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RESEARCH ARTICLE

Summer spatial patterning of chukars in relation to free water in western Utah

Randy T. Larsen · John A. Bissonette · Jerran T. Flinders · Mevin B. Hooten · Tammy L. Wilson

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Abstract Free water is considered important to wildlife in arid regions. In the western United States, thousands of water developments have been built to benefit wildlife in arid landscapes. Agencies and researchers have yet to clearly demonstrate their effectiveness. We combined a spatial analysis of summer chukar (*Alectoris chukar*) covey locations with dietary composition analysis in western Utah. Our specific objectives were to determine if chukars showed a spatial pattern that suggested association with free water in four study areas and to document summer dietary moisture content in relation to average distance from water. The observed data for the Cedar Mountains study area fell within the middle of the random mean distance to water distribution suggesting no association with free water. The observed mean distance to water for the other three areas was much closer than expected compared to a random spatial process, suggesting the importance of free water to these populations. Dietary moisture content of chukar food items from the Cedar Mountains (59%) was significantly greater ($P < 0.05$) than that of birds from Box Elder (44%) and Keg-Dugway (44%). Water developments on the Cedar Mountains are likely ineffective for chukars. Spatial patterns on the other areas, however, suggest association with free water and our results demonstrate the need for site-specific considerations. Researchers should be aware of the potential to satisfy water demand with pre-formed and metabolic water for a variety of species in studies that address the effects of wildlife water developments. We encourage incorporation of spatial structure in model error components in future ecological research.

Keywords Guzzler · Monte Carlo · Spatial pattern · Spatial structure · Water development

R. T. Larsen (✉)
Department of Plant and Wildlife Sciences, 407 WIDB, Brigham Young University, Provo, UT 84602, USA
e-mail: randy_larsen@byu.edu

J. A. Bissonette
United States Geological Survey, Utah Cooperative Fish and Wildlife Research Unit, Utah State University, 5290 Old Main Hill, Logan, UT 84322-5290, USA

J. T. Flinders
Department of Plant and Wildlife Sciences, 275 WIDB, Brigham Young University, Provo, UT 84602, USA

M. B. Hooten
Department of Mathematics and Statistics, Utah State University, 3900 Old Main Hill, Logan, UT 84322-3900, USA

T. L. Wilson
Department of Wildland Resources, Utah State University, 5230 Old Main Hill, Logan, UT 84322-5290, USA

Introduction

Available drinking water is considered an important habitat component for a host of wildlife species. Indeed, water was articulated as one of a limited number of fundamental wildlife needs as early as 1933 (Leopold 1933). This paradigm has led to large scale efforts designed to improve habitat in arid areas through the building and maintenance of wildlife water catchments (often termed guzzlers). Wildlife water developments come in many forms (see Fig. 1a, b for representative examples), but all operate on similar principles of capturing groundwater, rain, or snow melt; storing it, and providing drinking water to wildlife during at least part of the year. Use of guzzlers as a management tool began in the 1940s with quail in the southwestern United States (Glading 1947) and has continued to the present. The list of wildlife intended to benefit from water developments includes ungulates, small mammals, and bird species. Management of water resources is important given current and projected global water shortages—considered by some as the defining crisis of the 21st century (Pearce 2006). This crisis is due to reduced availability of drinking water for both humans and wildlife as a consequence of increasing global demand, disruptions in regional and global weather patterns, diversion of water resources for irrigation and industry, and drawdown of aquifers (Jackson et al. 2001).

Wildlife water developments are now considered a mitigation strategy to offset past or projected losses in water available to wildlife. In addition to mitigation, guzzlers are built to increase density, expand distribution, and influence movement patterns and habitat use of target species. Management agencies and private organizations have expended considerable resources on water development projects and ongoing programs or suggestions of such exist in many areas of the world (Borralho et al. 1998; Rosenstock et al. 1999). Nonetheless, and despite over 50 years as an active management tool, the effects of water developments on wildlife populations are poorly understood. More recently, water developments have been a source of controversy (Broyles 1995; Rosenstock et al. 1999; Krausman et al. 2006). The need for wildlife water developments has been questioned for species ranging from Gambel's quail

Fig. 1 **a** (*top*) and **b** (*bottom*) Showing examples of common water developments or guzzlers

(*Callipepla gambellii*; Brown et al. 1998) to bighorn sheep (*Ovis canadensis*; Broyles and Cutler 1999). Despite these questions and the general lack of evidence for effectiveness, water development has been a major management tool for several decades and is projected to become more frequently used as we attempt to manage wildlife in increasingly modified habitats.

