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Tools and Technology

Post-Release Acclimation of Translocated Low-Elevation, Non-Migratory Bighorn Sheep

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ABSTRACT Use of global positioning system (GPS) transmitters provides opportunities to evaluate ecological questions associated with fine-scale animal movements. One important application is to evaluate how animals acclimate to new surroundings after translocation. Our objective was to quantify temporal acclimation for low-elevation, non-migratory bighorn sheep (*Ovis canadensis*) from 3 translocations to the Seminoe Mountains in south-central Wyoming, USA, from 2009 to 2010 ($n = 38$) as well as for bighorns captured and released on-site in 2011 ($n = 24$). We used number of days for movements from individual bighorn to stabilize as a measure of acclimation. Mean acclimation for translocated bighorns after release was 29.3 days (SE = 2.5, range = 0–70). Mean acclimation for bighorns captured and released on-site was 5.0 days (SE = 2.4, range = 0–52). Paired comparisons indicated acclimation for 16 previously translocated bighorns that were captured and released on-site was reduced by 30.8 days (SE = 5.0) or 86%. Within translocation efforts, bighorn females in supplemental releases acclimated an average of 19.5 days sooner (or in 57% of the time) than animals from the first translocation. Because acclimation periods after translocation releases are associated with increased mortality risk, managers should consider supplemental releases to minimize acclimation periods.

KEY WORDS acclimation, bighorn sheep, data-censoring, functional data analysis, global positioning system, GPS, movement rate, *Ovis canadensis*, translocation, Wyoming.

The increasing availability of high-resolution global positioning system (GPS) location data for wildlife populations has provided opportunities to investigate ecological questions associated with fine-scale animal movements. One useful application of these data is to document how animals acclimate to new surroundings directly after translocations. Dispersal has been described as movement of one or more individuals away from the area or population where they were born to a new area where they settle and reproduce (Croteau 2010). However, movements after translocation are unlike dispersal because these movements are not related to an animal's natural and deliberate behavior (Letty et al. 2007). Mortality often increases directly after captured animals are released because of stresses associated with translocations (Dickens et al. 2010). The duration of this increased mortality risk after release has been defined as "acclimation period" (see Hamilton et al. 2010). In many cases, the intensity of movement (i.e., distance, frequency, and propensity) is high directly after release as animals explore new environments (Rittenhouse et al. 2007, Hester et al. 2008). This can be costly to animals, resulting in a decrease in foraging behavior, predator vigilance, and reproductive effort—leading to decreased survival and reproductive success—and in turn, a reduction in the probability of population establishment (Letty et al. 2000, LeGouar et al. 2012). Hofer and East (1998) and Creel (2001) document varying responses to stress induced by translocations according to multiple characteristics such as age, social status, sex, and physical condition, and the probability of animals successfully settling into a release area likely differs among individuals (Letty et al. 2007). Furthermore, some species are readily attracted to conspecifics in resident populations following release into new environments (Stamps 1988, Boulinier and Danchin 1997).

Initial locations from captured and released animals are often censored to ensure that biased locations are not included in subsequent analyses. For instance, White and Garrott (1990) recommended omitting location data up to 1 week after capture to account for post-release acclimation. When capturing, immobilizing, and releasing white-tailed deer (*Odocoileus virginianus*) on-site, Dechen Quinn et al. (2012) reported that decreased movements of individuals during acclimation after capture were ephemeral, with most

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individuals resuming normal movement patterns within 14 days. However, when translocated into new environments, animals have a tendency to exhibit highly sporadic and increased movement rates for extended periods of time before settling (Hunter 1998, Moehrenschlager and Macdonald 2003, Bennett et al. 2012). The removal of biased location data due to effects of capture, immobilization, or translocation of animals is often accomplished by visual inspection of the location data, but may be difficult to quantify (Dechen Quinn et al. 2012).

