2007-11-20

The ecology of translocated greater sage-grouse in Strawberry Valley, Utah

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THE ECOLOGY OF TRANSLOCATED GREATER SAGE-GROUSE IN STRAWBERRY VALLEY, UTAH

A dissertation submitted to the faculty of

Brigham Young University

in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

Department of Plant and Wildlife Sciences

Brigham Young University

December 2007

BRIGHAM YOUNG UNIVERSITY

GRADUATE COMMITTEE APPROVAL

of a dissertation submitted by

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This dissertation has been read by each member of the following graduate committee and by majority vote has been found to be satisfactory.

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As chair of the candidate's graduate committee, I have read the dissertation of Rick J. Baxter in its final form and have found that (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

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ABSTRACTS

THE ECOLOGY OF TRANSLOCATED GREATER SAGE-GROUSE IN
STRAWBERRY VALLEY, UTAH

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Department of Plant and Wildlife Sciences

Doctor of Philosophy

<u>Manuscript No. 1</u>

Translocations of greater sage-grouse (*Centrocercus urophasianus*) have been

attempted in 7 states and one Canadian province with very little success. To recover a

small remnant population and test the efficacy of sage-grouse translocations, we captured

and transported 137 adult female sage-grouse from 2 source populations to a release site

in Strawberry Valley, Utah during March-April 2003-2005. The resident population of

sage-grouse in Strawberry Valley was approximately 150 breeding birds prior to the

release. We radiomarked each female and documented survival, movements,

reproductive effort, flocking with resident grouse, and lek attendance. We used Program

MARK to calculate annual survival of translocated females in the first year after release,

which averaged 0.60 (95% CI = 0.515-0.681). Movements of translocated females were

within current and historic sage-grouse habitat in Strawberry Valley, and we detected no

grouse outside of the study area. Nesting propensity for first (newly translocated) and second (surviving) year females was 39% and 73%, respectively. Observed nest success of all translocated females during the study was 67%. By the end of their first year in Strawberry Valley, 100% of the living translocated sage-grouse were in flocks with resident sage-grouse. The translocated grouse attended the same lek as the birds with which they were grouped. In 2006, the peak male count for the only remaining active lek in Strawberry Valley was almost 4 times (135 M) the 6-year pretranslocation (1998 − 2003) average peak attendance of 36 males (range 24 – 50 M). Translocations can be an effective management tool to increase small populations of greater sage-grouse when conducted during the breeding season and before target populations have been extirpated.

Manuscript No. 2

Nesting habitat of resident greater sage-grouse in extant populations across the species range has been thoroughly described in the literature, yet very little is known about the use of nesting habitat by translocated sage-grouse. In order to better understand nesting habitat selection by translocated sage-grouse in a new environment, we trapped grouse during the spring on and near leks of source populations. We placed each female in a cardboard box and translocated them overnight to the Strawberry Valley. Each female was fitted with a radio-transmitter and released near the lek where males were actively strutting. We monitored grouse for nesting activity. We documented nesting attempts, nest success, clutch size and embryo viability. We recorded data on habitat variables associated with nest sites and paired-random sites. We used logistic regression

and an *a priori* information theoretic approach for modeling nest versus paired-random sites and successful versus unsuccessful nest sites. Our data suggested that crown area of the nest shrub and percent grass cover were the two variables that discriminated between nest and paired-random sites. Females that nested successfully selected sites with more total shrub canopy cover, intermediate size shrub crown area, a normal distribution of aspects, and with steeper slopes than unsuccessful nests. Translocated females selected suitable nesting habitat after being moved from source populations with differing habitats.

Manuscript No. 3

Equivalence testing in the field of wildlife ecology has been underutilized. Mistakenly, many researchers have concluded that two groups are the same based on failure to reject a null hypothesis of no difference. We used equivalence testing to provide preliminary evidence that resident and translocated bird movements were similar. Translocations are becoming more prominent in the field of conservation biology as a wildlife management tool. We translocated greater sage grouse into a fragmented habitat in order to conserve the metapopulation. We placed radio-transmitters on resident and translocated female greater sage grouse and used the distance moved from the release site or lek as a measure of translocation success and/or site fidelity. If translocated birds did not show site fidelity, the translocations would be judged a failure. The distributions of resident and translocated sage grouse movements for both summer and winter seasons were significantly different, primarily due to differences in the proportions of specific

habitat fragments used. Equivalence tests showed that site fidelity was statistically equivalent for translocated and resident grouse,when defined as a difference of ≤3 km, both in summer and winter. In particular, translocated females traveled no farther from the release site than resident females. Equivalence testing was the statistical tool used to determine equivalence of resident and translocated sage grouse movements and thus judge preliminary translocation success.

ACKNOWLEDGEMENTS

I also thank my wife, ReNae, for supporting me while I obtained this degree. Her love, appreciation, and work ethic are an example to me. I thank her for raising our children, for making my lunches, for taking care household and family matters, and for showing unconditional love and support when I wasn't around to help out at home. I couldn't have completed this degree without her. Thank you!

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Equivalence testing for assessing the success of
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**Survival, movements, and reproduction of translocated
greater sage-grouse in Strawberry Valley, Utah**

INTRODUCTION

Translocations and reintroductions of greater sage-grouse (*Centrocercus urophasianus*) have

been used as a management tool to restore or augment extirpated or declining populations (Reese

and Connelly 1997). Published data from translocations have been sparse and largely unavailable

(Reese and Connelly 1997). All pre-1970 efforts to re-establish or augment populations were

unsuccessful or contained insufficient data to determine success, and only 3 of 56 reported

attempts in 7 states and one province were judged to be a success by Reese and Connelly (1997).

Previous translocation efforts have usually failed to provide criteria for evaluating the success of

the translocation (Reese and Connelly 1997).

In the late 1930s Rasmussen and Griner (1938) reported spring estimates of 3,000-4,000

greater sage-grouse (hereafter sage-grouse) in Strawberry Valley, Utah. In 1998, Bunnell (2000)

estimated this population at 150 breeding birds. Only one lek was known to remain in the valley.

In response to this decline, a study was initiated in 1998 to identify factors limiting growth of the

population. Bunnell (2000) suggested that red fox (*Vulpes vulpes*) predation may have limited

the population by lowering survival of adult sage-grouse, although subsequent efforts at predator

control did not result in a population increase. Other research showed that year-round habitat met

or exceeded the standards set forth in the sage-grouse management guidelines (Connelly et al.

2000, Bambrough 2002, Baxter 2003, Bunnell et al. 2004) for self-sustaining populations.

Because habitat appeared adequate, researchers from Brigham Young University recommended

to the Utah Division of Wildlife Resources (UDWR) that sage-grouse be translocated from

source populations in Utah to Strawberry Valley during 2003–2005 to increase population size.

Herein we describe the methods used to translocate sage-grouse to Strawberry Valley and evaluate the efficacy of the translocation effort.

Success of translocations of sage-grouse should be based on compatibility of courtship behavior, survival, and reproductive success of translocated birds, as well as their fidelity to the release area, integration into the extant population, and contribution to population growth. To test the efficacy of our translocations we measured: 1) annual survival of translocated females and contrasted survival between years, source populations, and age classes, 2) movements of translocated females from the release area, 3) nesting propensity of translocated females, 4) nest survival based on translocated female age, residency in Strawberry Valley, year effects, and source population, 5) chick survival of translocated females between hatch and 50 days of age, 6) flocking (integration) of translocated females with resident sage-grouse, and 7) attendance of translocated females at the only known active lek in Strawberry Valley and changes in resident male attendance after releases. We evaluated the efficacy of our translocation effort by comparing our estimates of survival, nesting propensity, nest survival, and chick survival of translocated females to previously published estimates from resident sage-grouse populations in other regions.

STUDY AREA

Core Release Area

Our study area was centered in the Strawberry Valley of north-central Utah. The area was a montane sagebrush-steppe with big sagebrush (*Artemesia tridentata*) as the predominant shrub; silver sagebrush (*A. cana*) was found in less abundance in wet meadows and riparian areas. The valley is approximately 24 km long and 8-9 km wide. The area has mountain ridges and high

mountain meadows with elevations ranging from 2,330 m to 3,050 m. The valley experienced cool dry summers and cold wet winters. Average annual precipitation was about 58 cm. Strawberry Reservoir was the most dominant feature of the valley covering 6,950 ha of historical riparian and sagebrush-steppe habitat. Over 9,000 ha of sagebrush habitat remained for sage-grouse use.

Source Capture Areas

Parker Mountain (PM) is located in south-central Utah and was characterized by black sagebrush (*A. nova*) on the ridges and slopes with big sagebrush, bitterbrush (*Purshia tridentata*), and rabbitbrush (*Chrsyothamnus viscidiflorus)* in the drainages. Elevation ranged from 2,140 m to 3,000 m. The terrain was rolling hills and plateaus that gently sloped to the north and east. Parker Mountain had hot dry summers with precipitation that accumulated in the fall and winter (Jarvis 1973).

Diamond Mountain (DM) is located in eastern Utah. The dominant vegetation was big sagebrush with a mixture of perennial grasses and forbs in the understory (Ralphs and Busby 1979). Elevation ranged from 2,230 m to 2,850 m. The terrain was a high mountain plateau that gently slopes to the south. Average annual precipitation ranged between 51 cm and 61 cm (Ralphs and Busby 1979, Laycock and Conrad 1981).

METHODS

Because greater sage-grouse are a sensitive species of concern in Utah, we complied with all state laws and agency policies prior to undertaking our study. We received approval from the Institutional Animal Care and Use Committee (Project code: 05-0301) of Brigham Young

University. In addition, we worked collaboratively with the sage-grouse local working groups to accomplish the goal of population recovery.

Translocation Methodology

We used source populations of sage-grouse, designated as stable (≥500 breeding birds) by the UDWR, for translocations to Strawberry Valley. We chose these populations because of their robust size, their distant proximity to the release site, and their behavioral and genetic compatibility with Strawberry Valley sage-grouse (Barber 1991, Reese and Connelly 1997, Oyler-McCance et al. 2005).

Prior to removing birds from Parker Mountain, we captured 7 male sage-grouse on 30 March 2003 and drew blood to screen for Pullorum disease (*Salmonella pullorum*). After the disease analyses came back negative, we began capturing female sage-grouse on and near leks in late March and April at night, about 2 hours after sunset, (2100 hr to 0200 hr) using a modified spotlight method from pickup trucks and all-terrain vehicles (Wakkinen et al 1992). We placed each translocated female in an individual cardboard box (12" × 9" × 12") that had holes for ventilation. We placed wood shavings, chips, or straw inside each box to reduce moisture from cecal and fecal droppings. We transported the grouse overnight (0200—0500 hr) in the bed of a pickup truck to Strawberry Valley. Upon arrival, we moved birds into a heated facility where we weighed them with an electronic scale, assigned an age class as described by Crunden (1963) and Wallestad (1975), and fitted each female with a 16-g necklace style radio transmitter (Advanced Telemetry Systems, Inc., Isanti, MN; 19-hr duty cycle, 45 pulses per minute, with mortality after 8 hr and max. battery life of 30 months).   We inspected sage-grouse for obvious signs of injuries, placed them back in the cardboard box, and transported them to the release site. The release site was ≤250 m from the only known active lek in Strawberry Valley. We chose this

release location because of its proximity to the lek, the topography (a small hill north of the lek) allowed us to release birds without disturbing displaying grouse, and sagebrush was available for immediate escape cover (unless there was deep snow). We oriented the boxes in a straight line facing south toward the actively strutting grouse and into prevailing south winds to facilitate the ability of released females to fly. Before opening the boxes we scanned the immediate area with binoculars for avian and terrestrial predators. Then, approximately one hour after sunrise, we released the grouse as quickly as possible by opening individual boxes. If grouse flew or walked out in the direction we oriented them, they could see or potentially interact with grouse on the active lek.

Field Monitoring

A predator management program was initiated in 1999 by the United States Department of Agriculture (USDA) Wildlife Services to reduce numbers of red fox and coyotes (*Canis latrans*; Bunnell 2000). In addition, from 2003 through 2005, Wildlife Services used poison egg baits to control common raven (*Corvus corvax*) and black-billed magpies (*Pica pica*) during the breeding, nesting, and brood-rearing seasons.

We tracked all translocated females via radio telemetry from the ground using a 2-element Yagi antenna and an R-1000 digital radio receiver (Communication Specialists Incorporated, Orange, CA) to monitor survival, reproductive output, seasonal movements, flocking with resident birds, and lek attendance for up to 18 months after translocation. We used periodic flights in fixed-wing aircraft to locate radiomarked birds ($\bar{x}$ = 6 flights/yr). We searched for radiomarked sage-grouse within an 80-km radius of the release site and believe we would have detected any females with active radios that departed Strawberry Valley following translocation. We recorded all locations with a Global Positioning System (GPS) receiver.

We attempted to locate each translocated female sage-grouse at least once weekly throughout the calendar year, and we found mortalities as quickly as possible. We documented dispersal or movements of translocated radiomarked females during the summer (1 Apr to 31 Oct) and winter (1 Nov to 31 Mar) seasons. We report maximum dispersal as the farthest straight-line distance between the bird and the release site or lek during each season. Residency for translocated females was defined by the number of years lived in Strawberry Valley after release. First year females were translocated adults or yearlings that had been present in Strawberry Valley ≤12 months. Second year females were adults that survived >12 months after translocation.