Management of chukars (*Alectoris chukar*) provides a motivating example. Chukars have been widely introduced throughout the world. The most successful widespread introductions occurred in North America (Long 1981) where chukars now occupy roughly 252,800 square kilometers of habitat in eleven western states and one Canadian province (Christensen 1996). Habitat management for chukars has been limited to water development with particular emphasis placed on the installation of guzzlers to expand populations into new areas (Christensen 1970; Benolkin and Benolkin 1994). Nevada, for example, has installed at least 918 guzzlers specifically designed to benefit chukars (S. Espinosa, Nevada Department of Wildlife, personal communication).

Similar to most target species, this widespread management action has occurred with little evaluation (Krausman et al. 2006) of the impact of water availability at demographic or spatial levels. Physiological evidence from the laboratory suggests that chukars would not require free water in the spring or winter when metabolic or pre-formed water satisfies their needs (Alkon et al. 1982, 1985; Degen et al. 1983, 1984). While informative and focused on water balance, such results do not provide evidence from the field for managers concerned with the effects of wildlife water developments. High water content in the diet, for example, could reduce the need for drinking water and water developments even during summer months. The limited information from field studies on the response of chukars to guzzlers is equivocal (Messerli 1970; Shaw 1971) or anecdotal (Christensen 1954; Benolkin 1990).

Given estimated short average daily movements of approximately 280 meters and small home ranges <1 km^2 (Lindbloom 1998; Walter 2002) compared to the distribution of water sources in arid landscapes, we should expect chukars to demonstrate a spatial response to available free water if it is important to them. If a spatial response is not present, then other sources of water (preformed or metabolic) must satisfy chukar needs. Such a scenario would imply that water developments built for chukars are likely ineffective. We combined a spatial analysis of summer covey locations with dietary moisture evaluation. Our specific objectives were to determine if chukars showed a spatial pattern associated with free water and to document summer dietary moisture content in relation to average distance from water. We expected chukars that do not show a spatial response to available free water to have higher moisture content in their diet than those that do. The spatial relationship of chukars to water has never formally been evaluated despite the large scale installation of guzzlers and this information should prove beneficial to those interested in the influences of wildlife water developments.

Fig. 2 Map of four study areas in western Utah, USA

Methods

Study areas

We evaluated the spatial patterning of summer chukar coveys in relation to known water sources on study areas in western Utah (Fig. 2). All study areas are encompassed within the Great Basin physiographic region—characterized by roughly parallel mountain ranges separated by desert basins (Fenneman 1931), hot summers (Dice 1943), and low precipitation during all seasons (Thornthwaite 1931). Annual precipitation averages from 102 to 508 mm along an altitudinal gradient and daily summer high temperatures over 35°C are typical (Christensen 1996). Generalized vegetative communities found in the study areas include the following: Great Basin Xeric Mixed and Inter-Mountain Basins Sagebrush Shrubland, Great Basin Pinyon Juniper Woodland, Inter-Mountain Basins Mixed Salt Desert Scrub, Invasive Annual and Perennial Grassland, and Inter-Mountain Basins Semi-Desert Grassland (Lowry et al. 2005).

Spatial location sampling

We collected spatial locations (UTM coordinates) of chukar coveys from helicopter flight surveys and ground-based sampling from 2002 to 2007. We conducted helicopter surveys in August or September of each year. Surveys consisted of a low altitude and low speed flight across the survey area in a sinuous pattern. We attempted to cover the entire flight area without duplication. Upon detection, we recorded the spatial location (UTM coordinates) and number of birds observed per covey. We limited observations from ground-based sampling to those collected between July and September to coincide with the summer period of water use (Larsen et al. 2007). We collected these samples during the same 2002–2007 time frame and made significant effort not to double count coveys during the same day. Previous work (Walter 2002) suggested that 24 h was adequate (elimination of temporal autocorrelation) for independence in movement and home range analyses.

