History, Status, and Population Structure of California Bighorn Sheep in Utah

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Abstract: Bighorn sheep (*Ovis canadensis*) are native to Utah, and although nearly extirpated, they have been successfully restored to many of their former ranges. Since 1997, 3 populations of California bighorn sheep (*O. c. californiana*) have been established in Utah on Antelope Island, the Newfoundland Mountains, and the Stansbury Mountains. Our objectives were to examine factors contributing to the extirpation of bighorn sheep populations in the Great Basin of northern Utah, to document population growth and habitat use of reintroduced herds of California bighorns, and to discuss population structure and movements of these animals. We compiled information on the historical distribution of bighorns in our study area from published reports and historical accounts. Furthermore, for each reintroduced herd, we calculated growth rates and lamb survival from winter population estimates. To document habitat use, we observed bighorn sheep on 960 occasions and estimated home ranges using a 95% fixed-kernel estimator. We documented intermountain movements of bighorns by reviewing agency reports and contacting those individuals who reported bighorns outside of reintroduction areas. Population home ranges varied in size (18-130 km^2) and appeared to be determined by escape terrain and vegetation structure. Population growth was positive for all areas and varied between 0.110 and 0.190. Also, all populations had high lamb survival to first winter (0.67-0.92). In this area of the Great Basin, >11 groups of bighorn sheep (mean group size = 1.9, *SD* = 1.2) moved from reintroduction areas to 6 neighboring mountain ranges, an average distance of 29.3 km (range = 13-60 km). The primary limiting factor for the continued establishment and success of California bighorns in Utah is the presence of domestic sheep. We recommend that bighorns in our study areas be managed as a metapopulation and that domestic sheep be removed from areas adjacent to populations of established bighorns. Additionally, we recommended that future research focus on documenting movement corridors of bighorns, which will highlight areas where bighorn and domestic sheep movements may coincide, thus threatening the persistence of these new herds.

Key Words: bighorn sheep, California bighorn sheep, domestic sheep, Great Basin, metapopulation, *Ovis canadensis californiana*, population growth, translocation, Utah.

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Bighorn sheep (*Ovis canadensis*) are native to Utah and have inhabited the state for at least 12,000 to 15,000 years (Stokes and Condie 1961, Geist 1985). Historically, this species occurred throughout Utah and occupied the Rocky Mountains, the Great Basin, and the desert canyons portions of the state (Dalton and Spillett 1971, Smith et al. 1988). The ubiquity of bighorn sheep is indicated by abundant skeletal remains (Dalton and Spillett 1971), historical accounts (Wilson 1967), and depictions of these animals in Native American petroglyphs.

Although bighorn sheep were widely distributed historically, their distribution and numbers were greatly reduced by the influences of European settlement (Buechner 1960). By the 1930s, the combination of unrestricted grazing, disease, and over-hunting resulted in the extirpation of all bighorns in the Great Basin of Utah and the near extirpation of bighorn sheep in the state (Dalton and Spillett 1971, Smith et al. 1988, Bates 2003). Following the loss of native sheep in Utah, a concerted effort to reestablish bighorns did not begin for another 30 years.

Reintroduction has been an effective practice to restore bighorn populations (Krausman 2000), and this management technique has been used extensively in Utah (Smith et al. 1988). Early reintroduction efforts focused on restoring the Rocky Mountain subspecies (*O.c.canadensis*) to northern Utah and the desert subspecies (*O.c.nelsoni*) to the southern portions of the state. Additionally in the 1980s, two populations of Rocky Mountain bighorns were established in the Great Basin on the Utah/Nevada border. However, since 1997, only the California subspecies (*O.c.californiana*) has been used to populate this region of the state.

This paper focuses on populations founded with California bighorns. Recent evidence indicates, however, that the current taxonomy of bighorn sheep, particularly the California subspecies, is questionable and needs revision (Krausman and Shackleton 1999, Shackleton et al. 1999, Wehausen and Ramey 2000, Wehausen et al. 2005). We used the traditional taxonomy of California bighorns because these animals are designated and managed currently as such in Utah.

Populations of California bighorns have been in Utah > 10 years, and the number of animals has increased substantially. The Utah Division of Wildlife Resources (UDWR) has conducted 8 translocations, moved 194 animals, and established three populations of California bighorns in Utah. Our objectives were: (1) to examine factors that contributed to the collapse of historical populations of bighorns in the Great Basin of northern Utah, (2) to document habitat use and population growth of reintroduced herds of California bighorns, and (3) to quantify movements and discuss population structure of these bighorns in northern Utah.

STUDY AREA

Our general study area is located in the eastern portion of the Great Basin within northern Utah (41°16´N, 113°38´W) (Fig. 1). The area encompassed a series of long, narrow mountain ranges that were separated by desert valleys, salt flats, and the Great Salt Lake. Elevation ranged from 1285 to 3362 m, but most mountain ranges were < 2200 m. Precipitation averaged < 310 mm annually, with spring and fall being the wettest seasons. Cover types of vegetation exhibited clinal variation with elevation. Valley elevations (~1,285 m) were characterized by salt-desert shrub communities and barren salt flats. Mid-elevations (1,300-2,200 m) contained grasses, brush, and pinyon (*Pinus edulis* and *Pinus monophylla*) /juniper (*Juniperus osteosperma*) cover. The highest elevations (> 2,300 m) were dominated by conifers and alpine habitat.

