Acta Theriologica 54 (2): 127–136, 2009.
PL ISSN 0001–7051

Annual use of water sources by reintroduced Rocky Mountain bighorn sheep *Ovis canadensis canadensis*: effects of season and drought

Jericho C. WHITING, R. Terry BOWYER and Jerran T. FLINDERS

Whiting J. C., Bowyer R. T. and Flinders J. T. 2009. Annual use of water sources by reintroduced Rocky Mountain bighorn sheep *Ovis canadensis canadensis*: effects of season and drought. Acta Theriologica 54: 127–136.

Water sources are important for the conservation and management of bighorn sheep *Ovis canadensis* (Shaw, 1804). Little is known, however, regarding the use of water by reintroduced Rocky Mountain bighorns *O. c. canadensis* (Shaw, 1804). Our purpose was to quantify use of water sources by bighorns to test hypotheses related to the value of these sites on Antelope Island, Utah, USA, from July 2005 to December 2006. We predicted that bighorns would increase the number and duration of visits to water during summer. Moreover, we predicted that animals would visit and spend more time at water during drought. Our results indicate that bighorns visited and spent more time around water in summer. These animals, however, did not visit and spend more time at water during drought. Nevertheless, use of water sources increased during times of similar precipitation that followed drought, indicating a potential time-lag in water use by bighorns. Our results underscore the importance of water for reintroduced bighorns in the deserts of western USA, and indicate that animals congregate in riparian areas near water and thereby may facilitate the spreading of diseases and parasites.

Department of Biological Sciences, Idaho State University, Pocatello, ID 83209, USA, e-mail: jwhiting@stoller.com (JCW); Department of Biological Sciences, Idaho State University, Pocatello, ID 83209, USA (RTB); Department of Plant and Wildlife Sciences, Brigham Young University, Provo, UT 84602, USA (JTF)

Key words: Rocky Mountain bighorn sheep, Great Basin, motion-sensor cameras, reintroduction, water

Introduction

Free-standing water is an important habitat component for ungulates occupying arid environments (Bowyer 1984, Berger 1986, Rautenstrauch and Krausman 1989, Kie *et al.* 2003, Cain *et al.* 2006). Although much debate surrounds the use of artificial water sources by bighorn sheep *Ovis canadensis* (Shaw, 1804) (Broyles and Cutler 1999, Rosenstock *et al.* 1999, Broyles and Cutler 2001, Rosenstock *et al.* 2001, Rosenstock *et al.* 2005), this habitat component is important for the management and conservation of bighorn sheep in desert ecosystems (Buechner 1960, Turner 1970, Leslie and Douglas 1979, Bleich *et* *al.* 2006, Marshal *et al.* 2006a). 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), and the lack of perennial water in some areas may increase the probability of population declines (Douglas 1988, Dolan 2006). For example, populations of native and reintroduced desert bighorn sheep *O. c. nelsoni* (Merriam, 1897) in California became extinct in areas that received < 200 mm annual precipitation and lacked dependable water sources (Epps *et al.* 2004). Furthermore, those authors indicated that global climate change may have influenced the persistence and distribution of populations of bighorn sheep by altering precipitation patterns and thereby influencing growing seasons of plants and availability of water sources, especially for low-elevation mountain ranges (Epps *et al.* 2004).

Use of water sources by bighorn sheep varies with periods of increasing ambient temperature, greater day length, intensified mating activities, and reduced moisture content in forage (Rubin *et al.* 2002, Turner *et al.* 2004). Native desert bighorn sheep have remarkable adaptations to limited water. Indeed, some populations can occupy areas with no known perennial sources of water (Alderman *et al.* 1989, Broyles and Cutler 1999), and in other areas, the distribution of water is not an important habitat component for these animals (Krausman and Leopold 1986a). Conversely, water sources can be a critical habitat component especially during summer (Rubin *et al.* 2002, Turner *et al.* 2004). For reintroduced bighorn sheep, range use during summer by males may be influenced by the distribution of water sources (Payer and Coblentz 1997). Also during summer, groups of reintroduced females and young Rocky Mountain bighorn sheep *O. c. canadensis* (Shaw, 1804) occurred within 80 m of escape terrain and 1 km of water (Brundige and McCabe 1986). Indeed, female bighorn sheep with young used areas near steep, rugged habitat and close to water (Bleich *et al.* 1997). For some native and reintroduced populations of Rocky Mountain bighorn sheep, the presence of water sources during particular seasons can influence range use and population persistence; however, data are lacking regarding the specific use of water sources by Rocky Mountain bighorn sheep (Shackleton *et al.* 1999).

Bighorn sheep that congregate in riparian habitat associated with water sources can exacerbate the transmission of diseases and parasites. For example, bighorn sheep congregate around man-made water sources (swimming pools, birdbaths, and irrigation systems) and artificial areas of foraging (lawns of golf courses and residential areas); these gathering places may promote the spread of diseases and passage of parasites through fecal contamination (Rubin *et al.* 2002, Turner *et al.* 2004). Nonetheless, quantitative data demonstrating such a relationship are sparse (Turner *et al.* 2004). On Antelope Island State Park, Utah, USA, all infected gastropods, intermediate hosts between parasitic lungworm larvae *Protostrongylus stilesi* and *P. rushi* and bighorn sheep, occurred in moist riparian areas associated with water sources (Rogerson *et al.* 2008). Of gastropods occupying habitat types on the island, only those in riparian areas around water sources were active during summer (Rogerson *et al.* 2008). Rogerson *et al*. (2008) indicated that the most probable site of lungworm transmission to bighorn sheep was during summer in limited riparian areas associated with water sources (Rogerson *et al.* 2008). Unfortunately, during that study, bighorn sheep were observed rarely at water, but the authors conjectured that animals likely visited these areas repeatedly during summer, as fresh deposits of feces of bighorn sheep occurred frequently around water (Rogerson *et al.* 2008).