For each covey location, we calculated distance to nearest water source and distance to nearest water source likely to be used by chukars based on presence of shrub-canopy cover. Larsen et al. (2007) found chukars reluctant to use water sources in the study areas with <11% shrub canopy cover surrounding them. We therefore, categorized water sources as used or unused based on this previous work. We made distance measurements in ArcMap 9.2® using Hawth's Tools. We logarithmically transformed both distance measurements to correct for non-normality and used these for analysis, but report back-transformed values in the original scale for discussion and interpretation. All identified water sources were known to have free water available for drinking throughout the study.

Statistical analysis

A suite of spatial analysis tools exist to make inference regarding natural or physical processes that give rise to spatial point patterns. Prominent examples include intensity estimation, nearest neighbor methods, and the *K* or *L* function (Bailey and Gatrell 1995; Fortin and Dale 2005). The latter, in particular, allows for inference of clustering or regularity across distance scales by analysis of point patterns. Conventional application of these methods, however, generally requires complete observation of the point process. Although we gave our best effort to flush and count all coveys on helicopter flights, we cannot assume complete observation of the process—even for flight surveys. Some research suggests, for example, that low elevation flights rarely detect more than a third of an area's chukars (Stiver 1993). Consequently, we modified our approach by first conditioning on the location of chukar coveys and then measuring the distance to nearest water and distance to used water from that conditioned location. Such an approach is consistent with geo-statistical analyses and relaxes the assumption of complete observation thereby allowing for analysis of sampled points while accounting for non-independence in error terms.

Given the differences in sampling, we first compared mean distances to nearest water source and nearest water source likely to be used between sampling types (ground or air) for each study area. Given the spatial nature of our data and the likelihood of non-independence in errors, we estimated parameters associated with 2nd order spatial structure by visually inspecting variograms. We evaluated exponential, Gaussian, and spherical models and used Akaike's Information Criterion (AIC) to determine, within model types, whether allowing for a nugget effect (i.e., small scale variability) improved the fit (Akaike 1973). We then incorporated range, sill, and nugget parameters from the best model of spatial structure into a linear regression with dummy variables coded for observation type (ground or air). We used the generalized least squares (GLS) procedure in program R (R Development Core Team 2007) with Cressie weights (Cressie 1985) for the variance to account for non-independence in error terms based on observation proximity.

After determination of any differences in mean distance to water between sampling types for each site, we used a similar procedure to compare mean distances to water across sites. These regressions functioned as a *t*-test or analysis of variance (ANOVA) with corrected errors and allowed for evaluation of differences between sampling types, but also for robust (incorporation of spatial structure) estimation of mean distance to water for each site. Error terms need not be independent under this approach as non-independence, due to similar locations in space generating similar distances to water, can be modeled based on proximity of respective observations. For all null-hypothesis tests, we set $\alpha = 0.05$.

Simulations

To determine an expected random distance from water, we used Monte Carlo simulations to generate a distribution of mean distances to water for each site to compare with our observed data. We generated random points ($n =$ number of observed covey locations per site) within flight survey polygons using a random spatial process in program R. These random points represented locations where coveys were not associated with water or with other coveys and formed a basis for comparison. We calculated distance to nearest water for each of the points within the realization and then the mean distance to water from all points in a given set. We iterated this procedure 999 times for each of the study sites. We then plotted a histogram of mean distances to water for each area. We compared these mean distributions from the simulations with the mean values from the linear models representing the observed mean distances to water. We calculated one-sided Monte Carlo P-values for observed mean distances to water as the number of simulations $\leq$ or $\geq$ to the observed value divided by 1,000.