This portion of the Great Basin was and still is an important area for livestock grazing. Upon settlement in the 1840s, livestock owners steadily increased the number of domestic sheep and cattle in this region. Livestock grazing peaked between 1905 and 1925, and during this period > 250,000 sheep were trailed annually (Allred 1976). Today livestock grazing is regulated, but > 40 allotments for domestic sheep still exist on public land where thousands of animals graze. These allotments for domestic sheep are typically used between November and April each year.

Antelope Island

The first California bighorn population in Utah was established on Antelope Island (40°95´N, 112°21´W) in 1997. This study area (113 km^2) is a mid-elevation (2,134 m) island, mountain range that is located in the southeast portion of the Great Salt Lake (Fig. 1). Precipitation averaged 390 mm a year and perennial water was abundant. Vegetation on the island was dominated by grasses that included wheat grasses (*Elymus spp.*) and bromes (*Bromus spp.*), and low-growing brush, such as sagebrush (*Artemisia spp.*). Potential predators of bighorn sheep were coyotes (*Canis latrans*), bobcats (*Lynx rufus*), and golden eagles (*Aquila chrysaetos*). Wild ungulates that occupied the study area included bison (*Bison bison*), mule deer (*Odocoileus hemionus*), and pronghorn (*Antilocapra americana*).

Recently discovered skeletal remains indicate bighorn sheep were present on the Island ≥1,000 years ago (R. Rood, Utah Department of Natural Resources, personal communication), but a period of extensive livestock grazing likely caused the extirpation of native sheep. During the 1870s at least 10,000 domestic sheep were grazed on Antelope Island, and by the turn of the twentieth century, domestic sheep grazing was the primary land use (Holt 1994). Domestic livestock grazing on Antelope Island ended in 1981, when the state of Utah purchased the Island and designated it as a park. Antelope Island State Park received an average of 300,000 visitors annually, and most of these visitors come to view the wildlife (S. Bates, Utah State Parks and Recreation, personal communication).

Newfoundland Mountains

Five years after the reintroduction of bighorns on Antelope Island, a second population of California bighorns was established on the Newfoundland Mountains (41°16´N, 113°38´W) in 2001. The Newfoundland Mountains (190 km^2) are a long, narrow, mid-elevation (2,129 m) range located in the Great Salt Lake Desert. Vegetation varied from salt desert shrub communities in the valleys to a mixture of grasses and shrubs at mid-elevations that included bromes (*Bromus spp.*) three-awn (*Aristada purpurea*), and wheat grasses (*Elymus spp.*), cliff rose (*Conwania mexicana*) and rabbit brush (*Chrysothamnus spp*). Sparse juniper cover occurred at higher elevations. Perennial water was available but concentrated on the northern half of the range. Most of the land was managed by the Bureau of Land Management (BLM), although the United States Air Force had an operational bombing range which encompasses the southern portion of the study area. Public use was minimal on the Newfoundland Mountains due to limited access and the remoteness of the range. Potential predators of bighorns were coyotes, bobcats, and golden eagles. Mule deer were sympatric to bighorns in limited numbers, and no grazing permits were available for domestic livestock.

Bighorn sheep historically inhabited the Newfoundland Mountains (Dalton and Spillett 1971), but like many extirpated populations, little is known of their history. The mountain range was mined for various metals from 1870 to 1957 (BLM 1992) and livestock grazing was allowed until 2000. Presumably, the same factors that caused the extirpation of bighorns in Utah (e.g. livestock grazing, disease, and hunting) were responsible for the loss of this population. Today, most of these factors have been reduced or eliminated on the Newfoundland Mountains. For example, the Utah Chapter of Foundation for North American Wild Sheep (UFNAWS) spent $75,000 to close domestic sheep allotments on this range prior to reintroducing bighorn sheep (D. Peay, Utah Chapter of Foundation for North American Wild Sheep, personal communication). Domestic sheep grazing allotments still exist in several valleys and mountains ranges that are adjacent to the Newfoundland Mountains (Fig. 1).

Stansbury Mountains

A third population of California bighorns was established on the Stansbury Mountains (40°71´N, 112°63´W) in 2005. The Stansbury Mountains are located near the southwest shores of the Great Salt Lake (Fig. 1). They are a relatively large (650 km^2), high-elevation (3,362 m) range. Precipitation (350 mm) at low elevations was similar to Antelope Island, but higher elevations received considerably more moisture (> 1400 mm) (Taye 1981). Below 2200 m, vegetation was similar to Antelope Island, but with more extensive stands of trees. Above 2200 m, there was substantial tree cover that included aspen (*Populus tremuloides*), Douglas fir (*Pseudotsuga menziesii*), and Englemann spruce (*Picea englemannii*), as well as alpine habitat. The majority of the land is managed by the Forest Service and the BLM with small amounts of state, private, and tribal lands interspersed throughout the area. Potential predators of bighorn sheep were mountain lions (*Puma concolor*), bobcats, coyotes, and golden eagles. Sympatric wild ungulates included elk (*Cervus elaphus*) in limited numbers and mule deer. Domestic cattle were permitted to graze on public and private lands in the study area. Active mountain lion control was conducted in this study area from reintroduction in 2006 to the present by the Utah Division of Wildlife Resources and Wildlife Services. Individual mountain lions were removed if they killed 2 bighorn sheep within 90 days or 3 within a year.