Our objective was to quantify the use of water sources by reintroduced bighorn sheep on Antelope Island. We hypothesized that use of water by these animals was influenced by increasing temperature, greater day length, lactation, intensified mating activities, and reduced moisture content in forage (Rubin *et al*. 2002, Turner *et al*. 2004). More specifically, we predicted that the number and duration of visits to sources of water would increase substantially during summer relative to other seasons (Payer and Coblentz 1997, Rubin *et al.* 2002, Turner *et al.* 2004), which could facilitate the transmission of diseases and parasites as animals congregate around water during dry conditions (Rubin *et al.* 2002, Turner *et al.* 2004, Rogerson *et al.* 2008). Furthermore, observing use of water sources by bighorn sheep during seasons of differing environmental conditions is critical to understanding their ecology in arid ecosystems (Burkett and Thompson 1994, Payer and Coblentz 1997). Consequently, we examined water use by bighorns during drought conditions and during seasons of similar rainfall, and we predicted that animals would visit and spend more time at water sources during drought.

Material and methods

Study area

We conducted research on Antelope Island State Park (40°57'N, 112°13'W) in the Great Basin Desert of northern Utah, USA. Antelope Island is located in the southeast corner of the Great Salt Lake. The area is 24 km long and 11.3 km wide, with the highest peak at 2134 m and comprises 11 300 ha. Escape terrain for bighorns encompasses about 7% (8 km^2) of the study area (Olson *et al.* in press). The island has a mean annual temperature of 17.5°C and receives 562 mm of precipitation annually, with 95% of the snow falling from November to March. From 1948 to 2007, the mean total precipitation was 78 mm in summer (July to September) (Farmington Utah State University Field Station, Western Regional Climate Center 2007). Human use of the island is restricted to hiking, biking, and horseback riding on limited, designated trails (Fairbanks and Tullous 2002).

In March 1996, 26 bighorn sheep were captured near Kamloops, British Columbia, Canada (50°43'N, 120°25'W) and released on Antelope Island. This reintroduced herd consisted of 4 males, 18 females, and 4 young. Although these animals were considered California bighorns *O. c. californiana* (Douglas, 1829), recent morphometric evidence indicates that Rocky Mountain and California bighorn sheep should not be considered separate subspecies (Wehausen and Ramey 2000). Therefore, in this paper, we considered these animals to be Rocky Mountain bighorn sheep. The bighorn sheep on the island were not hunted, and during the study the average size of the population was 162 animals (J. C. Whiting, unpubl.). Sympatric ungulates on the island were bison *Bison bison* (Linnaeus, 1758) mule deer *Odocoileus hemionus* (Rafinesque, 1817), and pronghorn *Antilocapra americana* (Ord, 1815), and the 2 large mammalian predators occupying the island were coyote *Canis latrans* (Say, 1823) and bobcat *Lynx rufus* (Schreber, 1777). Those sympatric ungulates shared water sources with bighorns; however, at least 40 sources of water exist on the island (Olson *et al*., in press), with most of those springs occurring at low elevation in areas used by bison and deer. General vegetation types of the island varied from scattered Utah juniper *Juniperus osteosperma*, mountain brush, big sagebrush *Artemisia tridentata* grass complex, and forbs. Important forage species for bighorns included bluebunch wheatgrass *Elymus spicatus*, spike fescue *Luecopoa kingii*, and Sandberg's bluegrass *Poa secunda*. Plant nomenclature follows Welsh *et al.* (1993). Greater detail concerning the island and its habitats is provided by Fairbanks and Tullous (2002) and Rogerson *et al*. (2008).

Methods

Beginning in April 2004, prior to deploying cameras to document the use of water sources by bighorn sheep, we observed bighorns year-round from a designated trail on the west side of the island and from game trails leading to sources of water on 116 occasions to determine use of range and water sources. With this information, coupled with data regarding range and water use from a previous study (Rogerson *et al.* 2008), we deployed Reconyx Silent Image™ motion-sensor cameras, which are digital cameras with an infrared illumination and motion-detection system (Reconyx, LLP, 3600 Hwy 157, Suite 205, La Crosse, WI 54601) at 7 water sources located in areas used by bighorn sheep from July 2005 to December 2006. These springs were located in diverse habitat types and ranged in elevation from 1290 to 1680 m, with the mean (± SD) distance between any spring and its nearest neighboring spring of 1.2 km ± 0.66 km, which is a comparatively high density of water sources (Bleich *et al.* 1997, Payer and Coblentz 1997).

Water sources differed in the amount and duration of flow–when setting cameras we selected areas at the head waters of each spring that had demonstrated use by ungulates (ie, multiple game trails converging upon the head waters indicating active use). Cameras were set at the same general location throughout the study and were within 15 m of each centralized water source. When setting the field of view of the camera, we ensured that the headwaters, with associated riparian area, and the convergence of game trails were in view, and that cameras were oriented to optimize correct categorization of bighorns into sex and age classes (Jaeger *et al.* 1991, Bleich *et al.* 1997). We initiated the study with 5 cameras and randomly assigned the placement of these cameras to 5 of 7 springs. By November 2005, however, we placed cameras at all 7 springs. During our study, cameras were set at any particular spring on average 60% (range = 46–74%) of the total number of days in which cameras could have been deployed. Each camera used 8 AA batteries and a 512 mb compact flash card. About once each month, we hiked to each camera and changed the batteries and compact flash cards.