Efforts to restore bighorn sheep (*Ovis canadensis*) throughout North America have been ongoing since the early 1900s, with numerous translocation efforts undertaken to restore populations to historical habitat and augment waning populations (Hansen 1980). A substantial portion of current bighorn populations originated from translocation efforts (Bailey 1990, George et al. 2009, WAFWA 2013), making translocation a key component of bighorn restoration. Efforts are often implemented to monitor bighorns after translocations, which can accrue notable costs associated with both ground and aerial monitoring. Monitoring efforts may be implemented to observe or record animals wandering onto roadways, into surrounding areas where interactions with domestic animals are likely, or to document individuals leaving the habitat intended for occupation. Monitoring efforts are also implemented because released animals suffer higher mortality rates than those in established, wild populations (Craven et al. 1998). Increased predation of translocated animals (Yoder et al. 2004, Letty et al. 2007) may also influence the potential for successful bighorn establishment, and multiple studies report high vulnerability to predation in small bighorn populations, as well as setbacks in reintroduction efforts because of population declines due to predation (Broadbent 1969, Kilpatric 1982, Creeden and Schmidt 1983, Krausman et al. 1999). Estimating bighorn acclimation periods after translocation provides the ability to identify timeframes of increased mortality risk after releases, as well as to maximize effectiveness in monitoring efforts. Even with the substantial costs associated with the translocation of bighorn sheep, only an estimated 41% of bighorn sheep translocations are considered successful (Singer et al. 2000). Therefore, it is important that wildlife managers continue to evaluate factors influencing translocation efforts to increase the potential for successful bighorn sheep restoration.

Our objective was to estimate acclimation periods of low-elevation, non-migratory bighorn sheep by comparing dynamic bighorn movements directly after release to relatively stable movements when bighorns settled into new environments. We predicted acclimation periods of newly translocated bighorns to be longer than those in an on-site capture and release scenario. When examining scenarios that incorporate multiple bighorn releases as in the Seminoe Mountains, we also predicted acclimation periods to be reduced for animals in supplemental releases because of positive interactions with conspecifics already established in the area.

STUDY AREA

The Seminoe Mountains (106°56′0.000″W, 42°10′0.000″N) are a low-elevation (1,830–2,500 m) range located approximately 40 km north of Sinclair, Carbon County, Wyoming, USA, that encompass 80% federal, 10% state, and 10% private lands. The Seminoe Mountains form one of several independent ranges in south-central Wyoming that were historically inhabited by bighorn sheep (Beuchner 1960, Rea 2006). The Seminoe Mountains are separated by the North Platte River, flowing generally to the north through the range, with 2 hydroelectric dams (Seminoe and Kortes, respectively) within the confines of Seminoe Canyon. The Seminoe Mountains lie on a latitudinal orientation with prominent south and north faces, with the 16.7-km^2 Wyoming Game and Fish Department's Morgan Creek Wildlife Habitat Management Area positioned in the center of the mountain range. The Wildlife Habitat Management Area included mountainous terrain on the western side of the North Platte River containing Cottonwood, Marking Pen, and Morgan Creeks that converge and flow eastward into the North Platte River below Seminoe Dam. Topographical features in the Seminoe Mountains varied from vertical canyon walls on the eastern edge, to gentle slopes and long draws and ridges on the west, as well as numerous rock outcrops throughout the mountain range.

Primary vegetation cover types included sagebrush (*Artemisia* spp.), grassland, and conifer with a mixed shrub understory intermixed with mountain shrub, riparian meadow, and riparian broadleaf cover types. Limber (*Pinus flexilis*), lodgepole (*P. contorta*), and ponderosa (*P. ponderosa*) pines, and Rocky Mountain juniper (*Juniperus scopulorum*) comprised dominant coniferous trees. Deciduous tree species included aspen (*Populus tremuloides*), chokecherry (*Prunus virginiana*), and narrowleaf cottonwood (*Populus angustifolia*). Dominant shrub species included antelope bitterbrush (*Purshia tridentata*), big sagebrush (*A. tridentata*), and true mountain mahogany (*Cercocarpus montanus*). Hiatt (1997) provides lists of common grass and forb species for the study area. Our study area received a 30-year (1981–2010) average annual precipitation of 36 cm, with most precipitation occurring in spring (Western Regional Climate Center 2013). The 30-year (1981–2010) average annual temperature was 7° C (44° F), resulting in a short frost-free period of 70–90 days with 45% of annual precipitation falling as snow (Western Regional Climate Center 2013). High winds were common in the Seminoe area, especially on exposed slopes and ridges.

