NEST SITE CHARACTERISTICS AND NEST SUCCESS OF TRANSLOCATED AND RESIDENT GREATER SAGE GROUSE AT CLEAR LAKE NATIONAL WILDLIFE REFUGE

By

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ABSTRACT

Nest Site characteristics and nest success of translocated and resident Greater Sage Grouse at Clear Lake National Wildlife Refuge

Chad B. Bell

Translocation has been used to augment declining Greater Sage Grouse (*Centrocercus urophasianus*, hereafter sage grouse) populations for several decades. However, little or no data are available directly comparing translocated and resident sage grouse reproduction. I monitored translocated and resident (birds that had not been translocated) sage grouse during 2009-2011 at Clear Lake National Wildlife Refuge in Modoc County, California to examine vegetation characteristics associated with nest success and nest site selection. In addition, I identified nest predators to obtain information on nesting productivity and factors influencing nest success in this population. I monitored 17 translocated and 16 resident radio marked sage grouse females for a total of 63 nests and measured vegetation characteristics at nest sites and paired sites. I monitored 42 of the 63 nests using continuous videography to identify nest predators. I examined factors influencing the proportion of females that nested. In addition, I assessed the biotic and abiotic variables that influenced nest site selection, and examined daily nest survival using the nest survival model in program MARK. The highest ranked model (AIC_c weight = 0.60) describing nest initiation indicated that translocated sage grouse were less likely to nest in their first year than resident hens or translocated hens after their first year (post-translocated). The best supported model of daily nest survival (AIC_c weight = 0.53) included greater nest shrub diameter and grass height, but lower grass cover and shrub height. The second ranked model included the translocation status of the hen (translocated vs.post-translocated and resident). Nest success for this population (45%) was similar to other sage grouse populations (47%). The best model distinguishing nest sites from paired sites was strongly supported (AIC_c weight = 0.962) and included greater shrub diameter, grass cover, and shrub height and lower grass height at nest sites than paired sites. I found little support for the hypothesis that translocated hens used nest sites with different vegetation characteristics than resident hens. Of the six nest predations events I captured on video, five were coyotes and one was a badger. The relatively high proportion of females that attempted to nest and high nest success of the studied population suggests that nest productivity was not limiting the population. My results confirm that translocation can be an effective management tool for augmenting small or declining sage grouse populations. However, translocated hens may initiate nests at a lower frequency in their first year than resident hens. I recommend nesting habitat management focus on promoting larger sagebrush and increasing herbaceous cover.

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INTRODUCTION

Greater Sage Grouse (*Centrocercus urophasianus*; hereafter sage grouse) populations have declined sharply over their range in the past several decades with many populations decreasing by 45 - 80% since 1950 (Connelly and Braun 1997, Braun 1998, Schroeder et al. 2004). Sage grouse populations in California occur on the western periphery of the species' range and have experienced significant population declines (Schroeder et al. 1999). In western Modoc County, California, sage grouse populations have declined from 45 active leks in the 1960s to 1 lek with fewer than 100 individuals in 2005 (Hall 1995, Beckstrand 2009, personal communication). The reduction in active sage grouse leks prompted the U.S. Fish and Wildlife Service (USFWS) to translocate sage grouse to Clear Lake National Wildlife Refuge in 2005 to augment the population and boost genetic heterozygosity (Beckstrand 2009, personal communication).

In 2007, the U.S. Fish and Wildlife Service and California Department of Fish and Game monitored survival and reproduction of translocated sage grouse on Clear Lake National Wildlife Refuge to identify potential reasons for the lack of increase in the number of lekking males in response to the translocation. Their preliminary findings indicated that the proportion of females that nested and annual survival were high but nesting productivity was low on Clear Lake National Wildlife Refuge relative to other sage grouse populations. They concluded that low nesting productivity may be limiting the growth of the sage grouse population on Clear Lake National Wildlife Refuge (Beckstrand personal 2009, communication).

Even though translocations have been used as a management tool to augment or reestablish sage grouse populations since the 1930's, the efficacy of using translocations to augment populations has been questioned (Reese and Connelly 1997). Early translocation efforts often failed and methods were generally poorly documented providing little guidance for subsequent reintroductions. In the last two decades, however, translocation success has been much higher largely as a result of developing better reintroduction methods (Reese and Connelly 1997, Baxter et al. 2008). Recent evaluations of reintroduction success have focused on site fidelity, survival, and reproduction of translocated sage grouse and compared them to resident grouse in other populations (Musil et al.1993, Baxter et al. 2008). However, nest success is highly variable between sage grouse populations and from year to year making these comparisons difficult (Schroeder et al. 1997, 1999, Sveum et al. 1998). Thus comparing translocated sage grouse to resident sage grouse in the same location and over the same time periods could provide a better assessment of translocation and potential implications on population dynamics.

Population dynamics is a function of survival, productivity, and recruitment. Because adult female survival is high (range 60-80%), sage grouse population dynamics are strongly influenced by productivity and recruitment. Productivity is composed of the proportion of females that initiate a nest, clutch size, and nest success while annual recruitment is a reflection of offspring survival from hatching through the first year of life. The proportion of females that initiate a nest is high in most sage grouse populations with estimates ranging from 55 – 99% (Gregg et al. 1994, Connelly et al. 2000, Schroeder et al. 1997, Coggins 1998, Connelly et al. 2000). Clutch size is relatively constant across the sage grouse range, but nest success can vary considerably (Connelly et al. 2000). Nest success estimates range from 15 to 86% (Schroeder et al. 1999) and can directly influence recruitment.

Sage grouse, like other ground nesting species, use vegetation to conceal their nests (Gregg et al. 1994). A variety of vegetative characteristics around the nest have been identified as having a positive influence on nest success including sagebrush density (Connelly et al. 1991), shrub height (Gregg et al. 1994, Popham and Gutierrez 2003), shrub canopy cover (Wakkinen 1990, Gregg et al. 1994, Holloran et al. 2005, Kolada et al. 2009a), residual grass height (Gregg et al. 1994, Sveum et al. 1998, Holloran et al. 2005, Rebholz et al. 2009), grass cover (Gregg et al. 1994), and forb cover (Sveum et al. 1998). Vegetation structure can conceal and disrupt nest odor for predators that use visual or olfaction to find nests (Conover et al. 2010). Thus, vegetative structure surrounding the nest may influence the probability that a nest will be found by a nest predator (Gregg et al.1994, DeLong et al. 1995).

Nest predation is the main source of sage grouse nest failure and has accounted for up to 94% of nest loss (Moynahan et al. 2007). No single predator species has been identified across the range of sage grouse, but generalist nest predators have been linked to dramatic reductions in sage grouse nest success in different parts of their range (Schroeder and Baydack 2001, Manzer and Hannon 2005). One such generalist, the Common Raven (*Corvus corax*) has been identified as a frequent predator of sage grouse nests in Wyoming and Nevada (Holloran and Anderson 2003, Manzer and Hannon 2005, Coates et al. 2008). In the Pitt-Klamath bioregion of California which includes Clear Lake National Wildlife Refuge, ravens have increased 13.3% annually between 1966 and 1999 (Liebezeit and George 2002). Other predators including American badgers (*Taxidea taxus*), Black-billed Magpies (*Pica pica*), red fox (*Vulpes vulpes*), and coyotes (*Canis latrans*) have also been found to be significant predators of sage grouse nests in some regions (Connelly et al. 1991, Holloran and Anderson 2003). Because the principle sage grouse nest predators differ from location-to-location, it is crucial to identify nest predators at a site to understand predator-prey interactions that may influence nesting productivity.