Dietary analysis

We asked hunters to save crops from chukars legally harvested before the end of September in the study areas. Additional chukars were collected with shotguns during July, August, and the first half of September under approval of the Utah Division of Wildlife Resources (Permit #COLL6160). Collection of crops occurred in all summer months and across three (Keg-Dugway), four (Box Elder), and five (Cedar Mountains) years. Chukar crops were placed in plastic bags, labeled with location & date, and frozen until analyzed. We sorted crop contents into component parts, weighed them on an electronic scale to the nearest 0.01 grams (wet mass), and then reweighed them (dry mass) following dehydration (Walter and Reese 2003). We judged crop contents as completely dehydrated when reductions in mass no longer occurred. Both frequency and aggregate dry mass data are reported with all information pooled within each study site to represent general summer diet. We considered the data too sparse to include differences by year. Food items found in <3.0% of crops and constituting <3.0% of dry mass are not reported (Walter and Reese 2003). Given percentage measures, we used the logit transformation and then an analysis of variance (ANOVA) on transformed values to compare dietary moisture content between sites. We evaluated assumptions of specific tests both graphically and numerically and report back-transformed values for discussion and interpretation. We obtained dietary samples for all sites except the Silver Island study area.

Results

We included 196 (Box Elder), 214 (Cedar Mountains), 114 (Keg-Dugway), and 38 (Silver Island) covey locations in spatial analysis and considered the data too sparse to evaluate year effects. To describe the error structure, we selected an exponential model for Box Elder and Keg-Dugway, whereas Gaussian models preformed better for the Cedar Mountains and Silver Island sites (Fig. 3). None of the linear models were significant ($P > 0.05$) in the first stage of analysis indicating no difference in estimated mean distance from water by observation type (air or ground) in each area. This finding allowed us to pool observations from different sampling types within each area. Once the data were pooled, an exponential model best fit the spatial structure and we used it in a linear model with dummy variables coded to study area to estimate mean distance to water by site.

Average distance to nearest water was 390 (Box Elder), 1,330 (Cedar Mountains), 623 (Keg-Dugway), and 1,664 (Silver Island) meters. Mean values from the Cedar Mountains and Silver Island were significantly different ($P < 0.02$) from Box Elder while Keg-Dugway ($P = 0.25$) was not. Three of the four observed mean distances were much closer than random points to water and outside the distribution of random mean distances ($P < 0.01$). The observed data value for the Cedar Mountains fell within the middle part of the random mean distances distribution ($P > 0.05$) which differed from the other sites (Fig. 4). After correcting for water source use based on shrub canopy cover (Larsen et al. 2007), the average distance to water did not change for Box Elder (390 m) or Silver Island (1,664 m). Keg-Dugway increased slightly to 632 m and the Cedar Mountains increased substantially to 3,051 m.

Mean dietary moisture content of chukars from the Cedar Mountains (59%; $n = 82$) was significantly greater ($P < 0.01$) than that of birds from Box Elder (44%; $n = 43$) or the Keg-Dugway (39%; $n = 10$) study area (Fig. 5). This difference was largely due to

