



## Note

# Population Vital Rates of Resident and Translocated Female Greater Sage-Grouse

NATASHA W. GRUBER-HADDEN,<sup>1</sup> *Department of Wildland Resources, Jack H. Berryman Institute, Utah State University, Logan, UT 84322-5230, USA*

TERRY A. MESSMER, *Department of Wildland Resources, Jack H. Berryman Institute, Utah State University, Logan, UT 84322-5230, USA*

BRIAN D. MAXFIELD, *Utah Division of Wildlife Resources, Vernal, UT 84078, USA*

DAVID N. KOONS, *Department of Wildland Resources and the Ecology Center, Utah State University, Logan, UT 84322-5230, USA*

MICHAEL R. GUTTERY, *Alaska Department of Fish and Game, Palmer, AK 99645, USA*

**ABSTRACT** Translocations have been recommended to reestablish, augment, and sustain genetic diversity in declining wildlife populations, including greater sage-grouse (*Centrocercus urophasianus*; sage-grouse). Characteristics of successful sage-grouse translocations include suitable contiguous sagebrush (*Artemisia* spp.), seasonal habitats surrounded by geomorphic barriers, a residual resident population, and pre-nesting releases. From 2009 to 2010, we studied vital rates of 60 translocated and 15 resident radio-marked female sage-grouse and their broods on Anthro Mountain, in the Ashley National Forest, northeastern Utah, USA to determine whether translocations could augment a declining meta-population that inhabited suitable breeding habitats in a small spatially isolated landscape. Survival rates, and nest and brood success estimates for the resident and translocated sage-grouse we studied were lower than reported range-wide averages. Nest success was similar for resident and translocated birds (survival estimate: 0.468, 95% CI = 0.288–0.648) and we calculated weak, yet positive relationships to grass height and grass cover. Daily survival rates for chicks 0–19 days of age for resident females in 2009 (0.904, CI = 0.875–0.940) and in 2010 (0.910, CI = 0.888–0.945) were higher than for chicks raised by translocated females (0.883, CI = 0.850–0.915; 0.892, CI = 0.856–0.936, respectively), although differences were small and all 95% confidence intervals had substantial overlap. In 2009 and 2010, daily survival rates for chick 20–50 days of age were slightly higher for chicks reared by resident females (0.980, CI = 0.963–0.994; 0.998, CI = 0.978–1.000, respectively) than chicks reared by translocated females (0.877, CI = 0.623–0.959; 0.988, CI = 0.945–0.993, respectively). Chick survival for both groups was weakly correlated with grass cover. Although most translocated birds remained on the study area (82%), the low overall survival rates we report indicate that managers need to consider factors affecting survival of adult females, nests, and chicks when planning future translocations to augment sage-grouse meta-populations that occupy spatially isolated and space-limited habitats. © 2016 The Wildlife Society.

**KEY WORDS** *Centrocercus urophasianus*, greater sage-grouse, isolated landscapes, translocation, Utah, vital rates.

Long-term population declines resulting from range-wide habitat loss and fragmentation were cited as a primary reason for the 2010 decision by the United States Fish and Wildlife Service (USFWS) to list greater sage-grouse (*Centrocercus urophasianus*) as a candidate for protection under the Endangered Species Act of 1973 (USFWS 2010). Despite increasing efforts to conserve the species, the viability of some sage-grouse populations remains questionable because they occupy spatially isolated and space-limited landscapes. However, these landscapes may provide important habitat corridors and translocations may be a conservation strategy to sustain sage-grouse meta-populations inhabiting suitable but

space-limited seasonal habitats (Griffith et al. 1989, Connelly et al. 2011). Although most sage-grouse translocation efforts have not been successful (Reese and Connelly 1997), Baxter et al. (2008) identified criteria that may increase the chances of a successful translocation (e.g., suitable contiguous habitat surrounded by geomorphic barriers).