My study is unique because I compared nest success between translocated, post-translocated, and resident grouse within the same area. I analyzed factors that may influence nest success by comparing nest site characteristics between successful and unsuccessful nests. In addition, I examined nest selection by comparing vegetation characteristics between nest sites and paired sites and I directly identified nest predators using videography.

STUDY SITE

The study was conducted on the Devil's Garden Plateau located approximately 30 km south of Klamath Falls, Oregon. The core study area, located in Modoc County, California, encompassed approximately 121,000 ha ranging from 1200 to 1430 m in elevation. Annual precipitation averaged 35 cm and temperatures ranged from -6° C in January to 30° C in July (Western Regional Climate Center 2010). Land ownership is divided among the Modoc National Forest, Clear Lake National Wildlife Refuge, California State Lands, and a few private landowners (Figure 1).

The vegetation consists of generally treeless areas of sagebrush interspersed with patches of western juniper (*Juniperus occidentalis*). Shrub-dominated communities consist of low sagebrush (*Artemisia arbuscula*), big sagebrush (*A. tridenta*), green rabbitbrush (*Chrysothamnus viscidiflorus*), and bitter-brush (*Purshia tridentate*) with a ground layer characterized by perennial bunch grasses including bluebunch wheatgrass (*Aggropyron* spp.) and Sandberg's Bluegrass (*Poa secunda*) (Barbour et al. 1997). Common forbs included common yarrow (*Achillea millifolium*), Modoc hawksbeard (*Crepis modocendsis*), phlox (*Phlox* spp.) and desert parsley (*Lomatium vaginatum*).

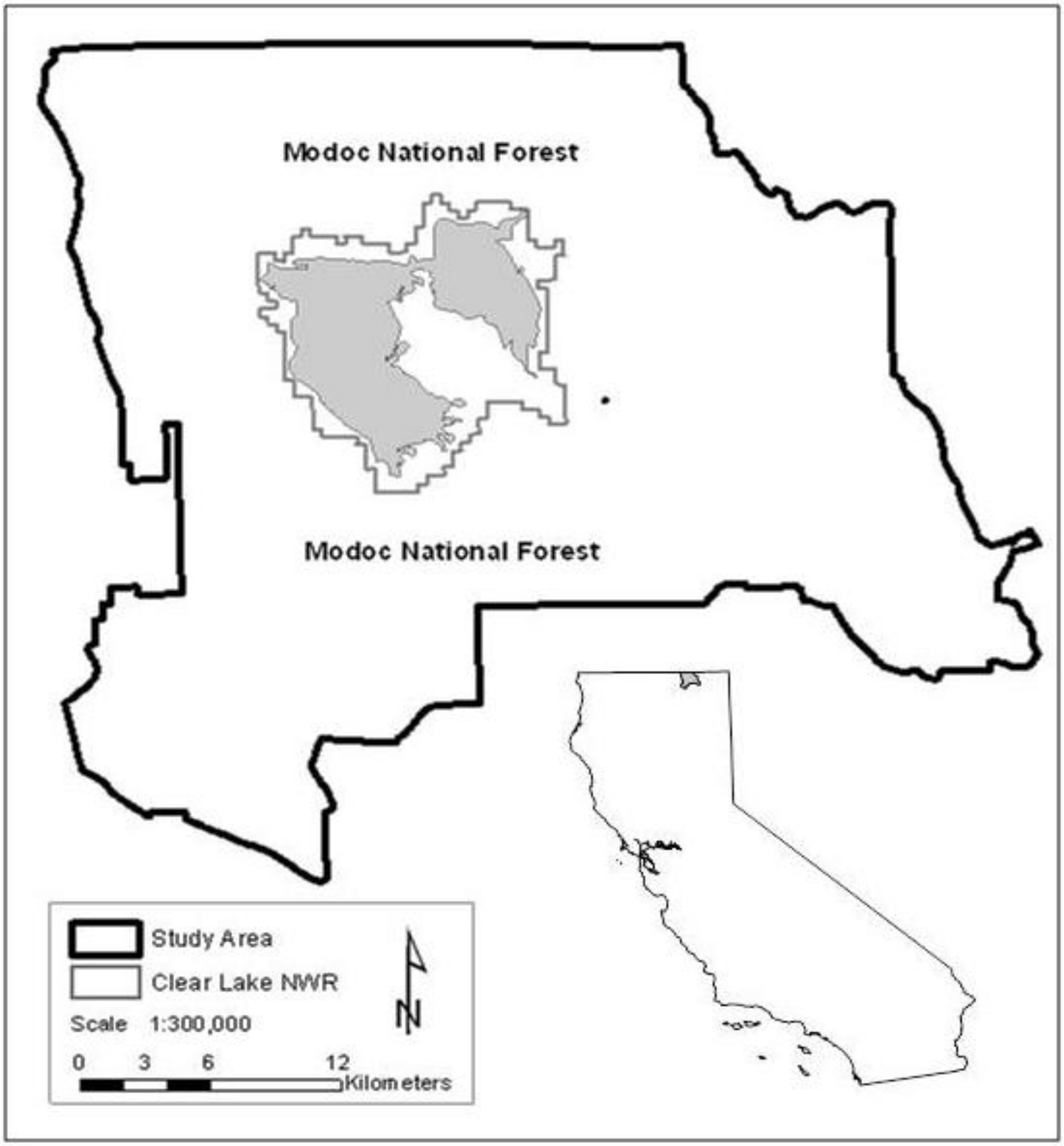

Figure 1. Sage grouse study area (black line) in Modoc County, California displaying federal land ownership.

METHODS

As part of a program to augment the sage grouse population in the Clear Lake National Wildlife Refuge area, the California Department of Fish and Game and U.S. Fish and Wildlife Service translocated sage grouse from nearby populations near Hart Mountain, Oregon (2009 and 2011) and Wall Canyon, Nevada (2010) to Clear Lake National Wildlife Refuge. Sage grouse donor populations were chosen based on genetic similarities between the donor and recipient populations (Oyler-McCance et al. 2005) and similar habitat to the release site. Sage grouse donor populations were selected from stable populations as determined by Oregon Department of Fish and Wildlife and Nevada Department of Wildlife for their respective state. Capture and translocation of grouse was coordinated and conducted by the U.S. Fish and Wildlife Service in cooperation with the various state wildlife agencies in order to augment the sage grouse population at Clear Lake National Wildlife Refuge and was not explicitly part of my thesis project.

