Anthropogenic and Natural Determinants of the Population of a Sensitive Species: Sage Grouse in Nevada

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ABSTRACT

This paper uses Nevada data to conduct regression analyses of the relationship between sage grouse (*Centrocercus urophasianus*) population sizes and potential causal factors. This is policy-relevant because of current petitions for listing this species under the Endangered Species Act. A key feature is that, although monitoring of sage grouse has occurred for many decades, data collection methods and level of monitoring effort have not been consistent. To account for this feature we use, as dependent variables, standardized measures such as population counts and harvest (hunting success) per unit of effort. Preliminary findings suggest that such measures have been particularly sensitive to whether or not humans used strychnine for predator control, with normalized measures of grouse populations higher in years when strychnine was employed. Our results also suggest a positive association between the number of cattle on the range and normalized measures of grouse population. This is a controversial finding as some studies suggest a negative impact of cattle grazing on grouse. Our data do not include indications of the timing and precise nature of grazing practices and so should be interpreted with caution.

Key words: population viability analysis and endangered species; factors affecting decline of sage grouse

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INTRODUCTION

The declining population of sage grouse (*Centrocercus urophasianus*) in western North America has prompted concern on behalf of biologists and game bird hunters since the early 1900s. Estimated decline from historic (pre-European settlement) to recent times ranges from 69 to 99 percent of the population (Deibert) and over the past three to four decades, long-term population declines in the Western States have averaged 30 percent (Bureau of Land Management (BLM)). As a result of habitat fragmentation and other factors, the distribution of the species has also declined over time (Figure 1). After receiving petitions calling for the sage grouse to be listed as threatened or endangered across its entire range under the Endangered Species Act, the U.S. Fish and Wildlife Service initiated a status review of the species in April 2004 (Deibert). Washington State declared it a threatened species in 1998 (Washington Department of Fish and Wildlife) and the State Bureau of Land Management (BLM) office in Nevada has designated it as "Sensitive" (Nevada Natural Heritage Program). Federal listing would require significant restrictions in land use and development, but BLM land managers in Nevada would prefer to continue with extant state action and avoid the extra costs that would otherwise result (Sonner).

Before a judgment can be made regarding the listing of the sage grouse as an endangered species, it is useful to determine if populations are actually declining in Nevada, and, if so, identify factors that contribute to this decline. Whether factors

contributing to decline are natural or human influenced, information about the species is needed before one can begin to implement range management or other strategies for its recovery.

One factor that may explain reduced sage grouse numbers is loss of suitable habitat (Aldridge and Brigham). Although dependent on the timing and intensity of grazing and other management variables, (inappropriate) livestock grazing has been implicated in much of the sage grouse habitat loss (Beck and Mitchell; Crawford et al.; Pedersen et al.). While not all conservation organizations agree, some are pressing public land agencies to curtail domestic livestock grazing on key sage grouse habitat (Clifford). Studies have also found that hunting has a negative effect on overall populations (Connelly et al. 2003; Johnson and Braun), but sage grouse are currently recognized as a game species, with permits to harvest birds issued annually to hunters in various regions of Nevada. Fire, predation by other wildlife, land development that affects susceptibility to exposure and predation, and other factors may also influence sage grouse populations. Understanding the impact of a variety of factors on grouse numbers will aid in identifying the optimal balance between risk to the population and the value gained from habitat and other management.

The purpose of this study is to use data from Nevada to examine factors that affect sage grouse populations. There has been much debate in Nevada about whether and under what conditions the sage grouse might go extinct and what should be done in response. Indeed, the issue was considered sufficiently important that the State Governor struck a Sage Grouse Task Force to examine the issue (Neel), but very little data on actual grouse populations and the factors that affect them was made available. We seek to

correct this deficiency by using available data to estimate a relationship between grouse numbers and potential causal factors. For convenience, it is assumed that 'replenishment' of grouse from outside the state does not occur – a meta-population analysis is not undertaken (see van Kooten and Bulte, pp.211-5). If the same factors that affect sage grouse in Nevada affect sage grouse throughout the western States, then the conclusions drawn from the Nevada analysis might apply more generally.

In the following sections, we discuss biological factors that influence sage grouse populations, summarize survey findings on the views of Nevada ranchers toward grouse population trends, and present the results of regression models that use environmental and human management variables to explain sage grouse population levels in northeastern Nevada.

FACTORS AFFECTING SAGE GROUSE POPULATIONS: THE BIOLOGY

Sage grouse are a large, upland game bird species found over a substantial area of rangeland in western North America, as indicated in Figure 1 (Schroeder). In Nevada they are found primarily in the northern and eastern parts of the state. They are semi-migratory, such that in parts of their range they migrate seasonally. More extensive reviews of sage grouse biology and habitat are provided by the U.S.D.A. Forest Service, the Policy Analysis Center for Western Public Lands (Wambolt et al.), and Connelly et al. (2000).

Sage grouse engage in a lek mating system. Birds congregate at a central location (known as a lek), with males seeking to draw the attention of females for mating purposes and several of the 'best' males eventually mating with all of the females. Leking occurs

in open areas of 0.1 to 5 hectares in size, surrounded by sagebrush. Nesting and early brood rearing by the female occur from April through June; males are absent as they do not participate in rearing the young. Nesting habitat is characterized by big sagebrush with 15% to 38% canopy cover and a grass and forb understory (Connelly et al. 1991; Gregg et al.; Sveum et al.; Terres). Clutch size usually ranges from seven to ten eggs, and incubation lasts 25 to 28 days; chicks fly at ten days and strongly after about five weeks (Schroeder; Wakkinen; Wakkinen et al.).

Although average clutch sizes vary from 6.0 to 9.5, juvenile success plays a more important role in population dynamics. To maintain or increase sage grouse populations it is necessary to have a ratio of at least 2.25 juveniles per hen in the fall (Beck et al.), but long-term ratios have varied from 1.40 to 2.96 while ratios of 1.21 to 2.19 since 1985 have been found, which is below that needed to stabilize populations (Connelly et al. 2000, pp.969-70).

When chicks are able to fly, sage grouse move to summer habitat that consists of wet areas, such as wet meadows, riparian areas or irrigated agricultural fields. They return to the sagebrush in the fall, which provides food and cover essential for winter survival. Sage grouse feed on forbs and insects during the summer, and their diet is comprised almost entirely of sagebrush leaves during other parts of the year. Winter survival rates range from a low of 40% to as much as 85% for females, but only 38% to 54% for males (Connelly et al. 2000, p.969).

Weather

Cold, dry years are likely bad for sage grouse because of energy expenditures. Annual and seasonal precipitation and temperature affect growth of forbs, which are

important for food (including production of insects) and provide cover from predators. As well, poor weather (cold and wet) for several days during peak hatching in May can negatively impact reproduction because of exposure and lack of insects for chicks.