It is unknown if bighorns historically inhabited the Stansbury Mountains, but it is possible. Bighorn sheep remains and petroglyphs have been found on several nearby mountains ranges: the Lake Side Mountains (12 km northwest), Stansbury Island (11 km north), and the Oquirrah Mountains (25 km west) (Dalton and Spillett 1971). Additionally, 4 rams from the Newfoundland Mountains wandered to the Stansbury Mountains prior to the 2005 reintroduction. Furthermore, precipitous terrain is abundant which indicates the range could have supported bighorns. Over the past 15 years, wild fires have burned much of the tree cover in the northern portion of the study area, which has increased the suitability of the habitat for bighorns. Additionally, UFNAWS spent $55,000 to close domestic sheep allotments on the Stansbury Mountains in 2005 (D. Peay, Utah Chapter of Foundation for North American Wild Sheep, personal communication), which was essential to prepare this area for a reintroduction of bighorn sheep.

Methods

Habitat

For each of the three study areas, we documented the amount of escape terrain and tree cover, and the number and distribution of water sources using ArcGIS 9.2 (ESRI, Redlands, CA). We defined escape terrain as habitat patches > 0.7 ha with slopes between 27 and 85 degrees (DeCesare and Pletscher 2006). We used a 10 m Digital Elevation Model obtained from the United States Geological Survey to create a slope layer using Spatial Analyst in ArcGIS. We then selected habitat patches in the slope layer that fit our definition of escape terrain and calculated their area. We totaled the area of all escape terrain patches within a study area to estimate available escape terrain.

To estimate the amount of tree cover in each study area, we used the Southwestern GAP layer obtained from the Utah GIS Portal (2008). This layer delineates 109 cover types and has a resolution of 0.4 ha. We selected all habitat types within this layer that contained tall vegetation (>1 m). These habitat types included the following: Great Basin pinyon-juniper woodland, Rocky Mountain Gambel Oak-mixed montane shrubland, Rocky Mountain montane mesic mixed conifer forest and woodland, Rocky Mountain aspen forest and woodland, and Rocky Mountain subalpine mesic spruce-fir forest and woodland. We totaled the areas of these polygons to estimate the amount of tree cover within each study area.

To document water availability, we used a GIS point layer that contained the locations of most springs within our study areas. This layer was obtained from the Utah GIS Portal (2008). We modified the layer by adding known water sources that were not accounted for within the layer.

To document habitat use, we observed bighorns on 960 occasions between 2004 and 2007 using radio telemetry, binoculars, and spotting scopes in all three study areas. Sightings were obtained year-round from both male and female groups. We estimated home ranges of each population using a 95% fixed kernel polygon created with the Home Range Tools extension for ArcGIS 9.2 (Rogers et al. 2005). We used an ad hoc approach to select the smoothing factor for home range calculations (Mills et al. 2006)

Population Dynamics

Bighorn population estimates, from 1997 to 2004, were obtained from aerial and ground counts conducted by UDWR and Utah State Parks employees. From 2005 to 2007, we conducted annual winter counts in all three study areas by observing bighorns from the ground. Additionally, we collected population data for only the Stansbury Mountains in 2008. For each population, we calculated growth rates (r) from population estimates using the instantaneous rate of growth equation ($N_t = N_0e^{rt}$); additionally, we estimated doubling times using ln 2/r (Johnson 1996). Growth rates for some populations were biased by the removal and addition of animals due to translocations, and we identified these biases in the results. We counted the number of lambs born during the parturition period (Apr-May) and estimated birth dates all lambs observed. We also counted the number of lambs that remained the following the winter. Lamb survival was estimated by dividing the number of lambs observed during winter counts by number of lambs counted during the parturition period.

Metapopulation

To describe the spatial structure of our study area, we used ArcGIS 9.2 to calculate the Euclidean distance between historical bighorn ranges and those ranges adjacent to them. Additionally, we gathered accounts of reintroduced bighorn moving between mountain ranges in our study area. This information was obtained from BLM reports and by interviewing those individuals who reported sighting bighorns outside of reintroduction areas.

Results

Antelope Island

Habitat.— Antelope Island had 8 km^2 of escape terrain, which represented 7% of the study area. The spatial distribution of escape terrain was concentrated in the center of the Island and was continuous. Tree cover (11 km^2) was dispersed throughout high elevations, and consisted of very sparse patches of junipers. Forty water sources existed on Antelope Island, and we observed bighorns using at least 7 of these springs throughout all seasons of the year. The home range for the Antelope Island population was 18 km^2 (Fig 2.). Habitat use by bighorns was restricted to high elevation areas in the center of the Island. During most years the island was completely surrounded by salt water, and no dispersal movements were documented.

