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Summer Watering Patterns of Mule Deer and Differential Use of Water by Bighorn Sheep, Elk, Mule Deer, and Pronghorn in Utah

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A thesis submitted to the faculty of
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Master of Science

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ABSTRACT

Summer Watering Patterns of Mule Deer and Differential Use of Water by Bighorn Sheep, Elk, Mule Deer, and Pronghorn in Utah

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Master of Science

Changes in the abundance and distribution of free (drinking) water can influence wildlife in arid regions. In the western USA, free water is considered by wildlife managers to be important for bighorn sheep (*Ovis canadensis*), elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), and pronghorn (*Antilocapra americana*). Nonetheless, we lack information on the influence of habitat and landscape features surrounding water sources, including wildlife water developments, and how these features may influence use of water by sexes differently. Consequently, a better understanding of differential use of water by the sexes could influence the conservation and management of those ungulates and water resources in their habitats. We deployed remote cameras at water sources to document water source use. For mule deer specifically, we monitored all known water sources on one mountain range in western Utah, during summer from 2007 to 2011 to document frequency and timing of water use, number of water sources used by males and females, and to estimate population size from individually identified mule deer. Male and female mule deer used different water sources but visited that resource at similar frequencies. On average, mule deer used 1.4 water sources and changed water sources once per summer. Additionally, most wildlife water developments were used by both sexes. We also randomly sampled 231 water sources with remote cameras in a clustered-sampling design throughout Utah in 2006 and from 2009 to 2011. In association with camera sampling at water sources, we measured several site and landscape scale features around each water source to identify patterns in ungulate use informative for managers. We used model selection to identify features surrounding water sources that were related to visitation rates for male and female bighorn sheep, elk, mule deer, and pronghorn. Top models for each species were different, but supported models for males and females of the same species generally included similar covariates, although with varying strengths. Our results highlight the differing use of water sources by the sexes. This information will help guide managers when siting and reprovisioning wildlife water developments meant to benefit those species, and when prioritizing natural water sources for preservation or enhancement.

Keywords: guzzler, mark-resight, Poisson-log, wildlife water development, remote camera, zero-inflated, negative binomial, *Ovis canadensis, Cervus elaphus, Odocoileus hemionus,* and *Antilocapra americana*

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CHAPTER 1

SUMMER WATERING PATTERNS OF MULE DEER IN THE GREAT BASIN DESERT, USA: IMPLICATIONS OF DIFFERENTIAL USE BY INDIVIDUALS AND THE SEXES FOR MANAGEMENT OF WATER RESOURCES

ABSTRACT

Changes in the abundance and distribution of free water can negatively influence wildlife in arid regions. Free water is considered a limiting factor for mule deer (*Odocoileus hemionus*) in the Great Basin Desert. Consequently, a better understanding of differential use of water by individuals and the sexes could influence the conservation and management of mule deer and water resources in their habitats. We deployed remote cameras at all known water sources (13 wildlife water developments and 4 springs) on one mountain range in western Utah, USA, during summer from 2007 to 2011 to document frequency and timing of water use, number of water sources used by males and females, and to estimate population size from individually identified mule deer. Male and female mule deer used different water sources but visited that resource at similar frequencies. Individual mule deer used few water sources and exhibited high fidelity to that resource. Wildlife water developments were frequently used by both sexes. Our results highlight the differing use of water sources by sexes and individual mule deer. This information will help guide managers when siting and reprovisioning wildlife water developments meant to benefit mule deer and will contribute to the conservation and management of this species.

INTRODUCTION

Free water is a critical resource for humans and wildlife in arid regions of the world. Several factors, however, influence both the current and future availability of water in these regions. Growing human populations have increased the need for water globally (Jackson et al. 2001).

Similarly, climate change will affect the quantity and distribution of water available to humans and wildlife (Brown and Thorpe 2008, Whiting et al. 2010). Loss and degradation of natural water sources in the arid western USA has occurred and likely will continue given ongoing and projected anthropogenic influences in that area (Dolan 2006, Krausman et al. 2006, Simpson et al. 2011, Larsen et al. 2012). This change in abundance and distribution of water can negatively influence populations of wildlife and has created a conflict between the needs of humans and wildlife for water resources. For example, in Joshua Tree National Park (JTNP), USA, the number of natural, perennial water sources declined from 19 in the 1950s to 5 in 2004, partly because of anthropogenic use of surface and ground water (Longshore et al. 2009). This reduction in water sources subsequently decreased critical summer habitat for bighorn sheep (*Ovis canadensis*) (Longshore et al. 2009). This reduction of summer habitat for bighorns in JTNP, however, was partially mitigated by construction of wildlife water developments (Longshore et al. 2009).

Constructing water developments is one way to mitigate the current and projected loss of natural water sources used by wildlife in arid regions. Indeed, since the 1940s, nearly 7,000 of these devices have been built in the western USA with more than $1,000,000 in combined annual expenditures (Rosenstock et al. 1999, Larsen et al. 2012). Several variations of wildlife water developments exist, but their primary function is to catch and store precipitation, which is then made accessible to wildlife during dry periods (Bleich et al. 2005) (Fig. 1). Construction of wildlife water developments, however, has become controversial, particularly in the southwestern USA. Concerns exist about the efficacy of water developments (Severson and Medina 1983, Deblinger and Alldredge 1991, Burkett and Thompson 1994, Broyles and Cutler 1999), the compatibility of these developments with wilderness values (Bleich 2005, Krausman et al. 2006), and the potential for negative effects from these devices (i.e., increased predation, competition, disease transmission (Severson and Medina 1983, Rosenstock et al. 1999), and negative ecosystem interactions between native and exotic species around these locations (Burkett and Thompson 1994)). Conflict over wildlife water developments has persisted for nearly 20 years, and even the decision processes, civility, and human dignity associated with constructing these devices has been criticized (Mattson and Chambers 2009, Larsen et al. 2012). This controversy has prompted numerous studies to expand our understanding of the ecological and biological effects of providing human-built water sources for wildlife in arid and semiarid environments (Krausman et al. 2006).

In the Great Basin Desert, water availability is suspected to be a limiting factor for mule deer (*Odocoileus hemionus*) (Cox et al. 2009), particularly during summer; however, little research has been conducted on this topic. Mule deer are a popular game species (Cox et al. 2009), an important prey item for carnivores (Berger and Wehausen 1991, Bleich and Taylor 1998), and an integral part of the ecosystems of the western USA (Kie et al. 2002). Indeed, these deer have been implicated as a central component of a potential disequilibrium of predators and prey in the Great Basin, which ostensibly has affected ecosystem and community dynamics across this region (Berger and Wehausen 1991). In much of the Great Basin, wildlife water developments have been built to mitigate scarcity of water and benefit mule deer populations. However, the extent to which additional water provided by water developments benefits these ungulates remains unclear (deVos Jr. et al. 1998, Krausman et al. 2006).

Moreover, very little research has been conducted on long-term use of water sources by mule deer in the Great Basin Desert, and a gap in knowledge exists regarding how sexes of these deer use water differently. Recent research on water use by bighorn sheep, for example, highlighted the need to understand how males and females use water differently in order to effectively conserve and manage these specialized ungulates and their habitats (Whiting et al. 2010). We used remote cameras to document use of 17 water sources (13 wildlife water developments and 4 natural springs) across five years during summer by individually identified mule deer in the Great Basin, USA. We determined frequency and timing of visits to water by mule deer, evaluated differences in the use of that resource between sexes and by year, and identified the number of water sources used by males and females. We also estimated population abundance using photographs of identifiable individuals visiting water sources. General information about how mule deer use water, including wildlife water developments, may help alleviate some of the conflict surrounding the loss of natural water sources. Further, information about how the sexes use water differently in arid ecosystems will aid the development of management and conservation strategies to ensure the long-term persistence of this species over the coming decades during a projected global water shortage.

STUDY AREA

We quantified use of 17 water sources (13 wildlife water developments and 4 springs) by mule deer on the Thomas-Dugway Mountains in western Utah. Those 17 water sources represented all known wildlife water developments and springs accessible to ungulates on the Thomas-Dugway range based on current and historical maps and other research regarding water use by chukars (*Alectoris chukar*) in that area (Robinson et al. 2009, Larsen et al. 2010). This mountain range is located in Juab and Tooele counties (N 39°51’33”, W 113°5’29”) within the Great Basin Desert. As with other mountain ranges in the Great Basin, the Thomas-Dugway range extends in a north-south direction, and is approximately 40 km long and 13 km wide. Elevations range from 1,380 to 2,135 m. Average annual precipitation over a thirty year period (1981-2010) for this area was 224.8 mm with only 45.0 mm occurring in summer (June-August). Summer high and low temperatures for the same time period averaged 33.5° C and 13.7° C (Table 1). Autumn (September-November) high and low temperatures were cooler and averaged 19.6° C and 1.7° C, with an average precipitation of 55.4 mm. Winter (December-February) high and low average temperatures were 5.5° C and -1.5° C, with an average of 47.5 mm of precipitation, largely as snow. Average spring (March-May) high and low temperatures were 18.8° C and 1.8° C, and average spring precipitation was 76.9 mm. The study area was hotter and drier than average during the initial years, then became cooler and wetter during later years (Table 1) (Western Regional Climate Center, www.wrcc.dri.edu). Major land-cover types and vegetation communities on the Thomas-Dugway Mountains included the following: Great Basin pinyon (*Pinus* spp.)-juniper (*Juniperus* spp.) woodland, Great Basin xeric-mixed sagebrush (*Artemisia* spp.) shrubland, inter-mountain basins semi-desert shrub steppe, inter-mountain basins mixed salt desert scrub, invasive annual grassland, and inter-mountain basins cliff and canyon (Lowry et al. 2005).

Water sources on the Thomas-Dugway Mountains occurred at varying elevations between 1,500 and 1,950 m and in several different vegetation types. Wildlife water developments were located in a variety of habitats, but generally occurred in washes or on small ridges at the base of the mountain range (1,561-1,772 m) (Fig. 1). All wildlife water developments we evaluated were constructed specifically for ungulate use and were within areas used by mule deer. Springs were also located in a diversity of habitats with three near the base of the mountains and one on a primary ridge (1,318-1,918 m). Average (± SD) distance from one water source to the next nearest water source was 3.3 km (± 1.4, range = 1.8 to 6.3). All water sources held water during the study period with the exception of one wildlife water development that sporadically malfunctioned during each year. Only one of the 17 water sources was fenced (Larsen et al. 2011).

METHODS

Sampling

We placed passive infra-red (PIR) cameras (The Digital 3.2, Camtrakker Inc®, Watkinsville, Georgia; Pixcontroller, universal controller board Sony DSC P-32 camera, Export, Pennsylvania; or PC900, Reconyx Inc, Holmen, Wisconsin) at all known water sources each summer from 2007 to 2011. Our PIR cameras required both heat and motion to activate, and we placed cameras 3-4 m from water sources to detect and photograph animals using that resource. We aimed cameras to detect motion 1 m in height above the water source and visited each water source every 10-14 days throughout the sampling period to replace batteries and memory cards and ensure cameras were functioning properly. To minimize disturbance to mule deer, we visited water sources primarily during daylight hours and typically spent less than 20 minutes at each water source. We assumed mule deer photographed at water sources drank, an assumption validated by O'Brien et al. (2006) using remote videography.

We selected a 40-day window from 15 July to 23 August for sampling because use of water sources was minimal before this period (A. Shields, unpublished data). This window also corresponded with the hottest and driest time of the year. Moreover, scars and other pelage irregularities became difficult to see in late August-early September as mule deer hair turned from red to grey. In 2008, cameras were deployed on 15 July but were removed from water sources in late July because several were stolen. During the other years (2007, 2009-2011) cameras were operational throughout the 40-day window with the exception of occasional times with cameras malfunctioned. For our analyses, we excluded one spring, because we did not photograph any deer at that location during the study.