Anthro Mountain in northeastern Utah has a small declining, spatially isolated population of sage-grouse that inhabit high-elevation breeding areas. Winter habitat is limited during years of heavy snowfall requiring sage-grouse to migrate >20 km to lower elevation winter ranges. The status of the sage-grouse population on Anthro Mountain declined from 2006 (44 M) to 2008 (13 M) prompting action (B. M. Maxfield, Utah Division of Wildlife, personal communication). Wildlife managers suggested translocating sage-grouse to Anthro Mountain to augment the population (B. M. Maxfield, personal communication).

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<sup>1</sup>E-mail: [natasha.gruber@gmail.com](mailto:natasha.gruber@gmail.com)

Because several of Utah's sage-grouse populations occupy smaller, naturally fragmented landscapes (Beck et al. 2003), we were interested in determining whether translocations could be used to augment populations that were spatially isolated from other populations. Our first objective was to determine whether translocated sage-grouse would disperse from the target area after release because the area did not exhibit geomorphic barriers cited as criteria in previous successful translocations (Baxter et al. 2008). However, because the translocated individuals were released during the breeding season near an active lek and the breeding habitat was spatially isolated (>20 km) from other sage-grouse habitat by a dense conifer forest, we hypothesized these conditions would prevent dispersal. Further, we investigated whether survival rate estimates of female sage-grouse, nest and brood success, and chick survival differed for radio-marked resident and translocated sage-grouse.

## STUDY AREA

We conducted this study on Anthro Mountain in northeastern Utah (Fig. 1). The area is managed by the United States Forest Service (USFS). The topography of the study area consisted of high, narrow, and flat ridges running north and south, separated by deep, narrow canyons and draws. Precipitation in the study area averaged 49 cm annually and the temperature ranged from  $-20^{\circ}\text{C}$  to  $26^{\circ}\text{C}$  (Natural Resources Conservation Service 2012). The elevation ranged from 2,400 m to 2,800 m. Sage-grouse hunting was not permitted on the site.

The vegetation community in the 2,500-ha study area that constituted sage-grouse breeding habitat consisted of mixed sagebrush and aspen (*Populus tremuloides*), with encroaching juniper (*Juniperus osteosperma*) and pinyon-pine (*Pinus edulis*) trees. The study area was surrounded by dense pinyon-juniper forests at lower elevations (Miller 2005). The dominant sagebrush species in this area were mountain big sagebrush (*Artemisia tridentata* subsp. *vaseyana*) with black sagebrush (*A. nova*) located primarily on the ridges. Smooth brome grass (*Bromus inermis*) was seeded in the 1950s in portions of the area and was the dominant grass species. The current, and historical, predominate land use is domestic livestock grazing. To protect livestock, the United States Department of Agriculture Wildlife Services conducted limited coyote (*Canis latrans*) control on the mountain in spring but at lower elevations than those occupied by sage-grouse. In addition to coyotes, bobcats (*Lynx rufus*) and non-native red fox (*Vulpes vulpes*) were also observed on Anthro Mountain (Gruber 2012).

The source population for the sage-grouse translocation to Anthro Mountain was Parker Mountain in south-central Utah (Fig. 1). Parker Mountain was selected as the source because the population was considered stable, was  $\geq 100$  km from the release site, and was genetically similar to Anthro Mountain sage-grouse (Dahlgren 2009, Breidinger et al. 2013). The source area exhibited topography and elevations similar to Anthro Mountain and was characterized as a high-elevation plateau that slopes to the north and east. The primary vegetation community was mountain big

sagebrush, black sagebrush, bitterbrush, and rabbitbrush. Common grass species included grama grass (*Bouteloua* spp.), wheatgrass, bluegrass (*Poa* spp.), squirreltail grass (*E. elymoides*), needlegrass (*Hesperostipa* spp.), and June grass. The area was predominately used for sheep and cattle grazing (Guttery 2010). Mammalian predator control (i.e., coyote) was a common practice used on Parker Mountain to protect livestock. The average annual precipitation was between 40 cm and 51 cm. The elevation ranged from 2,150 m to 3,000 m.