Mule deer (*Odocoileus hemionus*) were the most abundant ungulate species in the study area; however, elk (*Cervus elaphus*) were also common. The lower elevation foothills surrounding Seminoe Mountain provided habitat for abundant pronghorn (*Antilocapra americana*). Mammalian and avian carnivores included bobcat (*Lynx rufus*), coyote (*Canis latrans*), golden eagle (*Aquila chrysaetos*), mountain lion (*Puma concolor*), and occasionally black bear (*Ursus americanus*).

METHODS

Capture and Translocation of Bighorn Sheep

Despite multiple bighorn translocation efforts from 1958 to 1985 (Hiatt 1997), no known extant bighorns remained in the Seminoe Mountains prior to translocation efforts in 2009–2010 (G. Hiatt, Wyoming Game and Fish Department, personal communication). Low-elevation, non-migratory bighorn sheep were specifically chosen for translocation from source herds that occupied similar habitats and that exhibited life-history strategies (e.g., lambing chronology) congruent with habitat conditions in the Seminoe Mountains (Douglas and Leslie 1999, Kauffman et al. 2009). On 2 December 2009, 20 bighorns (15 F, 5 M) were released in the Seminoe Mountains from captures that occurred in the Diablo Rim and Coglan Butte areas in Lake County, central Oregon, USA. On 30 January 2010, 12 bighorns (9 F, 3 M) were translocated to the Seminoe Mountains from Devils Canyon in Big Horn County, north-central Wyoming. Finally, on 2 December 2010, 20 bighorns (16 F, 4 M) were released from captures that occurred in the John Day River Canyon in Wasco County, north-central Oregon. These 3 translocation efforts resulted in 52 bighorns released into the Seminoe Mountains from 2009 to 2010. All bighorns were captured via helicopter net-gunning, and were handled, marked, and translocated following state agency (Oregon Department of Fish and Wildlife, see Foster [2005]; Wyoming Game and Fish Department, Chapter 10–1535 and Chapter 33–750 permits) approved protocols.

After capture, bighorns were restrained using front and rear leg hobbles and blindfolded to minimize stress during processing. Each animal underwent a physical examination by trained animal handlers or a state veterinarian; this included documentation of age, sex, and physical abnormalities. Biological samples were taken from each captured bighorn for disease and parasite screening. Self-piercing metal or plastic ear tags were inserted in both ears of captured bighorns unless previous ear tags were evident. Forty store-on-board GPS neck collars ($n = 13$, GEN III, model TGW3500 collars [Telonics, Inc., Mesa, AZ]; $n = 27$, model G2110D [Advanced Telemetry Systems, Isanti, MN]) were affixed to 31 F and 9 M bighorn sheep translocated to the Seminoe Mountains. Twenty-two collars were configured to upload 1 GPS location every hour for 6 months, whereas 18 collars collected 1 GPS location every 5 hours for 18 months. Differences in collar fix rates assisted in providing high-frequency location data as well as extended data given limited battery life of GPS collars. All bighorns were held overnight to accommodate transit time and to ensure all releases occurred during midday hours. Release sites for bighorns translocated to the Seminoe Mountains were focused within 2.8 km near the center of the study area (Fig. 1). Global positioning system data were collected from translocated bighorns through spring 2011. On 2–3 December 2011, 25 refurbished GPS collars (Telonics = 4, ATS = 21) were attached to 20 F and 5 M bighorns captured and released on-site throughout the Seminoe study area following University of Wyoming Institutional Animal Care and Use Committee approved protocols (protocol 12012011) and Wyoming Game and Fish Department chapter 33–750 permit. Additionally, the same capture company was contracted to conduct all aerial captures throughout the study. Biological samples were taken from each captured bighorn for disease and parasite screening. Captured bighorns that were previously collared and released in translocation efforts ($n = 16$) were identified from existing ear tags, while metal ear tags were inserted into both ears of 5 bighorns born in the Seminoe Mountains that were never previously captured. Four bighorns captured in December 2011 were translocated individuals that were not previously collared, as identified by existing ear tags. Collars attached to these bighorn sheep collected location data every 5 hours for 18 months until they remotely detached in June 2013.

