

University of Nevada, Reno

**Changes in Selection of Resources by Newly
Introduced Bighorn Sheep**

A thesis submitted in partial fulfillment of the requirements for the degree of Master of
Science in Natural Resources and Environmental Science

By

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Abstract:

Wildlife movements through landscapes are influenced by the seasonal availability of resources including: food, water, cover, and space. Life-history characteristics of animals including sex, age, and reproductive status affect how animals use the landscape. Naïve animals introduced into a new area are required to learn the distribution and abundance of vital resources to subsist, thrive, and reproduce. I hypothesized that movement patterns and habitat selection by animals translocated to a new area would change over time, reflecting acclimation. I investigated how movement patterns and selection of resources by newly introduced California bighorn sheep (*Ovis canadensis californiana*) varied during two years following introduction into a new habitat during 2020-2021. I tested the hypothesis that newly introduced bighorn sheep would shift movements and patterns of seasonal resource selection between the first- and second-year following release as they become familiar with their new habitat and locations of resources. I used Brownian Bridge Movement Models to understand changes in habitat use, and resource selection functions to understand changes in selection of resources by bighorn sheep between years. My findings indicated that movement patterns were largely distributed throughout the study area during the first year, and exhibited a shift in habitat use and resource selection in year two as animals acclimated and became familiar with the distribution of resources. Steep slopes and high elevations were consistently selected during both years. Study animals selected areas close to water sources the first year, but moved further from water sources in the second year when they were familiar with the distribution of water in the study area.

Shifts in distribution of sheep likely resulted from learned knowledge associated with the distribution of resources. Those findings show the importance of distribution of resources, especially the availability of steep slopes and water in arid environments to understanding movement patterns by newly introduced bighorn sheep. Further, my findings indicate that sheep were more widely distributed across the range when adult females were newly introduced and naive to their new habitat.

Keywords: bighorn sheep, Brownian Bridge Movement Model, home range, Lake Range, *Ovis canadensis*, reintroduction, resource selection.

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Introduction:

Bighorn sheep inhabit some of the most arid, and rugged habitats from Canada to Mexico (Valdez & Krausman 1999). Prior to European exploration and settlement, bighorn sheep (*Ovis canadensis*) were widely distributed throughout the mountain ranges of western North America (Valdez & Krausma 1999). Throughout western North America, bighorn sheep have been extirpated over most of their historical range, with overall numbers reduced >95% (Krausman & Shackleton 2000). After widespread population decline and extirpation in many regions, translocation and reintroduction have become the principal management techniques for restoring the species to native ranges (Bailey 1990; Jessup et al. 1995). Over 15,000 bighorn sheep have been translocated since the 1920s throughout hundreds of habitats in western North America (Wild Sheep Working Group 2015; Novak, Phelan, & Weber 2021). Pioneering restoration programs primarily relied on translocation, but those early efforts did not produce high rates of success (Risenhoover et al. 1988). From 1927 to 1997, only 41 out of 100 translocations in 6 western states resulted in the classification of "successful" (Singer et al. 2000a).

Following translocation, animals must adjust to novel biotic and abiotic environments especially if they are moved long distances into dissimilar habitat (Pero et al. 2021). When animals are naïve to new habitats, they can experience higher rates of mortality and limited dispersal compared to extant populations (Le Gouar et al. 2012; IUCN 2013). With decades of advancement in the science of reintroduction and translocation, techniques have evolved that have resulted in improved success rates, yet

the successes and failures of many translocations are inadequately documented (Short et al. 1992).

Reintroduction projects focus primarily on reestablishing species through releasing individuals following extirpation or to augment existing or declining populations (IUCN 1998; Seddon et al. 2007). In the 1990s, several papers focused on the need for improved monitoring of reintroductions with an expanded focus on research through the application of experimental methods (Armstrong et al. 1994; Sarrazin & Barbault 1996; Seddon 1999). Douglas and Leslie (1999) stated that methodical monitoring of population demographics is necessary to determine the success of a reintroduction (Zimmerman 2008). The intensity of monitoring of reintroduction projects has steadily increased, and numerous researchers have published studies examining hypotheses related to techniques for improving the success of reintroduction (Seddon et al. 2007; Baxtor et al. 2009; Laws & Kesler 2012; Jenkins et al. 2015; Werdel et al. 2021; Hossack et al., 2022). Indeed, Werdel et al. (2021) recommended that translocations be vigorously evaluated to provide information on carrying capacity, post-release pioneering (i.e., exploratory movements), habitat selection, and home range to assist in the increasing success of translocating bighorn sheep (Douglas and Leslie 1999; Zimmerman 2008). The International Union for the Conservation of Nature (IUCN/SSC 2013) recommended the adoption of a standardized and academically sound approach to reintroductions and other conservation related translocations. One important subject is the quantification of the roles of the various

essential, environmental and management factors on translocation success, which in turn requires a standardized definition of success (Robert et al. 2015).