## METHODS

We captured and radio-marked 30 female sage-grouse/year ( $n = 60$ ) during the breeding season on Parker Mountain for translocation to Anthro Mountain. We also captured and radio-marked 15 resident female sage-grouse on Anthro Mountain in spring and fall 2009 and spring 2010. We captured and radio-marked birds using standard methods (Giesen et al. 1982, Mawhinney et al. 2004). Immediately upon capture, we fitted each grouse with a 16-g necklace-style radio transmitter (Advanced Telemetry Systems, Insanti, MN and American Wildlife Enterprises, Monticello, FL). We placed birds in individual ventilated cardboard boxes (30 cm  $\times$  24 cm  $\times$  30 cm) and transported them overnight by vehicle to Anthro Mountain. Birds were hard-released (Hardman and Moro 2006) the morning following capture within 200 m of an active lek. We released resident radio-marked sage-grouse at their capture locations.

During the nesting season, we located all radio-marked females 2–3 times a week to document nest initiation and incubation. We visually confirmed nesting, taking care to not flush birds off the nest. Once confirmed, we monitored nests 2–3 times a week from a distance of  $>30$  m to determine fate (i.e., hatched, depredated, and abandoned). We considered a nest to be successful if  $\geq 1$  egg hatched. Upon hatching, we estimated clutch size by counting eggshell membranes (Mawhinney et al. 2004). If a nest failed, we tracked the female 2–3 times a week to document re-nesting attempts. We re-located females without broods (i.e., broodless) 1–2 times a week.

Within 24–48 hours after hatch, we captured chicks by hand by locating and flushing successful radio-marked brood females. We captured most broods just before sunrise or after sunset. We randomly selected 3–6 chicks in each brood to radio-mark with a 1-g transmitter (Advanced Telemetry Systems and American Wildlife Enterprises) following the suture technique described by Burkepile et al. (2002). In between processing, we stored chicks in a soft, heated container to minimize loss of body heat. Once marking was completed, we released all chicks together at the capture location.

We located broods 3 times a week until the brood reached 50 days of age. We monitored chicks by first locating the females then checking for chicks via telemetry. We individually located chicks missing from the brood. We also recorded chick mortality and disappearance, although their radio-transmitters did not contain a mortality sensor. If we found a chick's transmitter without any remains or sign of predation, we presumed the chick to be dead even though the



**Figure 1.** Spatial location of Parker Mountain (Piute, Wayne, and Garfield counties) relative to Anthro Mountain (Duchesne County), the release area for the greater sage-grouse (*Centrocercus urophasianus*) translocation, 2009–2010, Utah, USA.

transmitter could have been lost because of other reasons (Guttry 2010).

We measured vegetation characteristics at each nest site and at 1 site per week for each radio-marked brood. We used the line intercept method to estimate percent shrub cover and height (Daubenmire 1959, Connelly et al. 2003). We measured vegetation visual obstruction (VOR) using a Robel pole (Robel et al. 1970, Connelly et al. 2003) and used Daubenmire frames along each transect to determine the percent cover of forbs and grasses at each site. We also recorded average height of the forbs and grasses within the Daubenmire frame (Daubenmire 1959).

We located radio-marked sage-grouse 2–3 times a week from March through October and monthly during the

months of November and December. We used bi-monthly flights in a fixed-wing aircraft to locate sage-grouse that were not detected from the ground throughout the year. We conducted all research activities and handling of sage-grouse in accordance with the Institutional Animal Care and Use Committee (IACUC) approved protocol at Utah State University (permit #1404).

### Data Analysis

*Female survival.*—We used data collected from year-round monitoring of translocated and resident females for survival analysis. Initially, we hoped to model female survival as a function of residency status and age; however, we were only able to radio-mark 9 adult and 6 yearling resident females

during the study. Thus, we created 4 competing models of female survival as a function of residency status: R1 = resident (0) versus translocated in current year (1) versus translocated in the previous year (2); R2 = resident or translocated in the previous year (0) versus translocated in the current year (1); RS = translocated (0) versus resident (1); null (intercept only). Birds that went missing or were undetectable or mortalities that occurred within a week after being radio-marked were right censored from the survival data analysis.