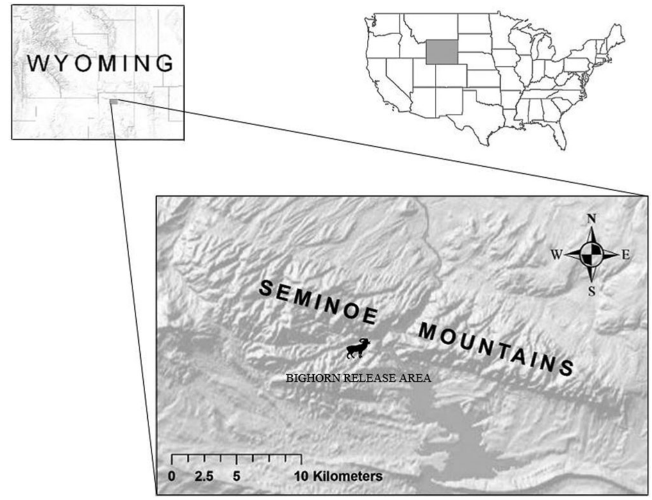

Figure 1. Study area for low-elevation, non-migratory bighorn sheep translocations on 2 December 2009 ($n = 20$), 30 January 2010 ($n = 12$), and 2 December 2010 ($n = 20$) in the Seminoe Mountains, Wyoming, USA. Bighorn silhouette represents the general release area for all translocation releases.

Data Analysis

We estimated individual daily movements (m/day) by calculating straight-line distances between successive locations, rendering $l - 1$ step lengths for each bighorn where l = total number of locations; we subsequently summed step lengths that fell within each day (Harris et al. 1990, Johnson et al. 2002, Dechen Quinn et al. 2012, Rowcliffe et al. 2012). To increase accuracy in daily movement estimates, we allocated the hourly proportion of any step length that overlapped a 24-hour period to the appropriate day. For example, if a GPS unit set to collect location data every 5 hours logged a location at 2200 hours on Day 1 and again at 0300 hours on Day 2, 0.40 of the step length was added to Day 1 and 0.60 was added to Day 2.

Fix rates differed (i.e., 1 or 5 hr) among collared bighorns, yielding different individual daily movement estimates (Rowcliffe et al. 2012). Differences were also observed in daily movement estimates independent of fix rate frequency >1 year after release, indicating variability in routine movements among bighorns. Therefore, we identified acclimation time relative to each individual regardless of actual distance moved. We justified the ability to detect change in movement variation utilizing different fix rates with a 2-tailed, 2-sample *t*-test, which revealed no significant difference in acclimation periods using data collected with 1-hour or 5-hour GPS fix rates ($t_{36} = 0.80$, $P = 0.429$).

We employed a functional data analysis (Zhao et al. 2004) to determine individual bighorn acclimation periods from consecutive daily movement estimates. Functional data analysis can be applied using longitudinal data where complex analyses (e.g., random effects modeling, repeated measures analyses) may be avoided by reducing multiple longitudinal responses into a summary measure analysis (Everitt 2002, Ramsey and Schafer 2002). This is done by fitting a function to each experimental unit and subsequently performing appropriate statistical tests on the functions or specific characteristics (summary measures) of the functions. In this scenario, the summary measurement consisted of the time elapsed to reach a value or threshold that indicated settling by the animal (Everitt 2002).