Naïve animals do not know the availability of resources in their new habitats following translocation, and those animals must learn locations and seasonal availability of resources to survive and reproduce. Therefore, an acclimation period should occur where translocated individuals learn the topography, location of steep slopes and high elevations (e.g. escape terrain), as well as the distribution of food, water, cover, and other important resources. Shifts in movements post traslocation have been observed, including changes in timing of reproduction of bighorn sheep that were translocated into new ranges (Whiting et al. 2011, 2012a, 2012b). Whiting et al. (2011) found evidence that within 5 years after reintroduction bighorn sheep adjusted timing and synchrony parturition to local environmental conditions. My research builds on the understanding of movement patterns and selection of resources during acclimation by translocated species (Jenkins et al. 2007; McLoughlin et al. 2002; Apps et al. 2001; Johnson 1980).

My goal was to monitor changes in habitat use and resource selection while bighorn sheep were acclimating to the landscape. I hypothesized that female bighorn sheep would have largely distributed habitat use within the study area in the first year as they learn the new habitat and then shift to more localized distributions and habitat use in the second year following translocation. I hypothesized that seasonal patterns of resource selection would change as bighorn sheep acclimated to their new habitats, but

selection for escape terrain would be similar as they establish stable home ranges during the second year. I also hypothesized that as naïve bighorn sheep learn the seasonal distribution and availability of resource in their new habitats, that their movement patterns and selection of resources would shift to improve access and use of those resources and that they will select more suitable habitat as they acclimate to their new habitats.

Materials and Methods:

Study Area

The study area is located on the Lake Range (40 ° 5'N, 119° 27'W), about 13 km north of Nixon, Washoe Co., Nevada (Figure 1). The Lake Range is about 48,600 hectares, and elevations range from 1,160 m to 2,494 m above sea level. Highly rugged terrain and abundant escape terrain dominates the western region of the range. Roads are limited, public access is restricted within the study area and no human development exists. The Lake Range runs parallel to Pyramid Lake, a desert terminal lake that is about 24 km long and 19 km wide, and encompasses 45,300 hectares within the Pyramid Lake Paiute Reservation. Water sources are abundant throughout the landscape with numerous springs, seeps, riparian drainages, and ephemeral and intermittent streams. Vegetation communities are generally described as sagebrush (*Artemisia spp.*) steppe, which is characteristic of the Great Basin Desert (Society for ecological restoration international 2004). There are limited densities of trees scattered through the landscape including: juniper (*Juniperus sp.*), single-leaf pinyon pine (*Pinus monophylla*),

cottonwood (*Populus sp.*), willow (*Salix sp.*), and quaking aspen (*Populus tremuloides*). Habitats that support the growth and distribution of tree species are limited to high elevation riparian drainages, mainly isolated on northwest slopes. Dominate vegetation types include, several species of sagebrush, four-winged salt brush (*Atriplex canescens*), rabbit brush (*Chrysothamnus nauseosus*), shadescale (*Atriplex confertifolia*), greasewood (*Sarcobatus vermiculatus*), winterfat (*Ceretooides lanata*), antelope bitterbrush (*Purshia tridentata*), and Mormon tea (*Ephedra nevadensis*).

Other ungulate populations in the study area are mule deer (*Odocoileus hemionus*), pronghorn (*Antilocapra americana*), and to a lesser extent feral horse (*Equus ferus*). Feral horse populations are currently low and widely dispersed in the Lake Range. No predator control was conducted prior to or during the study. Predator populations include mountain lions (*Puma concolor*), bobcats (*Lynx rufus*), golden eagles (*Aquila chrysaetos*), and coyotes (*Canis latrans*).

Bighorn sheep were endemic to the Lake Range in historic times. Explorer John C. Fremont wrote in his journal on Jan. 11, 1843 during his travels through the Lake Range noted that he “saw herds of mountain sheep” (Knack 1977). Bighorn sheep were extirpated from the Lake Range sometime after that written record. The range is currently used for grazing open range cattle at low densities and is permitted for summer rotational grazing. No domestic sheep are grazed on the Lake Range.

Animal Capture and Handling

The Nevada Department of Wildlife (NDOW) captured 22 California bighorn sheep, 3 adult males, 9 adult female and 7 yearlings, on the Sheep Creek Range (40° 50.6453', 116° 43.3782) in January 2020, using the netgun-helicopter technique (Krausman et al. 1985). All individuals were transported to a processing location near the capture site and marked uniquely with ear tags. All adults were fitted with Iridium Global Positioning System (GPS) satellite collars (VECTRONICS Aerospace) with very high frequency (VHF) transmitting capabilities. VHF allowed us to locate radio collared individuals in the field, track mortality, and collect radio collars after they dropped off the animals. Handling of animals was conducted by NDOW and was in accordance with the American Society of Mammologists guidelines for care and handling of wild mammals (Sikes et al. 2016). Three individuals died within 72 hours of release (one adult male, two adult female) and because those mortalities were suspected to be related to capture, they were eliminated from all analyses.