Translocated sage grouse hens were captured in late March and early April at night in 2009-2011 by the U.S. Fish and Wildlife Service. Captured hens were fitted with a necklace style radio transmitter with a mortality signal function (SeriesA4000, Advanced Telemetry Systems, Isanti, Minnesota) and a battery life expectancy of 522 days. Captured hens were transported to Clear Lake National Wildlife Refuge and released near the remaining active lek within two hours after sunrise. The release area was close to the active lek in an area with ample sagebrush cover to provide cover immediately after release.

Translocated sage grouse may suffer from higher predation rates and lower nesting success after translocation (Musil et al. 1993, Baxter et al. 2008, Connelly et al. 2011). Consequently, I divided translocated sage grouse into two groups for this analysis; summer following translocation (translocated) and more than one year after translocation (post-translocated). Resident sage grouse were birds from the local population. Resident grouse were captured by the U.S. Fish and Wildlife Service in October and November and fitted with the same model and weight necklace style transmitter as the translocated sage grouse. After processing (<10 min), resident hens were released at the capture sight. Several studies have used similar methods for capturing and marking sage grouse during the reproductive period with no reduction in nesting related to the capture process (Gregg 1991, Holloran 1999, Rebholz et al. 2009).

Sage grouse hens (resident, translocated, and post-translocated) were monitored for nesting activity during the laying and incubation periods (March 15-July 15) using radio telemetry every 2-3 days. A hen's location was estimated via triangulation from a distance of approximately 20 m. When a hen was located within the vicinity of the previous location on two consecutive occasions, the hen was approached until the nest was observed with binoculars. Nesting hens' location was checked using telemetry every 1-3 days, but if a hen was absent from the nest area for two consecutive observations the nest was visually inspected. Embryo viability was determined after the nesting event by the proportion of eggs that hatched at successful nests (Schroeder et al. 1997, Baxter et al. 2008). When hens could not be located from the ground an aircraft was used to obtain an approximate location. Subsequent ground surveys were completed to confirm location and nesting status.

A subset of nests were monitored with video cameras. Nests early in the incubation period were given priority for video monitoring to maximize the number of days (Coates et al. 2008). Small video cameras (4 x 6 cm, Qsee QD28414 CCD, 520 lines per inch resolution) were placed approximately 0.5-1.5 m from the nest in an adjacent shrub (to reduce visibility of the camera) with a 0.5 x 0.5 meter camera frame. Each camera contained 12 infrared emitting diodes (850-950 nm wavelength) for night video recording. Cameras were attached to rebar posts 10-20 cm above the ground. The camera was connected to a remote digital video recorder (DVR, Archos 705) via a cable which was covered with litter to reduce visibility to potential predators. The DVR was housed in a waterproof case and placed approximately 30 meters from the nest to minimize disturbance to the nest when servicing the DVR. One deep cycle marine battery (Interstate Marine SRM-27) was placed next to the DVR to power all camera equipment and was replaced with a freshly charged battery every two days. All nests with cameras, regardless of the fate, were video recorded for 24 hours after the nesting termination to identify any subsequent scavenging. All activities associated with my thesis research were approved by the Humboldt State University Institutional Animal Care and Use Committee (IACUC 09/10.W.25.E).

Vegetation Sampling

Vegetation measurements were collected at each nest site and paired site location 2 – 5 days after each nest event. Shrub canopy cover was measured using a line-intercept method (Canfield 1941). Shrubs were defined as woody plants less than 2 m in height. Four 10 m transects radiating in the four cardinal directions from the nest bowl were used to sample vegetation. Shrub cover was measured along each transect using the starting and ending point of all live shrubs that intersected the transect to the nearest centimeter and identified to species.

Open spaces or dead portions of the shrub greater than or equal to 3 cm were not included in the measurements. In addition, the maximum height (excluding inflorescences) of the closest shrub at 2.5, 5, 7.5, and 10 m along each transect was measured to the nearest centimeter. The distance was measured from the center of nest shrub to the center of closest shrub.

Herbaceous ground cover was measured in 20 x 50 cm microplots at 0, 2.5, 5, 7.5 and 10 m along each transect for a total of 17 microplots for each nest and paired site (modified from Daubenmire 1959). Within each microplot, forb, grass, and ground cover (bare ground, rock, and litter) were grouped into one of eight classes (0-5, 6-10, 11-20, 21-30, 31-40, 41-50, 51-75, 76-100%). In addition, the tallest live or residual grass (excluding inflorescences) was measured to the nearest centimeter within each microplot. Residual grass is defined as dead standing grass resulting from growth in the previous growing period.

Visual obstruction of each nest site was estimated using an 18 x 18 cm cover board with 36, 3 x 3cm squares (modified from Jones 1968). The edge of the cover board was placed on the nest bowl in a vertical position and observed from 1.5 m at 45° above the horizontal (to simulate visibility to aerial predators) and at ground level (to simulate visibility to ground predators) in the four cardinal directions and the visible squares were counted. Additionally, the cover board was placed horizontally on top of the nest bowl and observed from directly above at 1.5 m for a total of nine cover board measurements.

Vegetation measurements were summarized into nine variables that were used for statistical analyses. Grass height was calculated by taking the mean of the 17 height measurements. Grass cover and forb cover were the mean proportion of the 17 cover measurements in the microplots. Nest shrub diameter was the average of two perpendicular measurements of the diameter of the shrub over the nest. Nest shrub height was the maximum height of the nest shrub. Distance to the nearest shrub was the total distance between the nest shrub and the closest shrub. Total shrub height was the mean height of the 17 shrubs measured along the transects. Total shrub canopy cover was the proportion of the total transect that was intercepted by live shrub canopy, concealment was the mean of nine cover board measurements for each nest site.

Paired Sites

For each nest site, a conditional paired point was generated using a random azimuth and a randomly chosen distance 20-100 m from each nest site. Conditional points were centered over the closest sagebrush bush greater than or equal to 35cm high which was used as the minimum sagebrush height for nesting sage grouse (Holloran et al. 2005). The same methods for measuring nest sites were used to measure the vegetative characteristics for each paired site except obstruction (cover board measurement) which was not measured at paired sites. Vegetation measurements were collected at the paired site on the same day as the associated nest site to minimize the differences in plant phenology between the nest and paired site.