We visually identified stable movement durations from daily movement estimates within the first 180 days after release, and censored 10% of the durations from the beginning and end of these dates to ensure conservative estimates (Fig. 2A). The standard deviation (SD) of the stable movement duration was used as a benchmark; each animal was deemed to have acclimated when the SD among daily movements (in moving 5-day windows) reduced to within 75% of the SD among daily movements in the stable movement duration and stayed settled for 30 consecutive days. We excluded any movements that resulted in variation outside the threshold for ≤ 5 days because of stochastic factors that may sporadically influence bighorn movements (e.g., aircraft disturbances, anthropogenic proximity, escaping predation, weather events). This process resulted in a summary measurement of number of days to acclimate after release for each bighorn sheep (Fig. 2B).

We examined individual or group characteristics such as initial versus supplemental releases, sex, and source herd using independent 2-sample *t*-tests. Because 16 of 25 bighorns captured in the study area were radiocollared upon translocation, the comparison that included translocated bighorns captured and released on-site within the study area was conducted with a paired *t*-test. Prior to all tests, we visually assessed normality of residuals and conducted Levene's test for equality of variances (O'Brien 1981). If the assumption of equal variance was not met, we conducted *t*-tests assuming unequal sample variances. We set alpha levels at 0.05 for all statistical tests and report raw mean, standard error, and range for each estimate. Because we estimated acclimation individually (each bighorn as an experimental unit), we provided standard boxplots for visual representation relevant to sampling distributions, which include median lines, interquartile ranges, and outliers. We conducted statistical analyses with Minitab 16.2.3 (Minitab, Inc., State College, PA) and R 2.15.3 (R Development Core Team 2012).

RESULTS

Between 2009 and 2010, 40 of 52 (77%) bighorns translocated to the Seminoe Mountains were equipped