We located radiomarked females during nesting by triangulating their location. We verified nesting with a visual observation. Thereafter, we monitored all nesting females 2-4 times each week, from a distance, thereby diminishing disturbance. All nesting occurred from 1 April to 15 July. We determined nest fate for each female after she was no longer detected at the nest site. We considered a nest successful if ≥1 egg hatched. We used egg shells with a detached membrane or visual observation of a female with a brood to determine nest success (Klebenow 1969). We considered a nest depredated if no eggs hatched and we found ≥1 egg punctured, crushed, or missing or if we found the female dead on or near the nest. We defined nest desertion as a female not returning to a formerly incubated nest after ≥24 hours. Embryo viability was the percent of all eggs of successful nests that hatched (Schroeder 1997).

We monitored translocated female sage-grouse weekly throughout the summer from hatch date to 50 days posthatch (approx. mid-Aug) to determine chick survival and mean brood size per successful hen. We used trained hunting dogs to search the area for sage-grouse chicks for 10–20 minutes after a female flushed. We also monitored hen behavior to indicate whether a

brood was present. Hens with broods usually flew short distances, quickly returned to the area, and vocalized within 30 minutes of the initial disturbance. We estimated chick survival as the percentage of hatched chicks that survived until 50 days after hatch (Schroeder 1997). We used a t-test, with an α-level of 0.05 to test for differences in brood size at 50 days after hatch between adult and yearling females.

We monitored and recorded flocking and interactions of translocated females with resident sage-grouse each observation day. We defined flocking as a translocated female grouped or flocked with ≥1 resident sage-grouse (M or F). We identified resident sage-grouse from their radio frequency if they were marked or from the absence of a radio transmitter. We report flocking by month (per annum) for hens translocated in 2003, 2004, and 2005. Tracking radiomarked birds throughout the year allowed us to record lek attendance in the release year as well as the following year.

We documented lek attendance of resident male and female sage-grouse from 1998 to 2006. From 2003 through 2006, we documented all attendance by translocated sage-grouse, both in initial year of release and in subsequent years after release if they survived. We counted male sage-grouse on the lek in the morning ≥30 minutes prior to sunrise, until they began to leave the lek. We made ≥2 counts per week from late March through the end of May 1998 – 2006.

Data Analysis

We used observation and telemetry data from year-round monitoring of translocated females to calculate survival using known fate models in Program MARK. We recorded fates (alive or dead) for each bird at monthly intervals in our encounter history file. Because we attempted to locate each female on a weekly basis, there were ≥4 opportunities each month to determine fate. We included as indicator variables: 1) year of release (2003, 2004, and 2005), 2) female age

(yearling or ad) at release, and 3) source population (DM or PM). We examined candidate

models, in which monthly survival was partitioned into different time intervals. Our first model

was one of constant survival in which we constrained survival to be similar across months and

years, as well as between age groups and source populations. Our next model examined non-

constant survival, where each month assumed an independent survival rate. Next, we examined

a model in which survival during the nesting—early brood rearing (NS—EB) seasons (1 Apr

through 30 Jun; 1 parameter) differed from the remaining individual months (Jul to Mar), each of

which we estimated by unique parameters. We held survival constant during the nesting season

and included it in some models because we believed females were at greater risk of death during

the nesting and early brood rearing seasons than during the rest of the year. We also partitioned

the year into a nesting—early brood rearing (1 Apr to 30 Jun), late brood rearing—fall (1 Jul to

30 Nov), and winter (1 Dec to 31 Mar) seasons (3 parameters) for a model of seasonal variation.

We included effects of year of release, female age, and source population in some models for a

total of 18 a priori candidate models. We used a logit link function in our analysis. We used

Akaike's Information Criterion (AIC$_c$) corrected for small sample size and Akaike weights in

Program MARK to select the best candidate model (Burnham and Anderson 2002). Due to

uncertainty in model selection, we used model averaging to derive weighted monthly parameter

estimates and to compute annual survival and the 95% confidence intervals surrounding those

estimates.

We also estimated daily nest survival using nest survival models in Program MARK

(Dinsmore et al. 2002). For the purpose of estimating nest survival, we censored grouse if we

were unable to locate the bird during the nesting season, if we were unable to access the bird on

private lands, or if the radio transmitter discontinued working due to diminished battery life

during their second year of residency. We generated 9 a priori candidate models that included

combinations of the following indicator variables as covariates: date of the nesting season when

a nest was discovered, female age, year, residency, and source population. We defined the date

of the nesting season when the nest was discovered as the date a nest was found, normalized to

the first date of the nesting season. We used a logit link function in our analysis and an

information theoretic approach, with Akaike weights to select the best model (Burnham and

Anderson 2002). We used model averaging to estimate daily survival and expanded that

estimate over an incubation period of 27 days to calculate overall nest survival. All mean values

are reported ± one standard deviation.

RESULTS

We translocated 137 female greater sage-grouse from 2003 to 2005 (Table 1), which does not

include 3 females (1 in 2003 and 2 in 2005) that were injured in cardboard boxes during

transport and could not fly. We released all 3 injured females but found them dead on the lek the

following morning. The total also does not include a female killed by a golden eagle (*Aquila*

chrysaetos) in 2003 seconds after her release. No females died during transport or were

obviously injured during capture. With the exception of 6 grouse that we held overnight (3 in

2003 and 3 in 2004), mean translocation time, from when we caught the first female until we

released the last female on the lek in the new area, was 10 hours and 9 minutes ± 42 minutes.

Translocation and Post-Release Dispersal

We were able to monitor and determine fates of all 137 radiomarked translocated sage-grouse in

the first year after their release (Table 1). No transmitters failed prematurely in the first year

following release, and there was no evidence that any translocated females emigrated from

Strawberry Valley. All translocated sage-grouse settled into traditional and historic habitat. Average maximum summer and winter dispersal for adult and yearling translocated females combined during their first year in the new study area was 9.74 ± 7.7 km and 13.70 ± 9.3 km, respectively.

Survival

The most parsimonious model from our survival analysis was one in which survival was invariant across months and years and did not vary with female age or source population (Table 2). The next most supported model, with a model likelihood of 0.64, contained parameters for constant monthly survival and an additive year effect (Table 2). There was support in 4 of the top 5 models for constant monthly survival. We documented slightly lower monthly survival in 2004 (ϕ = 0.933, 95% CI = 0.269 - 0.594), compared to 2003 (ϕ = 0.964, 95% CI = 0.464 - 0.780) and 2005 (ϕ = 0.963, 95% CI = 0.508 - 0.741). Model averaged estimates showed that translocated females were somewhat less likely to survive during the nesting season (monthly ϕ = 0.945, 95% CI = 0.917 - 0.964) than during the rest of the year (monthly ϕ = 0.964, 95% CI = 0.949 - 0.974). In addition, there was no difference in estimated annual survival rates of translocated yearling females (ϕ = 0.620; 95% CI = 0.487 - 0.728) and translocated adult females (ϕ = 0.563; 95% CI = 0.439 - 0.669). Based on model averaged estimates of monthly survival across all candidate models, annual survival was 0.601 (95% CI = 0.515 - 0.681).

Reproduction

Five females died within the first 2 weeks after release and we did not include them in the reproductive sample. Nesting propensity for first year translocated females was 39% (52/133). Of those that survived their first year in the valley and were not censored, 73% (45/62) initiated a

nest the subsequent year. We documented only 2 attempts by translocated females to renest.

Both attempts (1 success and 1 failure) occurred in 2003.

Clutch size varied from 4 to 12 eggs. Clutch size for first year translocated females

averaged 5.7 ± 1.03 eggs and was 6.6 ± 1.59 eggs for second year females. Due to small sample

size and the likelihood of over-estimation we did not calculate clutch size for depredated or

deserted nests. Embryo viability was 97.8% (first yr eggs – 152/157 [96.8%] and second yr eggs

– 162/164 [98.7%]).

In the best supported model from the nest survival analysis, estimated daily survival of

nests was a function of the date the nest was discovered during the nesting season, normalized to

the first day of the season (Table 3), and in the model nest survival decreased as the nesting

season progressed (Fig. 1). There was modest support for the next 3 models that contained one

each of the following covariates: age, residency, and source population (Table 3). Nest survival

to 27 days, calculated using model averaging in Program MARK, was 0.60 (95% CI = 0.286 -

0.834). Translocated females experienced 32% (31/97) nest failure due to depredation,

abandonment, and disturbance due to observer error. First year females lost their nests 38.4%

(20/52) of the time. Second year females experienced 24.4% (11/45) nest loss. There was some

support for a difference in nest survival due to female age (Table 3, model 2), where first year

adults (0.62, 95% CI = 0.387 - 0.789) were more successful nesters than first year yearlings

(0.47, 95% CI = 0.269 - 0.654).

Chick survival of first and second year translocated females to ≥ 50 days was 47.2%

(68/144) and 58.1% (61/105), respectively. We did not include chicks of 2005 females in 2006,

because we initiated a chick survival study where we sutured transmitters to chicks and

monitored them every other day, thereby introducing a new source of bias. At 50 days after hatch

mean brood size of successful adults (2.30 ± 0.27) was similar to the mean brood size of successful yearlings (2.17 ± 0.55; $t_{16} = -0.22$ $P = 0.830$).

Flocking and Lek Attendance

Translocated females were increasingly found in flocks with resident sage-grouse in the first year (1 Apr to 31 Mar) after their release. The initial association between translocated and resident sage-grouse began between 15 May and 15 June. From December through late February, winter habitat became more constricted and flock size of translocated and resident sage-grouse increased. By the start of the breeding season (1 Apr) we found 100% of the translocated females that were still alive in flocks with resident sage-grouse (Fig. 2).

Observed lek attendance by translocated females in the same year as their release was 36% (13/36), 24% (8/34), 26% (9/34), and 18% (6/33) for the 2003 PM, 2004 PM, 2005 DM, and 2005 PM translocations, respectively. We observed 80% (59/74) of the surviving and non-censored females on the lek in the second year after release. The peak male count for the only remaining active lek in 2006 was almost 4 times (135 M) the 6-year pretranslocation (1998 − 2003) average peak attendance of 36 males (range 24 − 50 M).

DISCUSSION

We followed the suggestions of Reese and Connelly (1997) to: 1) capture female sage-grouse on or near active leks at night during the lekking season, 2) transport captured females to the release site overnight and release them the morning after capture, and 3) release translocated grouse into a sagebrush habitat surrounded by mountains or other geomorphic barriers distant from the source population (220 km from PM and 150 km from DM). In addition, we placed a radio-transmitter on each female and released it near an active lek. One of the commonalities of failed

translocations seemed to be the timing of the release (Reese and Connelly 1997). Reese and Connelly (1997) reported that only one of the 52 translocations performed during the late summer—fall was successful, whereas 3 of the 4 translocations in the spring were successful. Generally, late summer—fall habitats are the most ubiquitous habitat type, which allows birds to be distributed across a much larger area than they would occupy during the winter or breeding seasons. Strong attraction to leks and breeding habitats makes success of translocations of sage-grouse more likely when performed during the display season (Emmons and Braun 1984, Berry and Eng 1985, Dunn and Braun 1985, and Gibson 1992, Reese and Connelly 1997). Our data show that releasing sage-grouse females onto a lek during the breeding season increased the potential for interaction with resident sage-grouse and promoted continued breeding behavior and attraction to the lek. During one release in 2004, we observed 4 females that flew out of the boxes and landed on the lek between strutting males.

Survival and reproduction are 2 of the largest factors associated with population persistence and are likely key to the success of a translocation (Johnson and Braun 1999, Millar 2001, De Leo et al. 2004). Musil et al. (1993) reported very low (0.36 ± 0.07) short-term survival (22 weeks postrelease) for sage-grouse that were translocated into a nearly extirpated population in Idaho. Whereas, annual survival of females translocated into the small remnant population (100-120) in Strawberry Valley averaged 60%, which was slightly lower than annual survival of resident female sage-grouse in Idaho (75%) and Wyoming (67%) but higher than other resident females in Wyoming (35 and 40% survival for yearlings and ad) and Colorado (55%; June 1963, Wallestad 1975, Zablan 1993, Connelly et al. 1994). There was some evidence that survival during the nesting season was lower than in other months. Of 20 females that were killed by predators during the nesting season, 10 were killed while on a nest. Some of the factors

that may have contributed to higher survival in our study included: release of females during the spring near an active lek, excellent year-round habitat, minimal handling time, and integration of translocated females with experienced resident sage-grouse (Bambrough 2002, Baxter 2003, Bunnell et al. 2004).