We used the RMark package (Laake 2013), which implements Program MARK (White and Burnham 1999), to estimate monthly female survival rates; we chose the nest survival model because of the ragged monitoring intervals among individuals (Dinsmore et al. 2002). We ranked the 4 a priori defined models using Akaike's Information Criterion (Akaike 1973) corrected for small sample size ( $AIC_c$ ; Burnham and Anderson 2002). When multiple models were supported by the data ( $\Delta AIC_c \leq 2$ ), we retained the most parsimonious model for interpretation (Hamel et al. 2010).

*Nest survival.*—We estimated daily and overall nest survival rates, encompassing a 39-day exposure period to account for egg laying and incubation (Schroeder et al. 1999) using the nest survival models described above (Dinsmore et al. 2002). Females that were accidentally flushed off a nest by a researcher and did not return to the nest were censored from the nest survival data. We documented 1 re-nesting attempt by a translocated female after she was inadvertently flushed off her first nest by a researcher at the initiation of incubation. We included data from this re-nesting attempt in our nest survival analysis.

We evaluated 4 models with residency status, and 10 models with habitat covariates. Residency status was specified as described above for the female survival analysis. The most supported residency model was then used as a base model to build habitat models. For the habitat models we considered vegetation characteristics including: percent shrub, forb, and grass cover; average shrub, forb, and grass height; and visual obstruction readings measurements. We used a correlation analysis on all habitat covariates to test for multi-collinearity and covariates with a correlation coefficient  $>|0.7|$  were not included in the same model (Dormann et al. 2013).

*Chick survival.*—We evaluated factors influencing sage-grouse chick survival from hatching to 50 days of age by modeling survival using the maximum likelihood estimator developed by Manly and Schmutz (2001). We used the OPTIM function in R (R version 3.1.2, [www.r-project.org](http://www.r-project.org), accessed 10 Jan 2015) and a logit-link to attain maximum likelihood estimates of all parameters (Gutierrez 2010). We used bootstrapping ( $n=1,000$ ) to attain 95% confidence intervals for the parameters in the top models (Burnham and Anderson 2002). Chicks whose fate could not be determined were right censored from the data after the last date of observation and capture mortalities ( $n=6$ ) were omitted from the data set.

The Manly and Schmutz (2001) model includes an estimate of the dependence in fates ( $D$ ) among brood members, with estimates of  $D$  near 1 indicating that fates of chicks within broods are independent, whereas values

approaching the mean brood size indicate greater levels of dependency in individual survival probabilities (Manly and Schmutz 2001). We considered the size of the brood to be the number of chicks that were radio-marked in a brood (i.e., if there were 8 chicks in a brood, but only 4 chicks were radio-marked, the brood size was 4).

Parameterizations of age effects included continuous with first and second-order polynomials, and age divided into discrete categories based on biologically significant periods in chick development. Once we determined the best parameterization of chick age, we considered a categorical year effect in conjunction with the chick age model. We used the best parameterization of chick age and year as a base model for considering combinations of other temporal and individual explanatory variable effects on chick survival. Several covariates were modeled as a constant effect across the entire range of chick ages and also modeled as varying by discrete age categories. We attempted to use the best parameterization of chick age and year as a base model for considering combinations of other habitat-based explanatory variable effects on chick survival using the reduced data set for which this information was collected. However, inclusion of year effects resulted in the models being too complex for the amount of data and therefore year effects were not included in the final model set. Several of the original models tested did not converge because of small sample size and were not included in model comparisons.

We tested 21 models (originally 30 models) for the effects of individual and temporal variation on chick survival, and 19 models (originally 50 models) for habitat influences on chick survival. We compared all models using the quasi-likelihood version of the Akaike's Information Criterion ( $QAIC_c$ ) that is adjusted for sample size and takes overdispersion into account (Akaike 1973, Burnham and Anderson 2002). Habitat covariates included in the analysis were percent cover of shrubs, grass, and forbs; average height of shrubs, grass, and forbs; dominant shrub type (i.e., sagebrush, shrub-like Pinyon or Juniper, and other); and burn (vegetation that was burned within the last 5 year).