Because visits by bighorn sheep to water sources were unpredictable, cameras functioned continuously at high sensitivity and took a picture when an object triggered the motion sensor of the camera, which had a sensitivity range of up to 30.5 m and a 40° field of view (Reconyx Silent image, User Guide Recreational Edition). Pictures were taken while animals were in the field of view of the sensor, and there was a 20 s interval that elapsed between photographs. The image settings (brightness, contrast, sharpness, etc.) were preset by the manufacture (Reconyx Silent image, User Guide Recreational Edition). Few bighorn sheep on the island had identifying marks (ie, radio collars or ear tags), and it was difficult to determine whether a continuous stream of pictures of bighorns represented 1 animal activating the camera numerous times or multiple animals activating the camera (Cutler and Swann 1999). To help alleviate this problem, we arbitrarily considered a lapse of 25 minutes between a bighorn activating a camera as a new visit. With this criterion, the median number of hours between successive visits to a camera was 15 (upper and lower quantile distances = 2 to 26 h). Furthermore, each picture documented the date, time (Mountain Standard), and temperature, and we used the first picture in a visit to gather these abiotic data for that visit. For each visit, we categorized the total number of bighorns for each sex and age cohort (male, female, and young), and we further assigned males into size categories (Class I, II, III, IV) described in Geist (1968).

To investigate whether use of water sources by bighorn sheep varied by season, we defined seasons according to the behavior of bighorns on Antelope Island (sensu Marshal *et al.* 2006a): spring occurred from 1 April to 30 June and corresponded to when females became isolated prior to birthing (Geist 1971, Shackleton and Haywood 1985, Festa-Bianchet 1988), during birthing (mean ± SD birthdate from 2005 to 2007 on Antelope Island was 17 April ± 8.9 days, range = 31 March to 21 May; J. C. Whiting, unpubl.), and when females and young gathered in post-parturition groups (Geist 1971, Hass 1997). We designated summer as 1 July to 30 September. To determine the timing of rut, we subtracted the gestation time for bighorn sheep, which is about 175 days (Geist 1971, Blunt *et al.* 1972, Shackleton *et al.* 1984), from the mean birthdate (17 April). The calculated average rutting date was 24 October. Therefore, we designated 1 October through 30 November as the rutting period, because males arrived on rutting grounds and engaged in rut behavior during those months (Geist 1971, Bleich *et al.* 1997). Finally, we considered winter as 1 December to 31 March. We used data from the nearest weather station (Farmington Utah State University Field Station, Western Regional Climate Center 2007) to determine the total precipitation (mm) and average temperatures (°C) by seasons for our study area.

Data analyses

We could not identify individual bighorn sheep consistently; therefore, a group of animals may have visited multiple water sources in 1 day. This lack of independence between groups of animals visiting sources of water in a day was problematic (Jaeger *et al.* 1991). To help ameliorate this problem and to test for differences in the number of visits by season and year, we considered each day as the sampling unit. For example, if an animal, or a group of animals, visited at least 1 water source on a particular day, then that day was given a value of 1, or a visit. Conversely, if no bighorns visited any of the water sources in a day then that day was given a 0, or no visit. This provided a binomial response variable of visit or no visit for any particular day. We calculated the proportion of days in which bighorns visited water sources in a season by dividing the number of visits by the total number of days cameras were set at water sources. We then calculated the associated 95% confidence intervals (CI) for the proportion of days in which bighorn sheep visited water sources using the procedures outlined in Bowden *et al.* (1984) and Bowyer (1991). We recognize this procedure may overestimate the SE slightly (Bowden *et al.* 1984, Bowyer 1991). Nonetheless, this test is especially appropriate for our data because it allows sampling with replacement (Remington and Schork 1970). Moreover, these calculated values were conservative estimates of visits to water sources, especially during summer when animals visited this resource multiple times in a day. These values and CIs, however, allowed us to test for differences among the number of visits in spring, summer, rut, and winter, and between drought conditions (summer 2005) and non-drought conditions (summer 2006), and between times with little difference in precipitation (rut 2005 and 2006) using an unbiased statistical approach.

To test for differences in duration of a visit at a water source, we first calculated a derived variable of the highest count of animals for each cohort in a visit multiplied by the duration (minutes) of that visit (eg, a visit of 5 females and 5 young for 10 minutes equaled a duration of 100). Because the field of view of cameras was limited, we likely underestimated the total number of animals during visits of large groups (Jaeger *et al.* 1991). This predicament, however, was somewhat alleviated by our calculation of the duration of a visit, because we assumed that larger groups spent more time at water sources and thus had a greater duration time. Nevertheless, our methods were conservative because they underestimated the total duration of animals in large groups at water sources, which was probably most prevalent during summer and rut when large groups tended to frequent water sources. To test for differences in the duration of a visit at water sources, we calculated a test statistic (T) using the median test (Conover 1980) to detect differences for the median duration of visits among spring, summer, rut, and winter, and between drought conditions (summer 2005) compared with non-drought conditions (summer 2006) and between times of little difference in precipitation (rut 2005 and 2006). We ensured that the assumptions of this test were met prior to data analysis (Conover 1980). Furthermore, when conducting the median tests, we arbitrarily adjusted alpha to 0.02 to help reduce the potential problem of lack of independence (Bowyer *et al.* 2007) between groups visiting multiple water sources in a day.