Once photographs were collected, we identified individual mule deer based on antler characteristics (males), pelage irregularities (e.g., scars and cuts on males and females), and other distinguishing marks (Jacobson et al. 1997). For example, one female was missing an eye, another had several cuts in one ear, and a third was missing a large piece from one ear (Fig. 2). We assigned each deer a unique identifier, grouped all photographs of an individual taken throughout the summer sampling period, and repeated this process for each identifiable deer. Some female deer did not have clearly distinguishable marks, so we excluded photographs of those deer from our analyses of frequency, timing, and number of water sources used. We were able to identify a few individuals visiting water sources across years; however, we recorded them as separate deer each year because of the difficulty in identifying most individuals across years (different scars, different antler configurations, etc.).

Water Source Use

We extracted date and time from each photograph and standardized them to a Julian date. To determine frequency of visits by an individual mule deer to a water source, we calculated the difference in time between the first photograph of that individual at a water source and the last photograph of the previous visit to a water source. Occasionally cameras malfunctioned, and we did not use the elapsed times between visits to water when this occurred. We classified a visit as a photograph or series of photographs preceded by at least a 25-minute lapse of time since the last photograph of a mule deer (Whiting et al. 2009b). We calculated the mean elapsed time between visits to water for each identifiable deer within a year and used these values for further analysis. We used analysis of variance (ANOVA) to assess differences between years and sexes and the sex by year interaction in mean hours between visits. Following a significant ANOVA result ($P < 0.05$), we conducted post-hoc tests (Tukey's adjustment for multiplicity of tests, T) to investigate differences by year, sex, and the interaction of those variables.

To determine diel timing of water source use, we recorded the time of the first photograph of each visit by an identified deer to a water source. To test for differences between sexes and years, we used a MANOVA test. Because time of day was a circular variable, we used the sine and cosine function to transform this variable for analyses and used these transformed values as the two response variables (Zar 1999). To determine differential water source use by sexes, we recorded the number of times identified deer used each water source. We combined all years and plotted these data as proportion of visits by each sex. We determined that a water source was used primarily by one sex if >75% of the combined events occurred by one sex at that water source. For each identified deer, we recorded the number of water sources used and the number of times each deer changed water sources. To test for differences between sexes and years for those variables, we used an ANOVA test. We also calculated the minimum distance traveled by deer that changed water sources at least once by summing the distances of all known movements by an individual between water sources. We evaluated assumptions (e.g. normality, homogeneity of variance) of the ANOVA and MANOVA tests graphically and used Program R to conduct all statistical tests (R Development Core Team 2007).

Abundance Estimation

Using photographs of individually recognized mule deer at water sources, we estimated abundance of females using the Poisson log-normal mixed-effects mark-resight model (McClintock et al. 2009) in program MARK (White and Burnham 1999). We only generated abundance estimates of females because we could identify all males and did not have unidentified photographs of any males. For females, the method we used is a relatively new mark-resight model that allows for the estimation of the number of unmarked individuals in the population, and derives an estimate of abundance and mean resighting rate from the total number of marked and unmarked animals resighted (Jordan et al. 2011, Weckel et al. 2011). Rather than marking individuals, we considered deer that we had individually identified based on scars and pelage irregularities as marked. We used one sampling interval of 14 days (from 9 August to 23 August in 2007 and 2009 to 2011 and 16 July to 30 July in 2008) and sampled with replacement, where an individual was counted as resighted each time it visited a water source. Sampling dates were different in 2008 because cameras were stolen and we stopped sampling at the end of July. Some identifiable deer were not detected at water sources during resight sampling so we only considered deer marked if they were individually identifiable and photographed during the week prior to or during the 14-day sampling interval. To compensate for differences in the number of photographs of an individual per visit (longer visit = more photos), we treated each visit, rather than each photograph, as a resight regardless of how many photographs were collected of an individual during that visit.

RESULTS

Water Source Use

We sampled 2,193 camera days (camera active 24 hours at a water source) from 2007 to 2011 (mean per year = 439 camera days; range 164 to 572 camera days). We collected a total of 13,686 photographs of mule deer at 16 of the 17 water sources over the five years of sampling (Table 2). From these photographs, we identified 76 males and 116 females and tallied 790 drinking events by males and 1,179 drinking events by females from identified individuals during the study period (Table 2).

Mean number of hours (± SD) between visits for males was 38.2 (± 26.2; median = 29.8) and 39.9 (± 29.2; median = 30.9) for females across all five summers. Males visited water most frequently in 2009 (once every 32.8 ± 21.9 hours; median = 25.7) and least frequently in 2010 (once every 63.6 ± 33.0 hours; median = 66.0) (Fig. 3). Females visited water sources most frequently in 2008 (once every 29.3 ± 21.4 hours; median = 31.5) and least frequently in 2011 (once every 53.6 ± 37.1 hours; median = 43.3) (Fig. 3). Frequency of visits to water by males and females combined varied between years ($F = 6.25$, $df = 4, 158$, $P < 0.01$). Post-hoc means comparisons indicated low frequency of visits in 2010 and 2011 compared to early years. Significant differences existed for both sexes combined in 2007 ($T = 12.96$, $P = 0.04$), 2008 ($T = 15.82$, $P = 0.02$), and 2009 ($T = 20.09$, $P < 0.01$) compared with 2010, as well as in 2009 compared with 2011 ($T = 18.52$, $P < 0.01$). Combining all years, frequency of watering did not differ between sexes ($F = 0.20$, $df = 1, 161$, $P = 0.66$); however, there was a significant interaction with sex and year. Frequency of visits to water did not differ across years for females. During 2007 ($T = 33.89$, $P < 0.01$), 2008 ($T = 25.84$, $P = 0.05$), and 2009 ($T = 36.43$, $P < 0.01$), males visited water more frequently than in 2010 ($F = 3.97$, $df = 4, 153$, $P < 0.01$).

Mule deer visited water infrequently from 1100 hours to 1900 hours (3% of all visits, Fig. 4). Both males and females visited water more often during the evening than morning. The most visits in any hour were recorded from 2200-2300 hours for both males (12% of all male visits) and females (11% of all female visits) (Fig. 4). Most visits to water sources occurred at night, with 81% of male and 73% of female visits occurring between 2100 and 0600 hours. There was a difference in timing of visits between sexes across years ($F = 16.92$, $df = 1, 1967$, $P < 0.01$), however general patterns of use were similar (Fig. 4). There was also a difference in timing of visits between years for both sexes combined ($F = 2.99$, $df = 4, 1964$, $P < 0.01$).

Although 14 water sources were used by males and females, 2 water sources (9 and 10) were used primarily by males and 6 sources (4, 6, 7, 11, 12, and S2) were used predominately by females (Fig. 5). Four water sources (1, 2, 4, and S1) received 59% of female visits whereas nine water sources each received < 5% of female visits, including two water sources that were not used by females. Four water sources (1, 9, 10, and S1) received 69% of male visits whereas ten water sources each received < 5% of male visits. Wildlife water developments were used extensively with 90% of male visits and 88% of female visits to those water sources.

Individual males used an average of 1.5 (SD ± 0.8, range = 1 to 5) water sources each year, whereas individual females used 1.3 (SD ± 0.7, range = 1 to 5) water sources per year. Males changed water sources an average of 1.3 (SD ± 2.2, range = 0 to 8) times each summer and traveled an average minimum distance of 11 km (SD ± 7.8, range = 2.7 to 25.7, $n = 28$) across changes. Females changed water sources an average of 0.7 (SD ± 1.8, range = 0 to 12) times and traveled a minimum average distance of 13.4 km (SD ± 12, range = 1.7 to 38.7, $n = 20$) across changes.

Abundance Estimation

We included 109 female deer from all years in our model of abundance as individually identifiable and obtained 598 resightings of those individuals (Table 3). We also tallied 362 total visits by unmarked females. The Poisson-log normal model produced reasonable estimates of abundance of females using these marked individuals (Table 3). Abundance estimates indicated that number of female mule deer in our study area was stable from 2007-2011 (Table 3).

DISCUSSION

In our study, most water sources were used by both sexes, however, two (12.5%) wildlife water developments were used primarily by males and six (37.5%) different wildlife water developments were used predominately by females. Those patterns of water use by the sexes were consistent across the five years of our study, indicating high fidelity by the sexes for specific water sources. Recent research indicated that although home ranges overlapped considerably for male and female bighorn sheep, use of different water sources occurred and that consideration should be given to the separate habitat requirements for each sex when evaluating the use of water (Whiting et al. 2010). Additionally, wildlife water developments constructed in areas used by one sex may not be beneficial for the other (Bleich et al. 1997, Bleich 2009, Larsen et al. 2012). More work is needed on this topic to determine how habitat and landscape features may influence use of water sources by males and females differently.

Across the five years of our study, individual male and female mule deer used relatively few water sources. A pattern was not evident relating the number of water sources used to differing levels of precipitation across years. In other studies, when water catchments were closed, thereby eliminating availability of this resource, mule deer females traveled outside their home range to find other water sources (1986). In our study area, all water sources remained available to deer across the five years, and although deer used as many as five water sources, 81% of females and 63% of males were photographed at only one water source. Similarly, a mature male that we were able to identify (based on a tear in his right ear) used the same water source exclusively each year from 2007 to 2010. These results indicate that in our study area individual mule deer exhibit high fidelity to water sources both within and across years. Current research is stressing the importance of the variability in individual behavior of wildlife with regards to conservation and management of species (Festa-Bianchet 2003, Pelletier et al. 2004). Thus, loss of natural water sources may affect certain individuals and not others; and the siting, reprovisioning, and building of water developments for mule deer may benefit only certain individuals.

Researchers have stressed the importance of documenting water use by wildlife covering multiple years and wet-dry periods (deVos Jr. et al. 1998, Rosenstock et al. 1999, Krausman et al. 2006). Our study covered five years comprising dry (2007-2009) and wet (2010-2011) periods. The frequency of water use generally followed these weather patterns. Low precipitation and high temperatures early in the study period corresponded with greater frequency of use, and high precipitation and lower temperatures later in the study period corresponded with lower frequency of water use (Fig. 3, Table 1). These results are consistent with mule deer studies in other areas (Hervert and Krausman 1986, Hazam and Krausman 1988) and other ungulate studies in the Great Basin (Whiting et al. 2009a). Spring 2011 was much wetter than normal (196% of 30 year mean, Table 1), and thus, mule deer use of water sources during summer 2011 was much lower than other years. Indeed, males only visited water sources on ten occasions; whereas, females visited this resource on 104 occasions. We hypothesize that frequency of water use was influenced by the amount of moisture available in forage and availability of water in temporary sources (e.g. puddles). Availability of water in forage is further influenced by evapotranspiration rates which are correlated with humidity and temperature. We also hypothesize that females visited water sources more frequently than males during summer because of lactation demands (Short 1981, Turner et al. 2004).

Mule deer visited water sources primarily from late evening until early morning with very few visits recorded during the middle part of the day. Others studies showed peak visitation in the evening and a marked decrease in visits through the night and morning for females in Arizona (Hervert and Krausman 1986) and males and females in California (Boroski and

Mossman 1998). Our results indicated highest visitation rates in the evening, but showed continued high visitation through the night and into the morning before visits decreased. Other authors have suggested mule deer use water in the evening in response to dehydration that occurs throughout the day (Boroski and Mossman 1998) and to restrict movement during the hottest part of the day. Our results are consistent with this hypothesis.

