate, contrary to expectation. One explanation is that, if grouse are difficult to locate because they are spread evenly across the landscape, more hunters (if grouped together) may have a better chance of harvesting a grouse. An increase in season length (as measured by hunter-days), on the other hand, reduces hunting success (at least as measured by harvests per day), because more days are available to reach one's bag limit and/or grouse are more difficult to find as time goes on (as best hunting sites are visited first). Season length has a positive albeit statistically insignificant impact on harvests.

If hunting mortality is compensatory (Table 3), changes in the number of permits issued and/or season length are unlikely to affect grouse numbers. But if hunting mortality is additive, the results suggest that one should target the number of hunters more than season length if the desire is to reduce hunting impacts on sage grouse populations.

Concluding Remarks

Protection of sage grouse and their habitat poses a challenge for public land managers and politicians. The options available to decision-makers include: do nothing, reduce domestic grazing on public range, perhaps by purchasing grazing privileges from ranchers (van Kooten, Thomsen, & Hobby, 2006), or manipulate range and wildlife resources until desired outcomes are achieved (if at all possible). None of these strategies is particularly straightforward from a scientific or political standpoint. Politically, there still remains sufficient doubt about the effect that various human activities have on sage grouse. We provided some insights into the issue using empirical results from models of sage grouse numbers for Elko County, Nevada. Because sage grouse migrate within an area of not more than about 3,000 km^2 (Connelly et al., 2000, p. 969), the sage grouse in Elko County can be considered a single population. Hence, our conclusions might be applicable to other sage grouse populations occupying similar environments in the western United States.

In Nevada, reported sage grouse numbers appear to be largely a function of the effort spent enumerating them—the more effort devoted to counting sage grouse, the more one finds. It is not possible to state definitively that populations are in decline, but that stated declines in population may simply be the result of a failure to count grouse. Irregularity in data collection thus poses a challenge for analyzing grouse population trends and their underlying determinants. More effort is required to count (and archive) sage grouse populations.

Our findings are relevant to ongoing policy discussions regarding the conservation of sage grouse and the likely economic impacts of (and human responses to) actions to protect the bird. Currently there is substantial debate regarding the magnitude and causes of population decline, and a variety of opinions regarding whether changes in land management practices (e.g., grazing) would, in fact, lead to appreciable benefits in terms of enhancing populations. Our findings provide limited evidence that cattle grazing could contribute to reductions in sage grouse populations. Increases in cattle numbers were associated with lower grouse counts per unit of counting effort in the case of transects, *ceteris paribus*, but not for leks. The presence of cattle appears to reduce hunting success and harvests by hunters. Although changes in grazing management techniques (for a given cattle stocking rate) may be beneficial to the sage grouse, the data necessary to test this hypothesis were not available for our study. We can only conclude that more information and better data on forage consumed by domestic livestock (our data consisted only of AUMs allocated and cattle numbers) and wildlife ungulates are required to establish a definitive link between grazing on public range and sage grouse populations.

Our findings provide no support for the hypothesis that predators are a major driver of declining sage grouse populations. This is not to suggest that predators can be excluded as an important factor, only that we found no evidence of this impact in our data, which may have been a poor surrogate for actual predation pressure.

Finally, weather factors appear to be the most important drivers of sage grouse populations. We conclude that, if sage grouse are being driven to imperilment, climate change will probably be a significant factor in bringing this about. In that case, efforts should be devoted to identifying regions where sage grouse have the greatest chance of survival in the future and ensuring that grouse in those regions are adequately protected.

Notes

1. In a January 7, 2005 press release available at http://news.fws.gov/NewsReleases./R9/
2. The statements in this paragraph are based on an e-mail summarizing the workshop outcome and sent May 26, 2005 to various stakeholders by Dr. J. Christopher Haney, Director of Conservation Science, Defenders of Wildlife in Washington, DC.
3. Connelly et al. (2004) indicate that only 1,077 leks have been identified in Nevada and they do not provide estimates of sage grouse numbers, basing evidence of population decline only on limited lek data. Braun (1998) estimates there are 20,000 breeding sage grouse in Nevada.
4. Given the paucity of information on age and gender of observed birds, we employ only data of all enumerated birds, ignoring chicks.
5. Excel data were provided by Nanci Fowler of NDOW and are available from the authors.

6. The lek data used by Connelly et al. (2004) are likely similar to ours. However, it may be that they interpreted the transect data as having come from leks. Because we accessed the Excel spreadsheets before anyone else (including NDOW), it is possible that what we interpret to be data from transects was later judged to have come from leks. Further, unlike Connelly et al. (2004), we focus only on Elko County and do not include observations beyond 2001.
7. It is important to note, however, that the high average for 1951 might have been due simply to the small number of counts or the fact that biologists targeted areas where grouse were already known to be more plentiful (given this was the first year a census was reported).
8. In Figure 3, but not in the regression analyses, the average harvest level is used for years when no hunting occurred.
9. For purposes of tractability and because sage grouse do not migrate large distances, it is assumed that "replenishment" of grouse from outside the study area does not occur.
10. All statistical analyses were conducted using routines available in Stata, Release 8 (Stata Corporation, 2003). To take into account the high number of zero observations, we used a zero-inflated count model that also adjusted for observed over-dispersion (Table 2).
11. A reviewer pointed to anecdotal evidence of young sage grouse finding meals of insects in or near cow dung. The analysis provided in this article neither supports nor refutes this claim.
12. The authority determines both season length and number of hunting permits. Although it may not be the case, we use hunter-days as a proxy for changes in season length from one year to the next given the number of hunters.
13. This observation is based on discussions with NDOW staff. If hunting decisions are based on population estimates, it would necessarily be based on the population in the previous period. However, population lagged one period turned out to be statistically insignificant.

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