Results

Temperatures were similar between years within seasons; however, precipitation totals differed markedly for both years during spring and summer (Table 1). During 2005, precipitation was lowest in summer compared with other seasons. In 2006, however, precipitation was lowest during rut. Total rainfall in summer 2005

Table 1. Total precipitation and mean (± SD) temperature by season for Antelope Island State Park, Utah, USA, from April 2005 to December 2006. We terminated sampling in December 2006; therefore, precipitation and temperature values for winter 2006 are reported only for December.

Season	2005		2006	
	Precipitation (mm)	Temperature (°C)	Precipitation (mm)	Temperature (°C)
Spring	280	14±4.5	133	17±5.6
Summer	22	23±4.3	122	22±5.2
Rut	82	9±4.9	97	8±4.4
Winter	226	1±2.2	21	0.0

was 5 times less than total rainfall in summer 2006. Additionally, total rainfall during rut 2005 was similar to precipitation during rut 2006.

We deployed cameras for 2186 camera days: 444 in spring, 746 in summer, 574 in rut, and 422 in winter, of a possible 3633 camera days during that time (number of days during study multiplied by 7 water sources). Mean ± SD group sizes of bighorn sheep were similar during spring (4 ± 3.9), summer (4 ± 3.8), rut (3 ± 2.7), and winter (2 ± 2.3). Bighorn sheep visited water sources on 852 occasions (109 in spring, 561 in summer, 166 during rut, and 16 in winter). Those animals visited water sources significantly more often in summer, followed by spring and rut, and the least during winter (Fig. 1). Moreover, duration of time bighorns spent at and around water sources was 4 times higher in summer compared with winter ($T = 21.3$, df = 3, $p < 0.01$; Fig. 2). No difference existed between the number of visits by bighorn in summer 2005 and in summer 2006 (Fig. 3); however, bighorns visited water sources twice as often during rut 2005 compared with rut 2006 (Fig. 3). Our derived variable of duration of visits by bighorns at water sources did not differ between summer 2005 and summer 2006 ($T = 0.12$, df = 1, $p = 0.73$; Fig. 4), whereas the duration of visits between rut 2005 and rut 2006 was marginally not significant ($T = 4.62$, df = 1, $p = 0.03$; Fig. 4).

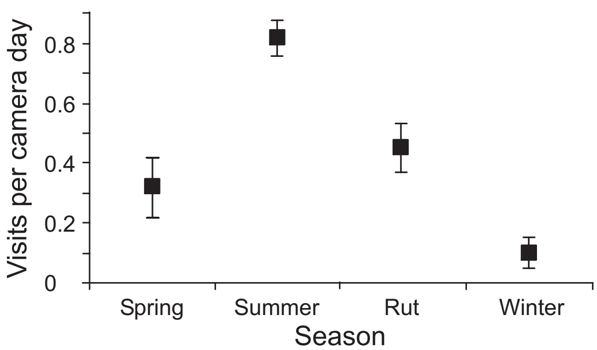

Fig. 1. Proportion of the number of visits divided by the number of days in which cameras were set (± 95% CI) at 7 water sources used by reintroduced Rocky Mountain bighorn sheep on Antelope Island State Park, Utah, USA, from July 2005 to December 2006.

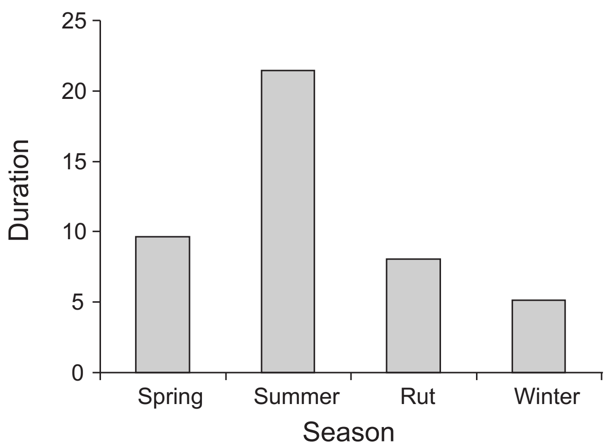

Fig. 2. Median duration of visits (number of animals in the group × duration in min) to water sources by reintroduced Rocky Mountain bighorn sheep during different seasons on Antelope Island State Park, Utah, USA, from July 2005 to December 2006.

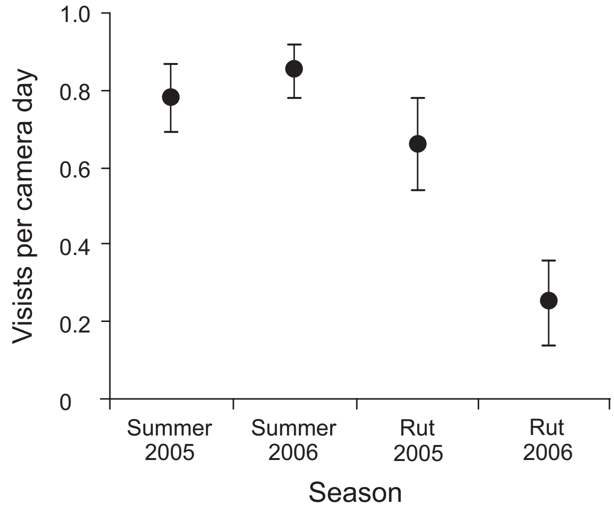

Fig. 3. Proportion of the number of visits divided by the number of days in which cameras were set (± 95% CI) at 7 water sources used by reintroduced Rocky Mountain bighorn sheep on Antelope Island State Park, Utah, USA, during drought conditions (summer 2005) and non-drought conditions (summer 2006) and during times of little difference in precipitation (rut 2005 compared with rut 2006).