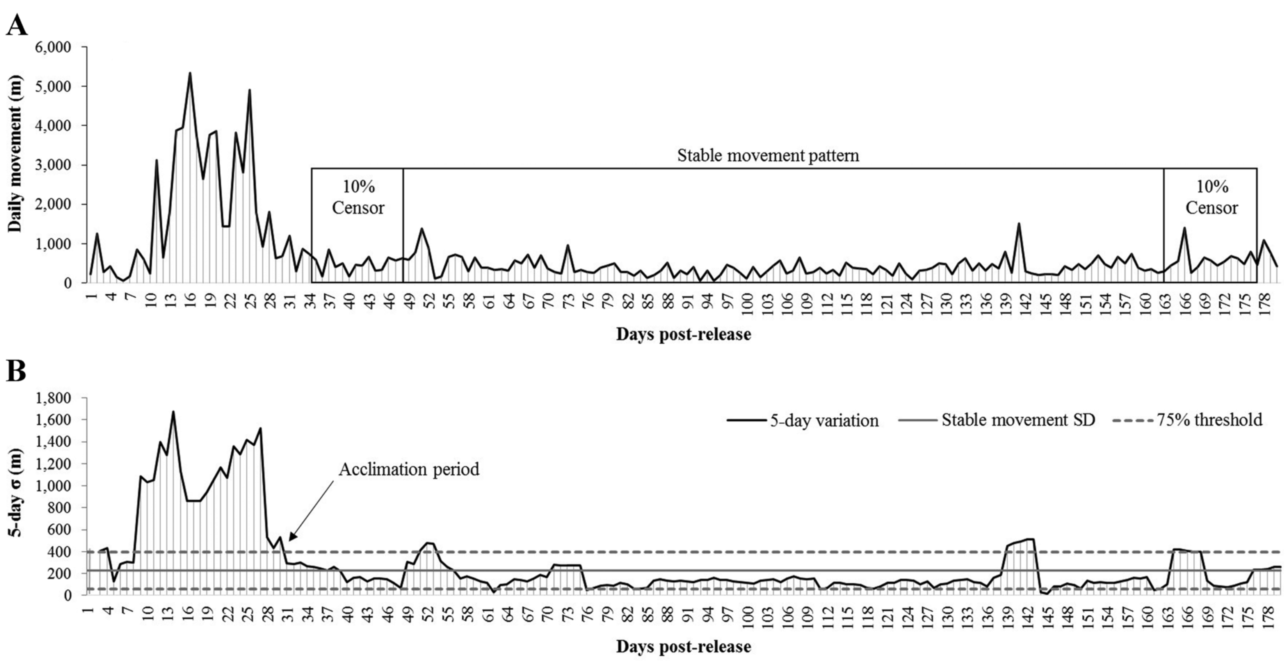

Figure 2. Summary measurement (acclimation period) from function applied to post-release daily movements of a bighorn female translocated on 2 December 2010 to the Seminoe Mountains, Wyoming, USA. (A) Visual estimation of stable movements from total daily movement rate (m/day) to 180 days after release. (B) 5-day standard deviation (moving window) of daily movements to 180 days after release. Solid gray line represents the standard deviation of stable movements identified in A. Dashed lines represent threshold to acclimation (±75% gray line value).

with GPS collars. Of these bighorns, 13 (F = 10, M = 3) were released in December 2009, 12 (F = 9, M = 3) in January 2010, and 15 (F = 12, M = 3) in December 2010. Our total sample thus consisted of 65 GPS-collared bighorns (including 25 bighorns captured and released on-site in December 2011). We successfully retrieved transmitters from 64 of 65 GPS-marked individuals. One GPS collar malfunctioned after deployment, yielding no usable data. One bighorn died within 7 days of release, with necropsy indicating mortality due to capture myopathy. All other study animals ($n = 62$) survived >60 days post-release and were included in subsequent analyses.

Movement rates (m/day) for all bighorn sheep increased during acclimation under translocation and capture–release scenarios (e.g., Fig. 2A). We estimated acclimation periods for bighorn cohorts released in translocation efforts and captured and released on-site (Fig. 3A), for translocated females and males (Fig. 3B), and for translocated females from 3 different release efforts (Fig. 3C). Average acclimation period for bighorns released in translocation efforts ($n = 38$) was 29.3 days (SE = 2.5, range = 0–70). Bighorns captured and released on-site ($n = 24$) showed an average acclimation period of 5.0 days (SE = 2.4, range = 0–52). A paired t-test revealed mean acclimation time for 16 translocated bighorns (mean = 36.0 days, SE = 4.5, range = 9–70) that were recaptured and released on-site (mean = 5.2 days, SE = 3.2, range = 0–52) was reduced by 30.8 days (SE = 5.0) or 86% ($t_{15} = 6.15$, $P \leq 0.001$). No difference was found between bighorns born in the study area ($n = 5$) and the 19 bighorns that had been involved in previous captures ($t_6 = 0.04$, $P = 0.967$). Within translocation efforts, mean acclimation period for females ($n = 29$) and males ($n = 9$) was 31.7 days (SE = 2.9, range = 0–70) and 21.4 days (SE = 3.9, range = 0–37), respectively, yielding no difference in acclimation periods between sexes ($t_{36} = 1.82$, $P = 0.077$). Mean acclimation for females released in the initial translocation effort ($n = 9$) was 45.1 days (SE = 6.0, range = 25–70), while the second ($n = 9$) and the third ($n = 11$) releases yielded mean acclimation of 21.7 days (SE = 4.4, range = 0–32) and 28.9 days (SE = 1.8, range = 23–32), respectively. Females from combined supplemental releases (i.e., second and third releases; $n = 20$) acclimated 19.5 days sooner (57% of the time) than those from the initial translocation effort ($t_{10} = 3.05$, $P = 0.006$; Fig. 4). However, we found no difference in acclimation time of females from differing source herds in supplemental releases ($t_{18} = 1.79$, $P = 0.099$); also the only comparison where different numbers of bighorns were released.