## RESULTS

### Female Survival

In 2009 and 2010, we translocated 13 and 17 yearling, and 17 and 13 adult females, respectively, from Parker Mountain to Anthro Mountain. We radio-marked 15 resident females in 2009 (7 adults and 6 yearling) and 2010 (2 adults) on Anthro Mountain. No sage-grouse were injured or died during the capture, transport, or release; however, we were unable to re-locate 1 resident and 8 translocated birds after their release. In addition, 3 translocated birds died within 1 week of translocation. Thus, the sample size used for analysis included 49 translocated and 14 resident female sage-grouse.

The top  $AIC_c$ -selected model for female survival included the effect of translocation status with 2 levels (Table 1). However, the null model (no covariates) was within 2  $AIC_c$  points of the top model, indicating that the effect of translocation was not strongly supported by the data. Annual

**Table 1.** Models assessing translocated and resident female greater sage-grouse survival based on residency status, Anthro Mountain, Utah, USA, 2009–2010.

Model <sup>a</sup>	$K^b$	$AIC_c^b$	$\Delta AIC_c^b$	$w_i^b$
R2	2	168.41	0.00	0.39
RS	2	169.12	0.71	0.27
Null (intercept only)	1	169.86	1.46	0.19
R1	3	170.18	1.77	0.16

<sup>a</sup> Explanatory variables are as follows: R1 = resident (0), translocated in current year (1), translocated in the previous year (2); R2 = resident or translocated in the previous year (0) or translocation in the current year (1); RS = translocated (0) or resident (1).

<sup>b</sup>  $K$  = number of parameters;  $AIC_c$  = Akaike's Information Criterion adjusted for small sample size;  $\Delta AIC_c$  = increase in  $AIC_c$  relative to the model with lowest  $AIC_c$ ;  $w_i$  = model weight.

survival for resident and translocated females, derived from the null model, was 0.398 (95% CI = 0.271–0.541).

### Nest Survival

Nest hatching occurred between late May and late June during both years. Apparent nest initiation rates for resident and translocated female sage-grouse in 2009 were 71% (5/7) and 62% (16/26), respectively. The overall average clutch size for successful nests, including infertile eggs, in 2009 was 8.3 (SD = 0.58) for residents ( $n = 3$ ) and 7.1 (SD = 0.83) eggs for translocated birds ( $n = 12$ ). In 2010, nest initiation rates for resident, previously translocated, and newly translocated birds were 100% (7/7), 100% (8/8), and 50% (11/22), respectively. In 2010, clutch size for successful nests averaged 7.6 (SD = 1.51) eggs for resident females ( $n = 6$ ), 8 (SD = 0) eggs for previously translocated females ( $n = 2$ ), and 6.33 (SD = 1.86) eggs for newly translocated females ( $n = 6$ ).

For the nest success analysis using residency status and temporal variation parameters, there were 3 competing models with  $\Delta AIC_c < 2$ , including the null model (Table 2). The model with the lowest  $AIC_c$  included the effect of translocation (translocated or resident); however, the parameters of this model were not strongly supported by our data. Average nest survival, calculated from the null model was 0.468 (CI = 0.288–0.648).

Three models for habitat effects on nest success were equally supported by our data, 2 of which were equally parsimonious (Table 2). Of these 2, the model with the lowest  $AIC_c$  indicated a moderately strong positive relationship between nest success and grass height ( $\beta = 0.181$ , CI = 0.016–0.345). The second model indicated a weak and imprecisely estimated positive relationship between nest success and grass cover ( $\beta = 0.093$ , CI = -0.018 to 0.205). There was no statistical evidence of a strong correlation between grass height and percent grass cover ( $r = 0.471$ ), indicating that the effects are largely ecologically independent.

### Chick Survival

Ninety-nine chicks from 24 sage-grouse broods were marked during the study (4.1 chicks/brood). Fifty chicks were radio-marked from resident and 49 from translocated females. Six chicks died because of capture injury over the 2-year study period. In 2009 and 2010, 8 and 14 chicks, respectively, were

**Table 2.** Models assessing residency status and habitat factors on nest survival of translocated and resident greater sage-grouse, Anthro Mountain, Utah, USA, 2009–2010.