Consistent use of water sources by mule deer in arid environments can provide opportunities for estimating abundance, and thus help determine how human-provided water sources influence wildlife populations. Hervert and Krausman (1986) suggested that because female deer are dependent on water sources when temperatures are high, and females visited water sources once per day, censusing female deer at water sources may be possible. Indeed, other researchers have been able to identify individual white-tailed deer using unique antler configurations (Jacobson et al. 1997) and several species of felids based on spot patterns in pelage (Karanth and Nichols 1998, Jackson et al. 2006, McCain and Childs 2008). The consistent use of water by mule deer in our study area and the ability to identify those individuals allowed us to estimate abundance non-invasively using mark-resight procedures. These methods can likely be extended to other species, particularly in small, isolated populations where animals consistently visit a particular area, such as water sources in an arid environment. Using these methods may be particularly useful in quantifying a decrease or increase in abundance of animals in relationship to changes in availability of water (e.g. loss of springs or addition of wildlife water developments).

Water is an important resource for many animals in arid environments (Robbins 2001, Cain III et al. 2006). Climate change will affect the future quantity and quality of water for wildlife around the world (Brown and Thorpe 2008, Whiting et al. 2010) and in the Great Basin, USA (Chambers and Pellant 2008). Human-provided water sources may help to reduce the conflict between the needs of humans and wildlife for water (Simpson et al. 2011, Larsen et al. 2012). Knowledge about the use of water sources by the sexes will help managers and scientists develop strategies to conserve and manage species that rely on this resource (Whiting et al. 2010). Our results indicate that male and female mule deer visited water sources at similar frequencies, but used different water sources. Individual male and female mule deer used relatively few water sources and exhibited high fidelity to this resource both within and across years. Additionally, most wildlife water developments were used extensively by both sexes, and may have mitigated the scarcity of naturally-occurring free water. Our results highlight the differing use of water sources by sexes and individual mule deer during summer. This information will help guide managers when siting, reprovisioning, and building wildlife water developments meant to benefit male and female mule deer and will contribute to the conservation and management of this species.

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Table 1. Spring (March to May) and summer (June to August) mean temperature (± SD) and total precipitation in western Utah, USA, 2007-2011 where we evaluated mule deer use of water sources.

	Spring		Summer	
Year	Temperature (°C)	Precipitation (mm)	Temperature (°C)	Precipitation (mm)
2007	10.9 ± 3.7	8.8	25.1 ± 2.3	31.6
2008	8.7 ± 4.1	33.7	24.5 ± 2.5	21.5
2009	10.2 ± 4.8	66.2	22.3 ± 2.6	43.4
2010	8.4 ± 2.5	101.2	24.1 ± 2.2	39.6
2011	8.6 ± 2.4	150.9	23.3 ± 3.1	39.4
30 year avg.	10.3	76.9	23.6	45

Table 2. Number of mule deer photographs taken and identified to individual, as well as the number of unique males and females detected using water sources during summer (July and August) in western Utah, USA, 2007-2011.

Year	No. Photos	No. Identified	Percent Identified	No. Males Identified	No. Females Identified
2007	3614	2803	0.78	27	26
2008	1566	829	0.53	19	19
2009	4727	4139	0.88	16	26
2010	2857	2290	0.80	9	21
2011	922	562	0.61	5	24
Total	13,686	10,623	0.78	76	116

Table 3. Number of identifiable deer, resightings, visits by unmarked individuals, abundance estimates ($\widehat{N}$), and mean resighting rates ($\bar{x}$ RR) along with standard errors (*SE*) and 95 percent confidence intervals (L95CI and U95CI for lower and upper 95% confidence intervals, respectively) for female mule deer in western Utah, USA, 2007-2011 estimated using program MARK.

Year	Identifiable Deer	No. Resightings	Unmarked Visits	$\widehat{N}$	*SE*	L95CI	U95CI	$\bar{x}$ RR	*SE*	L95CI	U95CI
2007	20	100	69	34	3.60	26	41	4.99	0.83	3.36	6.63
2008	19	84	142	52	6.49	40	65	4.22	0.60	3.05	5.40
2009	25	188	76	35	2.31	30	39	7.75	1.07	5.66	9.85
2010	21	141	45	28	1.51	25	31	6.60	0.76	5.11	8.09
2011	24	85	32	38	4.27	29	46	2.29	0.42	1.47	3.12

Figure 1. Typical wildlife water development on the Thomas-Dugway Mountains in western Utah, USA, including catchment apron (left) and drinker (right) where we photographed mule deer using water sources, 2007-2011.

Figure 2. Photographs of female mule deer taken by remote cameras showing distinguishing features including scars (left) and notches in both ears (right) that we used to identify individuals at water sources in Utah, USA, 2007-2011.

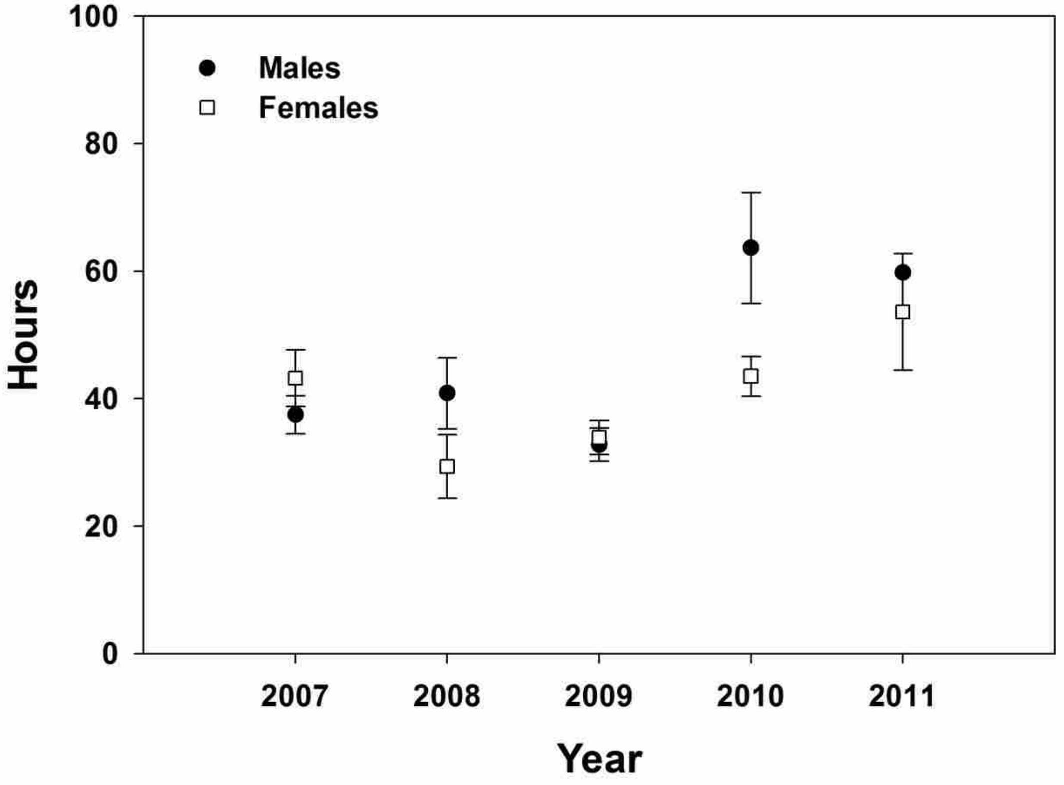

Figure 3. Hours between visits (± 95% CIs) to water sources by male and female mule deer during summer (July and August) in western Utah, USA, 2007-2011. The confidence interval is missing for males in 2011, because there were too few visits to water by males in that year to generate a meaningful interval.

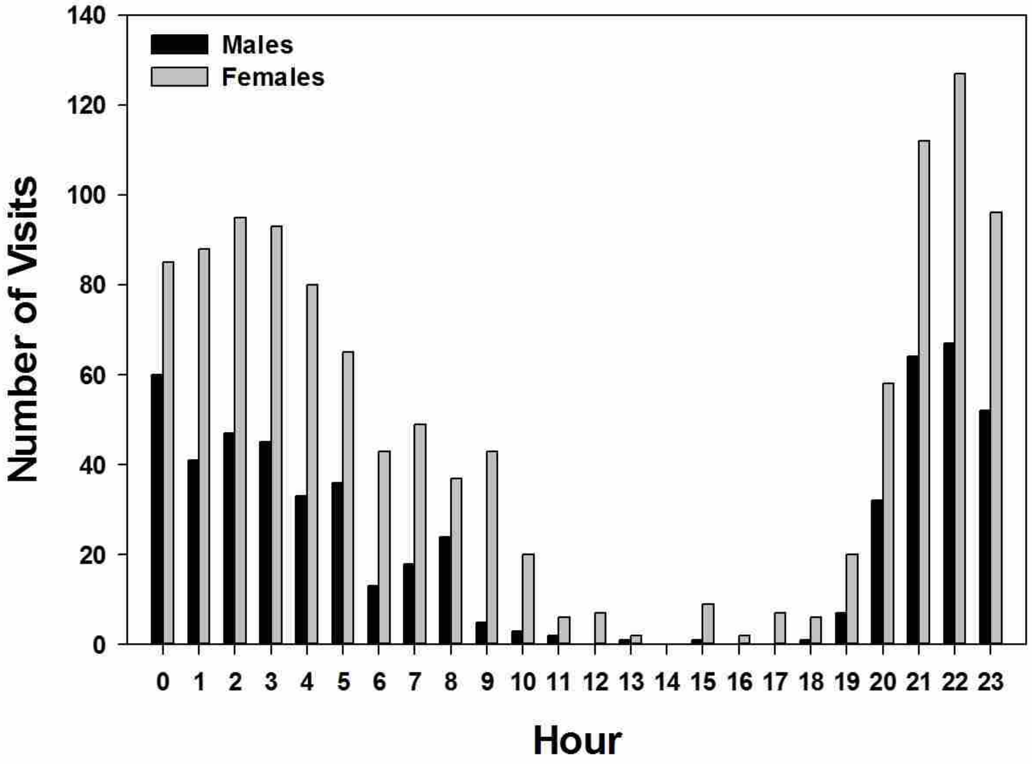

Figure 4. Timing of visits to water sources by identified male and female mule deer during summer (July and August) in western Utah, USA, 2007-2011.

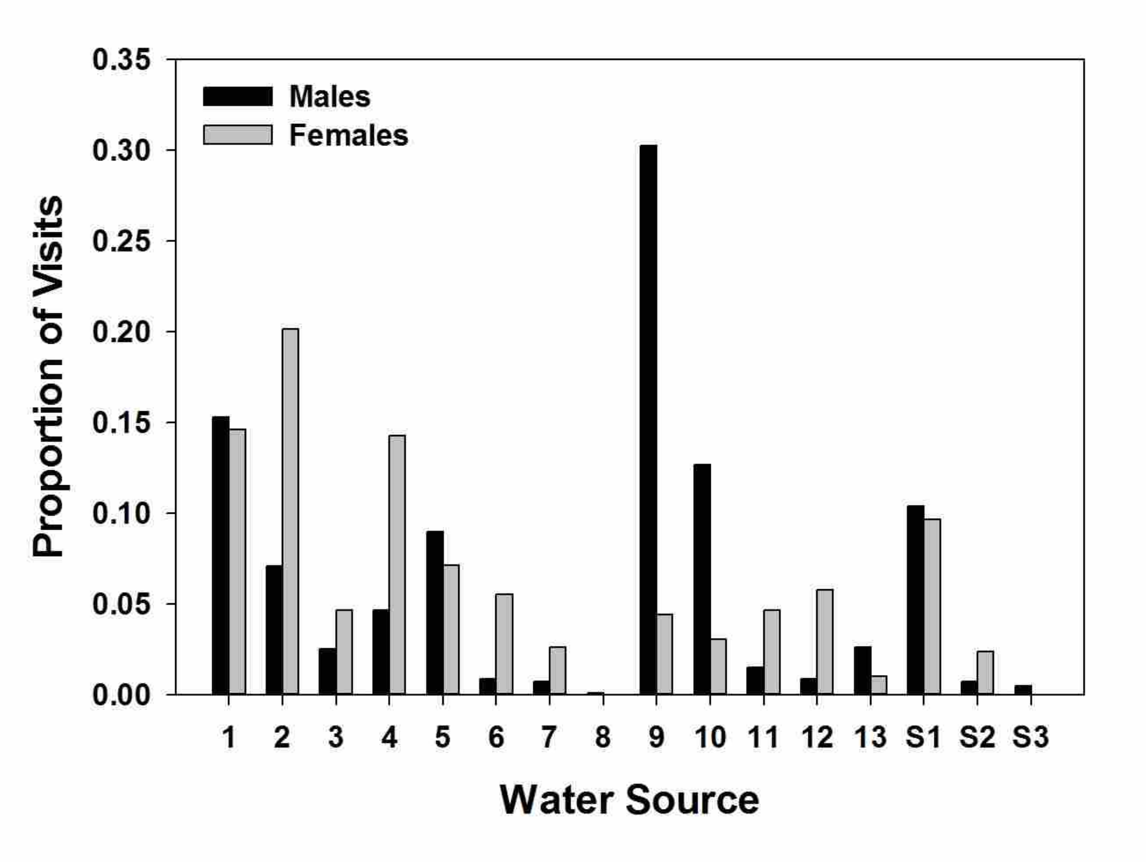

Figure 5. Proportion of visits by male and female mule deer to water sources in western Utah, USA, 2007-2011. Water sources 1 to 13 were wildlife water developments; S1 to S3 were natural and modified springs.