Although nesting propensity during the first year of translocations (39%) was lower than for resident females in Washington (99%), Oregon (78%), Wyoming (71%), and Idaho (68.6%), nesting propensity of translocated females in the second year after their release (73%) was comparable to most previous studies (Wallestad and Pyrah 1974, Gregg et al. 1991, Connelly et al. 1993, Schroeder 1997). We expected very little to no productivity during the initial year. Low first year nesting propensity may be due to one or a combination of the following factors that were beyond our control: timing of capture relative to the breeding phenology at the capture site (i.e. before or after peak M or F lek attendance and breeding or nest initiation prior to being captured), prelaying nutrition, stress associated with the translocation, and weather conditions on the day and time of release (Barnett and Crawford 1994). An increase in nesting propensity and nest success from first year translocated females to second year translocated females may be due to the shift in age class from yearlings to adults from year 1 to year 2.

We may have underestimated nesting attempts during our study for 2 reasons. First, we required visual observation of a female on a nest and could not determine if a female lost her nest during egg deposition (4-14 d) prior to incubation. Second, because of the large number of radiomarked females and the abrupt long distance movements made by some, we likely did not detect all nesting attempts.

Greater sage-grouse population declines are often related to poor nest success (Crawford and Lutz 1985, Gregg et al. 1994, Braun 1998, Schroeder et al. 1999). Schroeder et al. (1999)

compiled data from 14 studies (n = 1,328 nests) representing 7 states and found a combined observed nest success of 42.8%. In the Strawberry Valley, success for all nests of translocated females from 2003 to 2005 was much greater (68%; 66/97) than that of resident sage-grouse in other populations. Program MARK identified the nest date as a factor related to nest success. Females on nests found later in the nesting season were less successful than those found earlier. We did not measure embryo age, so there is potentially an unknown effect of nest age that may have contributed to declining nest survival later in the nesting season.

Nest and chick survival during the 2003 translocation year may have been low due to late winter snow storms. On 8 May 2003 a storm left 30.5 cm of snow on the valley floor and 9 days later on 17 May 2003 left another 12.7 cm. In Strawberry Valley, percent chick survival for all translocated females (2003 − 2005) was greater (51.8%) than in Idaho, Washington, or Canada (Schroeder 1997, Burkepile et al. 2001, Aldridge 2005). This may be due to constant predator (terrestrial and avian) control and the fact that unlike the aforementioned studies, we did not put radiotransmitters on chicks. Also, the mesic nature of the entire Strawberry Valley makes it a productive brooding-rearing habitat (Baxter 2003). Griner (1939) reported that all sites in the valley were <800 m from water, which is currently still the case.

Translocated sage-grouse can become integrated with the local sage-grouse population if released during the breeding season near leks in areas where sage-grouse are still extant. Our estimates of survival and reproductive effort were comparable to those of other populations across the species range and were sufficiently high to suggest that translocated birds could contribute to a local population increase. The large increase in displaying males on the lek is evidence of local population growth. Continued monitoring of survival, reproductive estimates, and lek attendance is needed to assess the long-term success of this translocation.

MANAGEMENT IMPLICATIONS

We suggest that wildlife managers not wait to translocate sage-grouse until local populations are at a level where stochastic events could result in extirpation. Translocations should occur during the breeding season and birds should be released near leks during the hours of breeding activity. We also suggest that sage-grouse be released into a sagebrush habitat surrounded by mountains or other geomorphic barriers distant from the source population (Reese and Connelly 1997). Additional research and efforts to translocate radiomarked sage-grouse are needed, across the species range, to provide wildlife managers with the best information regarding refinement of translocation techniques, optimal release sites, seasonal and annual movements, reproductive efforts, and habitat selection by translocated birds. Our study indicates that translocations can be an effective management tool to conserve and augment small declining populations of greater sage-grouse.

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Associate Editor:Hupp.

Table 1. Number of translocated female greater sage-grouse detected alive (A) and dead (D) at the end of each month in Strawberry

Valley, Utah from 2003 to 2006. PM represents Parker Mountain and DM represents Diamond Mountain.

Yr and source	No. of hens translocated	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
		A D	A D	A D	A D	A D	A D	A D	A D	A D	A D	A D	A D
2003 PM	36	34 2	30 4	29 1	28 1	27 1	26 1	23 3	22 1	20 2	19 1	19 0	18 1
2004 PM	34	30 4	27 3	26 1	25 1	24 1	21 3	20 1	19 1	19 0	18 1	16 2	16 0
2005 DM	34	34 0	31 3	27 4	27 0	25 2	25 0	24 1	24 0	24 0	23 1	21 2	20 1
2005 PM	33	32 1	29 3	25 4	25 0	22 3	22 0	22 0	22 0	21 1	21 0	21 0	20 1

Table 2. A priori models we used to determine the influence of time and ecological covariates on survival of translocated female greater sage-grouse in Strawberry Valley, Utah during 2003-2005.

Model[a]	K	AICc	ΔAIC_c	w_i	Deviance
$\{S_{(.)}\}$	1	441.611	0	0.2634	439.608
$\{S_{(.) + year}\}$	3	442.506	0.8953	0.1684	436.487
$\{S_{(NS) + (LB—F) + (W)}\}$	3	443.341	1.7302	0.1109	437.322
$\{S_{(.) + age}\}$	2	443.432	1.8208	0.1060	439.422
$\{S_{(.) + source}\}$	2	443.581	1.9705	0.0983	439.572
$\{S_{(NS) + (LB—F) + (W) + year}\}$	5	444.414	2.8027	0.0648	434.366
$\{S_{(.) + age + year}\}$	4	444.457	2.8457	0.0635	436.425
$\{S_{(NS) + (LB—F) + (W) + age}\}$	4	445.180	3.5688	0.0442	437.148
$\{S_{(.) + age + year + source}\}$	5	446.161	4.55	0.0270	436.113
$\{S_{(NS) + (LB—F) + (W) + age + year}\}$	6	446.374	4.7628	0.0243	434.307
$\{S_{(NS) + (LB—F) + (W) + age + year + source}\}$	7	448.091	6.4799	0.0103	434.001
$\{S_{(NS) + ncs}\}$	10	448.943	7.3322	0.0067	428.767
$\{S_{(NS) + ncs + year}\}$	12	450.084	8.473	0.0038	425.834
$\{S_{(NS) + ncs + age}\}$	11	450.808	9.1972	0.0026	428.597
$\{S_{(ncs)}\}$	12	451.429	9.8177	0.0019	427.178

{S(NS) + ncs + age + year}	13	452.068	10.4567	0.0014	425.775
{S(ncs) + year}	14	452.606	10.9954	0.0010	424.269
{S(ncs) + age}	13	453.303	11.6921	0.0007	427.011

[a] The temporal components of the models are defined as follows: (.) = constant survival across monthly intervals; (ncs) = no. of months of non-constant survival, where each time interval assumes a non-constant or independent rate of survival; (NS) = nesting season— early brood rearing (1 Apr to 30 Jun), (LB—F) = late brood rearing—fall (1 Jul to 30 Nov), and (W) = winter (1 Dec to 31 Mar), where we held survival constant during each of these ecologically meaningful time periods. The covariates in each model are as follows: age = age of the F upon release, source = source population where we captured bird, year = yr of release, constant = constant survival with no covariates.

Table 3. A priori models we used to determine the influence of ecological covariates on estimated daily nest survival of translocated greater sage-grouse in Strawberry Valley, Utah during 2003-2005.

Model[a]	K	AICc	ΔAIC_c	w_i	Deviance
{S$_{\text{date of nesting seaon}}$}	2	252.758	0.000	0.3094	248.750
{S$_{\text{age}}$}	2	254.230	1.473	0.1482	250.223
{S$_{\text{residency}}$}	2	254.749	1.992	0.1143	250.742
{S$_{\text{source}}$}	2	254.878	2.120	0.1072	250.870
{S$_{\text{constant}}$}	1	255.150	2.392	0.0936	253.147
{S$_{\text{year}}$}	3	255.386	2.628	0.0831	249.372
{S$_{\text{age + residency}}$}	3	255.740	2.982	0.0697	249.726
{S$_{\text{age + residency + source}}$}	4	256.582	3.825	0.0457	248.558
{S$_{\text{age + residency + year}}$}	5	257.501	4.744	0.0289	247.465

[a] The covariates are as follows: date of nesting season = date of the nesting season when we discovered nest, normalized to the first day of the nesting season; age = age of the female upon release; residency = no. of yr of residency since release; source = source population where we captured bird; year = yr of release; constant = constant daily survival with no effect of covariates.
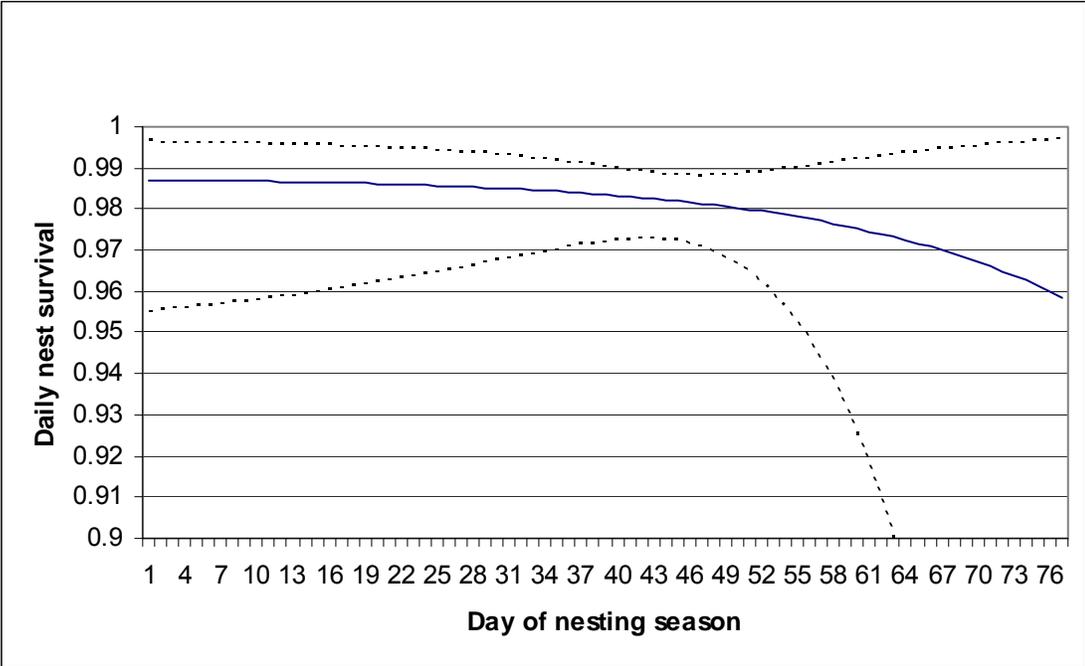
Figure 1. Daily nest survival probabilities and 95% confidence intervals (dotted lines) of translocated greater sage-grouse through the nesting season scaled by the earliest nest in Strawberry Valley, Utah, 2003-2005.
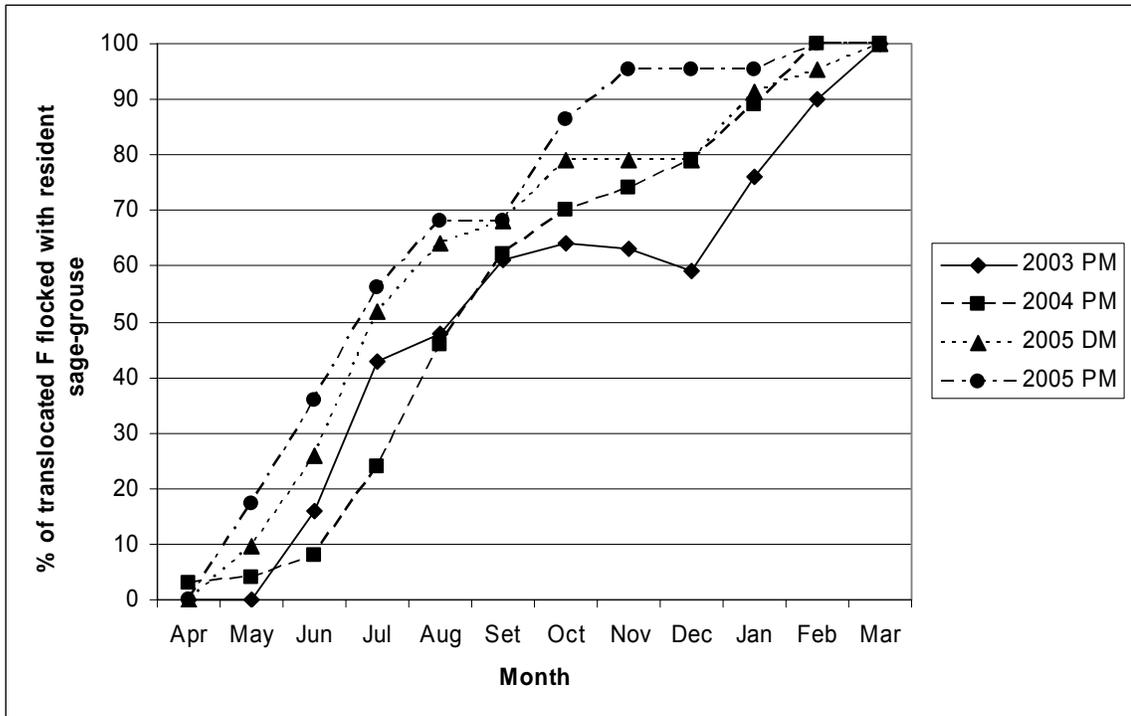
Figure 2. Percent of translocated female sage-grouse with active radio transmitters that were observed in flocks with resident sage-grouse by month for one year after release in Strawberry Valley, Utah from April 2003 to March 2006. We translocated Parker Mountain (PM) sage-grouse in all years but only translocated Diamond Mountain (DM) sage-grouse in 2005.