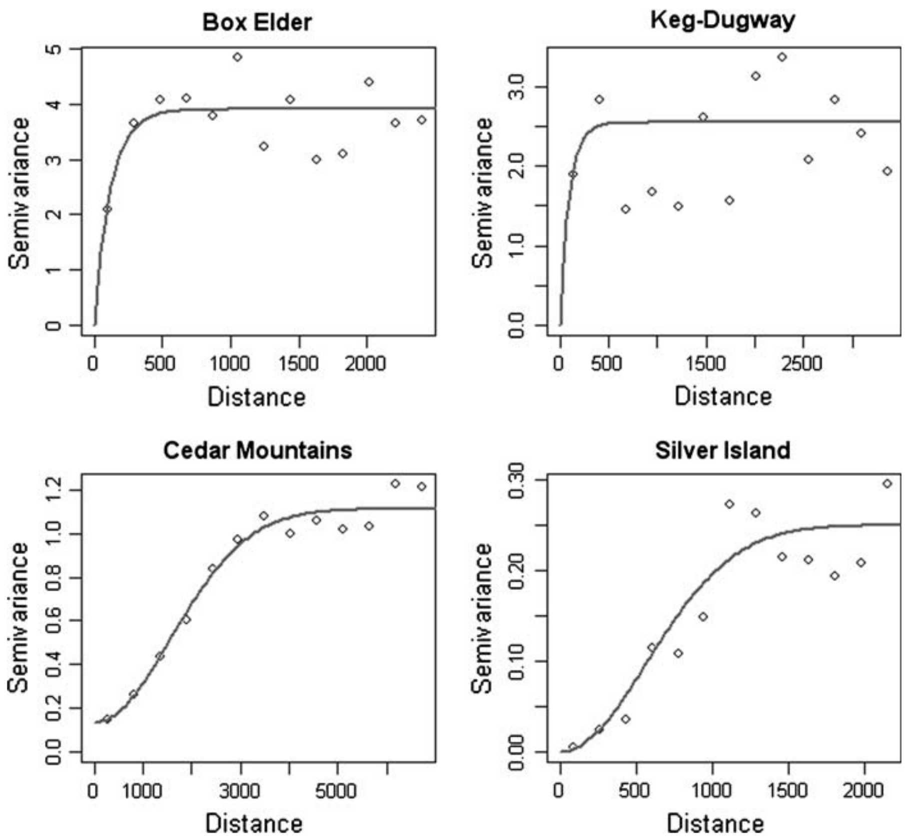

Fig. 3 Fitted variograms to describe spatial autocorrelation for each study area. We selected an exponential model for the Box Elder and Keg-Dugway sites compared to a Gaussian for the Cedar Mountains and Silver Island site

consumption of wild onion bulbs (*Allium* spp.), bulbous blue grass bulbs (*Poa bulbosa*), and hawksbeard seedheads (*Crepis* spp.) which contained between 55 and 75% moisture content. These plants were absent or present only in very limited frequencies and amounts in analyzed crops from birds on both the Keg-Dugway and Box Elder study areas (Table 1). Chukars in Box Elder and Keg-Dugway consumed a higher percentage of dry seeds such as Indian ricegrass and cheatgrass than Cedar Mountain birds.

Discussion

Adaptations to secure water are often most extreme in arid environments where water is usually limiting and available only sporadically (Serventy 1971). Both birds from Box Elder and Keg-Dugway averaged <625 meters from used sources of free water. Given reported (Lindbloom 1998; Walter 2000) short daily movements of approximately 280 m, these values suggest use of free water daily or perhaps every other day. On the other hand, birds on the Cedar Mountains and Silver Island site were on average >1,300 meters from water indicating less frequent use of water or perhaps greater movement to it. Small distances to water have been reported in California where 89% of chukar broods in Inyo-Mono and 95% in the Temblor Mountains were reported within ¼ mile (~400 m) of free water during the summer of 1955 (Harper et al. 1958). During a multiyear study in the early 1990s on the Trinity Mountains, Nevada the number of summer covey locations observed from low-elevation helicopter flights within this same distance averaged 85% (Stiver 1993). Similar small mean distances to water (328 and 285 m) were reported for red-legged partridge (*Alectoris rufa*) during two different summers in Spain leading Borralho et al. (1998) to suggest free water was important to this related species.