Higher winter temperatures and precipitation are assumed to have a positive impact on grouse numbers, while the effect of snowfall is unknown. Sage grouse bury in the snow to stay warm when it is cold (below 14° F), but sagebrush must be exposed 10-12 inches above snow to provide sufficient food and cover. Hence, we expect the coefficient on annual snowfall to be positive but that on the quadratic term to be negative. Precipitation of any form is good for shrub growth, while the negative foraging effect of too much snow can be offset by rainfall that reduces snow cover. Precipitation in the form of rainfall could reduce any positive (or negative) effect of snow. Since the effect of temperature depends on precipitation, and vice versa, the interaction between precipitation (snowfall) and temperature during winter months may have an important effect on population. The cross product of temperature and snowfall (moderate temperatures imply that high snowfall makes it harder for grouse to obtain food) is postulated to be negative, but the interaction between precipitation and temperature is assumed to impact grouse positively.

While anticipated global warming will likely have a negative impact on sage grouse range, it is not clear how various weather components affect sage grouse populations, mainly because of the complexity that the interaction effects have on birds and their reproduction from one year to the next. An attempt to sort out some of this is provided in Table 1.

Habitat Loss and Modification

Three factors affect habitat – fire, habitat conversion and grazing. Constriction in sage grouse range, habitat fragmentation and degradation seriously affect sage grouse populations (Beck et al.). If fires occur too infrequently and are intense ('hot'), land may be converted from perennial range (suitable habitat) to annual grassland (cheatgrass, *Bromus tectorum*), which is considered detrimental to sage grouse (D'Antonio and Vitousek; Pyne). Throughout the Intermountain West, the number of fires doubled and average fire size increased by 400% between 1988 and 1999 (Pyke and McArthur). Although fire may rejuventate and invigorate sage brush and make it more palatable for sage grouse, it might also reduce habitat by controlling the sage brush and favoring annual grasses. Therefore, the effect of fire on sage grouse habitat is hypothesized to be unclear (Table 1).

Habitat conversion was particularly pronounced during the 1950s and 1960s as sagebrush areas were converted to crested wheatgrass (*Agropyron cristatum*). Land converted amounted to 158,000 acres 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. Although these areas are now used for leking, lost sagebrush habitat has impacted nesting, early brood survival and winter range. Hence, planting of crested wheatgrass is thought to be detrimental to grouse survival (Braun and Beck; Connelly et al. 2000). Thus, we postulate that planting of crested wheatgrass is negatively correlated with sage grouse populations (Table 1).

Finally, the effects of cattle grazing on sage grouse are controversial. Some level of grazing may be acceptable or even beneficial, but, while 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" (see also Beck and Mitchell; Connelly et al. 2000,

p.974). Grass cover (taller vegetation) is important for sage grouse and it is likely

affected by cattle and wildlife ungulates. While the federal land management agencies

(BLM and Forest Service) have responded to environmental concerns about their

management practices primarily by reducing grazing by nearly 506,250 AUMs, or by

30.7%, between 1981 and 2001, timing, intensity and location of grazing can be used as a

range management tool for good or bad. However, there is no information on these more

subtle aspects of grazing as a management tool.

Lacking basic annual data on key aspects of range management in Nevada, cattle

numbers, AUMs of grazing made available by public land agencies, area affected by

wildfire and annual area planted to (mainly) crested wheatgrass are used as proxy

variables for the true effect that fire and range management have on habitat loss.

Predation

Predation is the largest source of mortality for sage grouse and occurs at every life

stage, although nest predation is thought to be most important. The major predators on

sage grouse nests are corvids (ravens, crows and magpies), ground squirrels, and badgers

In Nevada, nest predation (primarily by ravens) on artificial sage grouse nests was found

to be high in northern Washoe County (Stigar) but low in Elko County (Alstatt).

Predation levels vary due to differences in the availability of vegetation cover (Watters et

al.).

Predator control in Nevada happened at intensive levels through the first half of

the 20th century, but bait poisons and similar forms of predator control were prohibited from the 1970s on. Strychnine was used prior to 1973, primarily to target large mammals, although scavenging corvids also fell victim to this method of control. It is postulated that strychnine use had a positive effect on sage grouse populations (Table 1).

The State of Nevada continues to control predators, but in ways that target species in more direct fashion. If the predator control program targets species that kill grouse or eat their eggs, such a program will benefit sage grouse. Assuming this is the case, we postulate that the size of Nevada's predator control program, as measured by inflation-adjusted expenditures, is directly correlated with sage grouse numbers (Table 1).

Harvests/hunting

Annual sage grouse harvests should be included as a determinant of population, although it is not clear what the effect of hunting might be. Braun and Beck found that harvest of sage grouse in Colorado was independent of season length and bag limit, but, rather, a function of total birds available in the fall, with 7% to 11% of the population being harvested. It is important to determine if hunting leads to additive or compensatory mortality. Additive mortality occurs if harvest increases total mortality, while compensatory mortality simply results in a shift of the causes of mortality. Compensatory mortality occurs when adult mortality is 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) suggest 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). Our hypothesis is that hunting limits sage grouse populations, or that hunting leads to

addictive mortality (Table 1).

FACTORS AFFECTING SAGE GROUSE NUMBERS: THE RANCHERS' VIEW

A survey of all ranchers in Nevada with public grazing allotments was conducted between March 29, 2002 and July 5, 2002. The response rate was 47.9 percent, or 246 returned surveys (Thomsen). Several questions in the survey addressed respondents' perceptions about sage grouse. Responses to the following question are of particular relevance to the current study: "Do you think sage grouse populations are in decline?" All ranchers answered this question, with 103 responding 'yes', 97 'no', and 44 declaring that they were uncertain whether population had declined. Those who had responded 'yes' were asked to identify reasons why they thought sage grouse populations had declined (Table 2). The most important factor cited by respondents was predation, followed by hunting and wildfire (with many respondents identifying ravens and coyotes as particular problems and/or ranking predation above the other reasons). After range management policies and invasive weeds, other reasons given for perceptions about declining populations included over- and under-grazing, urban encroachment, and climate. Of respondents who did not think grouse populations declined or did not know whether they had, twenty-eight indicated that predation was a major threat to sage grouse.

In addition, ranchers were asked to respond to the statement, "Wildlife species that are considered threatened or endangered are unaffected by livestock grazing," using a five-point likert scale with +2 indicating strongly agree, +1 agree, 0 neutral, −1 disagree and −2 strongly disagree. The average of 244 responses was +1.05, indicating that most ranchers do not consider livestock grazing to be detrimental to the habitat of species such

as sage grouse. Indeed, 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. This is contrary to the hypotheses in Table 1.