Analysis

I used a one-way ANOVA to test for differences in clutch size between translocated, post-translocated and resident sage grouse. I used a logistic regression to evaluate the proportion of females that initiated a nest between translocated and resident and post-translocated sage grouse hens using five *a priori* models. First I compared the proportion of females that initiated a nest between translocated and post-translocated and resident hens. The second model compared the proportion of females that initiated a nest between resident, translocated, and post-translocated. The third model compared translocated hens to post-translocated and resident hens that attempted to nest plus the covariate year. The forth model compared nest attempts between years and the final model was the null model (without groups)

I examined the influence of vegetation variables along with age and time covariates on the daily survival rates (DSR) for nests using program MARK (White and Burnham 1999, Shaffer 2004, Rotella et al. 2004). I used the following covariates in the models; date the nest was found, residency (translocated hens vs. others), hen age (juvenile vs. adult), nesting year, visual obstruction, and the nine vegetation measurement collected at each nest. I considered a nest successful if one or more eggs hatched. Explanatory variables were examined for correlation prior to developing candidate models using Pearson correlation coefficients. Variables with correlations of $r \geq 0.70$ were not used in the model set (Wallestad and Pyrah 1974, Wakkinen 1990, Connelly et al. 1991, Gregg et al. 1994, Sveum et al. 1998, Holloran et al. 2005). I developed 14 *a priori* models using only additive combinations of covariates for each of the analyses based on results of similar analyses in the literature, as well as new hypotheses specific to the study area. Models were compared using Akaike Information Criterion (AICc) and coefficients from the top model (or models) were examined to identify those variables that influence nesting (Shaffer 2004). Relative importance of vegetation characteristics based on variables in the best competitive model were examined with (AICc) adjusted for small sample size (Burnham and Anderson 2002). All re-nesting attempts were distant (>200 meters) from all previous nesting attempts for each hen. All nesting attempts were treated as independent for these analyses. The results from previous analysis using only first nesting attempts within each year were similar to analysis using all nesting attempts within each year using the same models. Thus I only present the results for all nests.

Differences in vegetation characteristics between nest and paired sites were examined using paired logistic regression. Before conducting the analysis, I computed Pearson correlation coefficients between variables and identified those that were highly correlated ($r \geq 0.7$). When two variables were highly correlated, I retained the variable that has been identified in the literature to influence sage grouse nest success. I included the variables center shrub diameter (nest shrub diameter for nest sites), shrub canopy cover, shrub height, grass height, grass cover, forb cover, and distance to the nearest shrub to the nest shrub in the model selection process. Visual obstruction is a function of the vegetative variables used in these analyses. I developed nine *a priori* models to examine nest site selection using vegetative characteristics between nest sites and paired sites. Models were developed using a combinations of variables associated with influencing nest success and nest site selection in other studies and my own observations. Grass height, grass cover, and forb cover variables represent the large proportion of the herbaceous nesting cover while nest shrub diameter, shrub canopy cover, shrub height, and distance to the nearest shrub represent the shrub characteristics for nest site cover. In addition, I used a logistic regression to compare nests sites between translocated to post-translocated and resident hens to identify difference in nest site use. I used the same nine *a priori* models developed for the nest site selection analysis with the addition of a null model and I used groups as response variables (translocated = 1and all others = 0).

RESULTS

I monitored 33 sage grouse females (17 translocated and 16 resident females) between 2009 and 2011. Twenty-three (21 post-translocated and 2 resident) hens had functioning transmitters over two nesting periods and their nests were monitored in both years. I documented 63 nesting attempts for all hens of which 12 (6 post-translocated and 4 residents) were re-nesting attempts (second nesting attempt within the same reproductive period). No re-nesting attempts were observed for translocated females. Mean values for vegetative characteristics were calculated for nest sites (successful and unsuccessful nests) and paired sites (Tables 1, 2).

The proportion of translocated, post-translocated, and resident hens that attempted to nest was 67, 86, and 92%, respectively. The model selection analysis provided support for a difference between translocated and other hens but no support for a difference between post-translocated and resident hens (Table 3). The model that distinguished all three types of hens had one more parameter and differed by less than 2 AIC_c units from the top model. This suggests that the post-translocated-resident distinction provided no additional information (Burnham and Anderson 2002). Clutch size varied from 4 to 10 eggs for all nests with a mean of 7.1 eggs per clutch. Clutch size for translocated (mean = 6.3 ± 0.32) and post-translocated and resident (mean = 6.8 ± 0.21) grouse were similar ($F = 1.28$, $P > 0.2$). Embryo viability for successful nests was 95.2%. Most nests (81%, n = 51) were placed under sagebrush, 11% (n = 7) under western juniper, and 8% (n = 5) under other shrub species or perennial grass.

Table 1. Habitat characteristics measured at successful and unsuccessful sage grouse nest sites in Modoc County, California, 2009-2011.

Variable	Successful Nests (n=27)		Unsuccessful Nests (n= 36)	
	Mean	SE	Mean	SE
Nest Shrub Diameter (m)	1.24	0.09	0.86	0.04
Nest Shrub Height (m)	0.66	0.34	0.51	0.02
Grass Height (m)	0.15	0.01	0.12	0.01
Grass Cover (%)	18.02	0.01	18.59	0.01
Shrub Height (m)	0.45	0.03	0.46	0.03
Total Shrub Canopy Cover (%)	18.03	0.02	17.18	0.02
Distance Near Shrub (m)	1.10	0.13	0.95	0.08
Forb Cover (%)	15.76	0.01	13.67	0.01
Visual Obstruction (%)	82.82	0.02	83.56	0.01
Near Shrub Height (m)	0.47	0.03	0.43	0.02

Table 2. Habitat characteristics measured at sage grouse nest sites and paired sites in Modoc County, California, 2009-2011.

Variable	Nests sites (n=63)		Paired sites (n= 63)	
	Mean	SE	Mean	SE
Nest Shrub Diameter (m)	1.03	0.13	0.74	0.03
Nest Shrub Height (m)	0.56	0.03	0.47	0.01
Grass Height (m)	0.14	0.01	0.13	0.01
Grass Cover (%)	18.34	0.01	9.78	0.01
Shrub Height (m)	0.47	0.02	0.39	0.01
Total Shrub Canopy Cover (%)	17.00	0.03	16.11	0.01
Distance Near Shrub (m)	1.02	0.12	1.01	0.07
Forb Cover (%)	14.25	0.01	7.70	0.01
Near Shrub Height (m)	0.45	0.03	0.41	0.02

Table 3. Logistic regression models comparing the proportion of hens that attempted to nest between groups (translocated, post-translocated, and resident) in Modoc County, California, 2009-2011.

Model	K[a]	AICc[b]	ΔAICc[c]	ω[d]	Deviance
Translocated vs. all others	2	44.68	0.00	0.78	40.68
Trans. vs. post-trans vs. resident	3	46.66	1.98	0.29	46.66
Null	1	47.51	2.83	0.19	45.51
Trans. vs. all others + Year	4	48.27	3.59	0.13	40.27
Year	3	50.87	6.19	0.03	44.87

[a] K = number of parameters
[b] AIC_c = Akaike's Information Criterion adjusted for small sample size
[c] ΔAIC_c = relative difference form most parsimonious model;
[d] ω_i = Akaike weight

Nest Success

The best approximating model predicting daily nest survival contained the variables nest shrub diameter, grass height, grass cover, and shrub height (Table 4). The top model had an AIC_c weight of 0.53, the second best model had a weight of 0.27. The relative importance of each variable based on AIC_c weights across all models was: nest shrub diameter (0.991), grass height (0.996), grass cover (0.994), shrub height (0.794), and group (0.326) (Table 5). Successful nests were under larger diameter nest shrubs, had taller grass, lower grass cover, and shorter shrub heights surrounding the nest than unsuccessful nests. Daily nest survival estimate for the top model was 0.971 (95% CI = 0.958-0.980). The second best model (ΔAIC_c = 1.35) contained the same variables in the top model with the exception of the grouping variable which distinguished translocated females from post-translocated and resident females, but the confidence interval for the grouping variable overlapped zero. Post-translocated and resident females had higher daily nest survival (0.973, 95% CI = 0.959-0.983) than translocated females of (0.960, 95% CI = 0.913 - 0.982). Due to model selection uncertainty, I used model averaging to estimate overall daily nest survival. The nest survival estimate for a 27 day incubation period was 0.45 (95% CI = 0.319 - 0.622).