Population dynamics.— The Antelope Island population was founded with 26 California bighorns from Kamloops, British Columbia, Canada in 1997. It was augmented 3 years later with 6 additional animals from Winnemucca, Nevada (Table 1). This population has grown from 26 animals to a high of 174 in 2005 (Fig. 3). From 1997 to 2007, the average growth rate (r) was 0.188, with a doubling time of 3.7 years. This, however, is a very conservative estimate of growth as 92 bighorns (51 ewes) were removed from this population during this period. From 2005 to 2007, we counted 105 young born (2005 = 38, 2006 = 32, 2007 = 35) on Antelope Island. In 2005, lamb survival to first winter was 0.71, and in 2006 it was 0.75. The mean and *SD* of lambing date for this population was April 17 ± 8.9 days.

Newfoundland Mountains

Habitat.— The Newfoundland Mountains had 33 km^2 of escape terrain which extended throughout 17% of the study area from mid to high elevations. Tree cover existed on 37 km^2 of the range and was comprised of sparse stands of junipers. Water sources were concentrated on the northern portion of the study area, and bighorns used at least 7 of 20 available springs. The population home range for bighorns on the Newfoundland Mountains was 130 km^2, which encompassed the entire length of the range (Fig. 2). Summer movements of bighorns were restricted to the northern portion of the range, near available water. Although few animals were radio collared, 10 dispersal movements from the Newfoundland Mountains have been documented since 2001 (Table 2).

Population dynamics.— Thirty-one California bighorn sheep from Nevada and Antelope Island were reintroduced to the Newfoundland Mountains during winter 2000-2001 (Table 1). The population was augmented in 2003 with 20 animals and again in 2008 with 18 additional rams, all of which were from Antelope Island. The Newfoundland Mountains population grew from 31 animals to almost 100 in 2007 (Fig. 3). The growth rate (r) from 2001 to 2007 was 0.190 with a doubling time of 3.6 years. The growth rate of this population is an over estimate as 20 animals (14 ewes and lambs) were added to the population during this period. From 2005 to 2007, we counted 86 lambs (2005 = 37, 2006 = 31, 2007 = 18) in this study area. Lamb survival was 0.65 in 2005 and 0.77 in 2006. The mean and *SD* lambing date for the Newfoundland

Mountains population was April 24 ± 4.8 days.

Stansbury Mountains

Habitat.— The Stansbury Mountains had 189 km^2 of escape terrain that comprised 29% of study area. Escape terrain was available throughout much of the mid to high elevations areas. Tree cover was extensive (349 km^2) and distributed throughout the entire range except the northern section. Water sources were scattered throughout the southern and central portion of the range, but there were few located in the northern portion of the study area. Bighorns, mostly rams, used 2 of 80 available water sources. The population home range for bighorns on the Stansbury Mountains was 24 km^2 (Fig. 2), which constituted only 4% of the study area. Bighorns used only the northern most extent of the range, in close proximity to the initial release site. Although > 90% of the animals were radio collared, we did not detect dispersal movements of bighorns from the Stansbury Mountains.

Population dynamics.— In the winter 2005-2006, 57 California bighorns were translocated from Antelope Island to the Stansbury Mountains (Table 1). The population was augmented in 2008 with 36 animals from Antelope Island (Table 1). From the 2006 to 2008, the growth rate (r) for Stansbury Mountains, excluding the 36 animals added in 2008, was 0.110. From 2006 to 2007, we counted 41 lambs born (2006 = 18, 2007 = 23). In 2006, lamb survival was 0.67 and in 2007 it was 0.91. The mean and *SD* lambing date for the Stansbury Mountains population was April 17 ± 7.8 days.

Metapopulation

Within the extent of our study area, 13 mountain ranges existed, and historically, bighorn sheep occupied at least 10 of these areas. The mean distance between mountain ranges was 22.3 km (*SD* = 4.8 km, range 8-45 km). Vegetation that occurred in the interspaces between ranges was low growing (< 1 m), which may have facilitated dispersal movements of bighorn sheep.

Today, 5 populations of bighorn sheep (3 California and 2 Rocky Mountain) exist within this region of Utah. With the exception of bighorns on the Stansbury Mountains, few of these animals were radio marked. Despite the lack of radio-marked animals, 11 dispersal movements have been documented since 2001 (Table 2). Bighorns have dispersed to at least 6 mountain ranges (Fig. 1), a mean distance of 29.3 km (*SD* = 13.9 km). Mean group size was 1.9 (*SD* = 1.2). Ten of 11 movements were animals dispersing from the Newfoundland Mountains. Eight of the dispersal groups consisted of only males. Male bighorns dispersed an averaged 31.7 km (*SD* = 14.3) and a maximum of 60 km. Additionally, one of these dispersing males reportedly contacted a herd of domestic sheep on the Grassy Mountains (21 km) in 2006, but we have no knowledge of the fate of that animal or where it moved after the encounter. The average distance that females dispersed was 16.7 km (*SD* = 4.0 km), and the maximum distance was 21 km.