SAGE GROUSE POPULATION AND RANGE MANAGEMENT DATA

Although monitoring of sage grouse has occurred in Nevada since 1947, data are not always consistent. According to the Nevada Governor's Sage Grouse Conservation Team, population data are derived from a combination of males observed to be strutting at leks (of which 1,362 have been identified statewide) and reported harvests (Neel, pp.10-1). Braun reports that there are only 20,000 breeding sage grouse in Nevada, while biologists from the Nevada Department of Wildlife (NDOW) and the BLM have estimated that there are some 60,000 breeding birds (Neel, pp.10-1).

The only population data that we could find consisted of lek data and reports of sightings by biologists (transect data).[1] Transect data are the most consistent historical data available. Handwritten transect data from files at NDOW in Reno, NV were compiled in Excel spreadsheets by an NDOW biologist.[2] The best available data are for Elko County located in northeastern Nevada. Lek data are only available for the period 1954 to 1985, with one additional observation available for 1988 (Figure 2). For the 32 years that an effort was made to count sage grouse at leks, the average number of leks enumerated per year was 52.25 (=32.15 if missing years are treated as zeros); the median number was 9.5. Transect data cover the period 1951 through 2001, but the number of sightings varies from a low of 0 (1992, 1993, 1996, 1997, 1998) to almost 300 (1968), as indicated in Figure 2. Ignoring the five years when no effort was made to enumerate sage

grouse (or collected data did not get recorded), the average number of 'transect' counts per period was 51.78 (=45.81 if missing years are treated as zeros); the median number was 15.5. Clearly, estimates of sage grouse population in any given year will depend on the effort expended to count birds.

In Figure 3, we plot annual population per unit of effort expended to count birds, both for leks and transects. The largest average number of grouse enumerated at any one time occurred in 1951, the first year in which an effort was made to count sage grouse, or for which data are available. In 1951, five transects were enumerated with an average of 56.4 birds per transect. Average population per count over the period was 15.8, with the average higher for leks (20.99 birds per unit of effort) than for transects (11.59).

In Figure 4, we plot annual sage grouse populations obtained from lek and transect measurements, plus their sum, for the period 1951–2001. The respective mean annual populations for transects and leks are 510.6 (SD=629.46) and 1141.0 (SD=1045.24), while the mean of the annual populations counted by all methods is 1313.6 (SD=1541.13). Upon comparing Figures 3 and 4, there does not appear to be a discernable secular decline in sage grouse population over time. Rather, measured sage grouse numbers are a function of the effort made to count them.

In addition to population data, harvests by hunters are available for the period from 1958 to 2000, except for 1963 (no reason given) and 1985 (when there was no hunting season). The average annual harvest over the period is 5069 (SD=2683.20), substantially greater than the enumerated population of grouse. In addition to enumerated population, harvests are plotted in Figure 4, with the average value of harvests replacing years for which information is not available. Notice that, with rare exceptions (e.g.,

1960), harvests exceed enumerated populations.

Also available from NDOW for this period are data on the number of hunters and days spent hunting. In Figure 5, we plot average annual take per hunter and per day spent hunting (replacing 1963 and 1985 with the mean values). There is a clearly discernable downward trend in harvests per day, while take per hunter also appears to be trending downward, with the exception of 1978 and 1979 when there were fewer hunters.

Annual real expenditures on predator control and use of strychnine in Nevada were collected by the authors in Spring 2002 from files at the State Department of Agriculture's Predator Control Division in Reno. The former variable was deflated by the U.S. CPI (CPI for 2000 = 100), while the latter was converted to a dummy variable that takes on a value of one in years when strychnine was used to control predators, and zero otherwise. State-level data on area affected by fire and Animal Unit Months (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 BLM Elko 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 is available from the U.S. Department of Agriculture's website (www.usda.gov), while average monthly weather data on temperatures, snowfall and precipitation are 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 is provided in Table 3.

REGRESSION MODELS

Our purpose is to determine the effect of weather, range management and habitat

factors on sage grouse population in Elko Country, Nevada. Three types of population information are available – population obtained by viewing leks, population from sightings, and harvest data. If we consider only enumerated population, it would seem that, since the effort to count sage grouse varied from one year to the next (Figure 2), a Poisson count model with varying effort would be appropriate (Ramsey and Schafer, pp.661-2). The count model was rejected because the number of counts in some years was substantial; the only variable that affected population in a statistically significant fashion was the effort made to count grouse. This was true whether separate equations for lek and transect populations were estimated, or whether we employed a total population model with lek and transect effort included separately.[3] Instead, we regress population per lek, and population per transect, on potential explanatory variables. Two problems arise: First, the error terms in the two population equations are likely correlated. To address this problem, we employ seemingly unrelated regression (SUR) with identical regressors. Let $\mathbf{y}_{it}$ be the enumerated grouse population per unit of effort in year t for i (=leks, transects) and e_{it} the correlated disturbance terms. The SUR regression model is (dropping the t subscript for convenience):

(1) $\mathbf{y}_i = X_i \, \boldsymbol{\beta}_i + \boldsymbol{e}_i$, i = leks, transects.

As demonstrated by Greene (, pp.614-22), the coefficient estimates are identical to those obtained under OLS, but, by taking into account correlation across the regression equations, the estimates are more efficient.

Second, there are a number of years for which there are no observations because no effort was made to monitor leks or 'walk' transects, or both. In that case, it is appropriate to use a censored regression (tobit) model (Greene, pp.905-26):

(2) $y_{it} = \boldsymbol{\beta}'_i \boldsymbol{x}_{it} + \boldsymbol{e}_{it}$, i = leks, transects, with $y_{it} = y^*_{it}$ if $y^*_{it} > 0$ and $y_{it} = 0$ if $y^*_{it} \leq 0$,

where $\boldsymbol{x}_i$ (i = lek, transect) are population-specific regressors. For a randomly drawn observation, which may or may not be censored,

(3) $E[y_{it} \mid \mathbf{x}_{it}] = \Phi\!\left(\dfrac{\boldsymbol{\beta}_i'\mathbf{x}_{it}}{\sigma}\right)\!\left(\boldsymbol{\beta}_i'\mathbf{x}_{it} + \sigma\dfrac{\varphi(\boldsymbol{\beta}_i'\mathbf{x}_{it}/\sigma)}{\Phi(\boldsymbol{\beta}_i'\mathbf{x}_{it}/\sigma)}\right)$, i = leks, transects,

where Φ is the normal cumulative distribution function and φ refers the normal density function. The censored model takes into account years when sage grouse were not enumerated, but information about the independent variables is available.