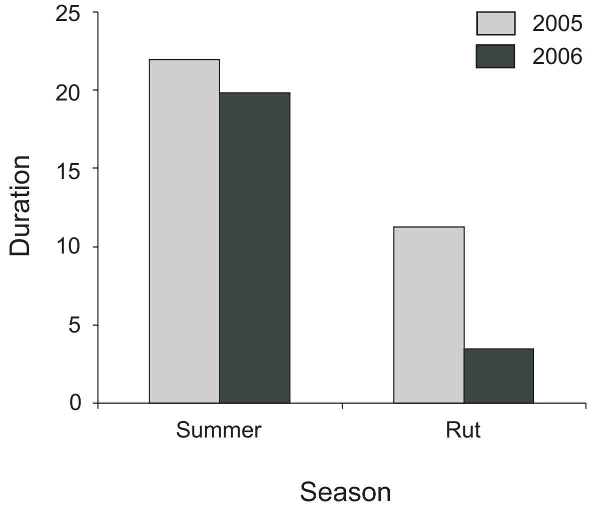

Fig. 4. Median duration of visits (number of animals in the group × duration in min) by reintroduced Rocky Mountain bighorn sheep at water sources during drought conditions (summer 2005) and non-drought conditions (summer 2006) and during times of little difference in precipitation (rut 2005 compared with rut 2006) on Antelope Island State Park, Utah, USA.

Discussion

Consistent with our prediction, Rocky Mountain bighorn sheep that were reintroduced on Antelope Island State Park used water sources considerably more in summer than during other seasons, which has been documented previously for populations of native desert bighorns (Leslie and Douglas 1979, Rubin *et al.* 2002, Turner *et al.* 2004). More importantly, our study provided a unique test of the differences in number and duration of visits at water sources during a time of little precipitation (summer 2005) with a time of substantially greater precipitation (summer 2006), and between seasons with little difference in the amount of precipitation (rut 2005 compared with rut 2006). Mean temperatures during summer 2005 and 2006 and rut 2005 and 2006 were similar; however, precipitation totals differed markedly during summer 2005 and 2006. Our results falsified our prediction that the number and duration of visits to water sources during the summer with less precipitation (2005) would differ from those during the summer with substantially more precipitation (2006). Furthermore, our results were counter intuitive as the number and duration of visits during periods of little difference in precipitation (rut 2005 and 2006) was drastically different. We hypothesize that this reverse pattern resulted from a time lag in water use by bighorn sheep in this arid system. During spring 2005, our study area received twice as much precipitation compared with spring 2006; thus, plants were probably succulent for longer during late spring and into early summer in 2005 (Beatley 1974), thereby ameliorating some effects of drought conditions during summer 2005, and potentially reducing the need for water by bighorns during this time. Low amounts of precipitation in summer 2005, however, were possibly evident in the use of water sources by bighorns during rut 2005, although the precipitation patterns were similar between rut 2005 and 2006. These results indicate that although particular seasons may experience drought conditions, the effect of those dry conditions on the number and duration of visits to water sources by bighorns may be postponed. Therefore, to detect increases or decreases in use of water sources by bighorns, investigators need to document such use over several seasons, especially during and following times of drought. This approach, and the knowledge it provides, may be critical in assessing potential affects of climate change on small populations of bighorn sheep.

Increased use and congregation by animals at watering sources, especially in associated riparian vegetation, may facilitate the spread of diseases and parasites and effect water quality (Bleich 2003, Rosenstock *et al.* 2005), particularly during summer (Swift *et al.* 2000, Rubin *et al.* 2002, Turner *et al.* 2004). Bighorn sheep that visit water sources spend time lingering and foraging around those areas (Campbell and Remington 1979, Rogerson *et al.* 2008). Our results indicate that reintroduced Rocky Mountain bighorn sheep increase use of water sources and their associated riparian habitat during summer and rut following drought conditions. Infections of parasitic lungworms combined with pneumonia have contributed to the historic decline of populations of bighorn sheep (Buechner 1960, Forrester and Littell 1976, Krausman and Bowyer 2003). On Antelope Island, the only active gastropods (an intermediate host between bighorn and parasitic lungworm larvae) were evident during summer in riparian areas associated with limited sources of water (Rogerson *et al.* 2008). Our results support those of Rogerson *et al.* (2008) in concluding that the most probable site of lungworm transmission to bighorn sheep is around water sources during summer. Wildlife managers and conservationists need to consider water sources and how the distribution of this resource may cause overcrowding and thereby facilitate the spreading of diseases and parasites, especially for small populations of reintroduced bighorns using limited sources of water (Rogerson *et al.* 2008).

A need exists for wildlife researchers and mangers to assess the response of populations of bighorn sheep to artificial water sources (Broyles and Cutler 1999, Rosenstock *et al.* 1999). Although building artificial water sources may increase competition between bighorns and other ungulates (Krausman and Leopold 1986b), this resource may reduce the amount of use and congregation of animals around perennial water sources and thereby decrease the transmission of parasites (Marshal *et al.* 2006b, Rogerson *et al.* 2008). Furthermore, Rogerson *et al*. (2008) detected differences in the number of lungworm larvae in the feces of male and female bighorns, and suspected that this discrepancy may have resulted from use of different water sources by the sexes. Indeed, female bighorn sheep use different habitat than males outside the mating season (Bleich *et al*. 1997), and this segregation may have important implications for diseases and parasite transmission for this species (Bowyer 2004, Rubin and Bleich 2005). Future research regarding use of water should focus on the different use of habitat and water sources by the sexes during different times of the year and how that difference can influence range and water use, and possibly disease and parasite transmission (Rubin and Bleich 2005).