Nest Site Selection

The best supported model (AICc weight = 0.962) for nest site selection included nest shrub diameter, grass height, grass cover, and shrub height (Table 6). The next best model (AIC weight = 0.034, ΔAICc > 6.0) contained the same variables with the exception of the nest shrub diameter. The remaining seven of the nine candidate models were > 13.0 ΔAICc units from the best supported model. The variables nest shrub diameter (0.96), grass height (0.99), grass cover (0.99), and shrub height (0.99) all received strong support among the

Table 4. Comparison of daily nest survival models of sage grouse in Modoc County, California, 2009-2011.

Model[a]	K[b]	AIC_c[c]	ΔAIC_c[d]	ω_i[e]	Deviance
S(.)+NSD+GH+GC+SH	5	289.92	0.00	0.53	279.86
S(g)+NSD+GH+GC+SH	6	291.27	1.35	0.27	279.19
S(.)+NSD+GH+GC	4	292.56	2.64	0.14	284.52
S(g)+NSD+GH+GC	5	294.35	4.43	0.05	284.29
S(.)+GH+GC	3	300.88	10.96	0.00	294.86
S(.)+GH	2	302.62	12.70	0.00	298.61
S(g)+GH+GC	4	302.72	12.81	0.00	294.68
S(.)	1	304.27	14.35	0.00	302.26
S(g)+GH	3	304.63	14.71	0.00	298.61
S(.)+nesting day	2	305.32	15.40	0.00	301.31
S(.)+age	2	305.55	15.64	0.00	301.54
S(.)+VO	2	305.59	15.68	0.00	301.58
S(g)	2	306.27	16.36	0.00	302.26
S(.)+yr	3	307.01	17.09	0.00	300.98

[a] Variable abbreviations for translocated vs. post-translocated and resident hens: (g), nest shrub canopy diameter (NSD), grass height (GH), grass cover (GC), forb cover (FC), distance to closest shrub from nest shrub (DNS), mean shrub height (SH), nearest shrub height to nest shrub (NSH), day within nesting period normalized to first Julian day (nesting day), age of female for each given year juvenile or adult (age), visual obstruction (VO), and year (yr).

[b] K = number of parameters

[c] AIC_c = Akaike's Information Criterion adjusted for small sample size

[d] ΔAIC_c = relative difference from most parsimonious model

[e] ω_i = Akaike weight.

Table 5. Beta estimates for top model resulting from the comparison of daily nest survival models of sage grouse in Modoc County, California, 2009-2011.

	β estimates	95%CI Lower	Upper	AIC Weights
S(.)+NSD+GH+GC+SH				
Intercept	2.37	0.88	3.88	0.67
NSD	1.95	0.71	3.19	0.99
GH	11.04	1.12	20.96	0.99
GC	-6.49	-11.66	-1.33	0.99
SH	-2.63	-5.05	-0.22	0.79

candidate models. The top model results described nest shrub diameter, grass cover, and shrub height were all higher while grass height was lower at nest sites when compared to paired sites (Table 7).

I also compared differences in nest site characteristics between translocated, post-translocated, and resident hens to analyze nest site use (Table 8). The best model indicated that there was no difference between the groups while the second best model suggested translocated hens (translocated vs. post-translocated and resident, ΔAIC_c=0.02) had nest sites with larger nest shrub diameter. The second model, however, had confidence intervals that overlapped zero suggesting that the parameter estimates in this model had little influence on the response variable.

Nest Predation

Of the 42 nests monitored with video cameras, 11(26%) were predated, 7 (17%) were abandoned, and 24 (57%) were successful. No partial nest predation was observed. Nests were monitored with video cameras for approximately 7,500 hrs with an average of 11 days of monitoring (during incubation period) per nest. I observed no nest abandonment immediately following camera setup (mean time to abandonment of video monitored nests was 12d) and thus the placement of the video cameras probably did not precipitate nest abandonment in the study area. I captured six nest predation events on video and one nest predation attempt that did not result in the failure of the nest. Predation events were not recorded at five nests because of camera failure. Five of the nests were preyed upon by coyotes and the sixth nest was preyed upon by an American badger (*Taxidea taxus*). In all five of the coyote predation events, the females flushed from the nest more than 5 minutes prior to the time the coyote appeared in the video.

Table 6. Paired logistic regression models comparing vegetation characteristics of sage grouse nest sites with paired sites in Modoc County, California, 2009-2011.

Model[a]	K[b]	AICc[c]	ΔAICc[d]	ω_i[e]	Deviance
CSD + GH + GC + SH	4	27.83	0.00	0.96	30.83
GH + GC + SH	3	34.54	6.71	0.03	41.79
CSD + GH + GC	3	41.02	13.19	0.00	42.26
CSD + GH	2	41.69	13.86	0.00	43.48
CSD + GH + GC + FC	4	42.13	14.30	0.00	42.85
CSD	1	42.31	14.48	0.00	49.44
CSD + DNS	2	43.88	16.05	0.00	54.38
GH + GC	2	61.78	33.95	0.00	67.29
GH + GC + SC	3	63.66	35.83	0.00	68.11

[a] Abbreviations for vegetation variables included in models: center shrub canopy diameter (CSD), grass height (GH), grass cover (GC), forb cover (FC), distance to closest shrub from nest shrub (DNS), mean shrub height (SH), and shrub cover (SC).
[b] K = number of parameters
[c] AIC_c = Akaike's Information Criterion adjusted for small sample size
[d] ΔAIC_c = relative difference from most parsimonious model
[e] ω_i = Akaike weight

Table 7. Coefficients from top model comparing nest sites and paired sites of sage grouse in Modoc County, California, 2009-2011.

Variable	Coefficient	SE	95% C.I. Lower	Upper
Center Shrub Diameter	4.47	2.04	1.071	7.77
Grass Height	-22.20	16.71	-39.66	-5.37
Grass Cover	34.58	16.01	8.26	60.89
Shrub Height	15.74	6.06	5.76	25.71

Table 8. Models used to compare nest site vegetation characteristics between translocated vs. post-translocated and resident sage grouse in Modoc County, California, 2009-2011.