**Factors affecting nest site selection and nest success of translocated
greater sage-grouse in Strawberry Valley, Utah**

Introduction

Nesting habitat of resident greater sage-grouse (*Centrocercus urophasianus*) in
extant populations across the species range has been thoroughly described in the literature
(Moynahan et al. 2007, Hagen et al. 2005, Holloran et al. 2005, Popham and Gutierrez
2003, Connelly et al. 2000, Schroeder et al. 1999, and Connelly et al. 1991), yet very
little is known about the use of nesting habitat by translocated sage-grouse (Musil et al.
1994). Some of the most common causes of population decline across the species range
include habitat degradation, destruction, and fragmentation (Braun 1998 and Schroeder et
al. 1999) and reduced reproductive success (Schroeder 1997, Braun 1998, and Schroeder
et al. 1999). Connelly and Braun (1997) suggest that insufficient or unsuitable nesting
habitat could decrease nesting success. Others find that sagebrush canopy cover
(Holloran et al. 2005, Sveum et al. 1998, Fischer 1994) and residual and current year
grass cover (Svuem et al. 1998, Gregg et al. 1994, Connelly et al. 1994, and Wakkinen
1990) are related to nest success.

The objectives of our study were to describe the nesting habitat utilised by
translocated greater sage-grouse and to identify factors related to nest success. We
described habitat variables selected by translocated grouse and compared them to the
sage-grouse management guidelines (Connelly et al. 2000). We used fourth order habitat
selection (Johnson 1980) to compare nest sites to paired-random sites and successful to
unsuccessful nest sites.

Materials and methods

Core release area

The study area was centered in the Strawberry Valley (SV) of north-central Utah (UTM 0492078/4445216). The area is characterised as a montane sagebrush steppe with mountain big sagebrush (*Artemesia tridentata vaseyana*) as the predominant shrub; silver sagebrush (*A. cana*) is found in less abundance in wet meadows and riparian areas. The valley is approximately 24 km long and 8-9 km wide and characterised by mountain ridges and high mountain meadows with elevations ranging from 2250 to 2600 m. The valley experiences cool dry summers and cold wet winters. Average annual precipitation is about 58 cm. Strawberry Reservoir is the most dominant feature of the valley covering 6950 ha of historical riparian and sagebrush steppe habitat. Over 9000 ha of sagebrush habitat remain for sage-grouse use.

Translocation (source) capture areas

Parker Mountain (PM) is located in south central Utah. It is characterised by black sage (*A. nova*) on the ridges and slopes with big sagebrush (*A. tridentata*), bitterbrush (*Purshia tridentata*), and rabbitbrush (*Chrsyothamnus viscidiflorus)* found in drainages. Elevation ranges from 2140 to 3000 m. The terrain is marked by rolling hills and plateaus that gently slope to the north and east. Parker Mountain has hot dry summers with precipitation accumulating in the fall and winter (Jarvis 1973).

Diamond Mountain (DM) is located about 40 km north east of Vernal, Utah in extreme northeastern Utah. The dominant vegetative community is big sagebrush with a mixture of perennial grasses and forbs in the understory (Ralphs and Busby 1979). The elevation ranges from 2130 to 2550 m. The terrain is marked by a high mountain plateau that gently slopes to the south. Average annual precipitation ranges between 51 and 61 cm (Ralphs and Busby 1979, Laycock and Conrad 1981).

Dry Basin is located in Box Elder County (BEC) in northwestern Utah. It is dominated by big and black sagebrush. The understory consists of grasses in the generas, *Agropyron*, *Elymus*, and *Poa* spp., with the most common forb genera being, *Phlox*, *Astragalus*, and *Lupine*. Elevation ranges from 1500 to 2100 m. Grazing by cattle and sheep is the primary range use (Knerr and Messmer 2005).

Deseret Land and Livestock (DLL) is a 400 km^2 privately owned ranch located mostly in Utah along the northeast border with Wyoming, near Evanston. The primary use of the ranch is cattle and sheep grazing. Elevations range from 1920 to 2650 m. The habitat is characterised by Wyoming big sagebrush (*A. t. wyomingensis*), with crested wheatgrass (*A. cristatum*), needle-and-thread grass (*Stipa comata*), Indian rice grass (*Oryzopsis hymenoides*), and western wheatgrass (*A. smithii*) in the understory (Bromley and Gese 2001). Average annual precipitation totals 27.6 cm, with most precipitation coming during the winter.

Field methods

We trapped greater sage-grouse (Baxter et al. 2008) from source populations in the state of Utah. Those source populations were designated stable by the Utah Division of Wildlife Resources (UDWR) because population estimates totaled ≥500 breeding birds for three consecutive years. These populations were chosen because of their robust size, their distance from the release site, and their behavioral (Barber 1991) and genetic compatibility (Oyler-McCance et al. 2005) with resident Strawberry Valley sage-grouse. We began capturing female sage-grouse from pickup trucks and all-terrain vehicles on and near leks in late March and April at night, about two hours after sunset, (2100 hr to 0200 hr) using a modified spotlight method (Wakkinen et al 1992). We transported,

attached radio-transmitters, and released them as reported by Baxter et al. (2008). Animals were handled according to the techniques approved by the Institutional Animal Care and Use Committee (Project code: 05-0301) of Brigham Young University.

We tracked all hens via radio telemetry from the ground using a 4-element Yagi antenna and an R-1000 digital radio receiver (Communication Specialists Incorporated, Orange, CA) to monitor and record use of nesting habitat and reproductive estimates. Periodic flights were taken in fixed-wing aircraft to locate radio-collared birds ($\bar{x} = 8$ flights/year). All locations were recorded in a Global Positioning System (GPS) unit in Universal Transverse Mercator (UTM) coordinates. We searched for radio-marked grouse within an 80 km radius of the release site and believe we would have detected any females with active transmitters that departed Strawberry Valley following translocation. Monitoring movements of resident and translocated radio-collared hens began between one and ten days post-release. Hens were located on nests via radio telemetry and each nest site was verified with a visual confirmation.

We collected habitat data, as described by Bunnell et al. (2004), on a macro and micro-habitat level at nest and paired-random sites. Macro-habitat data collected included UTM coordinates, slope, aspect, distance to habitat edge, shrub canopy cover by species, average herbaceous cover and species diversity. Micro-habitat data were collected at the nest site using a $0.25m^2$ quadrat. Data collected included shrub height, shrub crown area, distance and species of the closest shrub to the use site, herbaceous understory cover and diversity, and vertical and horizontal obscurity cover.

A compass with a clinometer was used to determine slope and aspect. Distance to habitat edge was measured from the nest site or paired-random site to the nearest

different habitat type. Live shrub canopy cover was measured and recorded by species according to the line intercept method (Bonham 1989) along two perpendicular 50m transects that intersected at the nest or micro-site. Using a T^2 analysis (Ludwig and Reynolds 1988), we measured the distance to the closest shrub from the nest site and the closest neighboring shrub to the first shrub. The process was repeated measuring the next closest shrub from the nest site and the closest neighboring shrub. Average shrub height and shrub crown area were calculated for all shrubs in the T^2 analysis. We estimated shrub crown area by taking two measurements of shrub crown diameter, the first length being the longest axis in the crown and the second measurement being the longest, perpendicular to the first. The area of an ellipse was determined from those measurements (Bunnell 2004). Ocular estimation was used to measure herbaceous understory cover by genus or species at the nest site (micro-site) and at both ends of each 50m transect. Frequency and diversity values were calculated from the species recorded in all understory quadrats.

Horizontal obscurity cover was estimated using a $1m^2$ cover board divided into 36 equal squares (Bunnell 2004). The cover board was positioned at 2.5, 5, and 10m from the nest site in the four cardinal directions and read at the average height of a sage-grouse (36cm). We considered a square obscured if any object or vegetation penetrated its perimeter. The number of squares obscured was recorded for each distance and direction. Vertical cover was read by placing an 18 cm^2 cover board divided into 36 equal squares on the ground at the nest site. We recorded the number of squares obscured when looking directly down on (90 degrees) the cover board.

After locating the nest, we monitored all nesting females two to four times a week, from a distance, thereby minimising disturbance. All nesting occurred from April 1 to July 15. Nest fate for each female was assessed after she was no longer detected at the nest site. A nest was considered successful if at least one egg hatched. Egg shells with a detached membrane (Klebenow 1969) and/or visual observation of a female with a brood were used to determine nest success. A nest was considered depredated if no eggs hatched and at least one egg was found punctured, crushed, or missing or if the female was found dead on or near the nest. Nest desertion was assumed if a female did not return to a formerly incubated nest after ≥24 hours.

A predator management program, administered by the United States Department of Agriculture (USDA) Wildlife Services (WS), began in 1999 and has continued through 2007. The purpose was to reduce numbers of red fox (*Vulpes vulpes*; Bunnell 2000) and coyotes (*Canis latrans*) in the study area. In addition, from 2003 to 2007, Wildlife Services used poison egg baits to control common raven (*Corvus corvax*) and black-billed magpies (*Pica pica*) during the breeding, nesting, and brood-rearing seasons. This may or may not have affected our results.

Data analysis

Logistic regression was used to identify habitat variables that discriminated between nest and paired-random sites and between successful and unsuccessful nest sites. Our *a priori* models represented hypotheses that were consistent with well known nesting habitat variables published in the sage-grouse literature, as well as new hypotheses specific to our study site and design. Prior to building our models, we tested pairs of variables with a Pearson correlation coefficient. One variable of each pair was eliminated

if the Pearson correlation coefficient (r) ≥ 0.7. We constructed 16 models to discriminate between nests and paired random sites and 13 models to discriminate between successful and unsuccessful nest sites. The variables used included: slope, aspect, crown area of the closest shrub (CA), total shrub cover (TSC), average sagebrush height (ASH), horizontal obscurity cover (HO), vertical cover (VC), grass cover at the nest site (GC), and height of the closest shrub (SH). We did not include a year or age effect because earlier research on the same project (Baxter et al. 2008) showed no statistical difference in daily nest survival using Program MARK (White and Burnham 1999) during the first three years of translocations. Some selected interactions were included that we believed would identify relationships between vegetative and/or abiotic factors explaining variation between nest and paired-random sites and between successful and unsuccessful nest sites. In addition, we tried to minimise the number of variables included in each model in order to accurately predict parameter estimates (Hosmer and Lemeshow 1989). The bias-corrected Akaike's Information Criterion (AIC_c) was used to account for small sample size, and Akaike weights (w_i) were used to select the best candidate model (Burnham and Anderson 2002). Our nest sites were independent. We reported all models with a ΔAIC ≤8. Relative variable importance was calculated by summing Akaike weights across all models in the candidate set that contain that variable (Hosmer and Lemeshow 1998). We used the le Cessie-van Houwelingen global goodness-of-fit statistic (le Cessie & van Houwelingen 1991) recommended by Hosmer et al. (1997) to verify whether each model fit the data.

Through initial exploratory analysis, we discovered that the placement of our vertical cover board at a number of paired-random sites was not comparable with vertical

cover at nest sites. Vertical cover at all but six nest sites was identically 1.0. Of those six, only two sites had vertical cover less than 0.9 (Fig. 1). In order to make valid comparisons, the nest versus paired-random site analysis was conditioned on vertical cover being greater than 0.9. In other words, we removed from consideration the two nest sites and any paired-random sites with vertical cover values less than 0.9. In comparing successful and unsuccessful nest sites, vertical cover was included without conditioning.

A graph of probability contours was created based on crown area of the nest shrub and percent grass cover to show the relationship between shrub crown size and percent grass cover in predicting the probability of a nest site. In addition, the probability of nest success was plotted against aspect in the successful versus unsuccessful nest analysis. Holding all variables associated with the best model at their mean values, we plotted predicted nest success at each of the eight major compass directions corresponding to our aspect values in order to identify any aspects that were more or less likely to succeed. All statistical tests were considered significant at an alpha level of 0.05.

Results

We translocated a total of 375 greater sage-grouse females from 2003 through 2007. During those translocation events, four females injured themselves while in the box and were euthanised, one was injured during the capture phase, but was still transported to Strawberry Valley and had to be euthanised at the release site, one was killed by a golden eagle within seconds of leaving the box, and two slipped radio-collars inside the box before being released. An additional five females were dropped from the sample because they died within the first 14 days post-release. We considered these mortalities capture myopathy related due to their close proximity to the release site and evidence

found at each mortality site. In 2006 and 2007 there were 15 and 17 transmitters respectively that malfunctioned and those females were not included in our sample. Only two females left the study area; both were not located until after the nesting season was over and were therefore not included in our sample. One of those females was found alive in a residential metropolitan area and was later euthanised; the other female was located in suitable sage-grouse habitat east of the study area. This made our effective sample size 328.