General guidelines indicate that reintroductions of Rocky Mountain bighorn sheep should occur in areas consisting of escape terrain and within 3.2 km of perennial water sources (Smith *et al.* 1991, Smith and Flinders 1992, Singer *et al.* 2000a, Singer *et al.* 2000b). Bighorns we studied came from Kamloops, British Columbia, Canada, an area which has been the source stock for reintroductions of animals into Washington, Utah, Oregon, Idaho, Nevada, and California, USA (Demarchi and Mitchell 1973, Whittaker *et al.* 2004). These bighorns in British Columbia do not encounter the degree of water stress that is evident in dry regions of the western United States where they have been released historically (Demarchi and Mitchell 1973). Even though reintroductions are commonly used to reestablish populations, since 1923, 30% of translocated populations of bighorn sheep throughout their distribution were deemed failures (Singer *et al.* 2000b). Many factors can influence the success of reintroductions (Smith *et al.* 1991, Singer *et al.* 2000b, Rominger *et al.* 2004). We hypothesize that the lack of water sources may have contributed to those failures. Indeed, one reintroduced population in the Great Basin Desert of northern Utah was unsuccessful at least in part because of lack adequate surface water (Smith *et al.* 1988). Although considerable debate exists regarding the use of artificial sources of water by bighorns (Broyles and Cutler 1999, Rosenstock *et al.* 1999, Broyles and Cutler 2001, Rosenstock *et al.* 2001), constructing additional artificial water sources may be necessary for populations of these reintroduced animals (Rosenstock *et al.* 1999). Indeed, much can be learned to improve reintroduction techniques and thereby enhance successful establishment of populations (Smith *et al.* 1988, Smith *et al.* 1991, Valdez and Krausman 1999, Krausman 2000, Whiting *et al.* 2008).

Relatively little is known regarding the importance of water for ungulates occupying deserts in North America compared with animals inhabiting deserts in Africa and the Middle East (Cain *et al.* 2006). Our results underscore the importance of water sources for populations of reintroduced Rocky Mountain bighorn sheep in arid ecosystems. Indeed, persistence of some populations of desert bighorn sheep is correlated with the presence of perennial sources of water (Epps *et al.* 2004). Summer and drought conditions increase the intensity of use at water sources and in their associated riparian habitat, especially for populations of bighorn sheep in deserts of the western USA. This increased dependence on water during summer and drought conditions could influence the persistence and distribution of this species, especially in the face of a changing climate (Epps *et al.* 2004). Clearly, more study is needed, and we hope that our results will provide an important first step in this process. In the interim, we recommend wildlife managers assess water sources prior to reintroductions, and consider adding artificial sources of water. Following reintroductions of bighorn sheep, managers should devise plans to monitor bighorn use around these water sites (Rosenstock *et al.* 1999, Broyles and Cutler 2001, Rosenstock *et al.* 2001, Cain *et al.* 2006).

Acknowledgments: We received financial support from the Utah Division of Wildlife Resources, the Utah Chapter of the Foundation for North American Wild Sheep, the Minnesota Chapter of the Foundation for North American Wild Sheep, the National Chapter of the Foundation for North American Wild Sheep, U.S. Forest Service, U.S. Department of Defense, Antelope Island State Park, Brigham Young University, and the Department of Biological Sciences at Idaho State University. We thank H. Hunter for compiling and sorting data. We thank L. Chase and J. Shannon for help with field work, and S. Bates and the employees of Antelope Island State Park for assistance with this project. We also thank J. Whiting and M. Whiting. We thank V. Bleich for many fruitful discussions about this topic, and J. Kie and 2 anonymous reviewers for providing helpful comments on the manuscript.

References

Alderman J. A., Krausman P. R. and Leopold B. D. 1989. Diel activity of female desert bighorn sheep in western Arizona. The Journal of Wildlife Management 53: 264–271.

Beatley J. C. 1974. Phenological events and their environmental triggers in Mojave Desert ecosystems. Ecology 55: 856–863.

Berger J. 1986. Wild horses of the Great Basin: social competition and population size. The University of Chicago Press, Chicago: 1–326.

Bleich V. C. 2003. The potential for botulism in desert-dwelling mountain sheep. Desert Bighorn Council Transactions 47: 2–8.

Bleich V. C., Andrew N. G., Martin M. J., Mulcahy G. P., Pauli A. M. and Rosenstock S. S. 2006. Quality of water available to wildlife in desert environments: Comparisons among anthropogenic and natural sources. Wildlife Society Bulletin 34: 627–632.

Bleich V. C., Bowyer R. T. and Wehausen J. D. 1997. Sexual segregation in mountain sheep: resources or predation? Wildlife Monographs 134: 1–50.

Blunt M. H., Dawson H. A. and Thorne E. T. 1972. The birth weights and gestation in captive Rocky Mountain bighorn sheep. Journal of Mammalogy 58: 106.

Bowden D. C., Anderson A. E. and Medin D. E. 1984. Sampling plans for mule deer sex and age ratios. The Journal of Wildlife Management 48: 500–509.

Bowyer R. T. 1984. Sexual segregation in southern mule deer. Journal of Mammalogy 65: 410–417.

Bowyer R. T. 1991. Timing of parturition and lactation in southern mule deer. Journal of Mammalogy 72: 138–145.

Bowyer R. T. 2004. Sexual segregation in ruminants: definitions, hypotheses, and implications for conservation and management. Journal of Mammalogy 85: 1039–1052.

Bowyer R. T., Bleich V. C., Manteca X., Whiting J. C. and Stewart K. M. 2007. Sociality, mate choice, and timing of mating in American bison (*Bison bison*): effects of large males. Ethology 113: 1048–1060.