CHAPTER 2

DIFFERENTIAL USE OF WATER SOURCES BY BIGHORN SHEEP, ELK, MULE DEER, AND PRONGHORN IN UTAH: INFLUENCES OF HABITAT FEATURES, SEXUAL SEGREGATION, AND PREDATORS

ABSTRACT

Free water is important for bighorn sheep (*Ovis canadensis*), elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), and pronghorn (*Antilocapra americana*) in the western USA. Habitat and landscape features surrounding water sources, including wildlife water developments, may influence the use of this resource by sexes and species differently. We randomly sampled 231 water sources on 304 occasions with remote cameras in a clustered sampling design throughout Utah in 2006 and from 2009 to 2011. We measured site and landscape-scale habitat features at each water source and determined which were associated with photo rates by males and females of those four species. Top models for each species were different, but supported models for males and females of the same species generally included similar covariates, although with varying strengths. Females demonstrated stronger selection than males for most covariates. Aspect and slope positively influenced bighorn sheep use of water, whereas greater amounts of cover and less visibility were important for elk and mule deer. Conversely, less cover and greater visibility were selected for by pronghorn. We encourage managers to consider habitat features surrounding water sources when siting, building, and reprovisioning wildlife water developments built to benefit these four species, and when prioritizing natural water sources for preservation or enhancement. We provide specific guidelines for placement of water developments for these species.

INTRODUCTION

Free water is an important resource for many ungulates in the western USA. Water has been identified as an influential habitat component for many bighorn sheep (*Ovis canadensis*) populations (Bleich et al. 2006, Krausman et al. 2006, Whiting et al. 2010), and the absence of perennial water sources may increase the probability of population declines of bighorns in some areas (Epps et al. 2004, Dolan 2006). Similarly, elk (*Cervus elaphus*) often select habitats within 1 km of water (Irwin and Peek 1983, Delgiudice and Rodiek 1984, Skovlin et al. 2002). Increasing the distribution and availability of water on many of the driest rangelands of the western USA will likely enhance the use of these areas by elk, especially during dry seasons or years (Wisdom and Cook 2000). Mule deer (*Odocoileus hemionus*) visit water sources every 1-4 days in arid habitats (Hervert and Krausman 1986, Hazam and Krausman 1988, Shields et al. 2012) and these ungulates occur closer to water sources during summer (Ordway and Krausman 1986, Rautenstrauch and Krausman 1989) and lactation (Bowyer 1984, Boroski and Mossman 1996). Pronghorn (*Antilocapra americana*) may meet water demands by eating forage with high moisture content (Beale and Smith 1970, Deblinger and Alldredge 1991), however, these ungulates drink free water when it is available during hot, dry conditions (Beale and Smith 1970, O'Gara and Yoakum 2004, Morgart et al. 2005). Although considered important to these four ungulates, availability of water sources may influence sexes of the same species differently.

Many ungulates sexually segregate during much of year, only coming together during the breeding season (Bowyer 1984, Main et al. 1996, Bleich et al. 1997); therefore, manipulating or modifying habitat may benefit one sex more than the other. Sexual segregation is a result of differing life-history strategies between males and females and is most likely driven by acquisition of resources or predator avoidance (Main et al. 1996, Bowyer 2004, Main 2008).

Sexual segregation at water sources has been documented in bighorn sheep (Bleich et al. 1997, Whiting et al. 2010) and mule deer (Bowyer 1984, Shields et al. 2012). Female mule deer and bighorn sheep occupied areas closer to water than males, and differences in water requirements has been proposed as an explanation of sexual segregation in both species (Bowyer 1984, Bleich et al. 1997), although this hypothesis had little support in one study (Bleich et al. 1997). Until recently, however, additional research on how males and females use water sources differently has been limited. This differential use of water sources by the sexes is important when preserving or enhancing natural water sources or when considering where to site artificial water sources, a common management action in arid regions for ungulates and other animals (Rosenstock et al. 1999, Krausman et al. 2006).

Building wildlife water developments is a frequently used, but somewhat controversial practice to provide free water for wildlife. Nearly 7,000 wildlife water developments have been built in the western USA since the 1940s (Rosenstock et al. 1999, Larsen et al. 2012), however, the efficacy of those developments has been questioned (Deblinger and Alldredge 1991, Burkett and Thompson 1994, Broyles and Cutler 1999). One reason for this controversy is that in some instances water developments placed in close proximity to known populations of animals receive little or no use by target species. Some wildlife water developments in western Utah, for example, received little use by mule deer while others in the same area were used frequently (Shields et al. 2012). Further, males and females of that species used different water sources (Shields et al. 2012). One possible explanation for this difference in use of water developments by males and females is differing habitat and landscape features surrounding water sources. Indeed, very little research has been conducted on how the habitat and landscape features surrounding these water developments may influence use by species and sexes.

Information about how the habitat, landscape, or anthropogenic features, or presence of predators influence the use of water by different species and sexes will inform the controversy surrounding wildlife water developments. Small perimeter fencing, for example, may negatively influence mule deer use of water sources (Larsen et al. 2011). Similarly, water sources far from steep, rugged, escape terrain or located within dense vegetation may not be used by bighorn sheep (Brigham and Stevenson 1997)—particularly females (Bleich et al. 1997). Sampling or monitoring water developments without considering these influences may result in inaccurate conclusions that those water developments are not used, and thus are of no value to those species. We used remote cameras to sample 237 water sources for use by bighorn sheep, elk, mule deer, and pronghorn. We measured several site, landscape, and other characteristics at each water source to identify features associated with use of water sources by males and females of those four ungulates. We hypothesized that each species would show evidence of selection, but for different features. Furthermore, given current understanding of sexual segregation, we predicted that females of each species would demonstrate evidence of stronger selection than males. The results of our study will help managers in siting, reprovisioning, and building wildlife water developments and in developing and conserving natural water sources.

STUDY AREA

We sampled water sources throughout Utah and at least one of our sampling clusters occurred in five different ecoregions (Central Basin and Range, Colorado Plateau, Mojave Basin and Range, Wasatch and Uinta Mountains, and Wyoming Basin) located in the state (Fig. 1). Sampled water sources ranged in elevation from 1,098 m to 2,953 m. Water sources where bighorn sheep were photographed ranged in elevation from 1,098 m to 2,953 m. Elk photographs occurred at water sources at elevations from 1,454 m to 2,953 m. Mule deer were photographed at water sources ranging in elevation from 1,098 m to 2,953 m. Water sources where pronghorn were photographed ranged in elevation from 1,305 m to 2,698 m.

The 50-year mean annual precipitation from > 200 weather stations near sample locations across the state was 13.6 cm (range = 11.7 cm to 137.0 cm) and mean precipitation during summer (June to September) was 9.5 cm (range = 3.1 to 21.1). Mean annual high temperature was 17.1° C (range = 6.3° C to 25.9° C) and mean high temperature during June to September was 28.9 ° C (range = 15.3 ° C to 36.5 ° C). Mean annual low temperature was 1.4 ° C (range = -6.4 ° C to 9.9 ° C) and mean low temperature from June to September was 10.6 ° C (range = 2.4 ° C to 20.7 ° C) (Western Regional Climate Center, www.wrcc.dri.edu).

Dominant vegetation species at sampled water sources included the following: big galleta (*Pleuraphis jamesii*), blackbrush (*Coleogyne ramosissima*), Douglas fir (*Pseudotsuga menziesii*), Engelmann spruce (*Picea engelmannii*), horsebrush (*Tetradymia canescens*), indian ricegrass (*Achnatherum hymenoides*), maple (*Acer* spp.), oak (*Quercus* spp.), ponderosa pine (*Pinus ponderosa*), pricklypear (*Opuntia* spp.), quaking aspen (*Populus tremuloides*), rabbitbrush (*Chrysothamnus* spp.), sagebrush (*Artemisia* spp.), saltbush (*Atriplex* spp.), sand dropseed (*Sporobolus crytandrus*), shadscale (*Atriplex confertifolia*), Utah serviceberry (*Amelanchier utahensis*), Utah juniper (*Juniperus osterosperma*), and white fir (*Abies concolor*) (Utah GIS Portal Dominant Vegetation Layer; http://gis.utah.gov).

METHODS

Sampling

We located wildlife water developments accessible to ungulates (*n* = 514) throughout Utah from information provided by the Bureau of Land Management, United States Forest Service, and Utah Division of Wildlife Resources. We then randomly selected (with replacement) a water development and sampled that water development and 2 to 11 of the closest known water sources (water developments, natural springs, livestock troughs, and ponds) within 10 km in a clustered sampling approach (Larsen et al. 2011). We did not sample clusters of water sources if there were < 3 water sources in the 10 km area (Fig. 1). Sampling in a clustered design allowed us to control for important influences of temperature, precipitation, and animal density, because we made comparisons of use among water sources in an individual cluster (same area, same time frame, similar environmental conditions) as well as between clusters. We sampled during summer (June to September) in 2006 and from 2009 to 2011.

We deployed passive infra-red (PIR) cameras from Camtrakker Inc.® (Sony Digital Camtrakker; Watkinsville, Georgia), PixController (universal controller board Sony DSC P-32 camera; Export, Pennsylvania), or Reconyx^{TM} (Reconyx Inc, Holmen, Wisconsin) randomly at each water source for approximately two weeks. We placed cameras 3-4 m from water sources and aimed cameras to detect motion and heat from animals using that resource (see Shields et al. 2012 for further details on sampling). We set cameras to operate with 10, 20, or 30 second delays between photographs (depending on constraints related to options available with each camera type), but standardized photograph numbers to a 20 second delay by dividing the number of photographs in half (10 second interval) or multiplying the number of photos by 1.33 (30 second interval). We recorded the length of time each camera was deployed and classified each photo of the four ungulates by species and sex. We also recorded the number of photographs of several predator species including black bears (*Ursus americanus*), bobcats (*Lynx rufus*), cougars (*Puma concolor*), coyotes (*Canis latrans*), golden eagles (*Aquila chrysaetos*), and humans at each water source.