Harvests per hunter and harvests per hunting day are specified as separate linear regression models and, since observations on sage grouse 'take' are missing for some years or no hunting was permitted, as separate censored regression models.

We also specify the following system of three equations that includes information on sage grouse harvests:

$$
\begin{aligned}
y_{lek,t} &= \alpha_{lek,0} + \alpha_{lek,1}h_t + \boldsymbol{\beta}'_{lek}\boldsymbol{x}_{lek,t} + \varepsilon_{lek,t}\\
y_{trans,t} &= \alpha_{trans,0} + \alpha_{trans,1}h_t + \boldsymbol{\beta}'_{trans}\boldsymbol{x}_{trans,t} + \varepsilon_{trans,t}\\
h_t &= \gamma_o + \boldsymbol{\delta}'z_t + \varepsilon_{h,t}
\end{aligned}
$$

(4)

where h refers to harvests of grouse by hunters, $\mathbf{x}_i$ (i = lek, transect) are population-specific regressors (as before), z are harvest-specific regressors, α, β, γ and δ are coefficients to be estimated, and ε_j (j = 1, 2, 3) are correlated disturbance terms. Notice that we do not first find the reduced-form equations, but, rather, include the endogenous variable, harvests, in the lek and transect equations. The system is estimated using three-

stage least squares regression (Stata Corporation, pp.306-25).

EMPIRICAL RESULTS

The empirical regression results are provided in Tables 4, 5 and 6. In all cases, the results of a restricted version of a full model are presented. A Wald test was used to compare the full model to the restricted version of the model. The only variables we eliminated from the regressions were weather variables (e.g., annual snowfall, snowfall squared, snowfall multiplied by average monthly minimum temperature, etc.) and precipitation multiplied by re-vegetation area. The t-statistics on the estimated coefficients of dropped variables were all below 1.0. In addition, with the exception of the harvest equation, the lag of population was not included as an explanatory variable. Because both the lek- and transect-derived population series are highly irregular, with bird population dependent on effort to count it, it does not make sense to include a lagged dependent variable. However, the authority may well use monitored population data in determining how many licenses to issue (although we have no evidence for this). Therefore, we included the lag of lek plus transect population in the harvest equation.

The results for the lek-derived population were much stronger than those for transect-derived populations, as indicated by the goodness-of-fit statistics. In all cases, the explanatory variables in the final regression model explained a statistically significant amount of the variation in lek-enumerated populations but not in transect-enumerated populations. Likewise, the explanatory variables in the OLS and Tobit regressions for harvests per hunter day explained a statistically significant amount of the variation in the dependent variable, but not in the success per hunter models. Overall, the three-equation

model, with harvests as a regressor in the population equations and as dependent variable in the 'hunting' equation, turned out to be statistically significant in explaining variation in the enumerated populations.

The models are consistent in demonstrating three main results. First, while weather has an effect on sage grouse numbers, it is not straight forward to determine. The effect of annual precipitation is dependent on temperature. If temperatures are above average, annual precipitation will have a positive effect on grouse numbers; if temperatures are below normal, precipitation has a negative effect. While this is what was expected, the other weather variables were found to have no impact on grouse numbers, at least as enumerated.

Second, it appears that, contrary to the view that livestock grazing has an overall negative impact on sage grouse, cattle grazing may have a positive impact on sage grouse numbers. Clearly, our results are unable to capture the nuances of grazing management, in the sense that some forms of grazing may be detrimental to sage grouse, but they do suggest that reductions in grazing are not necessary to protect sage grouse populations, and might have a negative impact on sage grouse survival.

Third, Nevada ranchers indicated quite vigorously that they thought predators were a major factor having a negative effect on grouse numbers (Table 2). The empirical results in Tables 4–6 provide support for this observation. When strychnine bait was used to poison predators, including corvids, enumerated sage grouse were higher than in years when this was not the case. Further investigation of this impact is warranted.

The failure to observe an effect of hunting suggests that mortality is compensatory rather than additive, contrary to recent thinking (Connelly et al. 2000, p.976). Indeed, it

may be the case that hunting contributes to the overall health of the population. However, the marginal positive effect of hunting is extremely small, so it is more likely that hunting has no impact on sage grouse populations, perhaps because hunting levels are quite restricted (U.S.D.A. Forest Service).

CONCLUDING REMARKS

The important question needing to be addressed is: Is the sage grouse threatened with extinction and should it be listed as an endangered species? We sought to provide at least a partial answer to this question using empirical results from models of sage grouse numbers reported from sightings and lek data in Elko County, Nevada. Sage grouse migrate within an area of not more than about 3,000 km^2 (Connelly et al. 2000, p.969). Thus, the sage grouse in Elko County can be considered a single population and the results derived here may be applicable to other populations in the western United States.

It should be noted that the State of Nevada does not do a good job enumerating sage grouse, and that efforts to do so have declined in recent decades. Sage grouse populations reported through sightings and observations at leks are a function of the effort that goes into enumerating them – the more effort that is spent counting sage grouse, the more grouse one finds. Thus, it may well be that, at least for Elko County in Nevada, stated declines in population numbers are simply the result of a failure to count grouse. More broadly, across many species and regions, inconsistency in data collection poses a challenge for analyzing population trends and their underlying determinants.

The analysis of this paper is relevant to ongoing policy discussions regarding the potential listing of this species under the Endangered Species Act and the likely

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economic impacts of (and human responses to) such listing. There currently is substantial debate regarding the magnitudes and causes of population decline, and therefore 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. The results of this paper fail to confirm that a reduced aggregate number of cattle on the range would enhance the population size of the sage grouse. In fact, increases in cattle numbers are associated with higher grouse counts per unit of counting effort, *ceteris paribus*. Though changes in grazing management techniques (for any given cattle stocking rate) may be beneficial to the sage grouse, the data necessary to test this hypothesis were not available for our study.

The research methodology employed here is generally applicable to analyzing factors influencing a variable that is estimated with varying effort. The approach may be transferable to other species currently proposed for listing under the Endangered Species Act as well as, more generally, species being considered for various designations under federal or State laws and regulations.

ACKNOWLEDGEMENTS

NOTES

1. We refer to the sightings data as transect data, as this would be the most logical and consistent means by which biologists would have collected such data, but we have no way of knowing. Given the paucity of information on age and gender of observed birds, we employ only data of all enumerated birds (ignoring chicks).

2. The authors wish to thank Nanci Fowler of NDOW for providing data.

3. All statistical analysis was conducted using routines available in Stata, Release 8. To take into account the high number of zero observations, we used a zero-inflated count model that also adjusted for observed overdispersion (see Table 3). See discussion in Long and Freese.