Data Collection and Analysis

I used locations collected from all adult female bighorn sheep obtained from the Pyramid Lake Paiute Tribe's Natural Resources Department. As the leading agency in the reintroduction and recovery of bighorn sheep within the Lake Range, the Pyramid Lake Paiute Tribe's involvement in the collection of data provided the foundation for my

analyses. I analyzed GPS locations collected from nine adult translocated bighorn sheep from January 2020 to October 2021. Collars were scheduled to collect locations at a two-hour sampling interval to maximize both number of locations and battery life of the collar. Moreover, I considered that sampling interval to be appropriate based on the assumptions of conditional random movement (Horne et al. 2007). Violations of the assumption of random movement between pairs of locations may become more prominent as the time interval between locations increases (Horne et al. 2007). Because bighorn sheep exhibit pronounced sexual segregation (Bowyer 2004), I did not include males in analyses for selection of resources because too few individuals were marked for separate analyses. I collected 51,341 GPS locations from collared females, and ensured that all locations had a >90% satellite fix rate (D'Eon 2003). To reduce location error associated with the dataset I removed all locations with only two-dimensional accuracy (Ironsides et al. 2017).

All data and analyses were delineated by season of use. I obtained data on climate from the Western Region Climate Station (Sutcliffe, NV weather station), and I used a climograph to define seasons specific to my study area using temperature and precipitation data from 2001-2021 (Figure 2, Stewart et al. 2002, McKee et al. 2015). This weather station is about 13 km west of the study area. I delineated winter as the months of November-March; Spring as April-May; Summer as June-September; and Autumn as October (Figure 2). Because bighorn sheep were released in January I limited

my analysis and inferences about winter to January – March for direct comparison of winter locations among years.

I used geospatial tools contained in ArcGIS 10.4.1 (Environmental Systems Research Institute, Redlands, California USA) to create a 30-meter buffered, gridded, minimum convex polygon (MCP) encompassing all movement locations to define the study area. I used geospatial statistics and created specific Brownian Bridge Movement Models (BBMM) in R (4.1.2, R Core Team) to quantify changes in seasonal movements (Horne et al. 2007). BBMMs allowed us to estimate the space-use of collared animals, conditional on temporally proximate locations (Walter et al. 2011; Werdel et al. 2021). BBMMs assume that location errors correspond to a bivariate normal distribution, and movement between successive locations is random conditioned on the starting and ending locations (Horne et al. 2007). Those models do not over-smooth the utilization density and more accurately depict use of landscape by ungulates over kernel density estimators (Lewis 2007; Walter et al. 2011; Werdel et al. 2021). The BBMM probability density connected each pair of successive locations as an estimate of the relative time spent in a habitat during the time interval between those locations (Horne et al. 2007; Sawyer et al. 2009). I created BBMMs for each individual across all seasons and years as a reflection of individual home ranges. I calculated the area of all individual home ranges surviving the research period using ArcGIS 10.4.1 (Environmental Systems Research Institute, Redlands, California USA), and ran a paired t-test to compare distributions of animals between the two years. I then combined all BBMMs within each

season as a representation of habitat use for direct comparison by season and year.

Some sheep died during the research period so sample sizes varied among seasons and years.

I created resource-selection functions (RSF) by fitting a generalized linear mixed-effects model with random slopes, a binomial error distribution, and logit link function using R (4.1.2, R Core Team; Gillies et al. 2006; Klop et al. 2007; Bolker et al. 2009; Zuur et al. 2009; Allred et al. 2011; Long et al. 2014; Mckee et al. 2015; Stewart et al. 2015). The RSFs were in a used- available design with used locations coded with a 1 and a 0 for available locations; individual bighorn sheep were included with random slopes for each variable in each of the models (Boyce 2006, Gillies et al. 2006, Zuur et al. 2009, Stewart et al. 2015). I selected biological relevant variables hypothesized to be important in explaining how bighorn sheep select resources (Stewart et al. 2015; Blum 2021). Resource selection was evaluated for all individuals at the scale of the extent of the study area or population, second order selection (Johnson 1980, Manley et al. 2007). To calculate availability within each season I generated three random points within the study area for every used location (Boyce et al. 2003; Johnson et al. 2006). I conducted a global model resource selection function for all adult female bighorn sheep to define variables included in all resource selection function models. I included variables known to be important to bighorn sheep, and used the same set of habitat variables in each model for direct comparison of selection by season and year. I used Akaike's

Information Criterion adjusted for small sample sizes (AICc) to evaluate and rank the models (Burnham and Anderson 2002; McKee et al. 2015; Stewart et al. 2015).

I ranked models using the full dataset, and used the MuMIn package in R to evaluate all possible model combinations (McKee et al. 2015). I considered top models within 2 AICc scores to be competitive, and reviewed those models for the presence of uninformative parameters (Burnham & Anderson 2002; Arnold 2010). I used diagnostics of residuals to determine appropriateness of the models (Burnham & Anderson 2002). After selecting a top model using all data, I then applied the top model to all seasons separately across all years to directly compare resource selection throughout the studied two-year acclimation period post translocation (McKee et al. 2015; Stewart et al. 2015). I evaluated collinearity among variables using a Pearson correlation analysis in R, and only covariates that were correlated ≤ 0.65 were selected for further modeling (Stewart et al. 2002; Long et al. 2014; McKee et al. 2015). When two variables were highly correlated, I removed one and retained the covariate with the greatest influence on use of space by bighorn sheep (Stewart et al. 2002; Long et al. 2014). Therefore, I omitted ruggedness because of its correlation to slope (0.72), and annual vegetation cover for its correlation to perennial vegetation cover (0.69).