Covariates

We measured the distance to several habitat features from each water source, including distance to nearest rock outcrops (cliffs at least 7 m x 7 m in size) and distance to nearest predator cover. We considered predator cover to be any object (i.e. rock, shrub, tree) at least 1 m^2 that could conceal a cougar-sized predator. We calculated density, cover, and height of woody plants (shrubs or trees) within 30 m of the water source. Because many sites had woody plants growing low to the ground that may not have influenced use of water sources by ungulates, we calculated density, cover, and height in two subsets: one in which all woody species regardless of height were included, and one in which we only included woody plants > 75 cm tall. We calculated density of woody plants of both subsets within 30 m of the water source using the T-squared method (Krebs 1999). For this method, we selected the closest woody plant to a random point (within 0 – 30 m of the water source; generated by a random number table) in each of the 4 cardinal directions. We then measured the distance between the random point and the closest woody plant as well as the distance from the measured plant to the next closest plant. For each measured plant, we recorded the height (cm) and area (cm^2) of the canopy. To provide an estimate of cover at each water source, we averaged the heights and multiplied the average area by the average density. We quantified visual obscurity at 5, 10, 15, 20, 50, 75, and 100 m from the water source and extending in each of the 4 cardinal directions using a Robel pole (Robel et al. 1970) with 3 cm bands and averaged values at each distance for each water source. We also recorded the type of water source (i.e., wildlife water development or spring). For each water source that was fenced, we recorded the type of fence, area (m^2) inside the fence, and the distance between the drinker and the nearest side of the fence (m) (Larsen et al. 2011).

To characterize surrounding habitat at a broader scale, we included measures of aspect (degree), curvature, distance to nearest water (m), elevation (m), ruggedness, slope (degree), tree cover, and visibility calculated using Geographic Information Systems (GIS) into our analysis. For aspect, curvature, and slope measures, we used a 10-m digital elevation model (DEM) obtained from the Utah GIS Portal (http://gis.utah.gov). We also used the 10-m DEM to measure landscape ruggedness using the vector ruggedness metric developed and tested by Sappington et al. (2007). For this ruggedness metric, we used a 3 x 3 cell size consistent with Sappington et al. (2007). To measure tree cover, we used the 2004 Southwestern Regional Gap Analysis Layer (Lowry et al. 2005), which classified 30 m pixels into vegetation types. We then further classified pixels into tree (plant community dominated by trees) or non-tree (plant community not dominated by trees) (Larsen et al. 2011). To further characterize vegetation at each water source, we recorded the dominant plant species associated with a Utah Division of Wildlife Resources dominant vegetation layer obtained from the Utah GIS Portal (http://gis.utah.gov) as a covariate potentially influencing water use.

For these layers, we created 3 different-sized buffers around each water source for each of the four species of interest. These buffers corresponded to the radius size of estimated home ranges for each species, one order magnitude lower than the radius associated with home range size, and a middle value between these two numbers. For bighorn sheep, we used a home range estimate of 19 km^2 (Singer et al. 2001) and radii for buffers of 245 m, 1,345 m, and 2,445 m. Elk approximate home range size was 50 km^2 (Irwin and Peek 1983, Edge et al. 1985, Peek 2003, Anderson et al. 2005), and we used radii for buffers of 400 m, 2,205 m, and 4,005 m. Mule deer approximate home range size was 10 km^2 (Relyea et al. 2000, Mackie et al. 2003) and radii for buffers were 175 m, 965 m, and 1,755 m. Finally, for pronghorn approximate home range size was 53 km^2 (O'Gara and Yoakum 2004) and we used radii of 410 m, 2,250 m, and 4,095 m for buffers. These buffer sizes provided several scales at which to assess selection of water sources (Fig. 1). We used zonal statistics (Hawth's tools and ArcGIS 9.3®, Redlands, CA) to calculate mean values for aspect, curvature, slope, and ruggedness or total counts of tree cover at each scale. In addition, we used the 10-m DEM and the viewshed tool (ArcGIS 10®, Redlands, CA) to produce an estimate of visibility associated with topography for inclusion as a covariate. This estimate of visibility was calculated as the proportion of pixels that were estimated as visible from the water source within a 500 m radius. We also used the 10-m DEM to calculate the elevation at each water source. Using our database of locations of water developments, lakes, springs, streams, and river layers obtained from the Utah GIS Portal, we determined the distance (m) from each sampled water source to the nearest water source and included that measure as a covariate potentially influencing use (Larsen et al. 2011).

We obtained temperature and precipitation data for each sampled water source using parameter-elevation regressions on independent slopes model (PRISM) data (Prism Climate Group, Oregon State University, http://prism.oregonstate.edu, created 30 Apr 2012). PRISM uses point data, a DEM, and other spatial data sets to estimate monthly temperature and precipitation over a continuous area (Daly et al. 1994). For each water source, we obtained maximum monthly temperature (°C), minimum monthly temperature (°C) and total monthly precipitation (mm) for the month during and the month prior to the sampling period. We included maximum monthly temperature (°C), mean monthly temperature (°C), and total monthly precipitation (mm) as potential covariates influencing photo counts.

Statistical Analysis

We used photo counts of males and females of the four ungulate species as a response variable and site (small scale characteristics at each water source), landscape (GIS-derived metrics at multiple spatial scales), weather, and photo counts of predators as explanatory variables in generalized linear models. Because most water sources were not used by all four species of ungulates, and many water sources were not within known distributions of one or several of the four species, we only included water sources in our analysis for each species if that water source or one in the same cluster received use by a particular ungulate. Because photo count data contained many zeroes, we used the zero-inflated negative binomial (ZINB) distribution for error structures.

We used a hierarchical information-theoretic approach (Burnham and Anderson 2002, Carpenter et al. 2010) in which we divided variables into site (small scale characteristics at each water source), landscape (GIS-derived metrics at multiple spatial scales), and other (e.g., predator photo counts, weather covariates) categories. For GIS-based metrics, we evaluated the scale at which each variable (e.g., slope, aspect, tree cover) best fit the data and included the extent with the lowest AIC (Akaike's Information Criterion, Akaike 1973) value in our models (Doherty et al. 2008) (Table 2). This method excluded the use of multiple extents for the same variable, which were often highly correlated ($r > |0.7|$). For other variables that were correlated, we only included the variable with the lowest AIC values from univariate analysis in multivariate models. We maintained the same variables in both the count and zero-inflation portions of each mixture model. We included sampling time as a variable in all models for mule deer and pronghorn to account for its influence; however, given smaller sample sizes for bighorn sheep and elk, we modeled photo rate (number of photos/sampling time) as the response variable to limit the number of estimated parameters.

We used Akaike's Information Criterion (Akaike 1973) adjusted for small sample sizes (AIC_c) to rank models (Burnham and Anderson 2002). After modeling covariates in three subsets, we advanced the top models and those with Δ $AIC_c < 2$ to a final stage of analysis. For mule deer and pronghorn, we tested all combinations of the top models in the final step. Because sample sizes were lower for bighorn sheep and elk, we limited overall number of parameters in evaluated models while assessing different combinations of variables from top models. In the presence of model uncertainty (competing models with > 5% AICc weight (W_i), we obtained model-averaged estimates of parameters (Burnham and Anderson 2002) for both the count and zero portions of models for each sex and species. We used the pscl (Zeileis et al. 2007) library in program R (R Development Core Team 2007) to perform statistical analyses.

RESULTS

We sampled 231 water sources a total of 304 times including 254 samples at water developments and 50 samples from springs across five ecoregions in Utah (Fig. 1). We sampled 7 water sources in 2006, 48 in 2009, 105 in 2010, and 144 in 2011. These sampled water sources occurred in 61 clusters with a mean (± *SD*) of 5 ± 1.7 water sources sampled per cluster. Total number of sampling days across all water sources was 4,052 and mean (± *SD*) sampling time at each water source was 13.3 ± 6.2 days. We included in our analyses 52 water sources used by bighorn sheep, 113 water sources used by elk, 226 water sources used by mule deer, and 172 water sources used by pronghorn (Fig. 1). Photo counts ranged from 0/site for each species to 4,813/site for bighorn sheep, 2,705/site for elk, 1,528/site for mule deer, and 1,219/site for pronghorn. We obtained 10,801 photos of bighorn sheep, 13,662 photos of elk, 19,951 photos of mule deer, 14,314 photos of pronghorn, 1,856 photos of predators, and 1,667 photos of humans (not including those associated with the project).

In the univariate analysis to determine the best scale for GIS-based and cover metrics, small and medium scales generally had lower AIC values than large scales (Table 2). The lowest AIC values for obscurity occurred at 20 m or less for both sexes of all four species except male mule deer, for which the lowest AIC value occurred at 75 m. Similarly, the lowest AIC value for the landscape covariates occurred at the small or medium scale extents in 25 out of 32 cases. For bighorn sheep, 7 out of 8 of the lowest AIC values for landscape covariates were at the medium scale, and the other value was at the small scale. For elk, only two of the lowest AIC values were at small scale, three were at medium, and three were at large scale. For mule deer, 4 were at small scale extents, one at medium scale, and three at large scale. For pronghorn, 5 out of 8 occurred at small scale, two at medium scale, and one at large scale (Table 2). The following sections discuss habitat-related covariates for which 95% confidence intervals (*CI*) around model-averaged parameter estimates did not overlap zero for each sex and species (Tables 4-7).

Bighorn Sheep

Of the 52 water sources included in the bighorn sheep analyses, 18 had photos of bighorns, 14 had photos of females, and 14 had photos of males. Two models carried ≥ 0.05 weight for female bighorn sheep (Table 3). Increasing aspect was associated with higher photo rates (estimate = 0.04, 95% *CI* = 0.01 to 0.07). Aspect was also positively associated with the probability of a zero count (estimate = 0.26, 95% *CI* = 0.02 to 0.50). For male bighorn sheep, three models had ≥ 0.05 weight (Table 3). An increase in slope was associated with higher photo rate (estimate = 0.37, 95% *CI* = 0.13 to 0.61). Springs were negatively associated with the probability of a zero count (estimate = -4.34, 95% *CI* = -7.16 to -1.52)

Elk

Of the 113 water sources included in our analyses for elk, 58 water sources had photos of elk, 33 had photos of females, and 47 had photos of males. For female elk, six models had ≥ 0.05 weight (Table 3). Presence of a fence was associated with higher photo rates (estimate 1.23, 95% *CI* = 0.45 to 2.01) and was in all top models. Decreasing density of woody species within

30 m of the water source was also associated with increasing photo rate (estimate = -2.55, 95% *CI* = -4.87 to -0.2). Fence presence was positively associated with the probability of a zero count (estimate = 1.11, 95% *CI* =0.15 to 2.07). Female elk used water sources with fences and with lower density of woody species.

For male elk, four models had ≥ 0.05 weight (Table 3). Wildlife water developments were associated with higher photo rates whereas springs were negatively associated with photo rates (estimate = -2.22, 95% *CI* = -3.85 to -0.60). Increasing proportion of tree cover at the middle scale (2,205 m) was associated with higher photo rates (estimate = 3.13, 95% *CI* = 1.75 to 4.50). Increasing slope at the small scale (400 m) was also associated with higher photo rates for male elk (estimate = 0.44, 95% *CI* = 0.22 to 0.65). Increasing obscurity measured 5 m from the water source was associated with higher photo rates (estimate 0.02, 95% *CI* = 0.01 to 0.03). Male elk used water sources with more tree cover, steeper slopes, and increased obscurity near the water source.