REFERENCES

Aldridge, C.L., and R.M. Brigham, 2003. Distribution, Abundance, and Status of the Greater Sage-Grouse, Centrocercus Urophasianus, in Canada. *Canadian Field-Naturalist* 117(1): 25-34.

Alstatt, A.L., 1995. The Potential Impact of Raven Reduction on Sage Grouse Production in Nevada. MS Thesis, University of Nevada, Reno.

Beck, J.L., and D.L. Mitchell, 2000. Influences of Livestock Grazing on Sage Grouse Habitat. *Wildlife Society Bulletin* 28(4): 993-1002.

Beck, J.L., D.L. Mitchell, and B.D. Maxfield, 2003. Changes in the Distribution and Status of Sage-Grouse in Utah. *Western North American Naturalist* 63(2): 203-214.

Braun, C.E., 1998. Sage Grouse Declines in Western North America: What Are the Problems? *Proceedings of the Western Association of Fish and Wildlife Agencies* 78: 139-56.

Braun, C.E., and T.D.I. Beck, 1996. Effects of Research on Sage Grouse Management. Paper read at Transactions of the North American Wildlife and Natural Resources Conference, 22-27 March 1996, at Tulsa, OK.

Bureau of Land Management (BLM), 2000. *Management Guidelines for Sage Grouse and Sagebrush Ecosystems in Nevada*. Carson City, NV: BLM.

Clifford, H., 2002. Can Cows and Grouse Coexist on the Range? *High Country News*, 4 February 2002.

Connelly, J.W., K.P. Reese, E.O. Garton, and M.L. Commons-Kemner, 2003. Response of Greater Sage-Grouse *Centrocercus Urophasianus* Populations to Different Levels of Exploitation in Idaho, USA. *Wildlife Biology* 9(4): 335-340.

Connelly, J.W., M.A. Schroeder, A.R. Sands, and C.E. Braun, 2000. Guidelines to Manage Sage Grouse Populations and Their Habitats. *Wildlife Society Bulletin* 28(4): 967-85.

Connelly, J.W., W.L. Wakkinen, A.D. Apa, and K.P. Reese, 1991. Sage Grouse Use of Nest Sites in Southeastern Idaho. *Journal of Wildlife Management* 55(3): 521-4.

Crawford, J.A., R.A. Olson, N.E. West, J.C. Mosley, M.A. Schroeder, T.D. Whitson, R.F. Miller, M.A. Gregg, and C.S. Boyd, 2004. Synthesis Paper - Ecology and Management of Sage-Grouse and Sage-Grouse Habitat. *Journal of Range Management* 57(1): 2-19.

D'Antonio, C.M., and P.M. Vitousek, 1992. Biological Invasions by Exotic Grasses, the Grass/Fire Cycle, and Global Change. *Annual Review of Ecology and Systematics* 23: 69-87.

Deibert, P., 2004. Endangered and Threatened Wildlife and Plants; 90-Day Finding for Petitions to List the Greater Sage-Grouse as Threatened or Endangered. Cheyenne, WY: Fish and Wildlife Service, Department of the Interior.

Greene, W.H., 2000. *Econometric Analysis*. 4th ed. Upper Saddle River, NJ: Prentice Hall.

Gregg, M.A., J.A. Crawford, M.S. Drut, and A.K. DeLong, 1994. Vegetational Cover and Predation of Sage Grouse Nests in Oregon. *Journal of Wildlife Management* 58(1): 162-166.

Johnson, K.H., and C.E. Braun, 1999. Viability and Conservation of an Exploited Sage Grouse Population. *Conservation Biology* 13(1): 77-84.

Neel, L.A., 2001. Nevada Sage Grouse Conservation Strategy. Final Report of the Governor's Sage Grouse Conservation Team. Carson City, NV: Office of the Governor, State of Nevada.

Nevada Natural Heritage Program, 2004. *Sensitive Animal List* Department of Conservation and Natural Resources, 18 March 2004 [cited 30 April 2004]. Available from http://heritage.nv.gov/sensanim.htm.

Pedersen, E.K., J.W. Connelly, J.R. Hendrickson, and W.E. Grant, 2003. Effect of Sheep Grazing and Fire on Sage Grouse Populations in Southeastern Idaho. *Ecological Modelling* 165(1): 23-47.

Pyke, D.A., and T. McArthur, 2002. Emergency Fire Rehabilitation of Blm Lands in the Intermountain West: Revegetation and Monitoring, Interim Report. Corvalis, OR: U.S. Bureau of Land Management, Forest and Rangeland Ecosystem Science Center and Dept. of Rangeland Resources, Oregon State University.

Pyne, S.J., 1997. *World Fire: The Culture of Fire on Earth*. Seattle, Washington: University of Washington Press.

Ramsey, F.L., and D.W. Schafer, 2002. *The Statistical Sleuth*. 2nd ed. Pacific Grove, CA: Duxbury.

Schroeder, M.A., 2004. *Sage Grouse Range-2000* Washington Department of Wildlife, 2000 [cited May 25, 2004 2004]. Available from http://mountain-prairie.fws.gov /species/birds/sagegrouse/map_sagegrouse_range2000.jpg.

Schroeder, M.A., 1997. Unusually High Reproductive Effort by Sage Grouse in a Fragmented Habitat in North-Central Washington. *Condor* 99(4): 933-941.

Sonner, S., 2004. Nevada Officials Work to Keep Bird Off Endangered List. *Reno Gazette-Journal*, 20 March.

Stata Corporation, 2003. *Stata Reference Manual, Volume 3, N-R, Release 8*. College Station, TX: Stata Corporation.

Stigar, M.S., 1989. Hunting Low-Density Sage Grouse Populations. M.S. Thesis, University of Nevada, Reno.

Sveum, C.M., W.D. Edge, and J.A. Crawford, 1998. Nesting Habitat Selection by Sage Grouse in South-Central Washington. *Journal of Range Management* 51(3): 265-269.

Terres, J.F., 1991. *The Audubon Society Encyclopedia of North American Birds. Reprint of 1980 Edition.* New York: Wings Books.

Thomsen, R., 2002. The Role of Social Capital in the Ranch-Public Range Community of Nevada. MS Thesis, University of Nevada, Reno, NV.

U.S.D.A. Forest Service, 2004. *Sage Grouse (Centrocercus Spp.) Biological Data and Habitat Requirements* 2004 [cited 30 April 2004]. Available from http://www.fs. fed.us/database/feis/wildlife/bird/cent/biological_data_and_habitat_requirements. html.

van Kooten, G.C., and E.H. Bulte, 2000. *The Economics of Nature: Managing Biological Assets*. Oxford, UK: Blackwell Publishers.