Model <sup>a</sup>	$K^b$	$AIC_c^b$	$\Delta AIC_c^b$	$w_i^b$
Residency models				
RS	2	112.64	0.00	0.40
R1	3	113.27	0.63	0.29
Null (intercept only)	1	113.78	1.13	0.23
R2	2	115.75	3.11	0.08
Habitat models				
Grass height	2	110.74	0.00	0.33
Grass height + grass cover	3	111.44	0.70	0.27
Grass cover	2	112.32	1.59	0.15
Null (intercept only)	1	113.78	3.04	0.07
Forb height	2	114.67	3.93	0.05
VO (out)	2	115.17	4.43	0.04
Forb cover	2	115.42	4.68	0.03
VO (in)	2	115.47	4.74	0.03
Shrub height	2	115.50	4.76	0.03
Shrub cover	2	115.78	5.04	0.03

<sup>a</sup> Explanatory variables are as follows: R1 = resident (0), translocated in current year (1), or translocated in the previous year (2); R2 = resident or translocated in the previous year (0) or translocation in the current year (1); RS = translocated (0) or resident (1), VO = visual obstruction (measured looking out from the nest [out] and in toward the nest [in]).

<sup>b</sup>  $K$  = number of parameters;  $AIC_c$  = Akaike's Information Criterion adjusted for small sample size;  $\Delta AIC_c$  = increase in  $AIC_c$  relative to the model with lowest  $AIC_c$ ;  $w_i$  = model weight.

missing and were censored after their last known location. Brood amalgamation (i.e., brood-hopping; Dahlgren et al. 2010) was observed for 2 chicks in 2010.

The top model of individual characteristics and temporal variation on chick survival indicated an influence of chick age (0–19 days or 20–50 days of age), year, and residency status of the female (resident or translocated; Tables 3 and 4). Daily survival rates for chicks 0–19 days of age for resident females in 2009 (0.904, CI = 0.875–0.940) and in 2010 (0.910, CI = 0.888–0.945) were higher than for chicks raised by translocated females (0.883, CI = 0.850–0.915; 0.892, CI = 0.856–0.936, respectively), although differences were small and all 95% confidence intervals had substantial overlap. In 2009 and 2010, daily survival rates for chicks 20–50 days of age were slightly higher for chicks reared by resident females (0.980, CI = 0.963–0.994; 0.998, CI = 0.978–1.000, respectively) than chicks reared by translocated females (0.877, CI = 0.623–0.959; 0.988, CI = 0.945–0.993, respectively). We also calculated period survival estimates for chick survival from 0 to 19 and 0 to 50 days of age for comparison with other published research (Table 5). Estimated dependency in chick survival ( $D$ ) in the top model was 1.546 (CI = 1.288–2.110), suggesting that fates of chicks in a brood are largely independent.

The top habitat model supported effects of grass cover and chick age but not female residency status (Table 6). The probability of survival to 0–19 and 20–50 days of age was positively, but weakly, correlated with grass cover ( $\beta = 0.058$ , CI = -0.063–0.183). Chick survival to 19 days with median grass cover (18.5%) was 0.211 (CI = 0.027–0.307) and 0–50 days with median grass cover was 0.091 (CI = 0.014–0.417).

**Table 3.** Models assessing the impacts of temporal and individual characteristics on greater sage-grouse chick survival, Anthro Mountain, Utah, USA, 2009–2010.

Model <sup>a</sup>	K <sup>b</sup>	QAIC <sub>c</sub> <sup>b</sup>	ΔQAIC <sub>c</sub> <sup>b</sup>	w <sub>i</sub> <sup>b</sup>
Age + year(v) + residency(v)	7	340.09	0.00	0.59
Age + year(v) + residency(v) + hatch date(v)	9	342.69	2.60	0.16
Age + year(v) + residency(c)	6	343.63	3.53	0.10
Age + year(v) + residency(c) + hatch date(c)	7	344.93	4.84	0.05
Age + year(v) + residency(c) + hatch date(c) + (residency × hatch date)	8	345.75	5.66	0.04
Age + year(v) + hatch date(c)	6	346.71	6.62	0.02
Age + year(v)	5	346.86	6.77	0.02
Age + year(v) + hatch date(v)	7	348.62	8.53	0.01
Age	3	350.20	10.11	0.00
Null (intercept only)	2	408.63	68.54	0.00

<sup>a</sup> Explanatory variables are as follows: age = chick age (categorical: 0–19 days post-hatch 20–50 days post-hatch); residency = effect of residency status (i.e., resident or translocated; (c) = modeled as a constant effect across the entire range of chick ages (0–50 days); (v) = modeled as varying by the 2 levels of chick age (0–19 days and 20–50 days).