Broyles B. and Cutler T. L. 1999. Effect of surface water on desert bighorn sheep in the Cabeza Prieta National Wildlife Refuge, southwestern Arizona. Wildlife Society Bulletin 27: 1082–1088.

Broyles B. and Cutler T. L. 2001. Reply to Rosenstock *et al.* (2001) regarding effects of water on desert bighorn sheep at Cabeza Prieta National Wildlife Refuge, Arizona. Wildlife Society Bulletin 29: 738–743.

Brundige G. C. and McCabe T. R. 1986. Summer habitat use by bighorn ewes and lambs. Northern Wild Sheep and Goat Council 15: 408–420.

Buechner H. K. 1960. The bighorn sheep in the United States, its past, present, and future. Wildlife Monographs 4: 1–174.

Burkett D. W. and Thompson B. C. 1994. Wildlife association with human-altered water sources in semiarid vegetation communities. Conservation Biology 8: 682–690.

Cain J. W., Krausman P. R., Rosenstock S. S. and Turner J. C. 2006. Mechanisms of thermoregulation and water balance in desert ungulates. Wildlife Society Bulletin 34: 570–581.

Campbell B. H. and Remington R. 1979. Bighorn use of artificial water sources in the Buckskin Mountains, Arizona. Desert Bighorn Council Transactions 23: 50–56.

Conover W. J. 1980. Practical nonparametric statistics. 2nd ed. John Wiley and Sons, New York: 1–493.

Cutler T. L. and Swann D. E. 1999. Using remote photography in wildlife ecology: a review. Wildlife Society Bulletin 27: 571–581.

Demarchi D. A. and Mitchell H. B. 1973. The Chilcotin River bighorn population. Canadian Field Naturalist 87: 433–454.

Dolan B. F. 2006. Water developments and desert bighorn sheep: implications for conservation. Wildlife Society Bulletin 34: 642–646.

Douglas C. L. 1988. Decline of desert bighorn sheep in the Black Mountains of Death Valley. Desert Bighorn Council Transactions 32: 26–30.

Epps C. W., McCullough D. R., Wehausen J. D., Bleich V. C. and Rechel J. L. 2004. Effects of climate change on population persistence of desert-dwelling mountain sheep in California. Conservation Biology 18: 102–113.

Fairbanks W. S. and Tullous R. 2002. Distribution of pronghorn (*Antilocapra americana* Ord) on Antelope Island State Park, Utah, USA, before and after establishment of recreational trails. Natural Areas Journal 22: 277–282.

Festa-Bianchet M. 1988. Age-specific reproduction of bighorn ewes in Alberta, Canada. Journal of Mammalogy 69: 157–160.

Forrester D. J. and Littell R. C. 1976. Influence of rainfall on lungworm infections in bighorn sheep. Journal of Wildlife Diseases 12: 48–51.

Geist V. 1968. On delayed social and physical maturation in mountain sheep. Canadian Journal of Zoology 46: 899–904.

Geist V. 1971. Mountain sheep: a study in behavior and evolution. The University of Chicago Press, Chicago: 1–383.

Hass C. C. 1997. Seasonality of births in bighorn sheep. Journal of Mammalogy 78: 1251–1260.

Jaeger J. R., Wehausen J. D. and Bleich V. C. 1991. Evaluation of time-lapse photography to estimate population parameters. Desert Bighorn Council Transactions 35: 5–8.

Kie J. G., Bowyer R. T. and Stewart K. M. 2003. Ungulates in western coniferous forests: habitat relationships, population dynamics, and ecosystem processes. [In: Mammal community dynamics: management and conservation in the coniferous forests of Western North America. C. J. Zabel and R. G. Anthony, eds]. Cambridge University Press, New York: 296–340.

Krausman P. R. 2000. An introduction to the restoration of bighorn sheep. Restoration Ecology 8: 3–5.

Krausman P. R. and Bowyer R. T. 2003. Mountain sheep (*Ovis canadensis* and *O. dalli*). [In: Wild mammals of North America: biology, management, and conservation. J. A. Chapman, G. A. Feldhamer and B. C. Thompson, eds]. The John Hopkins University Press, Baltimore: 1095–1115.

Krausman P. R. and Leopold B. D. 1986a. Habitat components for desert bighorn sheep in the Harquahala Mountains, Arizona. Journal of Wildlife Management 50: 504–508.

Krausman P. R. and Leopold B. D. 1986b. The importance of small populations of desert bighorn sheep. Transactions of the North American Wildlife and Natural Resources Conference 51: 52–61.

Leslie D. M. and Douglas C. L. 1979. Desert bighorn sheep of the River Mountains, Nevada. Wildlife Monographs 66: 1–56.

Leslie D. M. and Douglas C. L. 1980. Human disturbance at water sources of desert bighorn sheep. Wildlife Society Bulletin 8: 284–290.

Marshal J. P., Bleich V. C., Krausman P. R., Reed M. L. and Andrew N. G. 2006a. Factors affecting habitat use and distribution of desert mule deer in an arid environment. Wildlife Society Bulletin 34: 609–619.

Marshal J. P., Krausman P. R., Bleich V. C., Rosenstock S. S. and Ballard W. B. 2006b. Gradients of forage biomass and ungulate use near wildlife water developments. Wildlife Society Bulletin 34: 620–626.

Oehler M. W., Bowyer R. T. and Bleich V. C. 2003. Home ranges of female mountain sheep, *Ovis canadensis nelsoni*: effects of precipitation in a desert ecosystem. Mammalia 67: 385–401.