Discussion

Habitat

Bighorn sheep are habitat specialists that require steep terrain, open habitats, and in many areas free water for survival (Risenhoover and Bailey 1985, Smith et al. 1990, Dolan 2006). These variables help explain the distribution of bighorns within a study area and may provide insight as to why a population of reintroduced animals succeeds or fails. The amount and configuration of escape terrain are positively correlated with the number of bighorns within a population; in Arizona, McKinney et al. (2003) recommended that bighorns be reintroduced in areas with at least 15 km^2 of escape terrain.

In Utah, California bighorns have been reintroduced into habitats with 8 to 189 km^2 of escape terrain. The study area with the least of amount of escape terrain, Antelope Island, also had the smallest population home range. In the Newfoundland Mountains study area, escape terrain was distributed throughout the entire length of the range, and the population home range of bighorns reflected this availability. Similarly, the Stansbury Mountains had abundant escape terrain, but bighorns only used a small portion of the habitat. Possibly, bighorns failed to disperse throughout the study area because of extensive tree cover. Indeed, bighorns prefer habitats with high visibility and avoid areas with tall vegetation (Risenhoover and Bailey 1985, Hayes 1994, Smith et al. 1999). In the absence of substantial tree cover, the amount and distribution of escape terrain appeared to influence the distribution of reintroduced bighorns within our study areas.

Water is also an important habitat component for the management and conservation of bighorn sheep, especially those occupying desert environments (Turner 1970, Leslie and Douglas 1979, Bleich et al. 2006, Marshal et al. 2006). The distribution of water sources can influence range use by bighorns (Leslie and Douglas 1979; 1980, Rubin et al. 2002, Oehler et al. 2003, Turner et al. 2004). For example, 97% of observations of the endangered Nelson's bighorn sheep *O. c. nelsoni* were within 3 km of perennial sources of water (Turner et al. 2004). Moreover, the lack of perennial water in some areas may increase the probability of population decline (Douglas 1988, Dolan 2006). Additionally, persistence of some populations of bighorn sheep in California is correlated with the presence of perennial sources of water (Epps et al. 2004).

In all of our study areas, bighorns used free water. On Antelope Island, perennial water was abundant, and bighorns used several water sources year round with peak use occurring in summer (Whiting et al. in review). On the Newfoundland Mountains, free water was only available in the northern portion of the study area, and bighorns concentrated in this area during summer. On the Stansbury Mountains, water sources were available throughout the central and southern portions of the study area, but few occurred within the home range of bighorns. Despite water being limited in the area used by bighorns, at least two water sources were used during summer. For this region of Utah, observational data suggests that bighorns have a physiological need for free water, especially during the summer months. If water developments are placed in areas that meet basic habitat requirements of bighorns (i.e. adequate escape terrain and visibility), then distribution of bighorns, at least during summer, may be increased.

Population Dynamics

When bighorn sheep are reestablished in areas with adequate habitat, they are capable of rapid growth rates (Singer et al. 2000, Hedrick and Gutierrez-Espeleta 2001). After an initial period of growth, however, some populations have declined (Smith et al. 1988). Population declines of bighorn sheep may be caused by a variety of factors, but disease (Gross et al. 2000, Monello et al. 2001) and predation (Rominger et al. 2004, McKinney et al. 2006) appear to be the most important causes. Our study shows that neither disease nor predation appear to be substantially influencing population growth of California bighorns in Utah. However, mountain lion control may have contributed to the high growth rates and survival observed on the Stansbury Mountains.

In the past ten years, California bighorn populations have experienced excellent growth in Utah. Populations on Antelope Island and the Newfoundland Mountains grew 19% annually. The most productive population was Antelope Island. Because it is an island and a State Park, this study area was isolated from many factors that limit population growth in bighorn sheep. Additionally, the animals on Antelope Island have facilitated the restoration of California bighorns in Utah. Nearly 150 bighorns from Antelope Island have been used to found two additional populations within the state. Antelope Island bighorns will continue to be used as a source for future reintroductions. In the near future, the Newfoundland Mountains and Stansbury Mountains populations may also provide bighorns for future translocations.

The excellent population growth that California bighorn populations have experienced in Utah is, in large part, due to high lamb survival and recruitment. In all years of the study, lamb survival was greater than 67% and as high as 92%. Also, limited observational data suggests that adult survival is high. If California bighorn populations continue growing at the present rate, the statewide population could possibly exceed 600 individuals by 2012.

Metapopulation

Management of bighorn sheep has traditionally focused on individual populations, but in many areas a metapopulation model may be more appropriate (Bleich et al. 1996). Historically, the individual population approach was used, because bighorn habitat is patchy with separation between populations; additionally bighorn movements between populations were thought to be limited (Geist 1971b;a). Schwartz et al. (1986), however, noted bighorns occasionally moved 20 to 45 km between populations and through habitats that would be considered unsuitable for bighorn sheep. Intermountain and inter-population movements of bighorns are now well documented and have been reported for both males and females (Chow et al. 1988, Bleich et al. 1996, DeCesare and Pletscher 2006). Dispersing bighorns provide connectivity between populations, and bighorn metapopulations have been reported in Arizona, California, Idaho, and Montana (Bailey 1992, Bleich et al. 1996, DeCesare and Pletscher 2006, Cassirer and Sinclair 2007).