I used a 10-m resolution digital elevation model (DEM; United States Geological Survey, 2020) to create special layers calculating elevation (m), slope ($^{\circ}$), aspect ($^{\circ}$), distance to water (m), and terrain ruggedness using the vector ruggedness measure (VRM; Sappington et al. 2007). Because aspect is a circular variable, I used a

transformation of aspect by cosine (north-south) and sine (east-west) functions for my analyses (Heffelfinger et al. 2020). I used locations of perennial water sources developed by the Pyramid Lake Natural Resources Department to calculate distance to water using ArcGIS 10.4.1 (Environmental Systems Research Institute, Redlands, California USA). The shoreline of the Lake Range is dominated by steep slopes, and precipitous, rugged habitat with numerous springs directly adjacent to the shore line. Therefore, I masked the surface of Pyramid Lake as a water source, or area of movement for bighorn sheep to prevent bias in results. I used the Rangeland Analysis Platform to define cover of shrubs, annual forbs and grasses, and perennial forbs and grasses (<http://rangelands.app>). For discrete variables (i.e., vegetation type) resulting positive model coefficients designated selection of a covariate while negative values designated avoidance of a covariate (Stewart et al. 2015; Hefty & Stewart 2019). For continuous variables representing distance to a resource, such as distance to water, negative model coefficients designate selection for shorter distances because probability of selection decreases as distance to a point of interest increases, and positive coefficients designate avoidance of a resource as probability of selection increases as distance from a resource increase (Stewart et al. 2015; Hefty & Stewart 2019). All continuous variables were standardized for direct comparison among estimates (Neter et al. 1996; Stewart et al. 2015).

Lastly, to test the probability of a significant different in phenology from 2020 to 2021, I ran a t-test to compare average monthly temperature and precipitation data

between the 2 years from the Western Region Climate Station (Sutcliffe, NV weather station). Differences in the phenology between years could potentially influence results, as phenological events of plants and animals are sensitive to climate processes (Monteith et al. 2011).

Results:

Consistent with my hypothesis, all BBMMs indicated that, in general, movements were widely distributed throughout the study area in 2020, but they shifted to becoming more concentrated in the southern end of the study area during 2021 as animals became familiar with their new habitats (Figure 3 A-H). We observed no statistically significant changes in home ranges between years during winter, spring and summer. Nevertheless, home ranges during autumn were larger in the second year compared with the first (Table 1).

I observed little concentrated use of habitat, during winter 2020, with the exception of habitat located east of the release site (Figure 3A). Conversely, habitat use in winter 2021 was concentrated within the southern portion of the Lake Range (Figure 3B). Movement patterns in spring 2020 were throughout the northern and southern regions of the study area, with three disconnected areas of occupation that were widely distributed throughout the study area. Habitat use was subsequently isolated within the southern region in spring 2021. My results also indicated that there were two areas of concentration during 2020, but changed to a single area of concentrated use in the southern portion of the range during spring 2021 (Figure 3 C-D). During summer 2020

and 2021 the BBMMs indicated that movements had higher connectivity and concentrated use during the second year compared to the first (Figure 3E-F). During autumn of the first year, use of habitat included three disconnected areas of occupation that were widely distributed throughout the study area, which was similar to spring of the first year (Figure 3G). Conversely, movements during autumn 2021 were widely distributed throughout the southern portion of the range with little to no remaining use the north end (Figure 3H).

I examined resource selection by adult bighorn sheep seasonally during the initial two years post translocation (Table 2). I modeled resource selection using all the animal locations for both years, and I observed 2 competitive models that were within 2 AICc scores and I selected the top model (Table 3). The model included sine and cosine of aspect, distance to water, elevation, slope, and shrub cover (Table 3). During all seasons, bighorn sheep selected steep slopes, only slightly more than elevation, that were consistent with defined escape terrain, but during 2021 they moved farther from sources of water than observed during the first year following translocation (Figure 4A-F). Selection of resources during the winter was similar between 2020 and 2021 for most resources, but selection for south facing slopes was stronger in 2021 than 2020 (Figures 4A-B). Furthermore, selection for habitat close to water sources is observed in 2020 with a shift toward habitat further away from water sources in 2021. During spring, I observed the strongest selection for steep slopes and high elevation in 2020 compared with 2021 (Figure 4C-D), with a strong selection for habitat close to water sources in the 2020 and lessening in 2021. During summer, resource selection between

years shifted from selection of north slopes in 2020, to south west slopes in 2021. Additionally, I observed a strong shift in the use of habitat close to water in 2020, and habitat further from water in summer 2021. During autumn 2020 animals exhibited a strong selection for water and a profound shift in selection for habitat away from water in 2021, similar to the summer season (Figures 4G-H). Overall, I observed stronger selection for areas close to water in 2020 compared to 2021 when animals had time to learn the distribution of resources across the study area. I observed no significant differences in temperature and precipitation between 2020 and 2021 (Table 4). Results of resource selection and BBMM were not influenced by changing weather patterns between years.