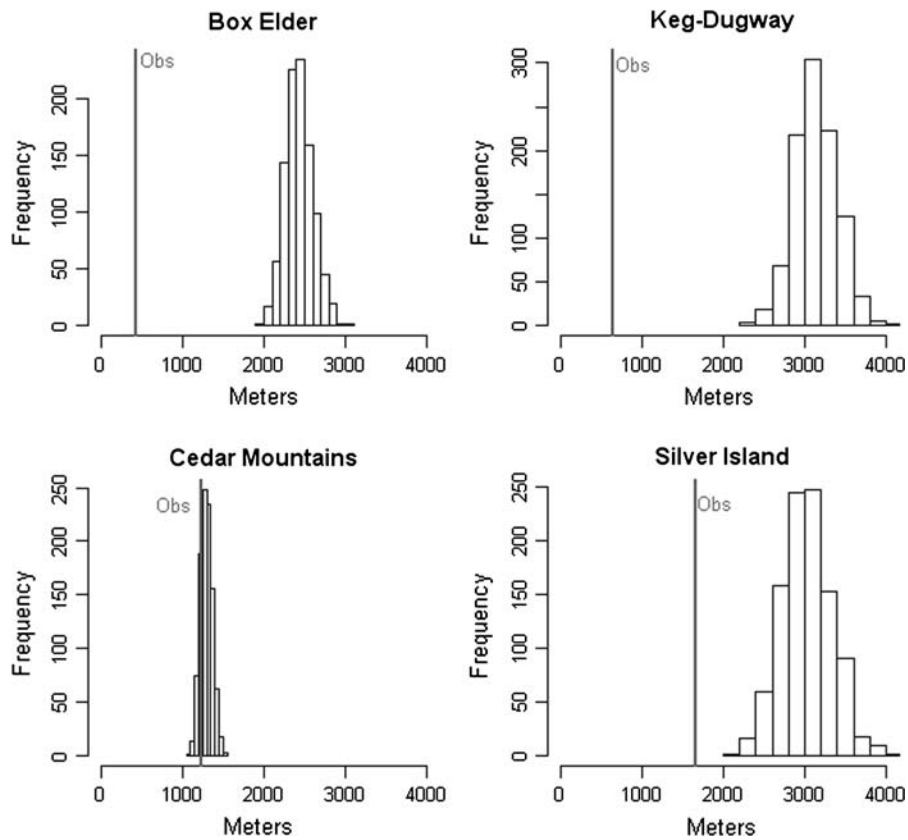

Fig. 4 Histograms of minimum mean distances from random points to nearest water with observed data shown as *grey line*

Chukar coveys in Box Elder, Keg-Dugway and Silver Island were closer to free water than expected under an assumption of completely spatial random (CSR) suggesting association with free water. Birds on the Cedar Mountains demonstrated the largest mean distance to used water sources (3,051 m) and average distance did not differ from random points (Fig. 4) suggesting no association with free water. Given estimates of chukar home range size at <1 km^2 (Lindbloom 1998; Walter 2002), most chukars on the Cedar Mountains likely do not have a source of free water within their home range. These chukars likely met water requirements without drinking free water during our study years.

It is possible that we missed a small spring or seep in our accounting of water sources. This possibility, however, is remote given annual flight surveys, the history of mining on the Cedar Mountains, and the importance of water resources to early explorers and settlers. Additionally, we and many volunteers spent considerable time during the course of the study on the Cedar Mountains as part of completed (Larsen et al. 2007) and ongoing research. All of these factors favor enumeration of available free water. Most importantly, however, chukars were widespread throughout the flight area on the Cedar Mountains and we would have needed to miss dozens of such springs or seeps in order to produce a pattern similar to the other three study areas.

Water developments targeting chukars on the Cedar Mountains ($n = 21$) are likely ineffective because chukar summer spatial distribution did not differ from random distribution despite the relatively small home ranges and daily movements of chukars. Our data suggest that chukars on the Cedar Mountains are able to eliminate the need for free water by use of metabolic and preformed water. This idea finds support in summer dietary analysis where birds from the Cedar Mountains had much greater moisture (59% compared to 44 or 39%) content in their diet than both Box Elder and Keg-Dugway (Table 1). Interestingly, this value of nearly 60% is close to the value of plant

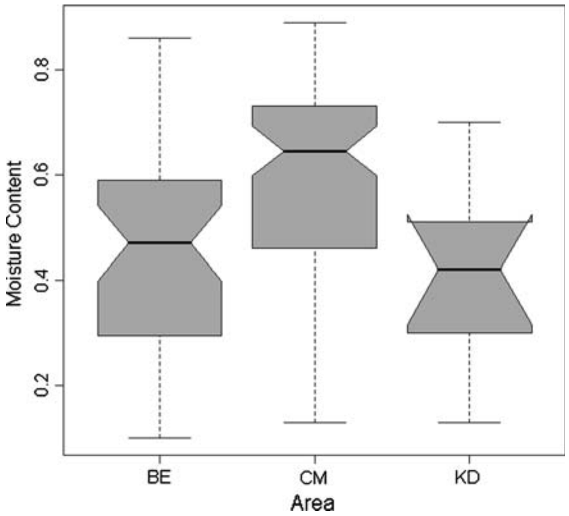

Fig. 5 Moisture content of summer food items from chukars collected during the summer (July–September)from three of the four study areas (no dietary information available from Silver Island study area) in western Utah between 2002 and 2007. Notches follow calculations from Chambers et al. 1983—no overlap represent strong evidence that medians of *different boxes* differ. *BE* Box elder ($n = 43$), *CM* cedar mountains ($n = 82$), *KD* Keg-Dugway ($n = 10$)

moisture projected by Nicolls (1961) associated with zero intensity of guzzler use. It is also the threshold suggested by Fischer et al. (1996) related to migration of greater sage grouse (*Centrocercus urophasianus*) between seasonal habitats.