Model[a]	K[b]	AICc[c]	ΔAICc[d]	ω[e]	Deviance
Null	1	60.35	0.00	0.44	58.35
NSD	1	60.37	0.02	0.20	56.37
NSD + GH	2	62.32	1.97	0.08	56.32
NSD + DNS	2	62.36	2.01	0.07	56.36
GH + GC	2	62.67	2.31	0.06	56.67
NSD + GH + GC	3	63.05	2.70	0.05	55.05
GH + GR + SC	3	64.32	3.97	0.03	56.32
GH + GR + SH	3	64.67	4.31	0.02	56.67
NSD + GH + GC + FC	4	64.96	4.61	0.02	54.96
NSD + GH + GC + SH	4	65.02	4.67	0.02	55.02

[a] Abbreviations for vegetation variables included in models: shrub canopy diameter (NSD), grass height (GH), grass cover (GC), forb cover (FC), distance to closest shrub from nest shrub (DNS), mean shrub height (SH), shrub cover (SC).
[b] K = number of parameters
[c] AIC_c = Akaike's Information Criterion adjusted for small sample size
[d] ΔAIC_c = relative difference from most parsimonious model
[e] ω_i = Akaike weight

None of the hens displayed any defensive behavior towards the approaching coyote. Females were observed returning to the nest more than 60 min after the last time the coyote was observed in the video. All of the coyote nest predation events occurred at night (2300 – 0300 hrs). In all of the coyote predation events, the egg remains were scattered in a small area (>3 m) from the nest, and the eggs were punctured on one side.

The behavior of the hen during the badger predation event was very different from those preyed upon by coyotes. When the badger approached the nest the female stretched her wings and lunged at the badger suggesting she was attempting to defend the nest. The badger did not show any aggression towards the female and appeared to only attempt to consume the eggs. The female left the nest while the badger consumed part of the clutch, but returned repeatedly while the badger was preying on the nest. The badger consumed four of the seven eggs in the clutch and buried the remaining three eggs adjacent to the nest bowl. Post-nest predation survey revealed that the predated egg remains were in small pieces and the nest bowl was highly disturbed.

A Pacific Gopher Snake (*Pituophis catenifer*) approximately 1 m in length attempted to prey on a nest but was unsuccessful. When the snake approached the nest, the female sage grouse lunged and pecked at the snake. The snake struck the hen several times and she finally left the nest after 7 minutes. The snake attempted to consume the eggs for more than 20 min but appeared to be physically incapable of swallowing the eggs. The female sage grouse returned to the nest and continued incubation immediately following the departure of the snake from the nest bowl.

The video also recorded cows, rodents, and rabbits visiting nests. Cows were observed in the video frame at two separate nests. The camera was disturbed by the cows during their approach to the nest (approx. 1 m), but the video did not show either female flush from their nests and both females were incubating their nests on the following day. In several cases, small rodents including deer mice (*Peromyscus maniculatus*), sagebrush voles (*Lemmiscus curtatus*), and unidentifiable rodents approached nests at night while the female was incubating, but no attempts of egg predation by rodents were observed. On one occasion, two Nuttall's cottontail rabbits (*Sylvilagus nuttallii*) approached an incubating female sage grouse at night but the sage grouse did not leave the nest.

DISCUSSION

Translocation of female sage grouse to Clear Lake National Wildlife Refuge effectively augmented the small population. Because some translocations have been unsuccessful, some authors have questioned the efficacy of translocation as an appropriate management tool (Griffith et al. 1989, Reese and Connelly 1997, Craven et al. 1998). However, using a variety of measures, it appears the hens that were translocated to Clear lake National Wildlife Refuge were very successful. The proportion of translocated hens that attempted to nest in my study was lower than for resident hens, but the clutch size and nest success was similar between translocated, post-translocated, and resident grouse. In addition, the proportion of hens attempting to nest, clutch size, and nest success of translocated hens was similar to resident hens in other sage grouse populations which were stable or increasing (Coggins 1998, Gregg et al.1994, Connelly et al. 1993, Schroeder 1997, Baxter et al. 2008). For instance, the proportion of translocated females that initiated a nest in my study (67%) was similar to the proportion of resident hens attempting to nest in Idaho (69%, Connelly et al. 1993), but lower than the proportion of hens attempting to nest in Oregon (78%, Gregg et al. 1994 and 99%, Coggins 1998), and Washington (99%, Schroeder 1997). It was also higher than translocated females in Utah (39%, Baxter et al. 2008). The proportion of post-translocated females that initiated a nest (86%) in my study area was higher than post-translocated hens from Utah (73%), and similar to resident hens in other areas (Baxter et al. 2008). The possible reasons for a lower proportion of translocated females initiating nests are many and may include timing of capture relative to the start of the nesting season capture stress, body condition, whether the hen had initiated a nest prior to capture, and their lack of knowledge of the release site (Musil et al. 1993, Davis 1995, Baxter et al. 2008).

Vegetative characteristics around the nest site likely influenced nest success by providing varying degrees of concealment from nest predators (Gregg et al. 1994). In my study area, nest sites with larger nest shrub canopy cover, greater grass height, lower grass cover, and lower shrub height had a greater likelihood of hatching successfully. Nest shrub diameter was positively associated with nest success in other studies (Connelly et al. 1991, Connelly et al. 2000). Mean nest shrub diameter in my population was similar to those in Idaho (mean = 1.09 m, Connelly et al. 1991). Mean grass height was higher around successful nests compared to unsuccessful nests which was consistent with studies in Oregon (Gregg et al. 1994). Successful nests had less grass cover than unsuccessful nests which was consistent with studies in Alberta, Canada (Watters et al. 2002). However, other studies have found greater grass cover at successful nests (Gregg et al. 1994, Rebholz et al. 2009). Grass cover in my study area differed by only 0.5% between successful and unsuccessful nests and therefore is unlikely to be biologically important. Mean shrub height around the nest was lower for successful than unsuccessful nests which was similar to sage grouse in Washington (Sveum et al. 1998). Mean shrub heights around the nest site in my study area fall near the mean for shrub heights around nest sites across the sage grouse's range (0.29 – 0.80 m, Heath et al. 1997, Keister and Willis 1986, Connelly et al. 2000). Like several studies throughout the sage grouse range, California studies reported a large proportion of sage grouse nesting under big sagebrush (59% and 64%) (Popham and Gutierrez 2003, Kolada et al. 2009b). However, only 19% of sage grouse nests' in my study area were found under big sagebrush even though big sagebrush stands appeared to be available throughout the study area.

The nesting success of sage grouse in my study area was comparable to other populations. My estimate of daily survival rate (0.971) was lower than translocated grouse from Utah (0.981), but similar to resident populations in Mono County, California (0.978) and higher than the sage grouse populations in Montana (0.959) (Moynahan et al. 2007, Baxter et al. 2008, Kolada et al. 2009a). Nest success estimates are variable across the sage grouse range, but my estimates (45%) was close to the mean (47.4%, Crawford et al. 2004). Thus, nesting success in the study area was similar to other regions and is not likely to be an impediment to increasing the grouse population in the study area.