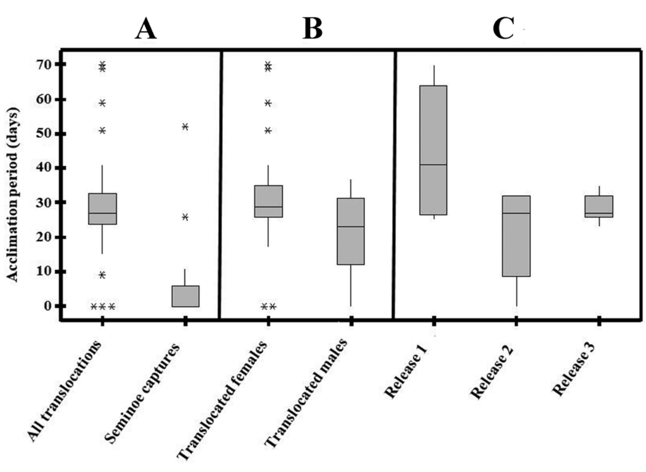

Figure 3. Boxplot depicting acclimation periods of differing cohorts of low-elevation, non-migratory bighorn sheep via translocation and capture-and-release efforts from 2009 to 2011 in the Seminoe Mountains, Wyoming, USA. (A) All bighorn cohorts; (B) females and males; and (C) females from 3 release efforts. Box plots include the interquartile range (25th–75th percentile) in days to acclimation; horizontal lines inside boxes represent median days to acclimation; lower and upper whiskers are 1.5 times the interquartile range; asterisks above and below whiskers are outliers in days to acclimation.

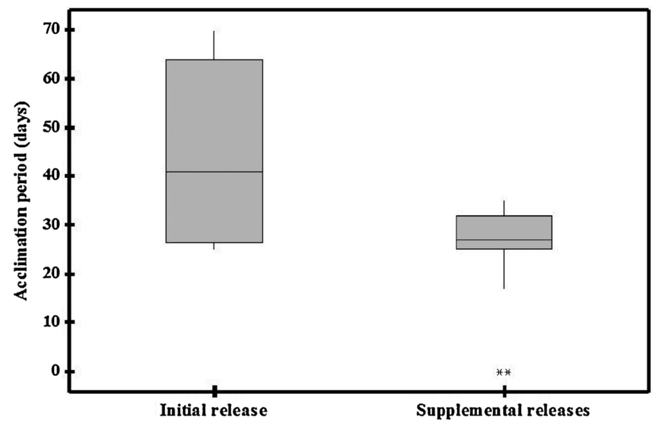

Figure 4. Boxplot depicting a decrease in acclimation period of translocated female bighorn sheep in supplemental releases, versus initial translocation release effort, to the Seminoe Mountains, Wyoming, USA, in 2009 and 2010. Box plots include the interquartile range (25th–75th percentile) in days to acclimation; horizontal lines inside boxes represent median days to acclimation; lower and upper whiskers are 1.5 times the interquartile range; asterisks above and below whiskers are outliers in days to acclimation.

DISCUSSION

Our results supported our prediction that mean acclimation for bighorn translocation releases would be longer in duration than those captured and released on-site. These results showed that releasing bighorns into novel environments increases dynamic movements as they seek out suitable habitats. The most profound difference in acclimation after translocation was identified between translocations involving initial and supplemental releases, where supplementally released bighorns most likely settled in response to attraction to conspecifics already established in the release area. This finding provided strong support for our second prediction. Bighorns in the 3 translocation releases were obtained from differing source herds in Oregon and Wyoming; however, no difference in acclimation for supplemental releases that included bighorns from Wyoming (second translocation) or Oregon (third translocation) indicated it was unlikely that source herd influenced post-release acclimation times. When considering the potential influence of the timing of releases, we remind the reader that only one release effort did not occur on 2–3 December (occurring during the same winter season on 30 Jan 2010), and with individuals exhibiting acclimation periods similar to the other supplemental release.