Such results are not unique to the Cedar Mountains. Lindbloom (1998) reported daily movements of 280 m and spring-summer home range of nearly 40 ha (~633 m on a side if the area was square) for radio-marked chukars in Idaho. Despite these relatively small values, the average distance they found chukars from permanent water was 1,103 m and the closest observation was 157 m. Unmarked chukars were commonly associated with the river in his study area leading Lindbloom to suggest different population demes existed with some birds remaining at higher elevations away from the river throughout the summer. Lindbloom did not look at diet, but similar studies (Walter and Reese 2003; Churchwell and Ratti 2004) in nearby areas documented prairie starflower bulbils (*Lithophragma parviflorum*) in up to 46.4% of examined crops. Bulbils dominated samples from all years in both studies and presumably have high moisture content. They are likely found across the Idaho border where Lindbloom (1998) reported average distance to water of 1,103 m. Radio-marked chukars demonstrating relatively small movements in comparison to distance from water in southwestern Idaho may have fulfilled water requirements with preformed and metabolic water during Lindbloom's (1998) study years.

These results raise the question of whether or not consumption of succulent food items is learned behavior or simply a response to availability. Bulbous bluegrass, hawksbeard, and wild onion are widespread throughout the Great Basin and are present to some degree at all our study sites. This fact suggests learned behavior. Chukar distribution within the Great Basin is restricted to mountain islands separated by desert basins creating the opportunity for populations to evolve in isolation. It is possible that chukars from the Cedar Mountains have evolved behaviorally to use succulent plants such as bulbous bluegrass, tapertip hawksbeard, and wild onion. If learned behavior explains this difference, then great potential exists for transmitting this knowledge and behavior to other populations through translocation.

Alternatively, these differences could be explained by abundance of succulent plant sources. We did not measure food abundance across study areas and suggest that future work try to determine whether or not the patterns we observed represent learned behavior or simply response to availability. Interestingly, these three plants and other succulent food items show up in other Great Basin (Alcorn and Richardson 1951; Christensen 1952; Nygren 1963; Weaver and Haskell 1967; Walter and Reese 2003), western United States (Knight et al. 1979), and Eurasian (Dayani 1986; Naifa 1995) studies, but they typically occur in smaller frequencies or amounts than documented from the Cedar Mountains. Arthropods, which constitute a readily available source of pre-formed water (62%, see Table 1) are generally not taken in great abundance although occasional crop samples contain many (Christensen 1970, 1996; Zembal 1977). Young chicks consume more insects than older chicks and adults (Alcorn and Richardson 1951) perhaps limiting their need for free water during early months. By 2 months of age, however, plants—particularly plant seeds—comprise most of their diet (R. Larsen unpublished data) and chukars would need to augment their diet with succulent plant parts or free water. The late summer and early fall period is likely the time frame of greatest water need

Table 1 Estimated percent moisture content, frequency of occurrence, and percent total dry mass of chukar food items removed from crops during summer (July–September) in three areas of western Utah (total $n = 135$)