Wakkinen, W.L., 1990. Nest Site Characteristics and Spring-Summer Movements of Migratory Sage Grouse in Southeastern Idaho. MS Thesis, University of Idaho, Moscow, ID.

Wakkinen, W.L., K.P. Reese, and J.W. Connelly, 1992. Sage Grouse Nest Locations in Relation to Leks. *Journal of Wildlife Management* 56(2): 381-383.

Wambolt, C.L., A.J. Harp, B.L. Welch, N. Shaw, J.W. Connelly, K.P. Reese, C.E. Braun, D.A. Klevenow, E.D. McArthur, J.G. Thompson, L.A. Torell, and J.A. Tanaka, 2002. Conservation of Greater Sage-Grouse on Public Lands in the Western U.S.: Implications of Recovery and Management Policies. Caldwell, ID: Policy Analysis Center for Western Public Lands.

Washington Department of Fish and Wildlife, 2004. *History of the Species of Concern List* 2000 [cited 30 April 2004]. Available from http://wdfw.wa.gov/wlm/diversty /soc/sochist.htm.

Watters, M.E., T.L. McLash, C.L. Aldridge, and R.M. Brigham, 2002. The Effect of Vegetation Structure on Predation of Artificial Greater Sage-Grouse Nests. *Ecoscience* 9(3): 314-319.

Table 1: Observable Variables that Potentially Affect Sage Grouse Populations

Variable	Expected Sign
Weather Related	
- Annual precipitation	+
- Average annual snowfall	+
- Average monthly temperature	−
- Average minimum monthly temperature (Dec, Jan, Feb)	+
- Annual precipitation × average month temperature	?
- Annual snowfall squared	−
- Precipitation × snowfall[a]	?
- Precipitation in May	?
Habitat Related	
- AUMs grazing made available by public land agencies	?
- Number of cattle	−
- Area affected by fire	?
- Area re-seeded to (primarily) crested wheatgrass	−
Related to Predation	
- Real expenditures on predator control	+
- Periods when strychnine is used	+
Harvest Related	
- Harvests of sage grouse by hunters	−

[a] If there is significant difference between snowfall and precipitation during this period, this variable says something about how close temperatures are to freezing in addition to the degree of moisture. However, it is also possible to consider this variable as a representing a quadratic term in the regression equation.

Table 2: 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 that they did not know if they had declined.

Table 3: Summary Description of Available Variables

Variable	Obs.	Mean	Std. Dev.	Min	Max
Lek dummy (=1 if leks counted)	53	0.6	0.49	0	1
Number of leks counted	53	31.6	43.74	0	182
Population from counting at leks	53	704.4	1034.57	0	4708
Sightings dummy (=1 if transect counts)	53	0.9	0.34	0	1
Number of transects counted	53	44.9	68.63	0	293
Population from counting transects	53	435.7	623.35	0	2466
Total annual population counted	53	1,140.1	1,502.32	0	6828
Area affected by fire (acres)	51	110,666	229,294.9	1,516	1,383,095
Area re-vegetated (acres)	52	9,849.4	19,864.1	0	121,240
Cattle in Elko Co.	52	179,220.8	17,233.6	147,000	220,000
Sage grouse harvested in Elko Co.	51	5,069.3	2,459.2	0	11,859
Strychnine dummy (=1 in years poison bait used)	52	0.4	0.5	0	1
Real NV expenditures on predator control ($2000)	52	361,747.6	425,395.6	0	1,373,365
Animal unit months of grazing permitted in NV	52	2,027,021	565,989.4	1,142,777	3,204,261
May precipitation	53	100.8	84.85	0	409
Annual snowfall (in. $\times 10$)	48	403.0	189.0	83	1,008
Average monthly temperature (deg F $\times 10$)	49	461.0	17.42	418	507
Annual precipitation (in. $\times 10$)	49	970.1	300.0	477	1,834
Minimum average monthly winter temperature (deg F $\times 10$)	51	268.3	43.68	138	348
Number of hunters	54	1,469.7	955.7	0	3,296
Number of days hunted	54	3,136	2,213.05	0	7,660
Harvest per hunting day	42	1.39	0.80	0	4.19
Harvest per hunter	42	2.74	1.19	0	5.97
Population per lek	53	12.67	12.33	0	43.90
Population per sighting	53	10.06	9.17	0	56.40

Table 4: SUR and Censored (Tobit) Regression Results for Sage Grouse Populations in Elko County, Nevada, 1951-2001 (Dependent variable: Population per Count)

Explanatory variable	SUR Regression Model[a]		Censored Regression Model[b]	
	Lek Data	Sightings Data	Lek Data	Sightings Data
Intercept	-56.931***	16.639	-103.579***	6.812
	(-4.23)	(1.07)	(-4.41)	(0.39)
Sage grouse harvested	0.00049	0.00056	-0.0000005	0.00049
	(0.89)	(0.88)	(-0.00)	(0.70)
Number of cattle	0.00034***	-0.000035	0.00059***	0.000023
	(4.37)	(-0.38)	(4.40)	(0.23)
Area affected by fire	-0.0000002	-0.0000004	-0.0000007	0.0000008
	(-0.04)	(-0.07)	(-0.07)	(0.12)
Area re-vegetated	0.00002	0.00002	0.00012	0.000029
	(1.14)	(0.20)	(1.13)	(0.31)
Year strychnine used (=1, 0 otherwise)	7.198***	2.684	13.874**	4.273
	(2.58)	(0.83)	(3.10)	(1.19)
May precipitation	0.017803	0.013608	0.022742	0.018063
	(1.18)	(0.78)	(1.05)	(0.93)
Annual precipitation	-0.111127***	-0.05890	-0.168786***	-0.07971*
	(-3.19)	(-1.47)	(-3.19)	(-1.77)
Average monthly temperature × annual precipitation	0.000244***	0.000116	0.000365***	0.000155
	(3.31)	(1.36)	(3.27)	(1.63)
Number of observations	45	45	45	45
OLS: R^2 Tobit: Pseudo R^2	0.578	0.087	0.146	0.019
LR χ^2 (8 df)	61.65***	4.28	40.69***	5.79

[a] Seemingly unrelated regression, 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.

[b] Tobit regressions with t-statistics provided in parentheses. Statistical significance denoted in the same manner as for SUR model.