We did not investigate the effect of release area size or the spatial distribution of resources within the release area that may influence translocated bighorns as they acclimated to new surroundings, and translocating bighorns into larger study areas may increase acclimation periods because of increased available habitat for bighorns to explore after release. A variety of potential influences (e.g., suitable habitat, predator densities, proximity to domestic livestock, availability of water sources) should be carefully considered prior to any translocation effort. In particular, extensive disease testing should be conducted from potential source herds to avoid the translocation of infected animals. However, if shortening acclimation reduces extensive, spatially broad investigations of novel environments after release, it may also reduce the likelihood of domestic livestock interactions and disease contraction during acclimation.

Calculating precise animal movements depends largely on the ability to acquire fine-scale GPS location data. However, even with improvements in data storage and battery life that are common in contemporary GPS technology, movement rates of animals are typically underestimated due in part to limitations in frequencies of fix rates (Pépin et al. 2004). For example, Rowcliffe et al. (2012) concluded typical telemetry studies would underestimate actual distances traveled by between 67–93%. Although fix rate frequencies continue to be problematic for research involving the census of animal movement rates, identifying relative change in movement rates seems an applicable approach to identify acclimation period for low-elevation, non-migratory bighorn sheep after translocation releases, and can be accomplished using differing fix rates up to 5 hours.

Other statistical methods for documenting acclimation period of ungulates consist of comparing the deviation between annual population-level average daily movement rates and post-release movements (see Dechen Quinn et al. 2012). In our study, functional data analysis enabled us to estimate acclimation periods from GPS data with differing fix rates, without the need to standardize individual movement rates to create a population average. We were also able to estimate acclimation periods without the need to collect location data across multiple years to establish average movement rates for each calendar day. Finally, Dechen Quinn et al. (2012) report that improper data censoring caused significant differences in movement estimate analyses when using data sets of <90 days. Because we used a summary measurement for each experimental unit, acclimation time was identified for each animal, providing the ability to incorporate individual variation during data-censoring. The ability to censor data for each experimental unit is especially beneficial when analyzing short data sets.

Although other studies document decreases in movement rates after capture and chemical immobilization of various species (Cattet et al. 2008, Dechen Quinn et al. 2012), we identified a consistent increase in movement rates for translocated bighorn sheep after release as well as those captured and released on-site, indicating reduced movement rates after capture may be attributed to residual effects of chemical immobilization. Because of the increased time taken for bighorn movements to stabilize after translocation, and because no bighorns were immobilized in our study, the documented increase in movement rates were most likely attributable to bighorns investigating novel environments to successfully establish home ranges that meet habitat requirements.

MANAGEMENT IMPLICATIONS

We recommend that managers invested in the restoration of bighorns into low-elevation ranges consider both timing and release strategies when planning bighorn translocations. Recognition of the increased risk of mortality associated with bighorn acclimation suggests managers minimize acclimation periods and focus bighorn monitoring efforts during that time. To decrease acclimation periods, we recommend augmenting waning bighorn populations prior to complete extirpation of residents to allow newly translocated bighorns to positively associate with conspecifics. Our results indicated that supplemental releases significantly reduced acclimation periods of translocated bighorn sheep. Thus, if multiple translocations are planned to re-establish extirpated populations, it may be beneficial to initially release a small group of bighorns to more efficiently assess where they seek suitable habitat, and then conduct larger subsequent releases within a reasonable distance from these animals. We recommend conservative monitoring efforts be implemented to assess acclimation of bighorns translocated to new environments. Although we estimated mean acclimation time approximately of 30 days after releases, individual acclimation ranged from 0 to 70 days, indicating that individual behaviors or site conditions may lead to variable acclimation times. Furthermore, biologists acquiring GPS data for use in subsequent analyses should consider identifying acclimation periods of translocated animals individually.

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