Crop item[a]	Scientific name	Moisture (%)[b]	Box elder ($n = 43$)		Cedar Mtns. ($n = 82$)		Keg-Dugway ($n = 10$)	
		Freq (%)	Freq (%)	Dry mass (%)	Freq (%)	Dry mass (%)	Freq (%)	Dry mass (%)
Hawksbeard seedheads	*Crepis acuminata*	72.5	2.3	0.1	69.5	50.5	0.0	0.0
Plant leaves	Various	70.0	51.2	4.0	30.5	1.6	50.0	0.3
Onion bulbs	*Allium* sp.	62.5	0.0	0.0	13.4	3.3	0.0	0.0
Arthropods	Arthropoda spp.	62.0	34.9	5.0	30.5	2.2	70.0	12.1
Other roots	n/a	60.1	4.7	0.4	2.4	0.0	10.0	0.0
Other seeds	n/a	58.7	7.0	8.7	7.3	0.7	20.0	0.1
Bulbous bluegrass bulbs	*Poa bulbosa*	55.2	7.0	0.3	18.3	1.6	10.0	0.6
Sage brush galls	*Artemisia* sp.	54.7	11.6	0.9	0.0	0.0	20.0	2.7
Insect eggs	n/a	50.0	9.3	0.1	0.0	0.0	0.0	0.0
Cheatgrass seeds	*Bromus tectorum*	39.1	88.4	44.3	65.9	25.8	90.0	47.1
Rodent feces	n/a	38.2	0.0	0.0	15.9	0.8	0.0	0.0
Unidentified	n/a	29.4	14.0	0.4	7.3	2.2	10.0	0.0
Red-stem filaree seeds	*Erodium cicutarium*	28.8	11.6	2.2	3.7	1.2	30.0	6.4
Spurge seeds	*Euphorbia* sp.	28.4	4.7	0.5	4.9	1.3	0.0	0.0
Stickseed	*Hackelia* sp.	27.7	2.3	0.0	0.0	0.0	20.0	0.1
Ricegrass seeds	*Achnatherum hymenoides*	22.6	60.5	31.1	19.5	4.1	70.0	26.5
Needlegrass seeds	*Hesperostipa comata*	13.6	2.3	0.0	1.2	0.1	20.0	0.1
Sunflower seeds	*Helianthus annus*	7.0	0.0	0.0	7.3	0.6	0.0	0.0
Grit	n/a	4.7	55.8	1.1	34.1	1.0	70.0	4.1
Lead	n/a	2.6	9.0	1.0	10.0	0.0	0.0	0.0
Feathers	n/a	–	4.7	0.0	1.2	0.0	0.0	0.0

Collection of crops occurred in 3 (2004–2006), 4 (2003–2006), and 6 (2002–2007) years for Keg-Dugway, Box Elder, and Cedar Mountains, respectively

[a] Only items occurring in >3.0% of sample or constituting of >3.0% total dry mass included

[b] Moisture content of removed food items

based on temperature and precipitation regimes in the Great Basin and corresponds to the period of greatest water use (Larsen et al. 2007).

We encourage further consideration of spatial structure in ecological questions. Spatial structure in model error has largely been ignored in much of the wildlife literature despite the potential for erroneous inference without its consideration. The theory and software are relatively well developed and all wildlife-habitat questions involve space and likely 2nd order spatial structure. Our approach is an alternative to use of spatial point process analyses such as the *K* or *L* functions that require complete observation of the point process.

Our results highlight the need for site specific information both for research addressing effects of wildlife water developments, but also management actions designed to benefit wildlife. We should not be surprised at different results from different places for even the same species. Perhaps some of the recent controversy (Broyles 1995, 1997; Rosenstock et al. 1999; Krausman et al. 2006) and debate concerning the effects of wildlife water developments can be explained by similar scenarios. Visits to water constitute a spatially and often temporally patterned activity which creates risk for prey species. Additionally, free water is limited and available sporadically in arid environments. Both factors create selective pressures to meet water requirements with pre-formed or metabolic water. Our data demonstrate that chukars on the Cedar Mountains did not differ in their spatial arrangement with respect to water from a random process, presumably due to use of succulent plant sources. Chukars from the other three areas did, however, show preference for areas near water. Water developments on the Cedar Mountains are likely ineffective and unlikely to benefit chukars. Guzzlers in the other three areas, however, may benefit chukars and further research in areas where target species demonstrate a spatial response to available free water is warranted.

We note with caution, however, that a spatial association with available free water is suggestive of importance, but does not provide evidence that additional free water influences important vital rates such as survival or reproduction. Such information is best obtained from a controlled experiment where manipulation of available water occurs. Cain III et al. (2008) provide an example of a removal study for bighorn sheep. Our results suggest that any similar effort for chukars should be conducted in an area where they show a spatial association with available free water. We encourage further efforts to address issues related to the controversy surrounding wildlife water developments.

As we attempt to manage wildlife in increasingly modified habitats while facing the brunt of a water crisis for both humans and wildlife (Pearce 2006), wildlife water developments remain a viable and important conservation option. Desired results, however, will only be achieved after considering species-specific and site-specific abilities to meet water requirements through pre-formed and metabolic water. If anything, future efforts to evaluate the effects of wildlife water developments or to benefit wildlife through provisioning of additional free-water should be made carefully after consideration of such possibilities.

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