We documented 143 nesting attempts. Only two renesting attempts (one success and one failure) were noted, both were not included in our analyses to maintain independence. Observed nesting propensity for all translocated females was 38% (adults 45% [SE = 9.6] and yearlings 30% [SE = 6.0]). Observed nest success averaged 66% (adults 69% [SE = 7.2] and yearlings 60% [SE = 7.9]). Clutch size ranged from 2-12, with a mean of 5.9 (SE = 0.2) eggs per clutch. Embryo viability for successful nests was 96.8%.

Habitat data were not collected on 37 nesting attempts in 2006. In addition we also excluded seven nest sites that we could not access due to private property rights, seven nest sites that were abandoned due to observer error, and five nest sites where success was undetermined. We used 87 nest sites (successful nests $n = 59$ and unsuccessful nests $n = 28$) and 87 paired-random sites for our habitat analyses (Table 1).

We found 85% ($n = 50$) and 89% ($n = 25$) of all successful and unsuccessful nests under sagebrush. Mean distance between the lek/release site and all translocated female nest sites was 6.47 km (SE = 0.65, Range 0.25 – 27.36 km). Successful and unsuccessful nest sites were an average of 5.98 km (SE = 0.71) and 7.51 km (SE = 1.33) from the

lek/release site respectively. The median distance for all nests was 3.24 km (successful

nests = 3.07 and unsuccessful nests = 3.55), demonstrating that a few hens in each

category accounted for a large portion of the variation.

Nests versus paired-random model selection

The best approximating model (AIC_c w_i= 0.7694) for the nest versus paired-

random site analysis contained the variable crown area of the closest shrub (CA) and

grass cover (GC; Table 2). The next best model (AIC_c w_i = 0.0504) contained the variable

crown area of the closest shrub (CA). Only the best model of our 16 candidate models

had a ΔAIC_c $\leq$ 4. Crown area was in five of the top seven models. The le Cessie-van

Houwelingen global goodness-of-fit tests showed that all candidate models with a ΔAIC_c

$\leq$8 statistically fit the data. Relative importance of each variable was as follows: crown

area of the closest shrub (0.93), grass cover (0.83), total shrub canopy cover (0.10),

horizontal obscurity cover (0.05), aspect (0.05), slope (0.05), average sagebrush height

(0.04), and height of the nest shrub (0.04). Models that contained the variables average

shrub height, horizontal obscurity cover, slope, aspect, and height of the nest shrub, as

well as any model with multiplicative interactions did not perform well.

When predicting nest sites, parameter estimates for crown area of the closest

shrub and grass cover from the best model were -0.0003 and 0.0718 respectively (Table

3). We graphed the probability that a sagebrush site in Strawberry Valley would be a nest

site given the crown area of the closest shrub and the percent grass cover in the

herbaceous understory (Fig. 2). Mean crown area was significantly (Z = -2.547; P-value

= 0.014) greater at nest sites (5117 cm^2; SE = 520) than at paired-random sites (1486

cm^2; SE = 239). Also, average percent grass cover at nest sites ($\bar{x}$ = 9.20; SE = 0.80) was

significantly ($Z = 2.447$; *P*-value $= 0.014$) less than at paired-random sites ($\bar{x} = 15.37$; SE $= 1.69$).

Successful versus Unsuccessful nest site model selection

The most parsimonious model predicting nest fate contained the variables crown area of the closest shrub, total shrub canopy cover, slope, and aspect (Table 4). The AIC_c weight was 0.8240, 17 times better than the second best model of crown area of the closest shrub and average shrub height (AIC_c weight $= 0.0479$). The le Cessie-van Houwelingen global goodness-of-fit tests showed that all candidate models with a ΔAIC_c ≤ 8 statistically fit the data. Crown area of the closest shrub was significantly ($Z = -2.46$; p-value 0.014) smaller at successful nests ($\bar{x} = 4497$ SE $= 530$) than at unsuccessful nest sites ($\bar{x} = 6424$ SE $= 1125$).

Relative importance of each variable was as follows: crown area of the closest shrub (0.96), total shrub canopy cover (0.86), slope (0.86), aspect (0.83), average sagebrush height (0.07), horizontal obscurity cover (0.01), vertical cover (<0.01), grass cover (<0.01), and height of the nest shrub (<0.01). There was almost no support for models that included the following variables and/or interactions: average sagebrush height, horizontal obscurity cover, vertical cover, grass cover, height of the nest shrub, slope*aspect, grass cover*height of nest shrub, and average shrub height*vertical cover.

Estimates for all parameters of the most parsimonious model were significant (Table 3). Successful hens nested on steeper slopes ($\bar{x} = 7.71$, SE $= 0.78$) than unsuccessful hens ($\bar{x} = 5.93$, SE $= 0.81$), and they utilised a relatively normal distribution of aspects. Unsuccessful hens used aspect disproportionate to its availability ($\chi_7^1 = 13.54$, $P = 0.05$). While holding all variables in the top model to their mean except

aspect, results showed that the probability of a successful nest decreased along a NW-SE gradient, while all other aspects were not significantly different from one another (Fig. 3).

Discussion

Nest site selection

Translocated greater sage-grouse females in Strawberry Valley selected nest sites with shrubs that had larger crown areas and less grass cover in the herbaceous understory than paired-random sites. Parameter estimates from our logistic regression model showed a positive effect associated with crown area, while percent grass cover had a negative effect. The best approximating model received more than 15 times the AIC_c weight of the next best model, suggesting high model selection certainty (Burnham and Anderson 2002). Our results were similar to Wakkinen (1990) and Fischer (1994), who demonstrated that crown area of the closest shrub at native sage-grouse nest sites was greater than at random sites. Although not included in our best model, translocated females also selected nest sites with slightly higher shrub canopy cover and horizontal obscurity cover. Other studies of resident sage-grouse have also reported the importance of shrub canopy cover (Holloran et al. 2005, Sveum et al. 1998, Fischer 1994, Klebenow 1969) and grass cover (Holloran et al. 2005, Gregg et al. 1994, Connelly et al. 1994, and Wakkinen 1990) in nest site selection.

Lower percent grass cover at translocated female nest sites may be a function of competition for light, water, and resources, by larger more dense shrubs associated with increased shrub canopy cover and larger crown areas rather than selection by sage-grouse for less grass cover. Grass cover averaged 9.2% at translocated nest sites in Strawberry Valley, greater than found at resident nest sites in Wyoming (Holloran et al. 2005) and

Colorado (Hausleitner 2003), but much less than resident nest sites in Alberta Canada (Aldridge and Brigham 2002), Washington (Sveum et al. 1998), Oregon (Gregg 1991), and California (Popham and Gutierrez 2005). Other researchers found that taller residual and current year's grasses distinguished between resident nest sites and random sites (Wakkinen 1990 and Holloran 1999). Since a large proportion of translocated nesting grouse were successful, we believed that grass cover at nest sites in Strawberry Valley was sufficient for obscuring incubating grouse; although this may not be the case since Aldridge and Brigham (2002) found no correlation between grass cover and grass height in Alberta Canada. We did not begin measuring current year or residual grass height until midway through the study, so we excluded it from our modeling exercise. However, we did record the genera of grasses associated with nest and paired-random sites. Those genera included *Poa*, *Elymus*, *Stipa*, and *Festuca* spp., and they had a combined average height of >30 cm.

Successful vs Unsuccessful nest sites

Translocated greater sage-grouse that nested successfully were found under sagebrush with a smaller crown area, in higher total shrub canopy cover, and on steeper slopes than unsuccessful nests. Unsuccessful females nested under sagebrush with crowns almost 2000 cm^2 larger than successful nests. Paired-random or non-nest sites from the conditional analysis were on average 2000 cm^2 smaller than successful nest sites. In contrast, Wakkinen (1990) and Fischer (1994) found no difference between crown area of the closest shrub at successful and unsuccessful nest sites. It appears that in Strawberry Valley there may be an optimal size of shrub crown area or that shrub crown

area in the presence of greater total shrub canopy cover, steeper slopes, and a favorable aspect provide a greater probability of nesting success.

In addition, and similar to other studies with native sage-grouse (Holloran et al. 2005, Fischer 1994, Klebenow 1969), total shrub canopy cover was greater at successful nest sites (32%) than at unsuccessful (29%). An earlier study of native greater sage-grouse in Strawberry Valley (Griner 1939) reported nests under canopy cover ranging from <15% to >50%. Other studies of native birds in Montana (Wallestad and Pyrah 1974; 27%), Oregon (Gregg 1991; 56% and 51%), Alberta (Aldridge and Brigham 2002; 32%), and Washington (Sveum et al. 1998; 51% and 59%) had high shrub canopy cover demonstrating that the ecological relationships of each meta-population and study area are site-specific and that application of a single standard management guideline (Connelly et al. 2000) to different areas is questionable.

In our study, slope was greater at successful nest sites ($\bar{x} = 7.7$) than at unsuccessful ($\bar{x} = 5.9$) and was included in the best model. With the exception of Wakkinen (1990) who found no difference between slope at successful and unsuccessful nest sites of native birds, no other studies addressed that factor. Strawberry Valley is somewhat unique in that it has highly variable topography with very few large flat areas or gently sloping plateaus. Grouse may have selected steeper slopes based on unknown behaviors or habitat factors or simply because slopes may increase their ability to see avian and terrestrial predators from greater distances.

Aspect was also included in our best approximating model predicting nest success. We currently have no biological explanation for the decreased probability of nest success on NW and SE aspects. Probabilities of nest success at all other aspects were not

statistically different from each other in Strawberry Valley. Wakkinen (1990) studied

resident sage-grouse and found no difference in aspect between successful nests,

unsuccessful nests, and random sites. A more accurate measurement may be solar

radiation factors calculated via GIS software.

We used an information theoretic approach, coupled with relative variable

importance estimates and the le Cessie-van Houwelingen global goodness-of-fit statistic

(le Cessie & van Houwelingen 1991) to substantiate our results. Each model fit the data

in our analyses. In addition, we had one model in each of the nest versus paired-random

and successful versus unsuccessful regression analyses that was significantly better than

the other models. The large AIC_c weights associated with the best models suggested high

model selection certainty. Translocated greater sage-grouse nest site selection may be

influenced by factors not included in our analyses such as precipitation, grass height,

female age, and year effects. We did not include female age or year effects because prior

research (Baxter et al. 2008) showed that neither had any effect on daily nest survival

rates. In addition, predator control was constant throughout the study period and may

have influenced female survival and/or nest depredation. The spatial scale and vegetative

study design, along with all these other factors should be taken into consideration when

making inferences from our data set.

Translocated greater sage-grouse selected nest sites that were similar to those

selected by resident grouse throughout the species range. Nest sites were characterised by

nest shrubs with larger crown area, less grass cover, greater total shrub canopy cover, and

greater horizontal obscurity cover than paired-random sites. Successful nest sites were

characterised by greater total shrub canopy cover, medium-sized nest shrub crown area,

and steeper slopes than unsuccessful nest sites. Successful grouse were more likely to nest closer to the lek/release site, but were less likely to successfully nest on NW and SE aspects. Our data suggest that greater sage-grouse can be translocated from distant allopatric populations and still initiate a nest, nest successfully, and select habitat variables similar to what other resident sage-grouse select across the species range.

Managers and researchers interested in preserving and enhancing sage-grouse nesting habitat should protect areas with greater total shrub canopy cover, shrubs with larger crown areas, and moderately low amounts of grass cover. Vegetative structure representing adequate amounts of vertical and horizontal obscurity cover appear crucial. Mechanical, herbicide, or other (i.e. fire) rangeland treatments in nesting habitat may negatively affect nest success by diminishing obscurity cover. Further, managers of greater sage-grouse habitat should address actual habitat requirements needed for their own sage-grouse meta-population. Blanket use of the sage-grouse management guidelines (Connelly et al. 2000) for managing nesting habitats may not provide optimal vegetative structure relative to site specific sage-grouse populations. Finally, if wildlife and land managers translocate sage-grouse for population augmentation, they must monitor the released birds in order to document movements, survival, reproductive parameters, and habitat requirements, and thus be able to assess translocation success.

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Table 1. These summarised data for translocated greater sage-grouse allow quick

comparisons of mean values for biotic and abiotic variables measured at successful and

unsuccessful nest sites as well as the same conditional data on paired-random sites in

Strawberry Valley, Utah, USA, during 2003-2007.