Sagebrush and herbaceous cover have been identified as important nest habitat characteristics influencing nest site selection (Connelly et al. 1991, Sveum et al. 1998, Hagen et al. 2007). My parameter estimates suggested sage grouse selected nest sites with greater nest shrub diameter, denser grass, taller shrubs, and shorter grass compared to paired sites. I found no support for translocated hens using nest sites that differed from post-translocated or resident hens. Larger nest shrub diameter was well supported in my analysis as an important component in nest site selection. My analyses also suggested grass cover was greater at nest sites than at paired sites. This is similar to a study in Lassen County, California (14% and 11%, Popham and Gutierrez 2003). Mean grass height, however, in my study was similar between nest sites and paired sites even though taller grass height has been identified in other studies as an important component in nest site selection (Gregg et al. 1994, Holloran et al. 2005). Shrub height was taller around nest sites than at paired sites, which was consistent with several other studies (Connelly et al. 1991, Gregg et al. 1994, Popham and Gutierrez 2003, Baxter et al. 2009). Overall, my results are consistent with other studies suggesting that sage grouse place their nests in locations with greater vegetation cover via vegetation height and canopy cover than paired sites perhaps providing better nest concealment.

Nest predation was the primary reason for nest failure in my study area and I was able to identify nest predators in six cases. During coyote nest predations, the hens' behavior suggested they detected the coyotes well before (>5 min) the coyote approached, left the nest and did not attempt to defend it. The only other successful nest predator that I recorded at a nest was a badger. Unlike the coyote nest predation events, the hen tried unsuccessfully to defend the nest and, despite their close proximity, the badger did not attempt to prey on the hen. The rapid departure of the hens in cases where coyotes preyed on the nest compared to the long (>5 min) period that the hen attempted to defend her nest from the badger indicates that hens respond very differently to coyotes and badgers and suggests that hens may view coyotes as a threat to their survival. Badgers are uncommon within the study area and therefore are unlikely to be an important nest predator (Larsen 1987).

I frequently observed rodents visiting grouse nests, but I never observed them attempt to prey on eggs. Ground squirrels have been reported as sage grouse nest predators in other studies (Petersen 1980, Niemuth and Boyce 1995). However, Coates et al. (2008) suggested that these studies may have erroneously concluded that ground squirrels and other rodents were nest predators based on sign observed in the nest cup. My observations support Coates et al.'s (2008) suggestion that rodents generally do not prey on sage grouse nests and that rodent sign in the nest cup are more likely a result of scavenging after the nest has fledged or failed. I had suspected that ravens would have been an important nest predator because ravens have been identified sage grouse nest predators in other studies and they are common in my study site. However, I did not record any ravens either preying on or scavenging sage grouse nests.

The lack of raven predation on sage grouse nests may be related to the small sage grouse population. Ravens may not target sage grouse nests because nest densities are relatively low in the study area. Alternatively, raven populations in my study area may not be as abundant as in other areas that report ravens predating sage grouse nests (Holloran and Anderson 2003, Manzer and Hannon 2005, Coates et al. 2008).

MANAGEMENT IMPLICATIONS

Translocation can effectively increase population size and boost reproductive output for small or declining sage grouse populations. Sage grouse habitat management should focus on maintaining or enhancing quality nesting habitat by promoting moderate levels of grass height and larger sagebrush diameter which appears to provide the majority of the vertical and horizontal nest cover in this study area. Nest success in the study area was similar to nest success across the sage grouse range and predator management is not warranted at this time.

LITERATURE CITED

Autenrieth, R. E. 1981. Sage grouse management in Idaho. Idaho Department of Fish and Game, Wildlife Bulletin 9. Boise, Idaho.

Barbour, M. G., T. Keeler-Wolf, A. A. Schoenherr. 1997. Terrestrial vegetation of California. University of California Press, Berkley and Los Angeles, California.

Baxter, R. J., J.T. Flinders, and D. L. Mitchell. 2008. Survival, movements, and reproduction of translocated greater sage grouse in Strawberry Valley, UT. Journal of Wildlife Management 72: 179-186.

Baxter, R. J., J. T. Flinders, D. G. Whiting, and D. L. Mitchell. 2009. Factors affecting nest-site selection and nest success of translocated greater sage grouse. Wildlife Research. 36:479-487.

Braun, C. E. 1998. Sage grouse declines in North America: what are the problems? Proceedings of the Western Association State Fish and Wildlife Agencies 78:139-156.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Second edition. Springer-Verlag, New York, New York.

Canfield, R. H. 1941. Application of the line interception method in sampling range vegetation. Journal of Forestry 39:388-394.

Coates, P. S., J. W. Connelly, and D. J. Delehanty. 2008. Predators of greater sage-grouse nests identified by video monitoring. Journal of Field Ornithology 79: 421-428.

Coggins, K. A. 1998. Relationship between habitat changes and productivity of sage grouse at Hart Mountain National Antelope Refuge, Oregon. Master's thesis. Department of Fisheries and Wildlife, Oregon State University, Corvallis, Oregon.

Connelly, J. W., and C. E. Braun. 1997. Long-term changes in sage grouse *Centrocercus urophasianus* populations in western North America. Wildlife Biology 3:123-128.

Connelly, J. W., R. A. Fischer, A. D Apa, K. P. Reese and W. L. Wakkinen. 1993. Renesting by sage grouse in southeastern Idaho. Condor 95:1041-1043.

Connelly, J. W., C. A. Hagen, and M. A. Schroeder. 2011. Charaterstics and dynamics of Grater Sage-Grouse populations. Pages 53-67 in S. T. Knick, and J. W. Connelly (editors). Greater Sage-Grouse: ecology and conservation of a landscape and its habitats. Studies in Avian Biology, volume 38, University of California Press, Berkeley, California.

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 28:967-985.

Connelly, J. W., W. L. Wakkinen, A. D. Apa, and K. P. Reese. 1991. Sage grouse use of nest in southeastern Idaho. Journal of Wildlife Management 55:521-524.

Conover, M. R., J. S. Borgo, R.E. Dritz, J. B. Dinkins, and D. K. Dahlgren. 2010. Greater Sage-Grouse select nest sites to avoid visual predators but not olfactory predators. Condor 112:331-336.

Craven, S., T. Barnes, and G. Kania. 1998. Towards a professional position on the translocation of problem wildlife. Wildlife Society Bulletin 26:171-177.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Science 33:43-64.

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. Ecology and management of sage-grouse and sage-grouse habitat. Journal of Range Management 57: 2-19.

Davis, R. 1995. Animal relocation: not a sound practice. Wildlife Control Technology 2: 38-40.

DeLong, A. K., J. A. Crawford, and D. C. DeLong. 1995. Relationships between vegetational structure and predation of artificial sage grouse nests. Journal of Wildlife Management 59:88-92.

Gregg, M. A. 1991. Use and selection of nesting habitat by sage grouse in Oregon. Master's thesis. Department of Fisheries and Wildlife, Oregon State University, Corvallis, Oregon.

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 58:162-166.

Griffith, B., J. M. Scott, J. W. Carpenter, and C. Reed. 1989. Translocation as a species conservation tool: status and strategy. Science 245: 477-480.