<sup>b</sup> K = number of parameters; QAIC<sub>c</sub> = Quasi-Akaike's Information Criterion adjusted for small sample size; ΔQAIC<sub>c</sub> = increase in QAIC<sub>c</sub> relative to the model with lowest QAIC<sub>c</sub>; w<sub>i</sub> = model weight.

Grass cover did not differ between translocated and resident brood sites ( $P = 0.206$ ).

## DISCUSSION

Forty-nine of the 60 female sage-grouse translocated to Anthro Mountain remained on the study area despite the absence of geomorphic barriers, which have been credited with deterring dispersal of translocated sage-grouse (Musil et al. 1993, Reese and Connelly 1997, Baxter et al. 2008). The dense conifer forest surrounding the study area may have constituted a pseudo-geomorphic barrier. The overall annual survival rate estimates for translocated and resident sage-grouse females (40%) were within the range reported for other sage-grouse populations in Utah and range wide (37–78%; Bunnell 2000, Baxter et al. 2007, Dahlgren 2009, Taylor et al. 2012). Adult female and chick survival have been identified as the major influences of sage-grouse population growth (Taylor et al. 2012, Dahlgren et al. 2016). Although our results suggest that translocated female

**Table 4.** Parameter estimates and 95% confidence intervals for all temporal and individual characteristics used to evaluate and explain greater sage-grouse chick (resident and translocated) survival on Anthro Mountain, Utah, USA, 2009–2010.

Parameter	Beta	Lower 95% CI	Upper 95% CI
D <sup>a</sup>	1.546	1.288	2.110
Intercept (0–19 days)	2.238	1.950	2.731
Year (0–19 days)	0.082	–0.305	0.602
Residency status (0–19 days)	–0.213	–0.651	0.227
Intercept (20–50 days)	3.886	3.258	5.119
Year (20–50 days)	2.468	0.140	4.204
Residency status (20–50 days)	–1.926	–4.335	–0.377

<sup>a</sup> Dependence in fates among brood members.

**Table 5.** Period survival probabilities by age, year, and residency status for 0–19 days and 0–50 days of age for greater sage-grouse chicks on Anthro Mountain, Utah, USA, 2009–2010.

Additive effect <sup>a</sup>	Survival	95% CI
0–19 days + year (1) + residency status (a)	0.143	(0.079–0.295)
0–19 days + year (1) + residency status (b)	0.083	(0.037–0.153)
0–19 days + year (2) + residency status (a)	0.168	(0.103–0.335)
0–19 days + year (2) + residency status (b)	0.112	(0.050–0.278)
0–50 days + year (1) + residency status (a)	0.078	(0.040–0.151)
0–50 days + year (1) + residency status (b)	0.002	(0.000–0.035)
0–50 days + year (2) + residency status (a)	0.159	(0.077–0.318)
0–50 days + year (2) + residency status (b)	0.078	(0.015–0.195)

<sup>a</sup> Explanatory variables are as follows: year 1 = 2009; year 2 = 2010; residency status a = resident; residency status b = translocated.

sage-grouse survival rate estimates did not differ from resident birds, caution should be used when interpreting these results because of our small resident bird sample size. If low female survival is limiting a population, the contribution factor should be identified and mitigated prior to attempting to supplement the population through translocations.