Mule Deer

Of the 226 water sources included in the mule deer analyses, 141 had photos of mule deer, 117 had photos of females, and 82 had photos of males. One model carried 0.99 of the weight for female mule deer (Table 3). A lower proportion of the surrounding area visible within 500 m of the water source was associated with higher photo counts of female deer (estimate = -4.06, 95% *CI* = -6.65 to -1.46). Curvature at the small scale (175 m) was positively associated with the probability of a zero count (estimate = 4.41, 95% *CI* = 0.59 to 8.22)

For male mule deer, three models had ≥ 0.05 weight (Table 3). Similar to female mule deer, a lower proportion of the surrounding area visible within 500 m of the water source was associated with higher photo counts of male deer (estimate = -3.37, 95% *CI* = -6.5 to -0.25. An increase in obscurity measured 75 m from the water source was also associated with increased photo counts (estimate = 0.02, 95% *CI* = 0.01 to 0.04). The presence of a fence was also associated with increased photo counts for male mule deer (estimate = 1.42, 95% *CI* = 0.6 to 2.24. Aspect at the small scale (175 m) was negatively associated with the probability of a zero count (estimate = -0.06, 95% *CI* = -0.12 to -0.01). Curvature at the large scale (1,755 m) was also negatively associated with the probability of a zero count (estimate = -65.86, 95% *CI* = -124.09 to -7.62)

Pronghorn

Of the 172 water sources included in the pronghorn analyses, 98 had photos of pronghorn, 70 with females and 93 with males. For female pronghorn, four models had ≥ 0.05 weight (Table 3). Ruggedness at the small scale (410 m) was negatively associated with increased photos (estimate = -1.72, 95% *CI* = -2.91 to -0.53). The proportion of tree cover around the water source at the small scale (410 m) was also negatively associated with increased photos for female pronghorn (estimate = -1.51, 95% *CI* = -2.84 to -0.17). The absence of a fence was associated with increased photos (estimate = -1.05, 95% *CI* = -1.79 to -0.31).

Three models carried ≥ 0.05 weight for male pronghorn (Table 3). Reduced obscurity measured 20 m from the water source was associated with more photos (estimate = -0.02, 95% *CI* = -0.03 to -0.01). Increased shrub height for shrubs less than 75 cm tall was also associated with increased photos (estimate = 0.01, 95% *CI* = 0 to 0.01). Similar to female pronghorn, the proportion of tree cover around the water source at the small scale (410 m) was negatively associated with increased photos (estimate = -1.91, 95% *CI* = -3.02 to -0.81). Slope at the small scale (410 m) was positively associated with the probability of a zero count (estimate = 0.31, 95% *CI* = 0.09 to 0.53

DISCUSSION

Within a species, males and females were influenced by similar features (e.g. more cover, less visibility) but at different scales and varying strengths (Fig. 2). Photo counts for mule deer were positively associated with less visibility of the surrounding area from the water source. Conversely, pronghorn photo counts were associated with decreased cover. These results for mule deer and pronghorn are similar to a previous study on water source use (Larsen et al. 2011) and may be indicative of differing strategies for predator avoidance between species and sexes.

The presence or absence of habitat or landscape features that affect susceptibility to predation may be associated with differing use of water sources among species and sexes. Indeed, predators in Hwange National Park, Zimbabwe changed behaviors when hunting near water holes (Valeix et al. 2010), and herbivores altered their use of water sources in response to predation risk (Valeix et al. 2009). Pronghorn tend to occupy areas that provide a vantage point to observe predators (O'Gara and Yoakum 2004) and photo counts of pronghorns in our study were associated with decreased cover. Conversely, mule deer photo counts were positively associated with cover suggesting increased predation risk in open habitats compared to edge and forested habitats (Altendorf et al. 2001).

Bighorn sheep females used steeper, more open terrain than males (Bleich et al. 1997) presumably to evade predators more easily. Our analysis method (i.e. including only water sources in the analysis for each species that were in clusters where that species was photographed), may have limited the strength that variables such as ruggedness, slope, distance to nearest outcrop, etc. had in bighorn sheep models, because water sources included in the bighorn analyses were located generally in steep, open terrain.

Many wildlife water developments in Utah were fenced to exclude non-target species (Larsen et al. 2011). Out of 231 water sources we sampled, 81 were fenced. Fence-related variables were in top models for female and male elk, male mule deer, and female pronghorn (Table 3). Female elk photo rate was positively associated with presence of a fence. Female elk may prefer fenced water sources to avoid competition with livestock. Male elk photo rate was positively associated with the area inside the fence suggesting preference for greater areas inside the fence, but minimally. Male mule deer photo counts were positively associated with the presence of a fence. These results differ from Larsen et al. (2011) where fences were negatively associated with mule deer photo counts. This difference may be because the cross members of most (52%) fenced sites in the mule deer analyses were logs or wood rails as opposed to barbed wire documented in Larsen et al. (2011), which may be associated with mule deer preference for more cover and less visibility of the surrounding area. Larsen et al. (2011) also combined male and female photo counts, possibly influencing results differently. Furthermore, we did not include any water sources in our analysis unless mule deer were detected within clusters, another difference between studies. Female pronghorn photo counts were negatively associated with presence of a fence. Fences can have a negative effect on pronghorns, causing entanglement, entrapment, and disruption in movement patterns (O'Gara and Yoakum 2004). Fences that allow pronghorns to pass under them and that encompass large (3 to 5 acre) areas can help mitigate the problems caused by fences (O'Gara and Yoakum 2004).

Males and females have different physiological requirements and often use different habitats. In our study, males and females of the same species generally had similar variables in top models, however at different strengths and scales. As availability of free water is reduced, the value of wildlife water developments as a mitigation strategy is likely to increase. Climate change will likely affect the quantity and quality of water available for wildlife in the future (Brown and Thorpe 2008, Whiting et al. 2010). Constructing wildlife water developments may help reduce the negative impacts of climate change to wildlife in arid regions, but only when units are located in areas likely to be used by target species.

MANAGEMENT IMPLICATIONS

We encourage managers to carefully consider where they construct wildlife water developments. Our results suggest slope and aspect are important for bighorn sheep. Presence of fence and lower shrub densities influenced female elk water use positively and increased obscurity, tree cover, and slope influenced male elk water use positively. Less visibility of the surrounding area was positively associated with female mule deer water use. Similarly, less visibility of the surrounding area, increased obscurity, and the presence of fence were positively associated with male mule deer use of water sources. Less tree cover, lower ruggedness, and absence of fence were associated with more female pronghorn photos and increased shrub height, reduced obscurity, and less tree cover were associated with more male pronghorn photos. Managers should take into consideration these results when placing wildlife water developments built to benefit these species, and when prioritizing natural water sources for preservation.

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Table 1. Variables used within an information theoretic approach to model water source use in Utah, USA, 2006, 2009-2011.

Variable name	Description
Site Features	
Site_Type	Type of water source (wildlife water development or spring)
FencePresence	Presence or absence of a fence surrounding the water source
Fence	Area inside the fence
FenceType	Type of fence surrounding the water source
FenceMinDist	Distance from the drinker to the nearest side of a fence
Outcrop	Distance to the nearest rocky outcrop or cliff
Predator_Cover	Distance to the nearest brush, tree, or rock large enough to conceal a cougar-sized animal
Robel5/10/15/20/50/75/100	Mean obscurity at 5, 10, 15, 20, 50, 75, and 100 meters in the 4 cardinal directions
Cover	Shrub density from measurements of any shrubs
ShrubHT	Mean shrub height from measurements of any shrubs
Cover75	Shrub density from measurements of shrubs ≥ 75 cm tall
ShrubHT75	Mean shrub height from measurements of shrubs ≥ 75 cm tall
Landscape Features	
Elev	Elevation at the water source
DomVegCode	Dominant vegetation at the water source site
D175/965/1755A	Mean aspect values for each buffer size, corresponding to mule deer home range
D175/965/1755C	Mean curvature values for each buffer size, corresponding to mule deer home range
D175/965/1755S	Mean slope values for each buffer size, corresponding to mule deer home range
D175/965/1755R	Mean ruggedness values for each buffer size, corresponding to mule deer home range
D175/965/1755Tree	Total number of pixels of tree cover for each buffer size, corresponding to mule deer home range
B245/1345/2445A	Mean aspect values for each buffer size, corresponding to bighorn sheep home range
B245/1345/2445C	Mean curvature values for each buffer size, corresponding to bighorn sheep home range
B245/1345/2445S	Mean slope values for each buffer size, corresponding to bighorn sheep home range
B245/1345/2445R	Mean ruggedness values for each buffer size, corresponding to bighorn sheep home range
B245/1345/2445Tree	Total number of pixels of tree cover for each buffer size, corresponding to bighorn sheep home range
E400/2205/4005A	Mean aspect values for each buffer size, corresponding to elk home range
E400/2205/4005C	Mean curvature values for each buffer size, corresponding to elk home range
E400/2205/4005S	Mean slope values for each buffer size, corresponding to elk home range
E400/2205/4005R	Mean ruggedness values for each buffer size, corresponding to elk home range
E400/2205/4005Tree	Total number of pixels of tree cover for each buffer size, corresponding to elk home range
P410/2250/4095A	Mean aspect values for each buffer size, corresponding to pronghorn home range

P410/2250/4095C	Mean curvature values for each buffer size, corresponding to pronghorn home range
P410/2250/4095S	Mean slope values for each buffer size, corresponding to pronghorn home range
P410/2250/4095R	Mean ruggedness values for each buffer size, corresponding to pronghorn home range
P410/2250/4095Tree	Total number of pixels of tree cover for each buffer size, corresponding to pronghorn home range
Visible	Number of pixels visible from the water source within a 500m radius
Water	Distance to the nearest water source
Other Variables	
Month_of_Max	Mean monthly maximum temperature for the month the water source was sampled
Month_of _Mean	Mean monthly mean temperature for the month the water source was sampled
Month_of_ppt	Total monthly precipitation (mm) for the month the water source was sampled
Month_Prior_Max	Mean monthly maximum temperature for the month prior to sampling
Month_Prior_Mean	Mean monthly mean temperature for the month prior to sampling
Month_Prior_ppt	Total monthly precipitation (mm) for the month prior to sampling
Predator	Total number of photos of bears, bobcats, cougars, coyotes, golden eagles, and humans

Table 2. AIC values for univariate models of ungulate use of water sources in Utah, USA, 2006, 2009-2011.

Covariate	**Bighorn Sheep Female**	**Bighorn Sheep Male**	**Elk Female**	**Elk Male**	**Mule Deer Female**	**Mule Deer Male**	**Pronghorn Female**	**Pronghorn Male**
Site Features								
FencePresence	309.0851	264.3501	617.2585	903.2211	1531.301	1112.423	1012.923	1172.874
Fence	309.0786	264.3539	617.9778	902.8161	1530.212	1113.693	1014.571	1173.564
FenceType					1522.951	1114.483		
FenceMinDist	309.0618	264.3829	618.05	903.1514	1530.597	1113.685	1014.414	1174.347
Robel5	307.7243	263.1565	621.651	902.8244	1531.406	1107.607	1010.187	1167.097
Robel10	307.7496	262.5433	621.0961	904.0848	1535.394	1111.424	1008.136	1158.071
Robel15	310.5233	264.6265	620.6443	918.7221	1534.182	1108.928	1005.537	1155.033
Robel20	307.8305	260.8487	628.8778	914.8239	1526.926	1102.416	1002.099	1150.761
Robel50	315.7243	262.118	626.9991	914.6916	1529.442	1104.398	1004.429	1157.622
Robel75	311.3435	265.0758	627.1858	912.2772	1530.19	1100.694	1004.779	1152.282
Robel100	311.1376	264.8233	622.9986	910.9785	1531.911	1104.909	1007.863	1162.254
Cover	311.4097	264.5191	627.515	918.6142	1535.284	1113.182	1005.111	1159.553
Cover75	310.5267	262.7505	623.1489	915.2248	1529.394	1110.521	1010.342	1164.865
ShrubHT	305.5998	263.1403	624.5425	914.7158	1530.929	1108.296	998.4362	1163.384
ShrubHT75	310.5578	258.4781	626.2554	917.2731	1526.784	1108.217	1010.587	1170.241
Landscape Features								
SS Aspect	311.5983	265.3828	626.2255	903.3034	1533.897	1101.954	1008.357	1170.854
MS Aspect	303.9727	262.4405	625.1549	918.7887	1536.312	1111.109	1016.735	1172.337
LS Aspect	308.0644	263.4621	625.9183	918.6869	1534.701	1108.634	1015.958	1168.62
SS Curvature	311.3884	265.1451	627.3066	917.285	1533.934	1106.791	1017.026	1174.964
MS Curvature	303.6938	261.6284	627.1674	914.1887	1536.151	1109.594	1010.807	1165.275
LS Curvature	310.074	263.7899	627.0568	913.3927	1536.529	1102.922	1015.902	1173.273
SS Slope	308.906	264.9901	627.3623	914.9254	1536.983	1112.765	998.2954	1161.145
MS Slope	306.9082	263.2564	624.5087	918.6991	1535.133	1107.563	1008.181	1168.538
LS Slope	309.3294	265.1268	622.2511	918.8844	1526.943	1109.93	1010.676	1172.097
SS Ruggedness	310.3585	264.7579	627.0908	915.169	1536.732	1111.066	998.016	1161.614
MS Ruggedness	307.3504	264.7669	624.3906	918.8623	1534.678	1105.829	1007.081	1172.266