Table 5: OLS and Censored Regression Results for Sage Grouse Harvests per Hunter and per Hunting Day, Elko County, Nevada, 1951-2001[a]

Explanatory Variable	OLS Regression Model		Censored (Tobit) Regression Model	
	Harvests per hunter	Harvests per day	Harvests per hunter	Harvests per day
Intercept	3.3821	2.0900	3.4288[*]	2.1267[*]
	(1.66)	(1.65)	(1.78)	(1.78)
Total population lagged one period	0.00034[*]	0.00026[**]	0.00035[*]	0.00026[**]
	(1.83)	(2.18)	(1.96)	(2.35)
Number of cattle	-0.000005	-0.000060	-0.000005	-0.000007
	(-0.44)	(-0.83)	(-0.50)	(-0.92)
Area affected by fire	-0.000005	-0.0000002	-0.0000004	-0.0000002
	(-0.38)	(-0.33)	(-0.50)	(-0.47)
Area re-vegetated	-0.00001	0.0000004	-0.0000007	0.0000006
	(-0.09)	(0.05)	(-0.06)	(0.09)
Year strychnine used (=1, else 0)	-0.50340	0.00501	-0.50811	0.00131
	(-0.80)	(0.01)	(-0.85)	(0.00)
Number of observations	40	40	40	40
R^2	0.123	0.253	0.041	0.121
OLS: F-statistic (5,34 df) Probit: LR χ^2 (5 df)	0.95	2.31[**]	5.26	11.70[**]

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

Table 6: Three-Stage Least Squares Regression Results for Sage Grouse Populations and Harvests in Elko County, Nevada, 1951-2001[a]

Explanatory Variable	Population per count from leks	Population per count from sightings	Harvest Equation
Intercept	-54.7222[***]	17.0970	2131.917[***]
	(-3.81)	(1.11)	(3.09)
Sage grouse harvested	0.0014	-0.0014	
	(1.20)	(-1.03)	
Number of cattle	0.0003[***]	0.000004	
	(3.28)	(0.12)	
Year strychnine used (=1, else 0)	7.2404[***]	4.8185	
	(2.79)	(1.63)	
May precipitation	0.0135	0.0221	
	(0.88)	(1.33)	
Annual precipitation	-0.0941[***]	-0.0789[**]	
	(-2.77)	(-2.16)	
Average monthly temperature × annual precipitation	0.0002[***]	0.0002[**]	
	(2.83)	(2.02)	
One-year lag in total population			0.402[**]
			(2.13)
Number of hunters			1.437[***]
			(3.85)
Number of observations	47	47	47
LR χ^2 (df)	60.95[***] (6)	9.18 (6)	24.38[***] (2)

[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.
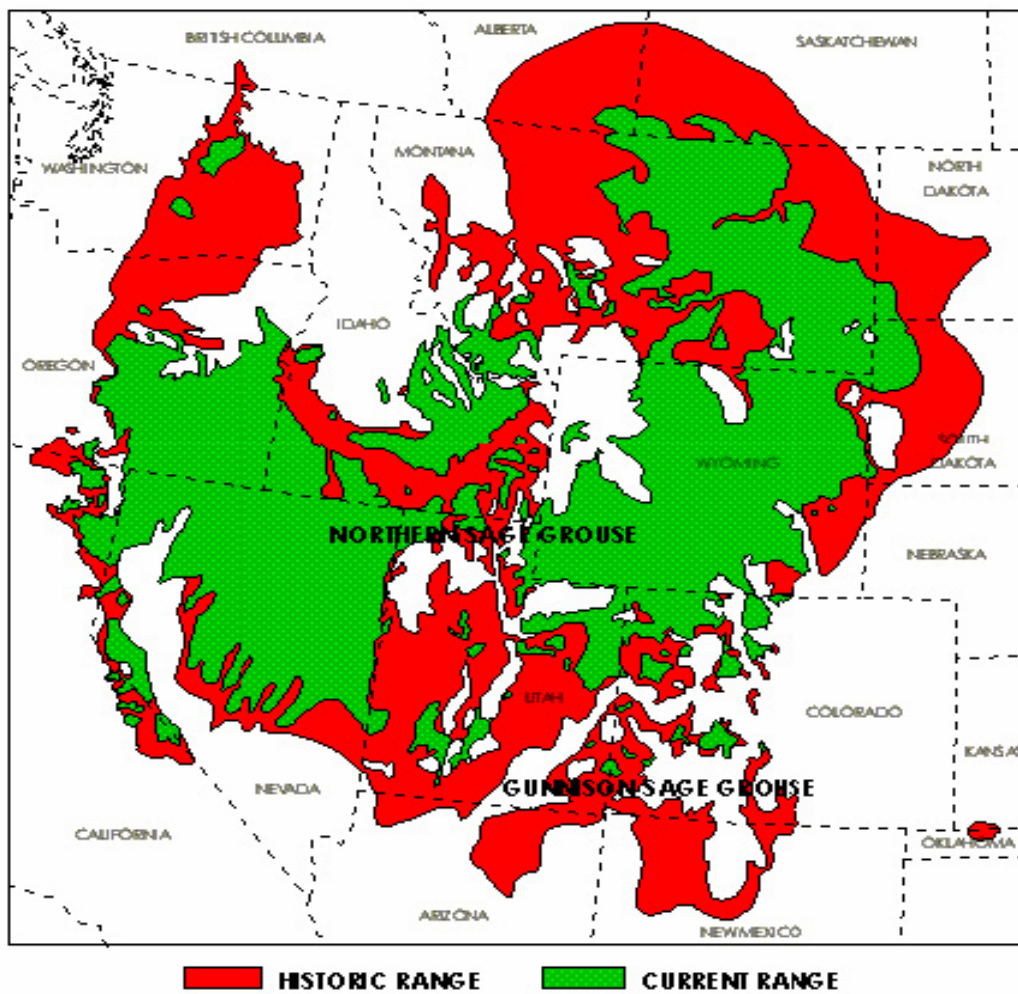
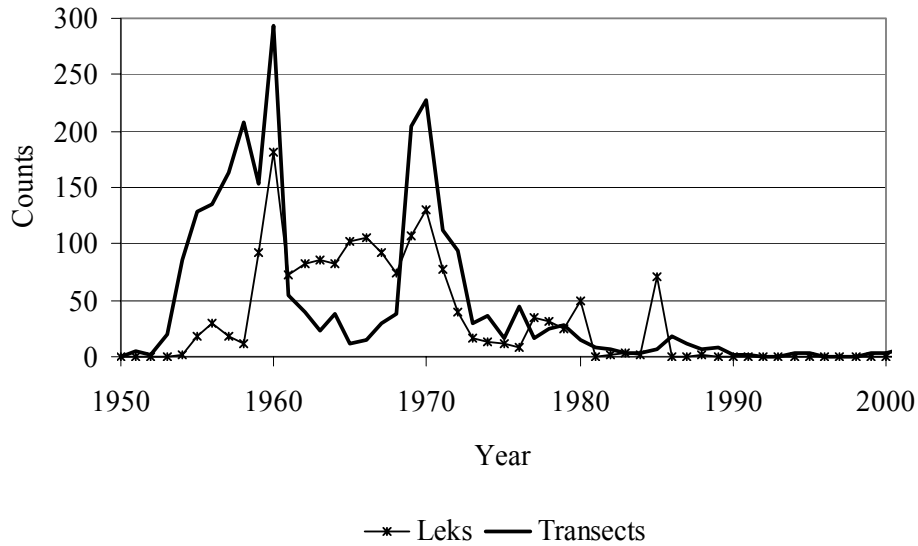**Figure 1: Sage Grouse Range: Current and Historic**