					Conditional	
	Successful		Unsuccessful		paired-random	
	nests (n=59)		nests (n=28)		sites (n=25)	
Variable	Mean	SE	Mean	SE	Mean	SE
Slope	7.71	0.78	5.93	0.81	4.40	0.65
Edge	132	17	118	26	126	28
Vertical cover	0.98	0.01	0.99	0.00	0.99	0.00
Crown area of nest shrub	4497	530	6424	1145	2413	483
Horizontal obscurity cover	0.94	0.02	0.95	0.01	0.92	0.04
Height of nest shrub	58.15	2.51	55.64	3.29	50.10	4.60
Average shrub height	52.56	1.93	47.63	2.74	44.90	3.30
% sagebrush in shrub canopy cover	0.70	0.03	0.75	0.05	0.74	0.06
Total shrub canopy cover	0.32	0.01	0.29	0.02	0.31	0.02
Grass cover	9.32	1.00	8.93	1.31	14.90	2.70
Forb cover	4.37	0.87	3.96	0.81	10.70	2.20
Bare ground	11.40	1.49	14.54	1.49	10.70	2.20
Litter	47.21	1.66	44.28	2.81	46.10	2.60

Table 2. Here listed are the logistic regression models used to predict translocated greater

sage-grouse nest sites (n=87) from paired-random sites (n=87) using biotic and abiotic

variables collected in Strawberry Valley, Utah, USA, during 2003-2007. All Akaike's

Information Criterion scores are adjusted for small sample size (AIC_c), difference in AIC

(ΔAIC_c), Akaike weights (w_i), Hosmer-Lemeshow goodness-of-fit statistic (Z) and

corresponding P-value. The models with a $\Delta AIC_c \leq 8$ are presented.

Model[a]	AIC_c	ΔAIC_c	w_i	Z	p-value
CA + GC	106.2	0.0	0.7694	1.044	0.297
CA	111.6	5.5	0.0504	0.174	0.862
CA + TSC + Slope + Aspect	111.8	5.6	0.0457	0.320	0.749
SH + GC	112.4	6.3	0.0338	0.468	0.640
CA + HO	112.5	6.3	0.0331	0.733	0.464
TSC + ASH + GC	113.3	7.1	0.0221	0.511	0.609
CA + TSC	113.7	7.5	0.0179	0.172	0.864

[a]Variable abbreviations included in candidate models are as follows: CA=crown area of

the closest shrub, GC=grass cover, TSC=total shrub canopy cover, SH=shrub height,

HO=horizontal obscurity cover, ASH= average shrub height, slope and aspect.

Table 3. For translocated greater sage-grouse, these data include estimates of maximum likelihood and their associated standard errors (SE), Z-statistic, and P-values documenting statistical differences between variables from the best approximating model of the nest versus paired-random site and successful versus unsuccessful nest site analyses.

Variable[a]	Estimate	SE	Z	P-value
Nest sites vs Paired-random sites				
Intercept	-1.1114	0.4462	2.490	0.0128
CA	-0.0003	0.0001	2.720	0.0065
GC	0.0718	0.0289	2.480	0.0130
Successful vs Unsuccessful nest sites				
Intercept	0.8873	1.3010	0.680	0.4954
Slope	0.1231	0.0617	2.000	0.0460
Aspect=N	-1.4637	1.7280	0.850	0.3969
Aspect=NE	7.4106	31.5100	0.240	0.8141
Aspect=NW	-3.7872	1.6280	2.330	0.0200
Aspect=S	-1.5066	1.3240	1.140	0.2550
Aspect=SE	-3.2632	1.3490	2.420	0.0155
Aspect=SW	-1.9133	1.4090	1.360	0.1745
Aspect=W	-1.2488	1.4600	0.860	0.3922

CA	-0.0001	0.0001	2.460	0.0138
TSC	5.8511	2.8530	2.050	0.0403

[a]Variable abbreviations are as follows: CA=crown area of the nest shrub, GC=grass cover, TSC=total shrub canopy cover, aspect directions include the 8 cardinal directions.

Table 4. Logistic regression models were used to predict successful (n=59) and

unsuccessful (n=28) nest sites of translocated greater sage-grouse using biotic and abiotic

variables collected in Strawberry Valley, Utah, USA, during 2003-2007. Also included are

Akaike's Information Criterion scores adjusted for small sample size (AIC_c), difference in

AIC (ΔAIC_c), Akaike weights (w_i), Hosmer-Lemeshow goodness-of-fit statistic (Z) and

corresponding P-value. Note that models with a $\Delta AIC_c \leq 8$ are shown.

Model[a]	AIC_c	ΔAIC_c	w_i	Z	P-value
Slope + Aspect + CA + TSC	103.6	0.0	0.8240	0.965	0.334
CA + ASH	109.3	5.7	0.0465	-0.043	0.966
Slope + CA	110.2	6.6	0.0298	1.236	0.216
CA	110.4	6.8	0.0265	-0.262	0.793
CA + ASH + TSC	110.7	7.1	0.0235	-0.464	0.643
ASH	111.2	7.6	0.0183	-0.170	0.865

[a]Variable abbreviations included in candidate models are as follows: CA=crown area of

the nest shrub, TSC=total shrub canopy cover, SH=shrub height, ASH= average shrub

height, slope and aspect.
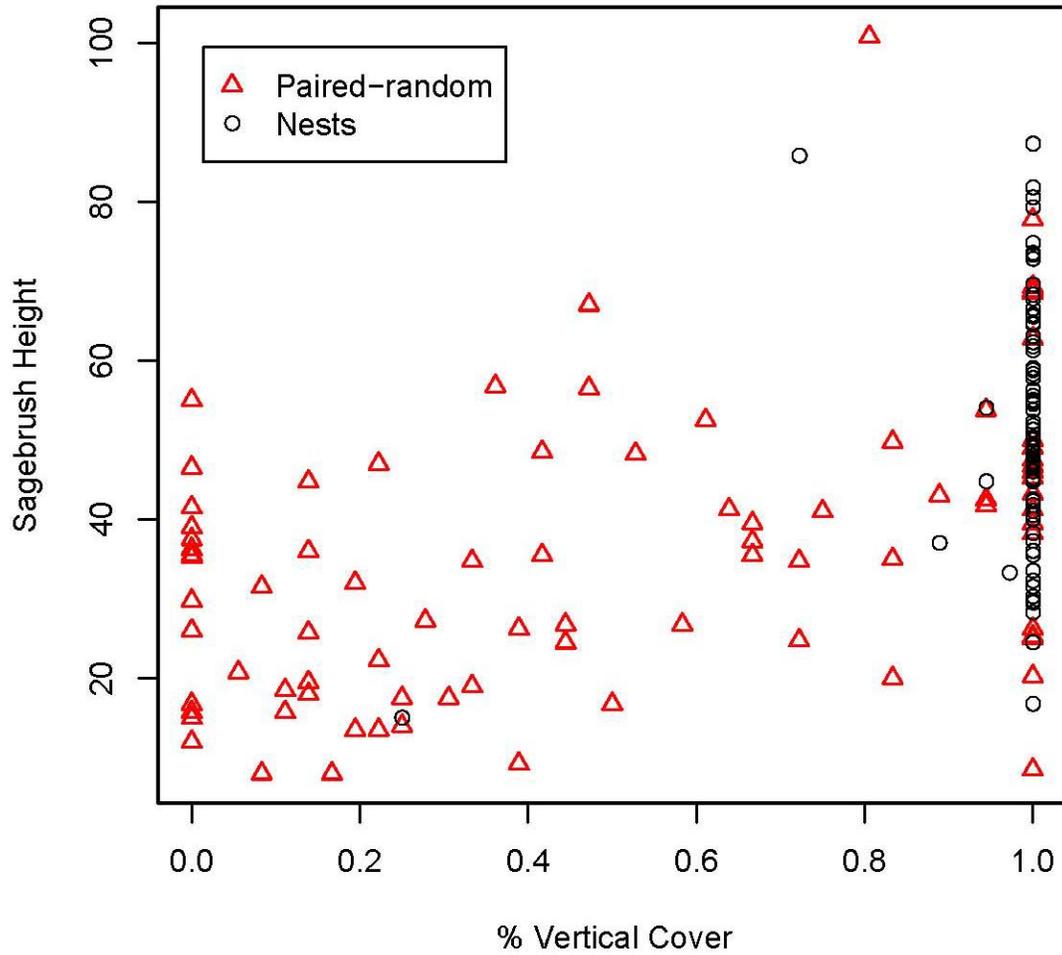
Figure 1. For translocated greater sage-grouse, this comparison shows percent vertical cover over nests (circles) and paired-random (triangles) sites in Strawberry Valley, Utah, USA, during 2003-2007.
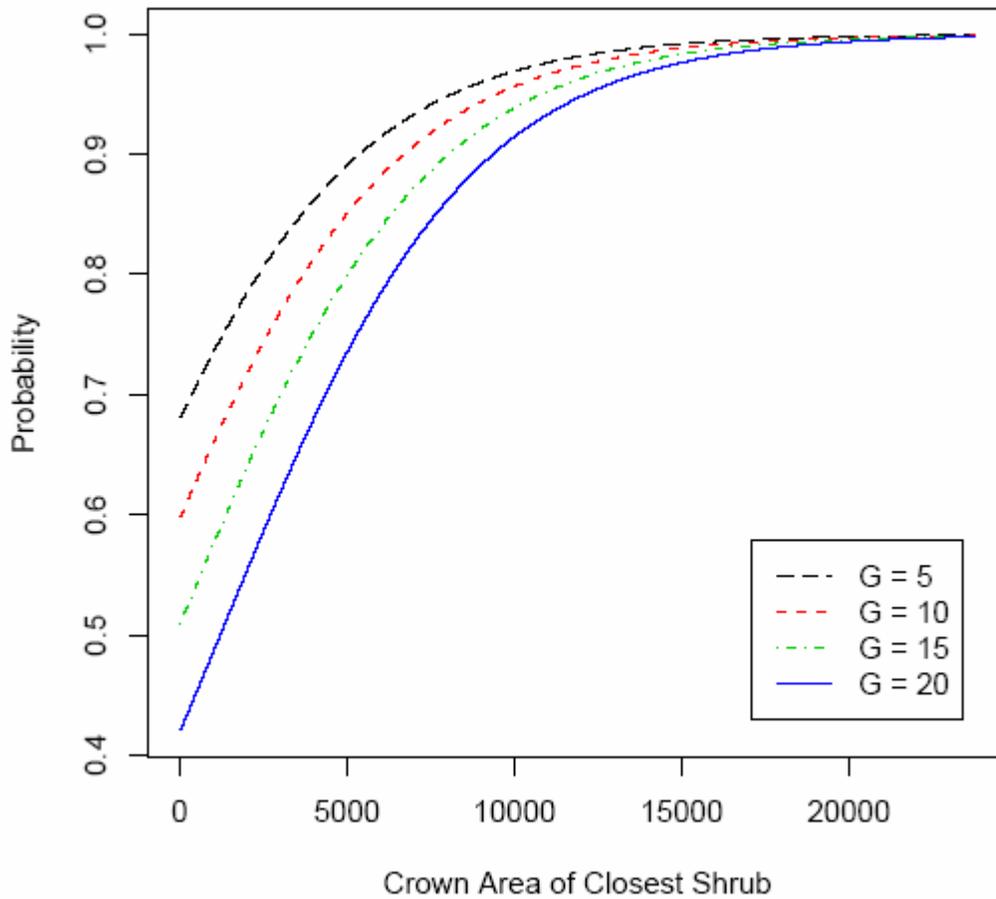
Figure 2. These curves represent the probability that a site in Strawberry

Valley, Utah, USA (2003-2007) would be a translocated female nest site given

the crown area of the closest shrub and percent grass cover in the herbaceous

understory. Percent grass cover is represented by the letter G (i.e. G = 5, G = 10).
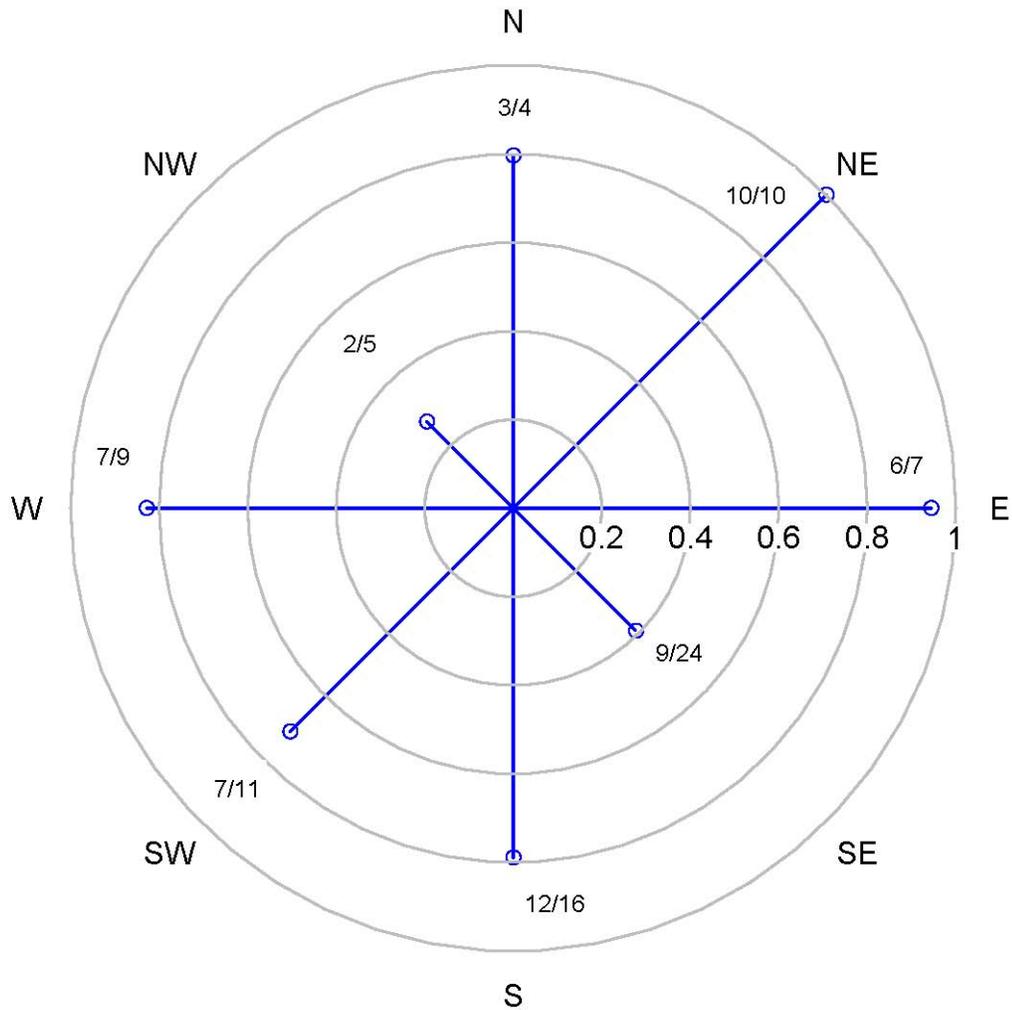
Figure 3. Displayed here are the probabilities of nest success for translocated greater
sage-grouse in relationship to one of the major aspects in Strawberry Valley, Utah, USA,
during 2003-2007. Nest relationships with NW and SE aspects were signficantly different
from nests in all other aspects.