LS Ruggedness	309.309	264.1942	626.5362	918.7867	1535.446	1108.731	1013.117	1174.751
SS Tree Cover	311.3321	263.6138	633.2622	903.3201	1522.982	1107.79	996.7535	1149.137
MS Tree Cover	310.713	264.7748	628.5816	892.2257	1530.048	1106.35	1002.334	1152.57
LS Tree Cover	311.2083	265.2922	634.2894	896.0531	1533.502	1098.896	1008.636	1159.642
Other Variables								
Month_of_Max	298.5769	253.5164	626.7599	915.5279	1519.463	1107.626	1031.812	1174.739
Month_Prior_Max	295.8469	252.326	625.4822	916.051	1531.615	1112.595	1016.746	1170.6
Month_of_Mean	301.4987	257.2883	625.9482	915.5143	1525.714	1107.145	1014.947	1174.414
Month_Prior_Mean	294.8402	250.8285	625.6412	916.5631	1527.319	1111.093	1017.071	1170.714
Month_of_ppt	311.278	265.1536	624.3726	912.7843	1527.714	1107.542	1015.98	1165.167
Month_Prior_ppt		275.1332	626.0293	904.6868	1534.538	1110.767	1027.18	1173.131

Table 3. Model structure, number of parameters (*K*), AICc, Δ AICc, model weight (w_i), and log likelihood (LL) for generalized linear models used to evaluate use of water sources by both sexes of four species of ungulates (bighorn sheep, elk, mule deer, and pronghorn) in relation to site, landscape, and other features in Utah during 2006 and from 2009 to 2011. Only models with ≥ 0.05 of the total weight were included in this table.

Model	*K*	AICc	ΔAICc	w_i	LL
Female Bighorn Sheep					
B1345A+Month_Prior_Mean	7	287.366	0.000	0.500	-135.410
Month_Prior_Mean+Predator	7	287.765	0.398	0.409	-135.610
Male Bighorn Sheep					
Site_Type+Predator	7	233.763	0.000	0.786	-108.609
Month_Prior_Mean+Predator	7	237.402	3.639	0.127	-110.428
B1345S+Elev+Month_Prior_Mean+Predator	11	238.625	4.862	0.069	-105.013
Female Elk					
Cover75+Fence Presence+Site_Type	9	616.203	0.000	0.216	-298.228
FencePresence+Elev+Water	9	616.239	0.036	0.212	-298.246
FencePresence+Month_of_Mean+Month_Prior_Max	9	616.889	0.686	0.153	-298.571
FencePresence+Water+Month_of_Mean	9	617.273	1.069	0.127	-298.763
FencePresence+Elev+Month_of_Mean	9	617.531	1.328	0.111	-298.892
FencePresence+Site_Type+Elev	9	618.372	2.168	0.073	-299.312
Male Elk					
E2205Tree+Fence+Month_Prior_ppt	9	880.240	0.000	0.739	-430.246
E2205Tree+Robel5+Month_Prior_ppt	9	884.703	4.463	0.079	-432.478
Robel5+Site_Type+Fence+Outcrop+Month_of_ppt+ Month_Prior_Max+Month_Prior_ppt	17	885.603	5.363	0.051	-422.580
E400S+Fence+Month_Prior_ppt	9	885.628	5.389	0.050	-432.940
Female Mule Deer					
Visible+D175C+D175Tree+Water+Elev+Month_of_Max+ Month_of_ppt+Month_Prior_Mean+Month_Prior_ppt	23	1487.855	0.000	0.990	-718.195
Male Mule Deer					
Visible+D175A+D1755C+D1755Tree+Elev	15	1084.697	0.000	0.611	-526.206
Visible+Robel75+FencePresence+D175A+D1755C+D1755Tree +Elev+Outcrop+ShrubHT75	23	1086.096	1.400	0.304	-517.316
Visible+D175A+D1755C+D1755Tree+Elev+Month_of_Mean+ Month_Prior_Mean+Month_Prior_ppt	21	1089.383	4.687	0.059	-521.427
Female Pronghorn					
FencePresence+P410Tree+Robel20+ShrubHT+Elev+Visible	17	991.688	0.000	0.231	-476.857
FencePresence+Robel20+ShrubHT	11	992.186	0.498	0.180	-484.268
P410R+FencePresence+P410Tree+Robel20+ShrubHT+Water	17	992.496	0.807	0.155	-477.261
P410R+FencePresence+P410Tree+Robel20+ShrubHT+P2250C	17	994.140	2.452	0.068	-478.083
Male Pronghorn					
P410Tree+ShrubHT+Robel20+Predator_Cover+Elev+P410S+ Month_of_ppt	19	1130.915	0.000	0.390	-543.958
P410Tree+ShrubHT+Robel20+Predator_Cover+Elev+Water+ Month_of_ppt	19	1131.342	0.427	0.315	-544.171
P410Tree+ShrubHT+Robel20+Predator_Cover+Elev+Water	17	1132.014	1.099	0.225	-547.020

Table 4. Model-averaged coefficients, standard errors, and 95% confidence intervals for parameters in top models (≥ 0.05 weight) of bighorn sheep photos collected at water sources in Utah during summer 2006 and 2009-2011).

Parameter	Estimate	SE	Lower 95% CI	Upper 95% CI
Female Bighorn Sheep Count				
Intercept	0.53	2.43	-4.23	5.30
B1345A	0.04	0.02	0.01	0.07
Month_Prior_Mean	0.13	0.06	0.01	0.26
Predator	0.00	0.00	0.00	0.01
Log(theta)	-0.31	0.34	-0.97	0.36
Female Bighorn Sheep Zero				
Intercept	-17.93	12.49	-42.40	6.55
B1345A	0.26	0.12	0.02	0.50
Month_Prior_Mean	-0.32	0.10	-0.52	-0.12
Predator	-0.06	0.03	-0.12	-0.01
Male Bighorn Sheep Count				
Intercept	5.57	0.55	4.49	6.65
Site_Type(Spring)	0.27	0.53	-0.77	1.30
Month_Prior_Mean	0.09	0.04	0.01	0.16
Predator	0.00	0.00	0.00	0.01
B1345S	0.37	0.12	0.13	0.61
Log(theta)	0.35	0.34	-0.31	1.01
Male Bighorn Sheep Zero				
Intercept	5.41	2.15	1.19	9.62
Site_Type(Spring)	-4.34	1.44	-7.16	-1.52
Month_Prior_Mean	-0.35	0.16	-0.67	-0.03
Predator	-0.10	0.04	-0.18	-0.03
Elev	0.00	0.00	-0.01	0.00
B1345S	0.14	0.16	-0.18	0.46

Table 5. Model-averaged coefficients, standard errors, and 95% confidence intervals for parameters in top models (≥ 0.05 weight) of elk photos collected at water sources in Utah during summer 2006 and 2009-2011).

Parameter	Estimate	SE	Lower 95% CI	Upper 95% CI
Female Elk Count				
Intercept	6.32	0.64	5.07	7.56
Site_Type(Spring)	-0.69	0.96	-2.56	1.19
FencePresence	1.23	0.40	0.45	2.01
Cover75	-2.55	1.18	-4.87	-0.23
Month_of_Mean	-0.14	0.04	-0.23	-0.05
Month_Prior_Max	0.05	0.06	-0.07	0.17
Log(theta)	-0.45	0.17	-0.78	-0.12
Female Elk Zero				
Intercept	1.21	0.51	0.20	2.22
Site_Type(Spring)	1.41	0.82	-0.20	3.02
FencePresence	1.11	0.49	0.15	2.07
Cover75	1.15	0.88	-0.58	2.89
Water	0.00	0.00	0.00	0.00
Month_of_Mean	-0.02	0.07	-0.16	0.11
Month_Prior_Max	0.12	0.07	-0.02	0.25
Male Elk Count				
Intercept	6.66	0.69	5.31	8.01
Site_Type(Spring)	-2.22	0.83	-3.85	-0.60
Robel5	0.02	0.01	0.01	0.03
Outcrop	0.00	0.00	0.00	0.00
E2205Tree	3.13	0.70	1.75	4.50
E400S	0.44	0.11	0.22	0.65
Month_Prior_Max	-0.25	0.08	-0.40	-0.09
Month_of_ppt	-0.02	0.02	-0.06	0.01
Month_Prior_ppt	-0.02	0.01	-0.03	0.00
Log(theta)	-0.33	0.15	-0.61	-0.05
Male Elk Zero				
Intercept	0.86	0.67	-0.45	2.17
Site_Type(Spring)	0.59	0.74	-0.85	2.04
Robel5	0.00	0.00	0.00	0.00
Outcrop	0.00	0.00	0.00	0.00
E2205Tree	-1.56	0.81	-3.15	0.04
E400S	0.06	0.11	-0.16	0.28
Month_Prior_Max	0.06	0.08	-0.11	0.22
Month_of_ppt	-0.04	0.02	-0.07	0.00
Month_Prior_ppt	0.03	0.01	0.01	0.05

Table 6. Model-averaged coefficients, standard errors, and 95% confidence intervals for parameters in top models (≥ 0.05 weight) of mule deer photos collected at water sources in Utah during summer 2006 and 2009-2011).

Parameter	Estimate	SE	Lower 95% CI	Upper 95% CI
Female Mule Deer Count				
Intercept	5.93	1.80	2.40	9.46
Duration	0.07	0.04	-0.01	0.15
D175C	-1.51	1.50	-4.44	1.42
D175Tree	-0.02	0.50	-0.99	0.95
Visible	-4.06	1.32	-6.65	-1.46
Elev	0.00	NA		
Water	0.00	0.00	0.00	0.00
Month_of_Max	-0.23	0.05	-0.33	-0.12
Month_of_ppt	-0.05	0.01	-0.07	-0.02
Month_Prior_Mean	0.12	0.05	0.02	0.22
Month_Prior_ppt	0.02	0.01	0.00	0.04
Log(theta)	-0.94	0.14	-1.22	-0.65
Female Mule Deer Zero				
Intercept	12.21	3.47	5.40	19.01
Duration	-0.06	0.04	-0.15	0.02
D175C	4.41	1.95	0.59	8.22
D175Tree	-1.17	0.68	-2.50	0.16
Visible	-1.31	1.81	-4.85	2.23
Elev	0.00	0.00	0.00	0.00
Water	0.00	0.00	0.00	0.00
Month_of_Max	-0.18	0.09	-0.36	-0.01
Month_of_ppt	0.03	0.02	0.00	0.07
Month_Prior_Mean	-0.13	0.06	-0.25	-0.01
Month_Prior_ppt	0.01	0.01	-0.01	0.04
Male Mule Deer Count			0.00	0.00
Intercept	6.33	5.01	-3.49	16.15
Duration	-0.02	0.04	-0.09	0.06
D175A	-0.02	0.03	-0.07	0.03
D1755C	-23.48	20.03	-62.73	15.78
D1755Tree	1.66	0.85	-0.01	3.32
Visible	-3.37	1.60	-6.50	-0.25
Outcrop	0.00	0.00	0.00	0.00
Robel75	0.02	0.01	0.01	0.04
ShrubHT75	0.00	0.00	0.00	0.00
FencePresence	1.42	0.42	0.60	2.24
Month_of_Mean	-0.18	0.07	-0.32	-0.04
Month_Prior_Mean	0.01	0.09	-0.16	0.19
Month_Prior_ppt	0.03	0.01	0.00	0.06
Log(theta)	-1.11	0.20	-1.49	-0.72
Male Mule Deer Zero				
Intercept	15.68	5.08	5.72	25.63
Duration	0.00	0.04	-0.07	0.08
D175A	-0.06	0.03	-0.12	-0.01
D1755C	-65.86	29.71	-124.09	-7.62
D1755Tree	-0.78	0.89	-2.52	0.97

Visible	-1.67	1.80	-5.21	1.86
Elev	0.00	0.00	0.00	0.00
Outcrop	0.00	0.00	0.00	0.00
Robel75	0.00	0.01	-0.01	0.02
ShrubHT75	0.00	0.00	0.00	0.00
FencePresence	-0.06	0.40	-0.84	0.72
Month_of_Mean	-0.18	0.10	-0.38	0.02
Month_Prior_Mean	0.01	0.08	-0.15	0.18
Month_Prior_ppt	0.03	0.02	-0.01	0.06

Table 7. Model-averaged coefficients, standard errors, and 95% confidence intervals for parameters in top models (≥ 0.05 weight) of pronghorn photos collected at water sources in Utah during summer 2006 and 2009-2011).