Discussion:

My hypothesis that female bighorn sheep had larger distributions in habitat use during the first year relative to the second year when they experienced a year of acclimation was supported. As I predicted, translocated bighorn sheep in my study were widely distributed in their use of habitat in the first year before shifting habitat use to reflect learned knowledge in the second year when animals became familiar with their new home ranges (Bleich et al. 1996; Kissell 1996; Singer et al. 2000a, b; Schmitz et al. 2015; Bleisch et al. 2017; Mertes et al. 2019; Werdel et al. 2021). Dispersal of introduced individuals into unfamiliar terrain has great implications to survival, because movements through unfamiliar or inhospitable habitats may increase vulnerability to predation, stress, and malnutrition (Van Vuren 1998; Zimmerman 2008), while also increasing

energetic costs and risk of mortality (Van Vuren 1998; Perrin and Mazalov 1999).

Introduced ungulates may establish a home range and concentrate use, with limited dispersion from suitable terrain adjacent to the release site, with concentrated use in close proximity to the release site (Van Vuren 1998; Zimmerman 2008). Contrary to the described progression of animals remaining close to the release site, I observed larger and more exploratory movements in the first season, when the area was unknown, followed by an overall habitat use once the distribution of resources was learned. I observed concentrated use of habitat within close proximity to the release site in 2020 compared to 2021. Indeed, newly translocated animals must learn the distribution of resources, such as forage and water, in addition to the location of areas of terrain essential for escape from predators.

Surface water can have a disproportionate influence on patterns of selection by desert species relative to scarcity of abundance (Noy-Meir 1973). High water demand during physiologically challenging times often leads to water sources being focal points of activity on desert landscapes for multiple species, increasing risk of competition and predation (Weir and Davidson 1965; DeStefano et al. 2000; O'Brien et al. 2006; Hall et al. 2021). Bighorn sheep in my study were closely associated with locations of water during the first year, especially during the arid seasons of summer and autumn when females were lactating and water needs were highest. Conversely, during the winter and spring seasons, water needs likely were minimal compared to seasons with higher thermal index and evaporative water loss (Schmidt-Nielson et al. 1956; Brook & Short

1960b; Monson & Sumner 1985). Water sources were likely more abundant during winter in the form of free water as snow and puddles, sources that cannot be included into the model. Under those conditions, bighorn sheep likely were able to meet hydration needs through other sources, and by selection of forage with high content of preformed water (Monson & Sumner 1985). My findings suggest that individuals learned the distribution of water resources in year one, and once those locations were known those individuals had limited need to remain within close proximity to water sources in the following year.

Most winter ranges occupied by bighorn sheep are on steep south and southwestern or southeastern facing slopes, which was consistent with our observations (Smith 1954, McCann 1956, Blood 1961; Sugden 1961; McCullough and Schneegas 1966; Schallenberger 1966; Stelfox & Taber 1969; Morgan 1970; Geist 1971; Oldemeyer et al. 1971; Erickson 1972; Riggs 1977; Valdez & Krausman 1999). During winter and spring, animals often use southern exposures to maximize heat gains from direct and indirect solar radiation, reducing cold stress. Those aspects usually have lower snow cover early growth of vegetation, thereby also increasing forage availability (Valdez & Krausman 1999). During the summer, however, when temperatures in those habitats were high, bighorn sheep moved to north-, east-, and west-facing slopes to feed and to reduce thermal index (Smith 1954; McCullough & Schneegas 1966; Stelfox 1975; Goodson 1978; Valdez & Krausman 1999).

Although use of steep slopes varied from habitat to habitat within and between populations, steep slopes were a strongly selected feature of habitats selected for most

populations of California bighorn sheep including my study population. At Hell Creek in Nevada, bighorn sheep selected slopes of 35-50% primarily in spring and summer, and 0-17% slopes in autumn and winter (Valdez & Krausman 1999; Hansen 1982). In contrast, a herd in Virgin Canyon, NV mostly occupied habitats with 18-33% slopes in spring and summer, compared to 34-50% in winter (Valdez & Krausman 1999; Hansen 1982). I observed a slight change in the use of slope grade, with a 29% average slope and the greatest slope grade observed in spring with 34%. Seasonal changes in use of different slope and aspects likely results in access to a larger mosaic of plant communities and phenological patterns that provide a variety of foraging opportunities for bighorn sheep, and allowed them to access forage in phenological stages with greatest nutritional value (Valdez & Krausman 1999). Surprisingly, vegetative cover did not appear to be a driver of resource selection in any season, but sourced remotely sensed data did not provide strong resolution of variability of forage available on the study area. Possibly, environmental factors (i.e., soil moisture, thermal index, aspect, slope) which affected the distribution of vegetation influenced observed movements in the study animals more strongly.