Olson D. D., Shannon J. M., Whiting J. C. and Flinders J. T. (in press). History, status, and population structure of California bighorn in Utah. Biennial Symposium of the Northern Wild Goat and Sheep Council.

Payer D. C. and Coblentz B. E. 1997. Seasonal variation in California bighorn ram (*Ovis canadensis californiana*) habitat use and group size. Northwestern Science 71: 281–288.

Rautenstrauch K. R. and Krausman P. R. 1989. Influence of water availability and rainfall on movements of desert mule deer. Journal of Mammalogy 70: 197–201.

Remington R. D. and Schork M. A. 1970. Statistics with applications to the biological and health sciences. Prentice--Hall, Inc., Englewood Cliffs: 1–418.

Rogerson J. D., Fairbanks W. S. and Cornicelli L. 2008. Ecology of gastropod and bighorn sheep hosts of lungworm on isolated, semi-arid mountain ranges in Utah, USA. Journal of Wildlife Diseases 44: 28–44.

Rominger E. M., Whitlaw H. A., Weybright D. L., Dunn W. C. and Ballard W. B. 2004. The influence of mountain lion predation on bighorn sheep translocations. The Journal of Wildlife Management 68: 993–999.

Rosenstock S. S., Ballard W. B. and deVos Jr. J. C. 1999. Viewpoint: benefits and impacts of wildlife water developments. Journal of Range Management 52: 302–311.

Rosenstock S. S., Bleich V. C., Rabe M. J. and Reggiardo C. 2005. Water quality at wildlife water sources in the Sonoran Desert, United States. Rangeland Ecology and Management 58: 623–627.

Rosenstock S. S., Hervert J. J., Bleich V. C. and Krausman P. R. 2001. Muddying the water with poor science: a reply to Broyles and Cutler. Wildlife Society Bulletin 29: 734–738.

Rubin E. S. and Bleich V. C. 2005. Sexual segregation: a necessary consideration in wildlife conservation. [In: Sexual segregation in vertebrates: ecology of the two sexes. K. E. Ruckstuhl and P. Neuhaus, eds]. Cambridge University Press, Cambridge: 379–391.

Rubin E. S., Boyce W. M., Stermer C. J. and Torres S. G. 2002. Bighorn sheep habitat use and selection near an urban environment. Biological Conservation 104: 251–263.

Shackleton D. M. and Haywood J. 1985. Early mother young interactions in California bighorn sheep, *Ovis canadensis californiana*. Canadian Journal of Zoology 63: 868–875.

Shackleton D. M., Peterson R. G., Haywood J. and Bottrell A. 1984. Gestation period in *Ovis canadensis*. Journal of Mammalogy 65: 337–338.

Shackleton D. M., Shank C. C. and Wikeem B. M. 1999. Natural history of Rocky Mountain and California bighorn sheep. [In: Mountain Sheep of North America. R. Valdez and P. R. Krausman, eds]. The University of Arizona Press, Tucson: 78–138.

Singer F. J., Bleich V. C. and Gudorf M. A. 2000a. Restoration of bighorn sheep metapopulations in and near western National Parks. Restoration Ecology 8: 14–24.

Singer F. J., Papouchis C. M. and Symonds K. K. 2000b. Translocations as a tool for restoring populations of bighorn sheep. Restoration Ecology 8: 6–13.

Smith T. S. and Flinders J. T. 1992. Evaluation of mountain sheep habitat in Zion National Park, Utah. Desert Bighorn Council Transactions 36: 4–9.

Smith T. S., Flinders J. T. and Olsen D. W. 1988. Status and distribution of Rocky Mountain bighorn sheep in Utah. Biennial Symposium of the Northern Wild Goat and Sheep Council 6: 5–12.

Smith T. S., Flinders J. T. and Winn D. S. 1991. A habitat evaluation procedure for Rocky Mountain bighorn sheep in the Intermountain West. Great Basin Naturalist 51: 205–225.

Swift P. K., Wehausen J. D., Ernest H. B., Singer R. S., Pauli A. M., Kinde H., Rocke T. E. and Bleich V. C. 2000. Desert bighorn sheep mortality due to presumptive type C botulism in California. Journal of Wildlife Diseases 36: 184–189.

Turner J. C. 1970. Water consumption by desert bighorn sheep. Desert Bighorn Council Transactions 14: 189–197.

Turner J. C., Douglas C. L., Hallam C. R., Krausman P. R. and Ramey R. R. 2004. Determination of critical habitat for the endangered Nelson's bighorn sheep in southern California. Wildlife Society Bulletin 32: 427–448.

Valdez R. and Krausman P. R. 1999. Description, distribution, and abundance of mountain sheep in North America. [In: Mountain sheep of North America. R. Valdez and P. R. Krausman, eds]. The University of Arizona Press, Tucson: 3–22.

Wehausen J. D. and Ramey R. R. 2000. Cranial morphometric and evolutionary relationships in the northern range of *Ovis canadensis*. Journal of Mammalogy 81: 145–161.

Welsh S. L., Atwood N. D., Goodrich S. and Higgins L. C. 1993. A Utah flora. 2nd ed. Brigham Young University, Provo: 1–986.

Whiting J. C., Bowyer R. T. and Flinders J. T. 2008. Young bighorn (*Ovis canadensis*) males: can they successfully woo females? Ethology 113: 32–41.

Whittaker D. G., Ostermann S. D. and Boyce W. M. 2004. Genetic variability of reintroduced California bighorn sheep in Oregon. The Journal of Wildlife Management 68: 850–859.

Received 25 May 2008, accepted 28 October 2008.

Associated editor was Joseph F. Merritt.