Parameter	Estimate	SE	Lower 95% CI	Upper 95% CI
Female Pronghorn Count				
Intercept	8.23	0.63	6.99	9.47
Duration	-0.05	0.02	-0.10	-0.01
Fence Presence	-1.05	0.38	-1.79	-0.31
Robel20	-0.02	0.01	-0.03	0.00
ShrubHT	-0.01	0.01	-0.02	0.00
P410Tree	-1.51	0.68	-2.84	-0.17
Visible	0.77	1.50	-2.17	3.71
P410R	-1.72	0.61	-2.91	-0.53
P2250C	-13.50	42.38	-96.56	69.56
Log(theta)	-0.58	0.12	-0.83	-0.34
Female Pronghorn Zero				
Intercept	-0.22	0.28	-0.78	0.34
Duration	-0.02	0.03	-0.09	0.04
Fence Presence	0.21	0.32	-0.42	0.85
Robel20	0.01	0.01	-0.01	0.02
ShrubHT	0.01	0.00	0.00	0.02
P410Tree	0.96	0.71	-0.43	2.35
Visible	-2.78	1.67	-6.05	0.49
P410R	0.43	0.67	-0.89	1.75
P2250C	10.56	39.18	-66.24	87.36
Male Pronghorn Count				
Intercept	5.60	0.47	4.68	6.52
Duration	-0.03	0.02	-0.06	0.01
Predator_Cover	0.00	0.00	0.00	0.00
Robel20	-0.02	0.01	-0.03	-0.01
ShrubHT	0.01	0.00	0.00	0.01
P410Tree	-1.91	0.56	-3.02	-0.81
Elev	0.00	0.00	0.00	0.00
Water	0.00	0.00	0.00	0.00
P410S	0.00	0.11	-0.22	0.22
Month_of_ppt	-0.02	0.01	-0.04	0.00
Theta(log)	-0.17	0.09	-0.34	0.01
Male Pronghorn Zero				
Intercept	-3.51			
Duration	-0.02	0.04	-0.09	0.05
Predator_Cover	0.00	0.00	0.00	0.00
Robel20	0.01	0.01	0.00	0.03
ShrubHT	0.01	0.00	0.00	0.01
P410Tree	0.38	0.78	-1.16	1.92
Water	0.00	0.00	0.00	0.00
P410S	0.31	0.11	0.09	0.53
Month_of_ppt	0.03	0.02	0.00	0.06

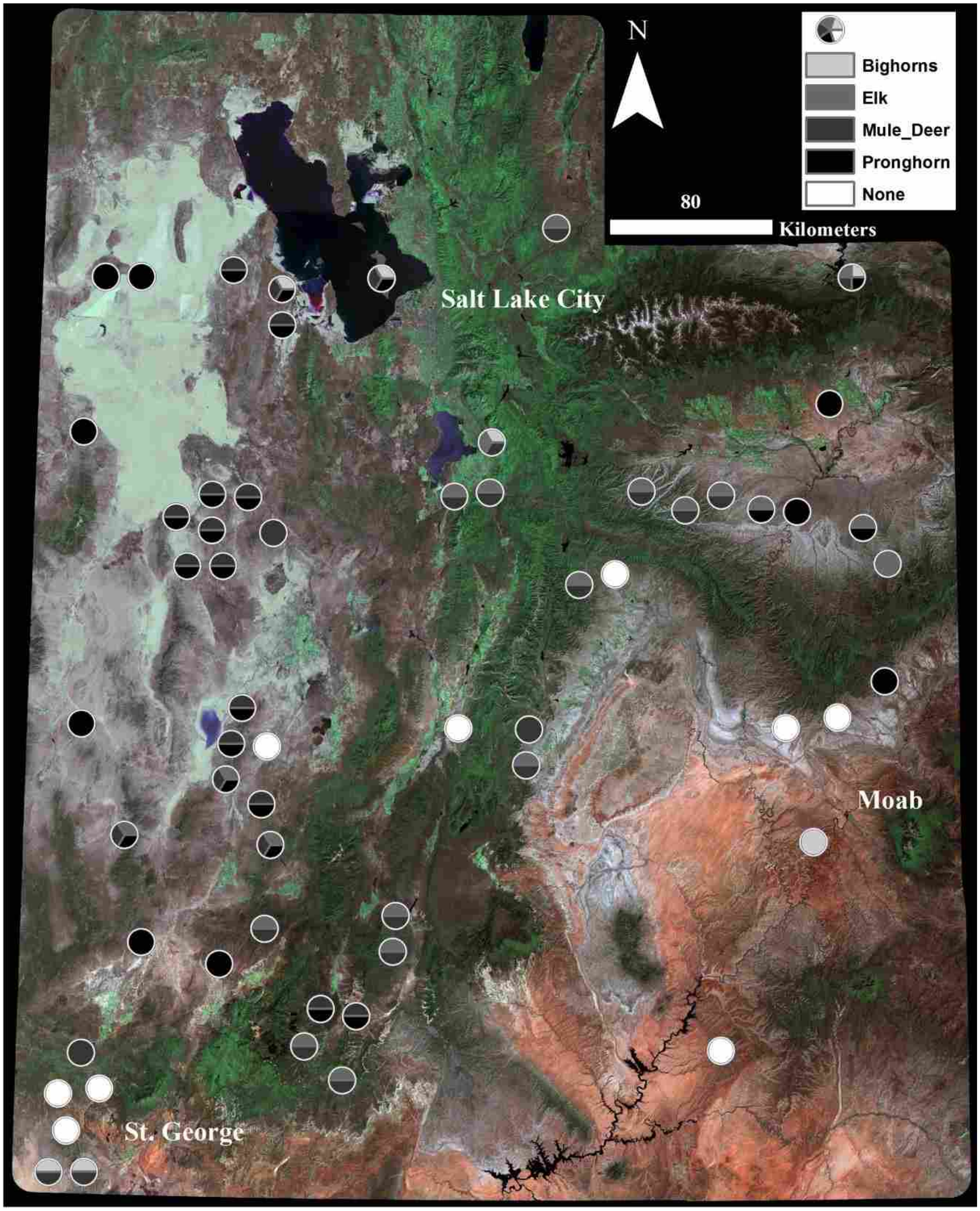

Figure 1. Locations of sampled water source clusters (3-12 water sources each) and presence of target species photographed in 2006 and from 2009 to 2011 in Utah, USA.

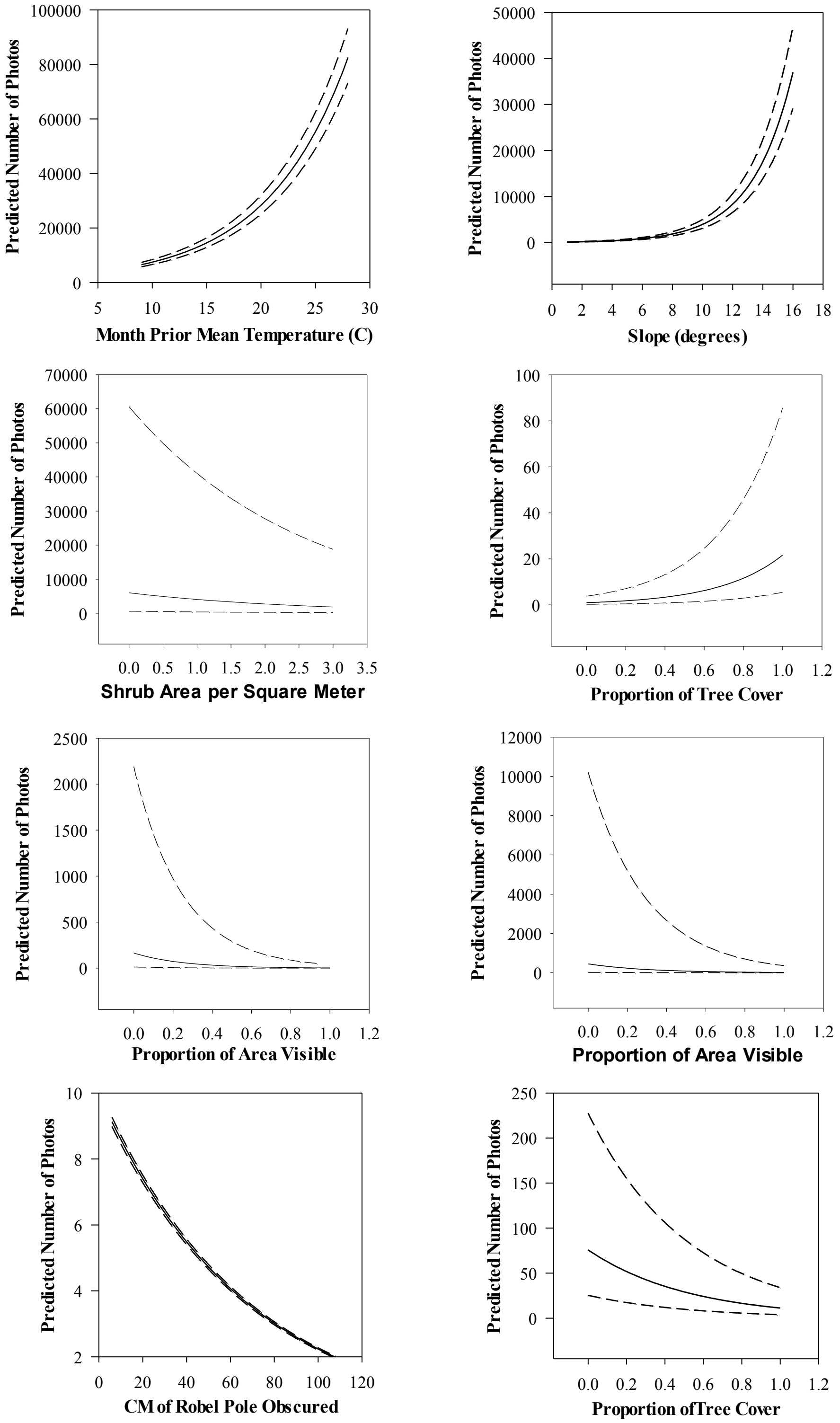

Figure 2. Selected covariates and predicted photo counts at water sources for female (left column) and male (right column) bighorn sheep (row 1), elk (row 2), mule deer (row 3) and pronghorn (row 4) from sampling in Utah, 2006 and 2009-2011.