For bighorn sheep, metapopulation structure has two vital implications: gene flow and disease transmission. Gene flow and the genetic health of bighorn populations has been a conservation concern (Whittaker et al. 2004). Indeed, some reintroduced populations have lost genetic variability due to the founder effect (Fitzsimmons et al. 1997), especially those occupying islands (Hedrick and Gutierrez-Espeleta 2001). Also, isolated populations may experience genetic drift due to inbreeding (Gilpin 1991). Schwartz et al. (1986) observed that only a limited movement between bighorn populations would be required to maintain genetic variability. In bighorn metapopulations, gene flow between populations is preserved largely through the movements of rams, because rams are more likely to disperse and move longer distances than ewes (Bleich et al. 1996).

Ram movements between populations, however, may also have a negative effect. Disease transmission is an inadvertent consequence of animals moving between populations (Gilpin 1991). This dynamic is particularly important in bighorn sheep, because they are highly susceptible to diseases carried by domestic sheep (Foreyt and Jessup 1982). Dispersing bighorns may leave traditional habitats and move through areas with domestic livestock. Additionally, during the breeding season bighorn rams may seek out domestic ewes (Gross et al. 2000). Animals that have contacted domestic sheep may then return to a bighorn population and precipitate a die-off. As a result, dispersal corridors and their juxtaposition to domestic sheep allotments should receive increased attention (Bleich et al. 1996).

Today, bighorns are being restored to the Great Basin of Utah, which may also result in the restoration of a historical metapopulation. Following reestablishment of bighorn sheep, there have been several reports of animals moving between mountain ranges. Dispersal movements are undoubtedly occurring at a higher rate than we documented. Bighorns moving between populations may preserve or increase genetic variation within this region. At least one dispersing ram, however, made contact with domestic sheep. Interactions, such as this, present a serious threat to established bighorn populations that are now healthy and growing. Although populations of California bighorns we studied have been disease free, it is conceivable that they may be severely reduced or eliminated by disease epizootics in the future. To reduce the probability of such an event, active measures should be taken to decrease the possibility that bighorn sheep will contact domestic sheep in this region.

Management Implications

In the Great Basin of Utah, managing bighorns on dispersed mountain ranges as a metapopulation will help ensure that reintroduced populations persist. As California bighorn populations in Utah increase in size and new populations are established, movements within this metapopulation will increase and more closely approximate historical movements. As a result, an increasing numbers of dispersing rams and possibly limited movements of females should be expected.

To date, UFNAWS has contributed >$1.4 million in northern Utah to close domestic sheep allotments and secure habitat for bighorn reintroductions. We recommend that the policy of removing domestic sheep prior to reintroduction be continued and expanded to include valleys and ranges adjacent to established bighorn populations. Additionally, an increased focus on the movements of rams within this metapopulation will elucidate movement corridors, while identifying domestic sheep allotments that pose the greatest threat to established populations.

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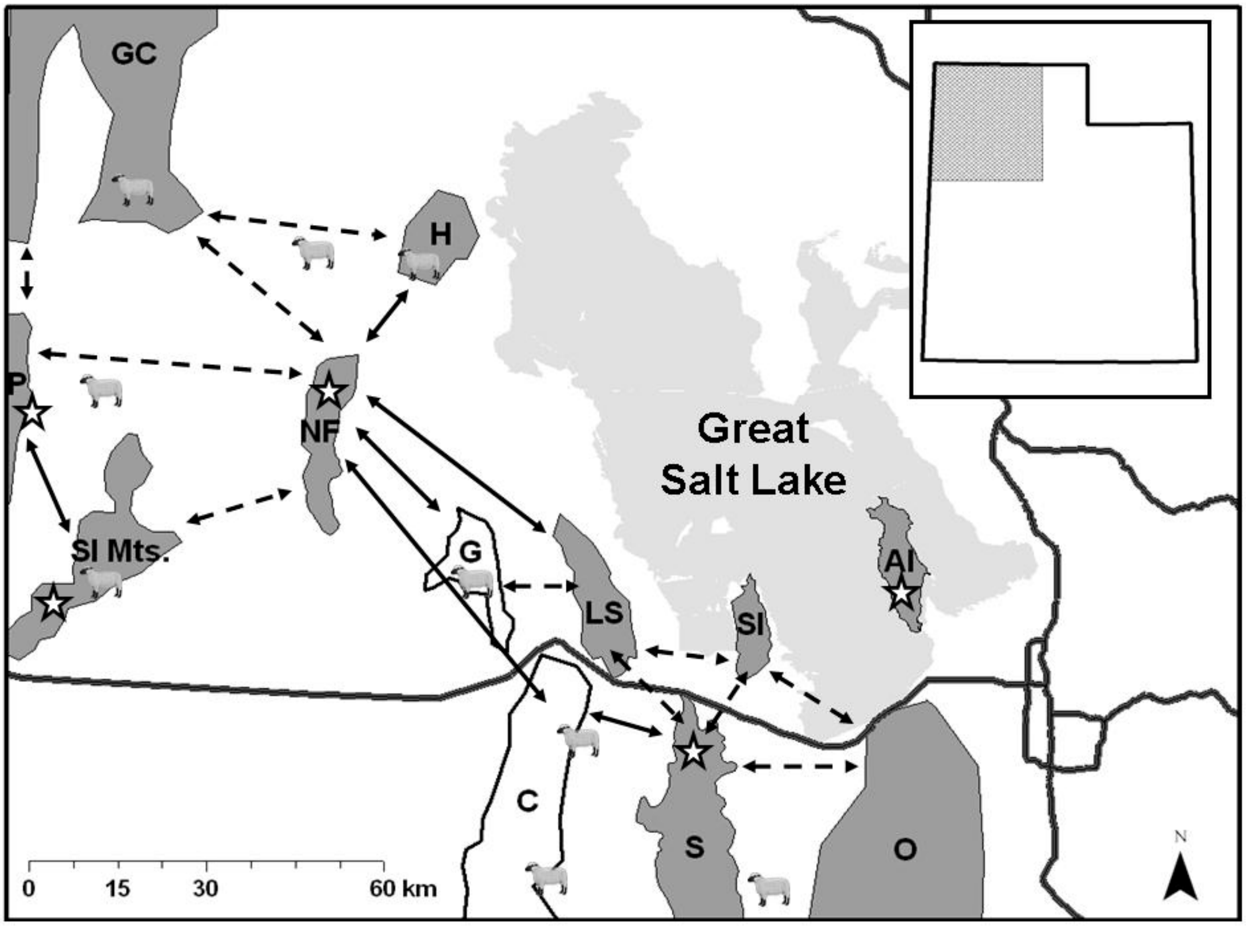