My research builds on well-established understanding of resource selection by bighorn sheep, and explores alterations in seasonal habitat selection by naïve and knowledgeable individuals. Females in the study altered movement patterns and habitat selection as the outcomes of a set of decisions influenced by learning the habitat that was newly available to them. I showed that distributions shift as sheep became

acclimated to the habitat the longer individuals were on the landscape. During some seasons there was little variation in selection, but pronounced variation in others, which supported predictions about population level information describing acclimation post translocation. Within habitats similar to the Lake Range in Nevada and denote of the reintroduced species, understanding shifts in selection of resources by naïve animals as they learn the new habitats can significantly contribute to improving the effectiveness of animal reintroductions, especially in arid environments.

I observed pioneering movements following release of adult females the first year following translocations to novel habitats. Areas inhabited by bighorn sheep and grazed by domestic sheep (*O. aries*) increase the likelihood of the introduction of pathogens including *M. ovipneumoniae* that have resulted in epizootic pneumonia and high mortality in wild sheep (Besser et al. 2014, Borg et al. 2017). Areas greater than 16 km from domestic sheep allotments has been shown to minimize the threat of introducing *M. ovipneumoniae* into wild populations (Desert Bighorn Council 1990; United States Department of the Interior, Bureau of Land Management 2006). Given my findings for females the risk of transmission of *Mycoplasma ovipneumoniae* maybe greater the first year when they are naïve to new habitats and should be closely monitored for long distance movements compared to following years.

In taking a multifaceted approach to reintroductions through the examination of habitat prior to translocation and close monitoring of individuals post-release to increase the success and viability of populations of translocated bighorn sheep (Werdel

et al. 2020). As translocation strategies adapt and improve, understanding tradeoffs that animals make to adapt to new habitats will further our understanding of large mammal ecology. The link between resource availability and patterns of population performance has important implications for understanding how newly introduced animals will adapt to new habitats.

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Table 1: Individual home range mean (mean + SD) size between seasons and years. Paired t-test and probability results for all 6 female bighorn sheep that survived the research period within the study area of the Lake Range, Nevada, USA, 2020-2021.

Season	Year 1 (2020) (mean \pm SD)	Year 2 (2021) (mean \pm SD)	t	P
Winter	3524.3 \pm 3332.91	2348.0 \pm 1344.37	1.00	0.178
Spring	1552.7 \pm 1269.66	2008.1 \pm 898.89	0.99	0.178
Summer	2117.4 \pm 511.37	4006.7 \pm 1755.71	2.66	0.245
Autumn	947.7.1 \pm 475.43	2130.3 \pm 936.77	3.06	0.014

Table 2: Descriptive statistics (mean + SD) of habitat variables for available (random) and used (bighorn sheep locations) for 9 female bighorn sheep in the study area of the Lake Range, Nevada, USA, 2020-2021. Parameters were standardized prior to analyses.

Covariate	Available	Used Locations							
		Winter		Spring		Summer		Autumn	
		2020	2021	2020	2021	2020	2021	2020	2021
Cosine aspect (°)	0.04 ±0.647	-0.18±0.589	-0.24±0.548	-0.06±0.589	-0.18±0.592	0.004±0.660	0.01±0.638	-0.01±0.639	.013±0.635
Sine aspect (°)	0.04±0.760	-0.12±0.78	-0.44±0.668	-0.11±0.799	-0.289 ±0.731	-0.25±0.707	-0.39±0.67	-0.37± 0.675	-0.024±0.722
Slope (°)	15.4±9.86	30.5±10.57	29.2±9.76	34.9 ±10.93	29.6±11.68	28.9 ±11.38	28.9±10.90	29.0±11.31	27.7±10.42
Elevation (m)	1555±265.2	1739±176.2	1692±128.9	17801 ±155.6	1753±164.8	1762±149.7	1815±217.3	1768±109.3	1694±191.5
Distance to water (m)	2998±3183.4	1863±1623.3	3695±2255.0	1763±1466.7	1888 ±1301.7	1134±595.6	1602±1285.0	1264±689.7	2271±1434.7
Shrub Cover (%)	12.8±6.89	16.0±5.74	16.1±3.82	17.2±5.87	17.1±5.40	16.5±6.03	18.1±6.05	17.1±5.25	16.4±5.71

Table 3: Mixed-effects logistic regression model, best fit model, all location data across all seasons from bighorn sheep introduced to the Lake Range, NV.

Model	df	logLik	AICc	d\Delta	Weight
- Intercept - Cosine aspect – Dist. to H2O + Elevation + Shrub cover - Sine aspect + Slope	8	-83661.5	167339	0	0.579
- Intercept - Cosine aspect – Dist. to H2O + Elevation - Perennial vegetation cover + Shrub cover - Sine aspect + Slope	9	-83660.8	167339.6	0.63	0.421
- Intercept - Cosine aspect + Elevation + Shrub cover - Sine aspect + Slope	7	-83779.3	167572.6	233.60	0.000
- Intercept - Cosine aspect + Elevation - Perennial vegetation cover + Shrub cover - Sine aspect + Slope	8	-83779.1	167574.2	235.20	0.000
- Intercept - Cosine aspect – Dist. to H2O + Perennial vegetation cover + Shrub cover - Sine aspect + Slope	8	-83848.5	167713	374.01	0.000

Table 4: Monthly weather data (mean \pm SD) from 2020 & 2021 from weather station in Sutcliffe, NV used to define whether climate influenced resource selection of bighorn sheep in the Lake Range, Nevada 2020-2021.