Equivalence testing for assessing the success of
species translocation in a fragmented habitat

Introduction

Equivalence tests are well used and described in fields such as chemistry

(Limentani et al. 2005), pharmacology (Van Steen et al. 2005), and medicine (Cleophas

2002, and Liu et al. 2002), yet in the field of wildlife ecology equivalence tests have been

largely underutilized (Robinson and Froese 2004). Mistakenly, many researchers using

traditional hypothesis testing have concluded that two groups are the same based on

failure to reject a null hypothesis of no difference. The absence of evidence against the

null hypothesis is not sufficient reason for concluding that the null is true (Altman &

Bland 1995). In our study, we use equivalence testing to compare movements of

translocated and resident greater sage-grouse (*Centrocercus urophasianus*) in a

fragmented landscape as a metric for assessing preliminary success of a translocation.

Translocation Success

Translocations of animals to augment a resident population are costly, time

consuming, and at times politically charged. Translocation decisions may be determined

more by whether the effort is socially acceptable rather than scientifically feasible

(Conover 2002). Furthermore, determining the success of such efforts may take years,

depending perhaps in part on the definition of success. However, persistence of

translocated animals in suitable habitat of the resident meta-population boundaries is a

requisite condition for success.

In addition, high quality habitat with minimum fragmentation is essential to

translocation success (Griffith et al. 1989), because large contiguous habitats can provide

all necessary life history requirements thus decreasing the need to emigrate in search of these biological necessities. Other criteria for judging translocation success include population persistence (Griffith et al. 1989, Wolf et al. 1996), site fidelity (Moehrenschlager & Macdonald 2003), survival (Baxter et al. 2008), and reproduction (Musil et al. 1993). Wolf et al. (1996), in a reevaluation of a meta-analysis by Griffith et al. (1989), report that successful avian translocation programs are dependent upon the number of animals released, whether released in core suitable habitat, and whether the species is native or threatened/endangered.

Unfortunately, many early translocation and reintroduction programs suffered from poor study design, precluding rigorous hypothesis testing, data collection, and justification of funding (Seddon et al. 2007, Haight et al. 2000). In a survey sent to all 50 state wildlife agencies in 1985, Boyer and Brown (1988) found that the principal factors for either failing to increase the number of translocations or discontinuing translocations altogether were cost, available funding, and manpower. In particular, large initial costs, plus generally higher mortality rates associated with translocations, create expensive high-risk research. Often translocation programs are discontinued after the first or second year if animals cannot persist in the area (DeNicola et al. 1997). Determining site fidelity is an important first step in measuring translocation success.

Habitat Fragmentation

Habitat fragmentation has received much attention during the past few decades (e.g., MacArthur & Wilson 1967, Saunders et al. 1991, Knick & Rotenberry 1995, Debinski & Holt 2000). Fragmentation results in both decreased patch size and increased space between each suitable patch (Wilcox & Murphy 1985). Most research has

addressed the effects of habitat fragmentation on population dynamics (Vander Haegen et al. 2000, Reed 2004) and biodiversity (Manu et al. 2007) in forest ecosystems (Hanski & Raivio 1993, Pavlacky & Anderson 2007).

Like forest ecosystems, the shrub-steppe ecosystem cannot recover quickly after disturbance. Thus the effects of habitat fragmentation by fire (Fischer et al. 1996, Nelle et al. 2000, Crawford et al. 2004), shrub control (Martin 1970), poor livestock management (Beck & Mitchell 2000), drought (McArthur et al. 1990), invasion of exotic plants (Mack 1981, Knick & Rotenberry 1997), or other anthropogenic influences are long lasting and can result in a permanently fragmented landscape where the existence of many species is dependent upon the size, juxtaposition, and separation of suitable habitat and the species' ability to find it (Doak et al. 1992, Fahrig & Merriam 1994, Flather & Bevers 2002). Sagebrush obligate species, such as greater sage grouse (*Centrocercus urophasianus*), may be more affected by habitat fragmentation than generalist species (Braun & Beck 1976). Sage grouse require large contiguous patches of multi-seral age stands with differing proportions of canopy cover in random mosaics (Griner 1939, Patterson 1952). Translocations provided an ideal setting wherein we were able to use equivalence testing to determine whether movements of resident and translocated sage grouse in a fragmented landscape were statistically equivalent.

Equivalence Tests

Equivalence tests allow the investigator to establish similarity between two groups or treatments by reversing the standard test hypotheses (Wellek 2003). Thus the null hypothesis is one of inequality, where we specify that the absolute value of the

difference between the groups is greater than some predetermined bound Δ. Rejecting this hypothesis leads to the conclusion that the two groups are equivalent.

Distance to the release site is one metric used in judging site fidelity in translocation efforts. In our study area, grouse movements are largely constrained by topography to a corridor running predominantly east to west. A 6,950 ha reservoir, multiple housing developments, campgrounds, highways and roads now exist within historically suitable habitat. Distance distributions in the presence of such habitat fragmentation are often multimodal.

In this paper, we demonstrate the use of equivalence tests for assessing the preliminary success of translocation efforts in the presence of habitat fragmentation using distance from the release site as a metric. Our objectives were to derive tests of equivalence using permutation methods (Mielke & Berry 2001) to determine whether the maximum distance traveled is similar for these two populations of grouse in the summer and winter seasons.

Methods

Study Area

The study area was centered in the Strawberry Valley of north-central Utah (UTM Zone 12T, E 0492078 / N 4445216). The area is characterized as a montane sagebrush steppe with mountain big sagebrush (*Artemesia tridentata vaseyana*) as the predominant shrub; silver sagebrush (*A. cana*) is less abundant in wet meadows and riparian areas. The valley is approximately 24 km long and 8-9 km wide. The topography is characterized by mountain ridges and high mountain meadows with elevations ranging from 2,250 to 2,600 m. The valley has cool dry summers and cold wet winters. Average

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annual precipitation is about 58 cm. Strawberry Reservoir is the most dominant feature of the valley covering 6,950 ha of historical riparian and sagebrush steppe habitat. During the last 70 years, habitat fragmentation helped precipitate a greater than 95% reduction in overall sage grouse numbers, with 9,000 ha of sagebrush habitat remaining.

Field methods

As part of a long-term (1998-2007) study of greater sage grouse in Strawberry Valley, Utah, we annually trapped resident females on and around the breeding site (or lek) from late March through May, about 2 hours after sunset, (2100 hr to 0200 hr) using a modified spotlight method from all-terrain vehicles (Wakkinen et al. 1992). We fitted females with 16-g or 22-g necklace style radio transmitters (Advanced Telemetry Systems, Inc., Isanti, MN; 19-hr duty cycle, 45 pulses per minute, with mortality after 8 hr and max. battery life of 30 months).

During the breeding season from 2003 to 2007, we translocated female greater sage grouse from selected source populations in the state of Utah (Baxter et al. 2008). Source populations were chosen because of their robust size, their distance from Strawberry Valley, and their behavior (Barber 1991) and genetic compatibility (Oyler-McCance et al. 2005) with residents. We used the same capture technique as described for resident sage grouse. Grouse were transported, fitted with radio-transmitters, and released within 11 hours of capture (Baxter et al. 2008). All translocated birds were released in the morning within 250 m of the lek during breeding activity.

All females were tracked via radio telemetry from the ground using a 4-element Yagi antenna and an R-1000 digital radio receiver (Communication Specialists Incorporated, Orange, CA). We also used periodic flights ($\bar{x}$ = 8 flights/year) in a fixed-

wing aircraft to locate radio-collared birds. All locations were recorded in a Global

Positioning System (GPS) unit in Universal Transverse Mercator (UTM) coordinates. We

searched for sage grouse with transmitters within an 80 km radius of the release site to

detect any females with active radios that departed Strawberry Valley following

translocation.

Modeling Distance Distributions

We modeled log distance from the lek site using a mixture of normal distributions

(see Titterington et al. 1985). Let $f(x; \mu, \sigma)$ denote a normal distribution with mean μ and

standard deviation σ. Then

$$g(x;\theta) = \pi\, f(x;\, \mu_1,\sigma_1) + (1-\pi)\, f(x;\, \mu_2,\sigma_2)$$

was a mixture of normals with mixing parameter π. The parameter π represented the

proportion of observations within each normal distribution. We constructed likelihood

ratios to test for differences in distribution according to resident-translocated group

status, season, and group-by-season interaction. Mixture models were fit using the

package mixtools in R (R Development Team 2007). All other computations were carried

out in R. We used a Bonferroni correction to ensure the family-wise error rate remained

0.05, thus $\alpha = 0.05/4$ for each comparison.

Testing Equivalence

We used a permutation test approach (Mielke & Berry 2001) to create inclusion

intervals for testing equivalence in the four comparisons of interest: (1) Summer:

Translocated vs. Resident, (2) Winter: Translocated vs. Resident, (3) Translocated:

Summer vs. Winter, and (4) Resident: Summer vs. Winter. Inclusion intervals were used

to create TOST (two one-sided test) equivalence tests (Wellek 2003). The null hypothesis

was that the means of two groups differ by at least Δ, as specified a priori. The alternative

hypothesis was one of equivalence, where the difference in means is less than Δ. A

100(1-α)% inclusion interval was created by calculating a 100(1-2α)% confidence

interval for the difference of interest (Schuirmann 1987). We rejected the null hypothesis

when the inclusion interval fell completely within our (-Δ, Δ) bounds, and concluded that

the two groups were equivalent.

For each equivalence test, our data consisted of the maximum distance from the

lek for each bird in each season. An inclusion interval was created for each of the four

comparisons. Using a Bonferroni correction, we set α = 0.05/4 for each comparison to

ensure that the family-wise error rate remained at level α = 0.05. Each inclusion interval

was based on n = 10,000 permutations. At each iteration, we randomly permuted group

labels (e.g., resident or translocated) and calculated $\overline{X}_1 - \overline{X}_2$, the difference in sample

means between the randomized groups. These n values constituted the sampling

distribution of the actual $\overline{X}_1 - \overline{X}_2$, centered at zero. We shifted this sampling distribution

by the actual $\overline{X}_1 - \overline{X}_2$, centering it about that point, and used this shifted distribution to

construct the interval. A 100(1-α)% inclusion interval was created by calculating the

endpoints at the α and 1-α quantiles of the sampling distribution.

Results

We collected 2,465 measurements on a total of 333 females (224 translocated,

109 resident). Observations per bird ranged from one (61 birds) to 42 (2 birds), with a

median (natural) log distance from the lek of 5.0 km and mean of 7.4 km. We created a

histogram (Fig. 1) of these distances, and the overall distribution clearly indicated

bimodality.

We calculated parameter estimates for the mixture of normal distributions model for each group-by-season combination (Table 1) and plotted the resulting estimated densities (Fig. 2). Likelihood ratio tests showed that all densities were significantly different by group status ($P=0.0002$), season ($P<0.0001$), and group-by-season interaction effects ($P<0.0001$).

We created inclusion intervals for determining equivalence in maximum distance traveled (Fig. 3). Two of these intervals (Summer: Resident vs. Translocated and Winter: Resident vs. Translocated) crossed a lower bound if $\Delta = \log(2$ km$)$, failing to conclude equivalence at this distance. All four intervals were completely contained within the bounds if $\Delta = \log(3$ km$)$. In this situation, we would have concluded equivalence for all four comparisons.