Hagen, C. A., J. W. Connelly, and M. A. Schroeder. 2007. A meta-analysis of greater sage-grouse *Centrocercus urophasianus* nesting and brood-rearing habitats. Wildlife Biology 13, supplement 1:43-50.

Hall, F. A. 1995. Determining changes in abundance of Sage Grouse *Centrocercus urophasianus* in California. California Department of Fish and Game, Wildlife Management Branch, Sacramento, California.

Heath, B. J., R. Straw, S.H. Anderson, and J. Lawson. 1997. Sage grouse productivity, survival, and seasonal habitat use near Farson, Wyoming. Wyoming Game and Fish Department. Project Completion Report, Laramie, Wyoming.

Holloran, M. J. 1999. Sage grouse (*Centrocercus urophasianus*) seasonal habitat use near Casper, Wyoming. Master's thesis, Department of Zoology and Physiology, University of Wyoming, Wyoming, Laramie.

Holloran, M. J., and S. H. Anderson. 2003. Direct identification of northern sage-grouse, *Centrocercus Urophasianus*, nest predators using remote sensing cameras. The Canadian Field-Naturalist 117:308-310.

Holloran, M. J., B.J. Heath, A. G. Lyon, S. J. Slater, J. L. Kuipers, and S. H. Anderson. 2005. Greater sage grouse nesting habitat selection and success in Wyoming. Journal of Wildlife Management 69: 638-649.

Jones, R. E. 1968. A board to measure cover used by prairie grouse. Journal of Wildlife Management 32: 28-31.

Keister, G. P., and M. J. Willis. 1986. Habitat selection and success of sage grouse hens while nesting and brooding. Oregon Department of Fish and Wildlife, Progress Report W-87-R-2 Subproject 285, Portland, Oregon

Kolada, E. J., J. S. Sedinger, and M. L. Casazza. 2009a. Nest site selection by greater sage grouse in Mono County, California. Journal of Wildlife Management 73: 1333-1340.

Kolada, E. J., J. S. Sedinger, and M. L Casazza. 2009b. Ecological factors influencing nest survival of greater sage grouse in Mono County, California. Journal of Wildlife Management 73: 1341-1347.

Larsen, C. 1987. Badger distribution study. California Department of Fish and Game Nongame Wildlife Investigations Report W-65-R-4, Sacramento, California.

Liebezeit, J. R. and T. L. George. 2002. A summary of predation by corvids on threatened and endangered species in California and management recommendations to reduce corvid predation. Calif. Department of Fish and Game, Species Conservation and Recovery Program Report 2002-02, Sacramento, California.

Manzer, D. L. and S. J. Hannon. 2005. Relating grouse nest success and corvid density to habitat: a multi-scale approach. Journal of Wildlife Management 69:110-123.

Moynahan, B. J., M. S. Lindburg, J. J. Rotella, and J. W. Thomas. 2007. Factors effecting nest survival of Greater Sage-Grouse in north-central Montana. Journal of Wildlife Management 71: 1773-1783.

Musil, D. D., J. W. Connelly, and K. P. Reese. 1993. Movements, survival, and reproduction of sage grouse translocated into central Idaho. Journal of Wildlife Management 57: 85-91.

Niemuth, N. D. and M. S. Boyce. 1995. Spatial and temporal patterns of predation of simulated sage grouse nests at high and low densities: an experimental study. Canadian Journal of Zoology 73:819-825.

Oyler-McCance, S. J., S. E. Taylor, and T. W. Quinn. A multilocus population genetic survey of the greater sage-grouse across their range. Molecular Ecology 14: 1293-1310.

Pettersen, B. E. 1980. Breeding and nesting ecology of female sage grouse in North Park, Colorado. Master's thesis. Department of Fish, Wildlife, and Conservation Biology, Colorado State University, Fort Collins, Colorado.

Popham, G. P., and R. J. Gutierrez. 2003. Greater sage-grouse *Centrocercus urophasianus* nesting success and habitat use in northeastern California. Wildlife Biology 9: 327-334.

Rebholz, J. L., W.D. Robinson and M. D. Pope. 2009. Nest site characteristics and factors affecting nest success of greater sage-grouse. The Open Ornithology Journal 2: 1-6.

Reese, K. P. and J. W. Connelly. 1997. Translocations of sage grouse *Centrocercus urophasianus* in North America. Wildlife Biology 3:235-241.

Rotella, J. J., S. J. Dinsmore, and T. L. Shaffer. 2004. Modeling nest-survival data: a comparison of recently developed methods that can be implemented in MARK and SAS. Animal Biodiversity and Conservation 27:187-205.

Schroeder, M. A. 1997. Unusually high reproductive effort by sag grouse in a fragmented habitat in north-central Washington. Condor 99:933-941.

Schroeder, M. A., C. L. Aldridge, A. D. Apa, J. R. Bohne, C. E. Braun, S. D. Bunnell, J. W. Connelly, P. A. Deibert, S. C. Gardner, M. A. Hilliard, G. D. Kobriger, S. M. McAdam, C. W. McCarthy, J. J. McCarthy, D. L. Mitchell, E. V. Rickerson, and S. J. Stiver. 2004. Distribution of Sage grouse in North America. Condor 55: 517-522.

Schroeder, M. A., and R. K. Baydack. 2001. Predation and the management of prairie grouse. Wildlife Society Bulletin 29:24-32.

Schroeder, M. A., J. R. Young, and C. E. Braun. 1999. Sage Grouse (*Centrocercus urophasianus*). Pages in A. Poole and F. Gill, editors, The birds of North America, No. 425. The Birds of North America, Inc., Philadelphia, Pennsylvania.

Shaffer, T. L. 2004. A unified approach to analyzing nest success. The Auk 12:526-540.

Sveum, C. M. 1995. Habitat selection by sage grouse hens during the breeding season in south-central Washington. Master's thesis. Department of Fisheries and Wildlife, Oregon State University, Corvallis, Oregon.

Sveum, C. M., W. D. Edge, and J.A. Crawford. 1998. Nesting habitat selection by sage grouse in south-central Washington. Journal of Wildlife Management 51: 265-269.

Wakkinen, W. L. 1990. Nest site characteristics and spring-summer movements of migratory sage-grouse in southeastern Idaho. Master's thesis, Department of Fish and Wildlife Resources, University of Idaho, Moscow, Idaho.

Wallestad, R. O., D. B. Pyrah. 1974. Movement and nesting of sage grouse hens in central Montana. Journal of Wildlife Management 38:630-633.

Watters, M. E., T. L. McLash, C. L. Aldridge, and M. Bringham. 2002. The effect of vegetation structure on predation of artificial Greater Sage-Grouse nests. Ecoscience 9:314-319.

Western Regional Climate Center 2010. National Climatic Data Center, Northern California Climate Summaries, http:/www.wrcc.dri.edu/, 12/5/2009.

White, G. C., K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46(supplement):120-138.

PERSONAL COMMUNICATION

Beckstrand, J. 2009. Personal Communication. Klamath Basin National Wildlife Refuge Complex, 4009 Hill Rd, Tulelake, CA 96134.