Figure 2: Effort to Measure Population in Leks and Along Transects, Elko County, Nevada, 1951-2001
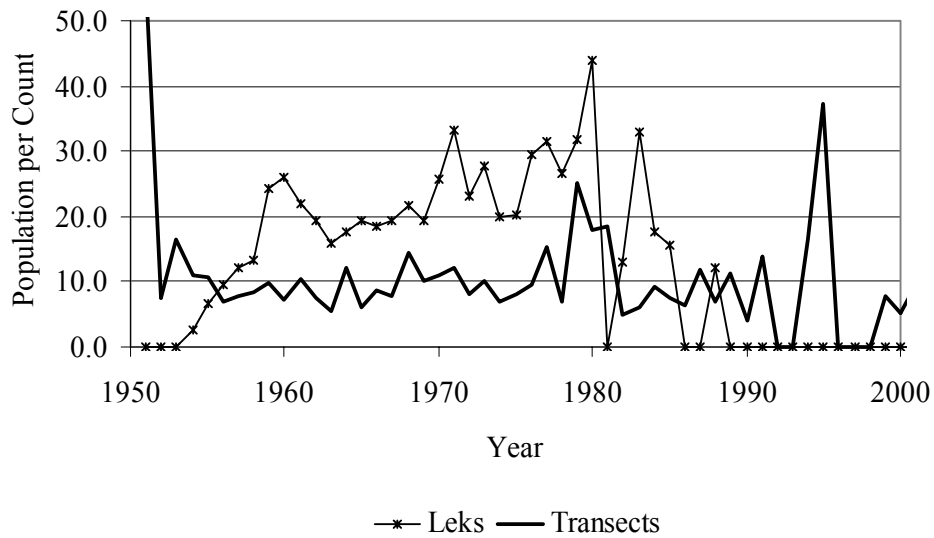

Figure 3: Annual Sage Grouse Population per Unit of Effort in Leks and Transects, Elko County, Nevada, 1951-2001
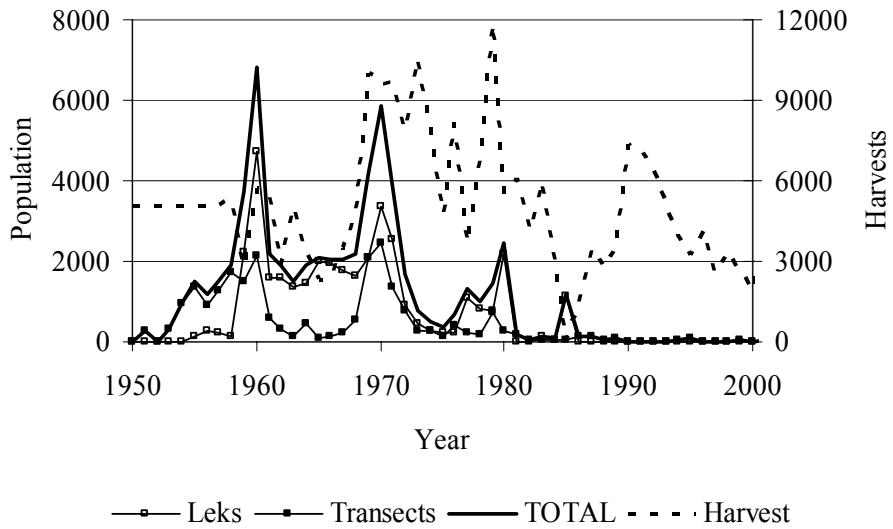
Figure 4: Sage Grouse Populations Counted in Leks and Transects and Total Population (left scale), and Annual Harvests by Hunters (right scale), Elko County, Nevada, 1951-2001
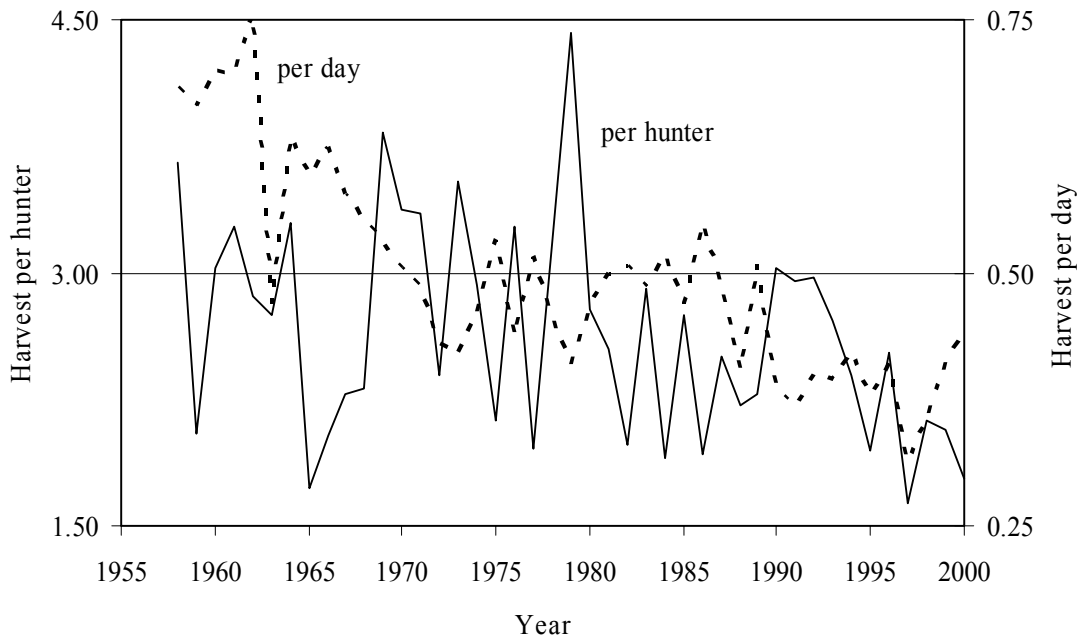

Figure 5: Hunting Success: Annual Harvests of Sage Grouse per Hunter and per Day Spent Hunting, Elko County, Nevada, 1958-2000