Figure 1. Probable historical distribution of a bighorn metapopulation in the Great Basin of Northern Utah. Mountain ranges that contained historical populations of bighorn sheep are indicated in gray; whereas those ranges where bighorns were not historically found are indicated in white. Broken arrows designate plausible movements of historical bighorns, and solid arrows designate movements of reintroduced bighorns. Sheep symbols indicate domestic sheep allotments, and stars represent extant bighorn populations. The names of the mountain ranges were abbreviated as follows: AI = Antelope Island, C = Cedar, GC = Grouse Creek, H = Hogup, LS = Lakeside, NF = Newfoundland, O = Oquirrah, P = Pilot, S = Stansbury, SI = Stansbury Island, and SI Mts. = Silver Island.

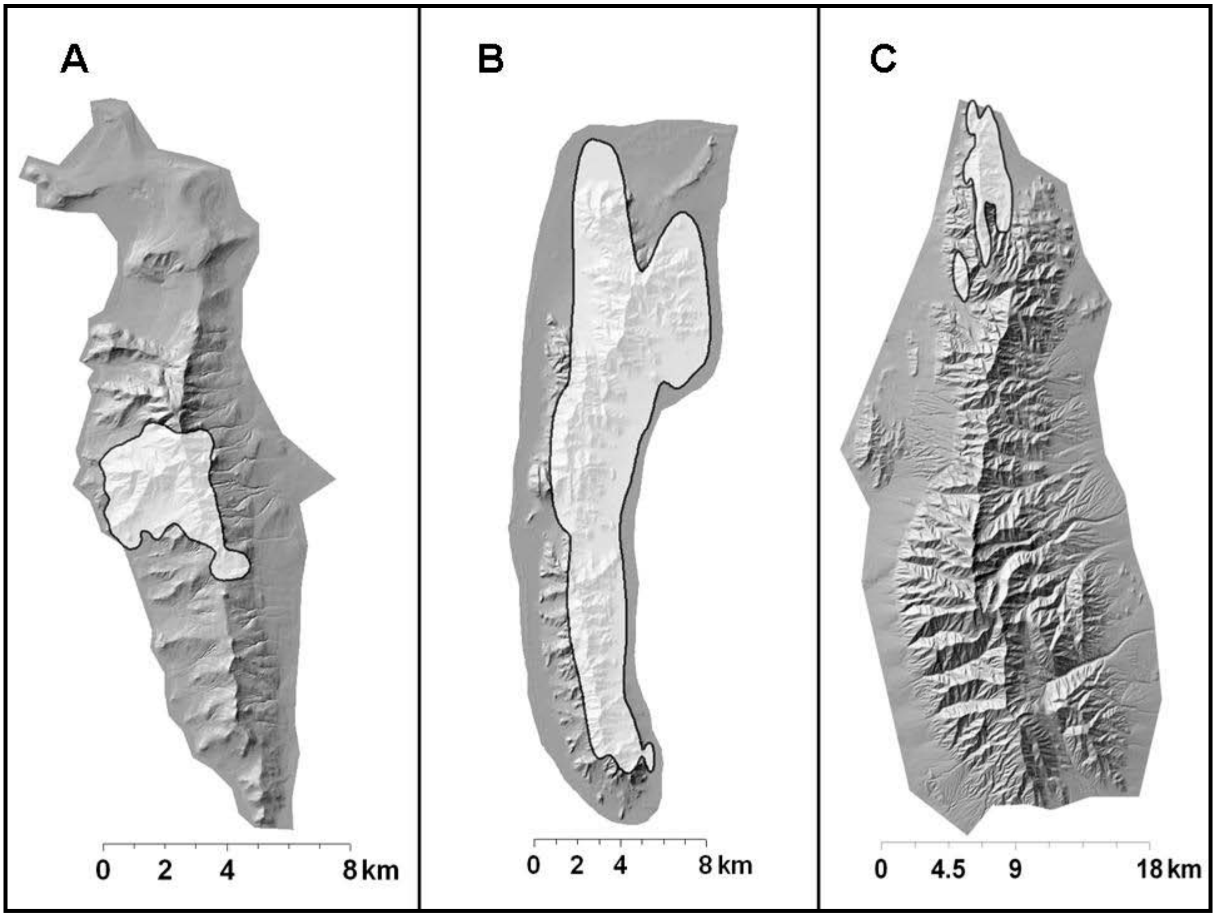

Figure 2. Shown here for comparison are 95% fixed-kernel home-range polygons for California bighorn populations in Utah from 2004 to 2007: (A) Antelope Island, (B) Newfoundland Mountains, and (C) Stansbury Mountains.

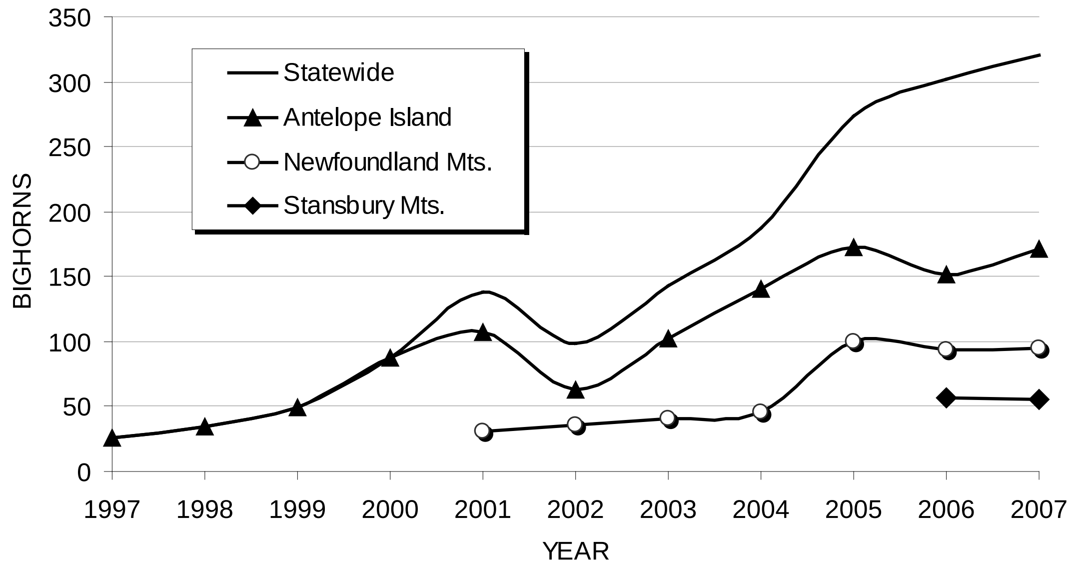

Figure 3. Population estimates plotted for California bighorn populations in Utah (1997-2007).

Table 1**.** Area of release, source herd, and demographics of California bighorn translocations in Utah from 1997 to 2008.