	Temperature (mean)		Precipitation (mean)	
	2020	2021	2020	2021
January	40.8 \pm 5.01	37.8 \pm 4.41	0.13 \pm 1.14	1.3 \pm 0.8
February	42.3 \pm 3.67	40.2 \pm 4.34	0.04 \pm 0.02	0.12 \pm 0.10
March	43 \pm 3.98	43.1 \pm 4.59	0.79 \pm 0.21	0.06 \pm 0.45
April	53.1 \pm 5.53	53.7 \pm 5.76	0.38 \pm 0.00	0 \pm 0.02
May	60.9 \pm 4.38	61.1 \pm 5.78	0.5 \pm 0.08	0.13 \pm 0.20
June	68.1 \pm 6.78	75.2 \pm 7.90	0.9 \pm 0.02	0.14 \pm 0.08
July	77.2 \pm 4.01	81.7 \pm 3.18	0.24 \pm	0.3 \pm 0.30
August	78.0 \pm 4.78	75.3 \pm 6.04	0.13 \pm 0.02	0 \pm 0.04
September	69.4 \pm 5.01	68.2 \pm 5.07	0 \pm 0.00	0.09 \pm 0.04
October	57.5 \pm 3.68	52.6 \pm 4.67	0 \pm 0.39	3.14 \pm 0.52
November	42.1 \pm 5.97	47.8 \pm 5.06	0.59 \pm 0.05	0.11 \pm 0.27
December	36.0 \pm 6.39	36.5 \pm 6.29	0.28 \pm 0.22	3.00 \pm 1.62
<i>t</i>		1.32		0.38
<i>P</i> -value		0.107		0.356

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Figure 3: Brownian Bridge movement models for seasonal home ranges of nine California bighorn sheep introduced to the Lake Range, USA, Nevada, 2020- 2021. Star indicates release site of transplanted sheep.

Figure 4: Mean \pm 95% confidence intervals for parameter estimates from resource selection functions with random slopes, from nine GPS collared adult female California bighorn sheep introduced into the Lake Range, NV, USA, 2020-2021. 95% confidence intervals that include 0 indicate no selection or use in proportion to availability. For Distance values, negative values indicate selection and positive values indicate avoidance.

Figure 1: Study Area of translocated bighorn sheep into the Lake Range, NV. Lake Range extent and MCP



Figure 2: Climograph of 20-year average weather data (2001-2021) from weather station in Sutcliffe, NV used to define seasons for the study area for translocation of California bighorn sheep, Lake Range, Nevada 2020-2021.