Discussion

Mixture of Normal Distributions Modeling

Modeling the entire distance-from-lek distributions for each group-by-season combination indicated that all the data were bimodal. This bimodality is likely a result of habitat fragmentation. Researchers who use normal distribution-based statistical techniques on these types of data may be seriously misled. The researcher may opt to use traditional nonparametric approaches, which would not be inappropriate. However, in replacing measured values with ranks, you not only ignore the actual distances, but you compromise the ability to interpret the parametric form fit to the data.

We determined that resident and translocated birds had similar, albeit statistically different, distance-from-lek movement distributions. These distributions differed primarily in the proportion (represented by π) of observations in each mode (Fig 2).

During summer, resident grouse in Strawberry Valley were observed in habitat farther from the lek than habitat closer to the lek. Conversely, in winter, residents were observed in habitat closer to the lek rather than farther. Similar patterns were found for translocated female grouse. The location of the second mode in winter for both resident and translocated grouse is almost identical. This may be indicative of flocking behavior exhibited by all translocated grouse. By the end of the winter (March) each year 100% of translocated females were flocked with residents (Baxter et al. 2008).

These parametric models can also be used to investigate patterns of habitat fragmentation. For example, the estimate of μ_1 for translocated birds in the summer is 0.72 (Table 1) This is equal to a distance of $\exp(0.72) = 2.0$ km from the lek. The parameter associated with the second mode, μ_2, is equal to a distance 12.1 km from the lek, more than 10 km farther. These distances may be representative of a behavioral response to habitat fragmentation.

Habitat fragmentation is becoming more common in the West as residential and commercial development, energy exploration, and recreation hit all-time highs. Translocating animals into a fragmented landscape to prevent extirpation is expensive high-risk research, but the information our study yielded for a native species of wildlife could be crucial to future conservation.

Determining Site Fidelity

Moehrenschlager & Macdonald (2003) report that translocated swift fox (*Vulpes velox*) were more prone to death when they dispersed farther from the release site. Similarly, Musil et al. (1993) found the lowest survival of radio-instrumented translocated greater sage grouse occured during the first three weeks post-release, which

coincided with large exploratory movements. Likewise, Kurzejeski & Root (1988) concluded that reintroduced ruffed grouse (*Bonasa umbellus*) with larger rates of movement experienced higher mortality rates.

We proposed measuring site fidelity using the maximum distance traveled from the lek site. All birds were either released less than 250 m from the lek during breeding activity (translocated) or were captured on or near the lek and immediately released after fitting them with a radio-transmitter (resident), making comparisons between resident and translocated grouse based on distance from the lek valid. Because we had resident birds with which to compare movements, we were able to determine whether translocated animals showed movements similar to residents using statistical tests of equivalence.

For illustrative purposes, had we set the difference metric to $\Delta = \log(2 \text{ km})$, we could not have concluded that maximum log distance from the lek was equivalent for resident and translocated sage grouse in either summer or winter seasons. However, $\Delta = \log(3 \text{ km})$ may be a reasonable distance in our study area. Using this bound, summer versus winter maximum log distance for both resident or translocated grouse are statistically equivalent.

While researchers may claim evidence for a hypothesis based on non-rejection of the null, it is not statistically defensible. Rather, one of a number of rigorous statistical methods for determining equivalence should be used. These procedures have been adopted in a wide variety of scientific fields of study (Cleophas 2002, Liu et al. 2002, Limentani et al. 2005, Van Steen et al. 2005). Their limited use in the ecological and conservation biology literature (Robinson and Froese 2004) can only be due to

unfamiliarity. Implementation of equivalence tests for addressing many ecological issues, not just success of translocations, is long overdue.

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Table 1. Parameter estimates for the mixture of normal distributions modeling the natural log distance from the lek for resident and translocated greater sage grouse in the summer and winter from 1998-2007 in Strawberry Valley, Utah, USA.

Group	Season	N	μ_1	σ_1	μ_2	σ_2	π
Resident	Summer	299	0.82	0.74	2.16	0.44	0.57
Resident	Winter	278	0.62	0.58	2.81	0.50	0.69
Translocated	Summer	1326	0.72	0.61	2.49	0.41	0.55
Translocated	Winter	562	1.06	0.63	2.93	0.37	0.70

Overall Sage Grouse Distance Histogram
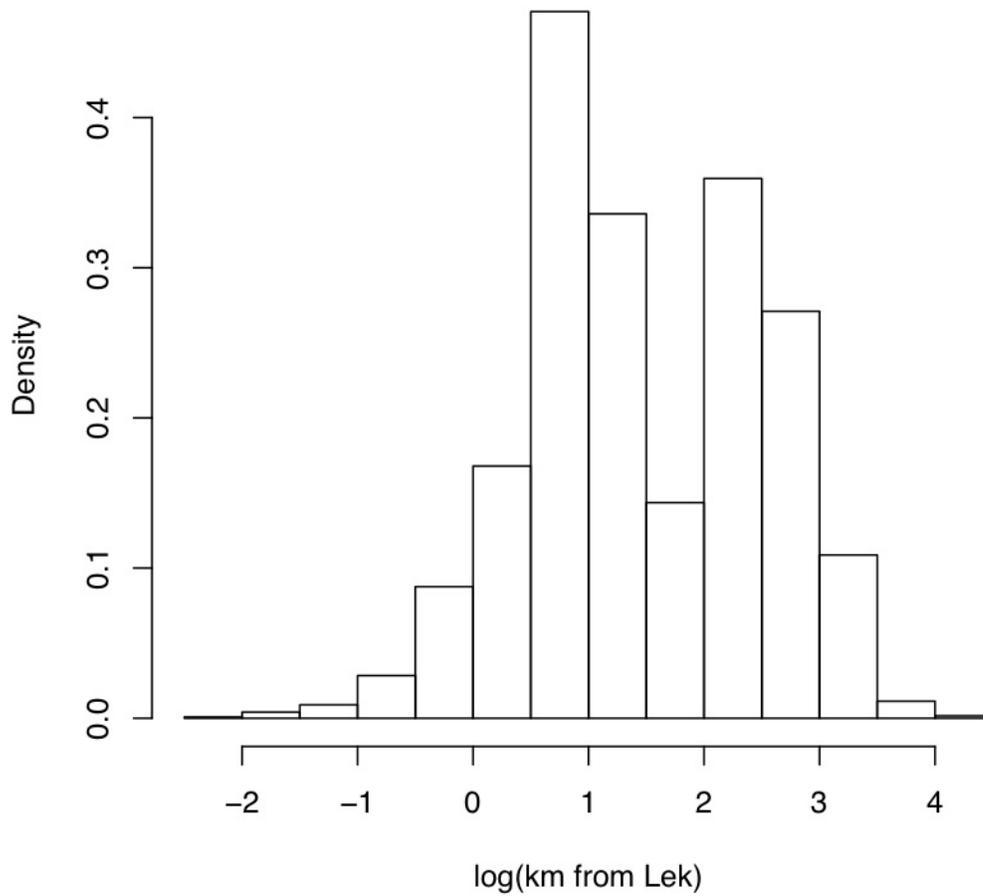
Figure 1. Shown here is a histogram of log distances from the lek for all resident and translocated female greater sage grouse from 1998 to 2007 in Strawberry Valley, Utah, USA.

Sage Grouse Distribution
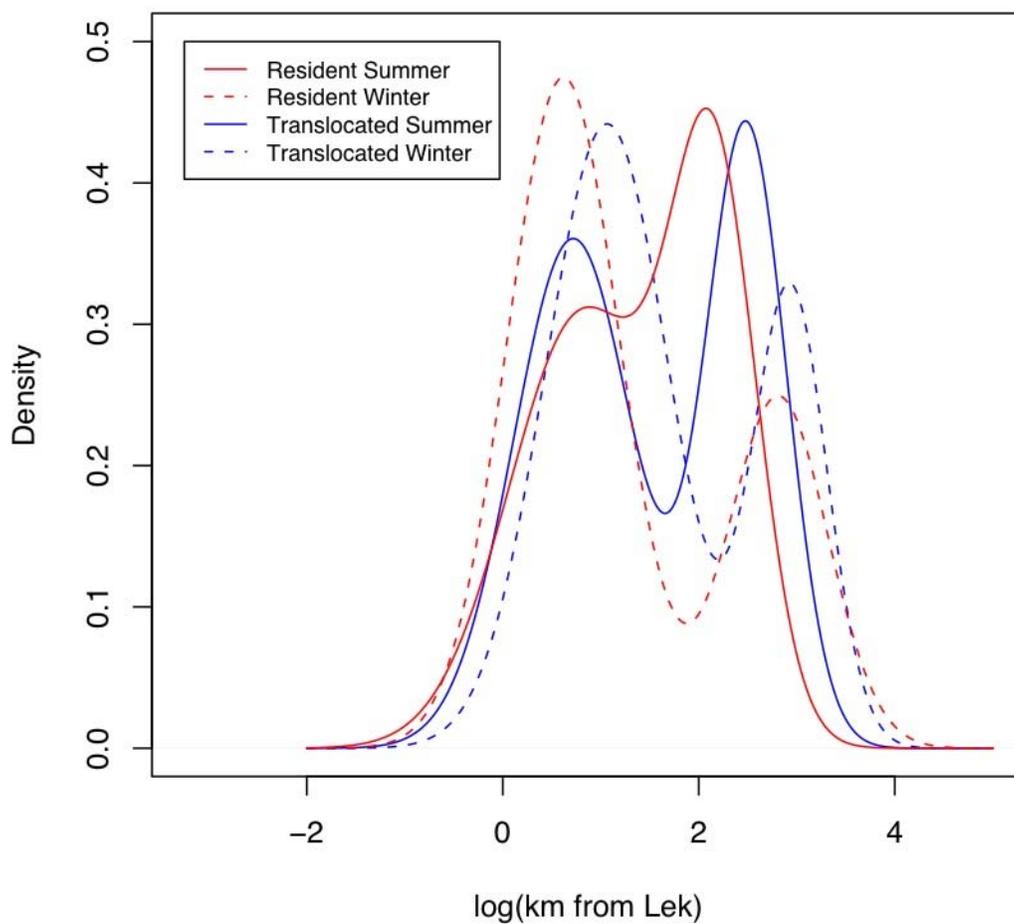
Figure 2. Shown here are the mixed-normal distribution densities of the natural log distances from the lek for resident and translocated female greater sage grouse in the summer and winter from 1998 to 2007 in Strawberry Valley, Utah, USA.

Equivalence Test Inclusion Intervals
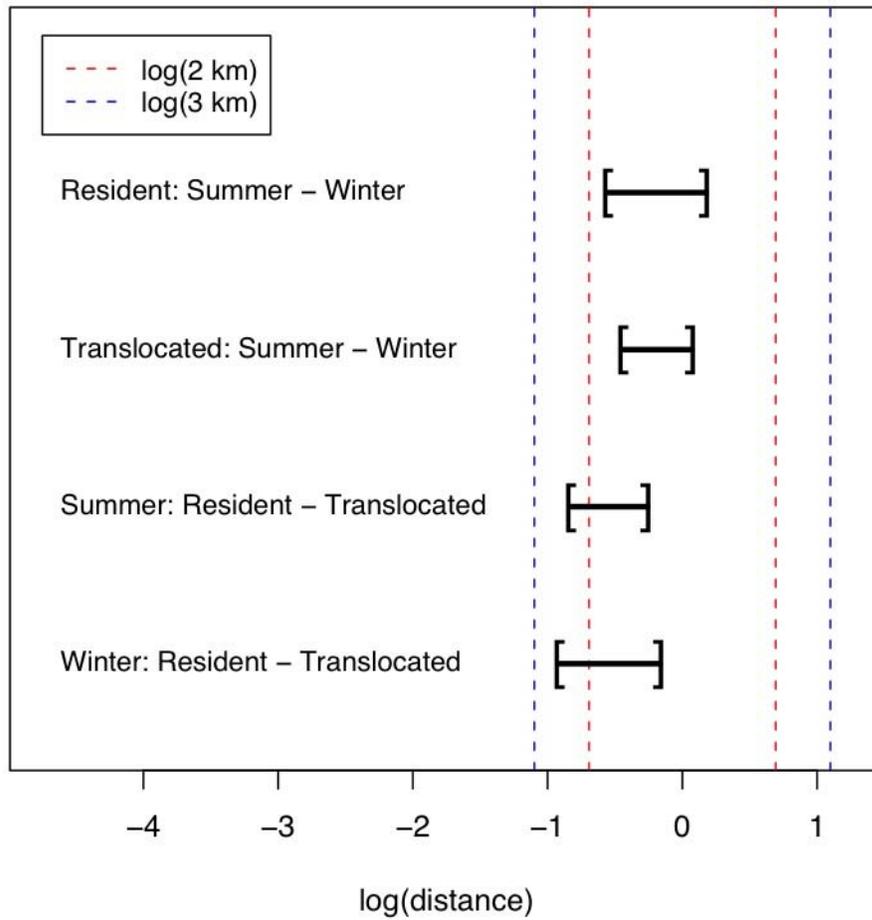
Figure 3. Shown here are the equivalence test inclusion intervals for log distances from the lek for resident and translocated greater sage grouse in Strawberry Valley, Utah, USA from 1998 to 2007.