Nest success estimates for resident and translocated birds (47%) did not differ. Nest success rates for resident birds could be biased because of the small number of resident birds in our sample. However, nest survival estimates are within the range reported for translocated sage-grouse (Baxter et al. 2008, Bell 2011) and approximate the average nest success estimates of 47.4% based on 14 studies across the sage-grouse range (Crawford et al. 2004). However, many of these studies reported apparent nest survival rates and therefore may not be directly comparable to our results because apparent nest survival is biased high due to failure to properly account for nests that fail prior to being detected (Mayfield 1961, Dinsmore et al. 2002). Our results suggest that in cases where nest survival may be a limiting factor for a population, translocations alone are unlikely to rescue the population unless the underlying factors leading to low nest success are addressed.

Model selection results indicated that grass cover and height were positively, but weakly, associated with nest success. Grass cover and height are also important factors for

**Table 6.** Models assessing the impacts of habitat factors on greater sage-grouse chick survival, Anthro Mountain, Utah, USA, 2009–2010.

Model <sup>a</sup>	K <sup>b</sup>	QAIC <sub>c</sub> <sup>b</sup>	ΔQAIC <sub>c</sub> <sup>b</sup>	w <sub>i</sub> <sup>b</sup>
Age + grass cover(c)	4	133.35	0.00	0.56
Age + burn(c) + grass cover(c)	5	135.38	2.03	0.20
Age	3	136.49	3.13	0.12
Age + burn(c)	4	137.80	4.45	0.06
Age + shrub cover(c)	4	138.66	5.30	0.04
Age + burn(c) + forb height(c)	5	139.96	6.61	0.02
Null (intercept only)	2	151.54	18.19	0.00

<sup>a</sup> Explanatory variables are as follows: age = chick age (categorical: 0–19 days post-hatch and 20–50 days post hatch); (c) = modeled as a constant effect across the entire range of chick ages (0–50 days).

<sup>b</sup> K = number of parameters; QAIC<sub>c</sub> = Quasi-Akaike's Information Criterion adjusted for small sample size; ΔQAIC<sub>c</sub> = increase in QAIC<sub>c</sub> relative to the model with lowest QAIC<sub>c</sub>; w<sub>i</sub> = model weight.

sage-grouse nest survival in other populations (Gregg et al. 1994, Doherty et al. 2014), although some studies have failed to find positive effects of grass cover or height (Webb et al. 2012). Maintaining sufficient vegetation structure may be an important factor in increasing nest success by affording sage-grouse females and their nests with adequate concealment and in obscuring nest odors from predators (Gregg et al. 1994, Moynahan et al. 2007); additional rigorous research is needed to further test this relationship.

Our top chick survival model indicated that chicks hatched to resident females had slightly higher survival than chicks hatched to translocated females. Although differences were small and confidence intervals overlapped, the effect was observed for chick survival to both 19 and 50 days of age in both years of the study. However, chick survival for both resident and translocated females on Anthro Mountain was substantially lower than reported by other studies using similar methodologies (Dahlgren et al. 2010, Guttery et al. 2013). These findings further imply that translocations should only be considered once the factors actually limiting populations are addressed.

We found evidence that chick survival was positively, but weakly, influenced by percent grass cover. Similarly, Gregg and Crawford (2009) reported that by increasing the cover of short grasses (<18 cm), an individual chick's chance of mortality decreased by 8.6%. Guttery (2010) reported similar findings on Parker Mountain, Utah. Chick survival may also be limited by the availability of mesic habitats with higher forb availability (Aldridge 2000). Mesic habitats on Anthro Mountain were restricted to lower elevation riparian zones, which were heavily used by livestock (Gruber 2012).

## MANAGEMENT IMPLICATIONS

Estimated vital rates for resident and translocated sage-grouse females and their chicks on Anthro Mountain were similar, and with the exception of nest success, were lower than range-wide estimates. Although inferences from our study may be limited because of small sample sizes, our results indicate that translocations to augment populations occupying suitable seasonal habitats that are spatially isolated from other populations may not yield the desired results unless the factors that have led to initial population declines are addressed. Our results suggest the sage-grouse population on Anthro Mountain may benefit from management strategies that increase grass cover and height especially during the nesting and early brood rearing period. The ultimate success of translocations should be determined by the effect the translocation has on the sage-grouse population growth rates ( $\lambda$ ) and trends over time in consideration with the cyclic nature of populations (Fedy and Aldridge 2011).

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