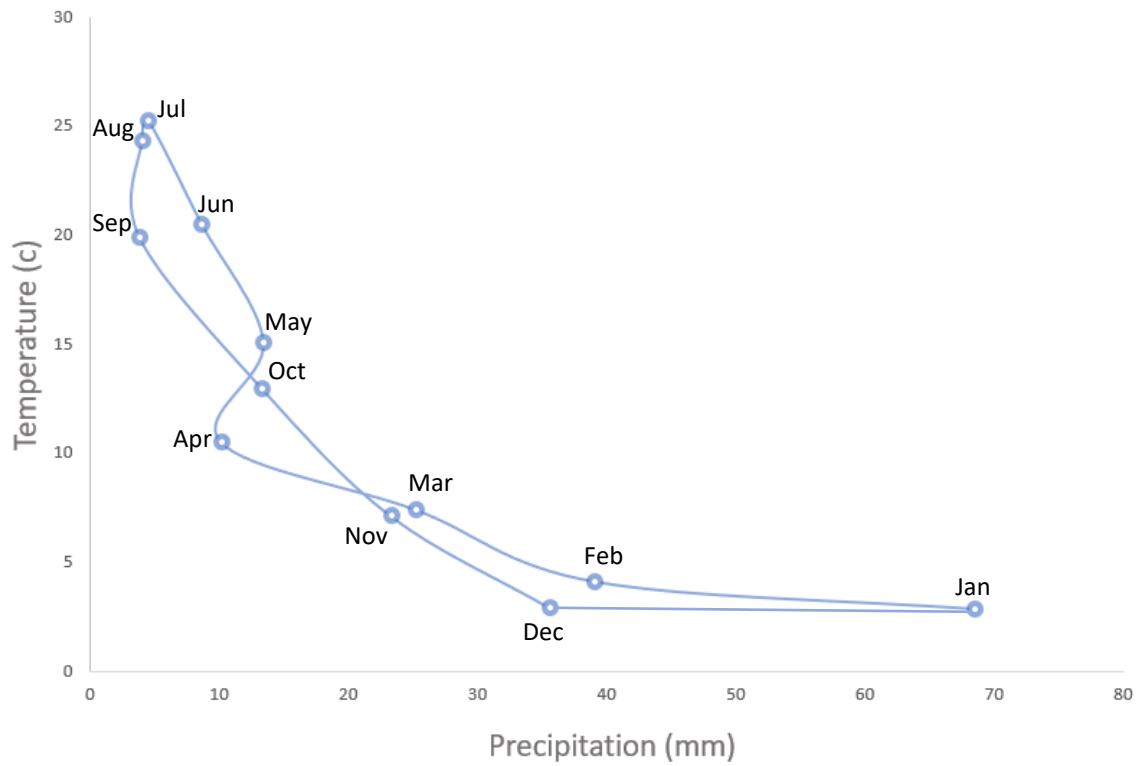


Figure 3: Seasonal Brownian Bridge home range results (2020-2021), used to compare home ranges of California bighorn sheep in the first year to the second year post-translocation, Lake Range, Nevada, 2020-2021. Sample size varies among seasons and years, Winter 2020 n=9, 2021n=7; Spring 2020 n=9, 2021 n=7; Summer 2020 n=9, 2021 n=6; Autumn 2020 n=8, 2021 n=6.

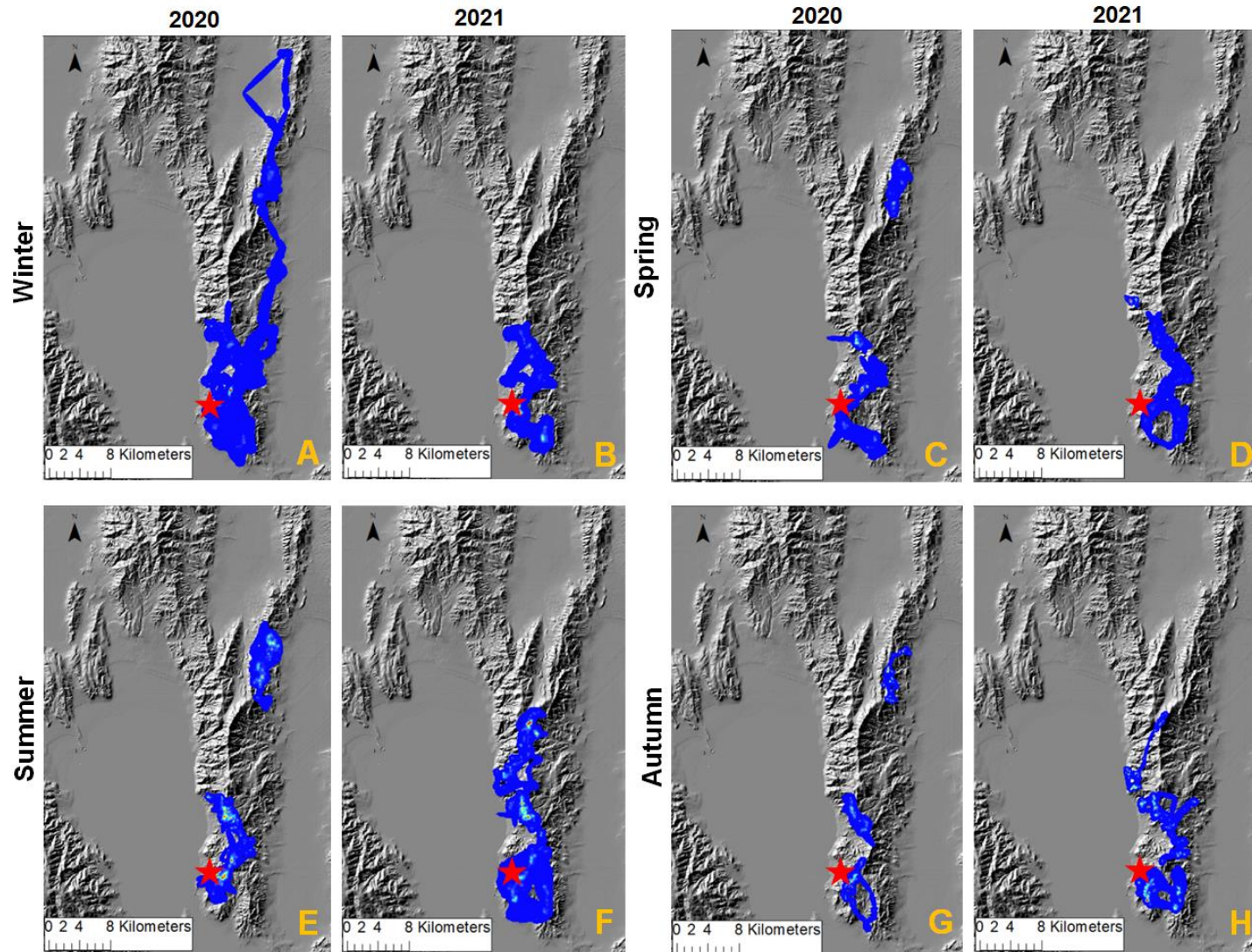


Figure 4: Seasonal resource selection function, parameter estimates and 95% confidence intervals, (2020-2021), used to compare resource selection of California bighorn sheep in the first year to the second year post-translocation, Lake Range, Nevada, 2020-2021.