Year	Area	Type	Source	Ewes	Rams	Lambs
1997	Antelope Island	Reintro.	Kamloops, B.C.	18	4	4
2000	Antelope Island	Aug.	Winnemucca, NV	2	4	0
2001	Newfoundland Mts.	Reintro.	Antelope Island, UT	6	7	2
2001	Newfoundland Mts.	Reintro.	Hart Mt., NV	12	3	1
2003	Newfoundland Mts.	Aug.	Antelope Island, UT	13	6	1
2006	Stansbury Mts.	Reintro.	Antelope Island, UT	32	13	12
2008	Stansbury Mts.	Aug.	Antelope Island, UT	12	21	3
2008	Newfoundland Mts.	Aug.	Antelope Island, UT	0	18	0

Table 2. Location, demographics, and distance traveled during dispersal movements by bighorn sheep in the Great Basin of northern Utah (2001-2007).

Date	Location	Males	Females	Source population	Distance (km)
May 2001	Grassy	0	1	Newfoundland	21
Aug 2001	Hogup	0	1	Newfoundland	16
Jun 2002	Cedar	4	0	Newfoundland	41
Sep 2002	Stansbury	4	0	Newfoundland	60
Dec 2003	Lakeside	1	0	Newfoundland	36
Jul 2005	Grassy	2	0	Newfoundland	21
Aug 2005	Silver Island	3*	22*	Pilot	13
Sep 2005	Grassy	1	0	Newfoundland	21
Jul 2006	Lakeside	2	0	Newfoundland	36
Dec 2006	Grassy	1	0	Newfoundland	21
Jul 2007	Lakeside	2	0	Newfoundland	36

*Dispersal group was believed to have moved several years prior to the sighting, and the actual number of dispersing individuals was unknown.

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