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Ecology of Gambel's Quail (*Callipepla gambelii*) in Relation to Water and Fire in Utah's Mojave Desert

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and Fire in Utah's Mojave Desert

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ABSTRACT

Ecology of Gambel's Quail (*Callipepla gambelii*) in Relation to Water
and Fire in Utah's Mojave Desert

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The efficacy of providing water sources in desert ecosystems to enhance wildlife populations and their distribution continues to be debated among wildlife managers. Some argue wildlife water developments provide a direct benefit to numerous species, while others point to the potential that wildlife water developments alter competition or predation dynamics and disrupt native communities. Additionally, some have argued that the availability of water may become more important to wildlife in the face of vegetative changes associated with expansive fire and conversion of shrub or forest lands to grasslands which alters the thermal landscape available to animals. I evaluated the influence of free water and expansive fire on aspects of the ecology (habitat selection, space use and survival) of Gambel's quail (*Callipepla gambelii*) in the Mojave Desert of southwestern Washington County, Utah, USA. I attached radio-transmitters to a total of 206 quail (74 adult males, 67 adult females, and 65 juvenile males and females) and monitored them from 2010 – 2013. For chapter one of my thesis, I evaluated the response of marked quail to removal of access to water in a before-after controlled impact (BACI) design. I found little influence of water removal on survival as models with this effect received little to no support and overlap in confidence intervals occurred between treatment and reference groups. Likewise, the distance from the center of the summer home range to the nearest water source did not differ by year ($F = 1.63$; $P = 0.19$) or treatment (removal of water) ($F = 0.89$; $P = 0.35$) and pairwise comparisons of distances for the treatment by year interaction were not significant ($P > 0.05$ in all cases). For size of home range area, however, I found strong effects for year ($F = 3.07$; $P = 0.03$), treatment ($F = 4.67$; $P = 0.03$), and their interaction ($F = 7.61$; $P = 0.01$). Mean home range size for quail was 6.10 and 1.63 km^2 for animals in the reference area during treatment years (2012 and 2013) compared to 5.07 and 8.99 km^2 for quail in the treatment area during 2012 and 2013, respectively. Removal of water influenced size of summer home ranges, but not the location of the summer home range or survival rates. I hypothesize that removal of access to free water required quail in the treatment area to expand their space use patterns in 2013 in order to satisfy water demands via pre-formed water. For chapter two of my thesis, I evaluated habitat selection of Gambel's quail in relation to vegetation type, topographic features, water, and recent (4-7 years) expansive fire. Gambel's quail selected areas of decreased roughness which were closer to water and fire boundaries than random locations. I found that quail preferred moderate (< 10 degrees) hillsides and ravine bottoms. I found no evidence that quail avoided the burned areas within their home ranges and 80% of their telemetry points were <500 meters from a burn edge. The Beaver Dam slope topography strongly influenced habitat selection for Gambel's quail and they showed strong selection for water sources during summer months. These data also suggest that wildfires have had limited impact on habitat selection by this species, four to seven years later.

Keywords: Gambel's quail, water, fire, radio-transmitters, Mojave Desert

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CHAPTER 1

INFLUENCE OF FREE WATER ON GAMBEL'S QUAIL (*CALLIPEPLA GAMBELII*) IN SOUTHWESTERN UTAH

ABSTRACT

The efficacy of providing man-made sources of water in desert ecosystems to enhance wildlife populations and their distribution continues to be debated amongst wildlife managers. Some argue wildlife water developments provide a direct benefit to numerous species, while others point to the potential of water developments to disrupt native communities by altering competition or predation dynamics. I evaluated the influence of water on space use and survival of Gambel's quail (*Callipepla gambelii*) in the Mojave Desert of southwestern Washington County, Utah, USA. I captured and marked quail with radio-transmitters and then monitored their response to removal of access to water in a before-after controlled impact (BACI) design. A total of 206 quail, 74 adult males, 67 adult females, and 65 juvenile males and females were captured and radio-marked during the four year study from 2010 – 2013. I found little influence of removal of water on survival of quail as models with this effect received little to no support and large overlap in confidence intervals around survival estimates occurred between treatment and reference groups. Likewise, the distance from the center of the summer home range to the nearest water source did not differ by year ($F = 1.63$; $P = 0.19$) or treatment (removal of water) ($F = 0.89$; $P = 0.35$) and pairwise comparisons of distances for the treatment by year interaction were not significant ($P > 0.05$ in all cases). For size of home range area, however, I found strong effects for year ($F = 3.07$; $P = 0.03$), treatment ($F = 4.67$; $P = 0.03$), and their interaction ($F = 7.61$; $P = 0.01$). Mean home range size for quail was 6.10 and 1.63 km^2 for animals in the

reference area during treatment years (2012 and 2013) compared to 5.07 and 8.99 km^2 for quail in the treatment area during 2012 and 2013, respectively. Removal of water influenced size of summer home ranges, but not the location of the summer home range or survival rates. I hypothesize that removal of access to free water required quail in the treatment area to expand their space use patterns in 2013 in order to satisfy water demands via pre-formed water.

INTRODUCTION

One third of the earth's land mass is classified as hot/dry desert biome with very low precipitation and high temperatures (Oliver 2005). Animals survive in these arid regions due to adaptations that help them conserve water and minimize heat stress. These adaptations allow some animals to meet water demands by using water obtained from metabolic processes (metabolic water) or in food (preformed water). The Kangaroo rat (*Dipodomys* sp.), for example, has specialized kidneys which use metabolic water so efficiently that urine is abnormally concentrated (Denny 2012). The water economy of this species is so effective, they do not require free water despite a diet of relatively dry seeds. Greater roadrunners (*Geococcyx californianus*), on the other hand, satisfy water demands with a diet consisting of small animals high in preformed water. Their special nasal glands also excrete salt which helps with water balance (Hughes 2011). Amphibians such as the Couch's spadefoot toad (*Scaphiopus couchii*), enter estivation during periods of excessive drought and heat (Hickman and Roberts 1995). These and other adaptations allow desert animals to persist in arid regions with limited availability of free water.

For some species, the lack of free or drinking water can be a limiting factor (Guillion 1960, Glenn and Nager 2005). As a result, wildlife managers have installed hundreds of wildlife water catchments (Nevada Division of Wildlife 1999) throughout arid regions in the Great Basin, Mojave, and Sonoran deserts of North America. These water features capture precipitation in the form of rain and snowmelt and retain the water for use by wildlife during dry periods (Johnsgaard, 1973, Rosenstock, 1999, Hungerford, 1960). The continuing practice of providing artificial or man-made sources of water in deserts is an ongoing controversial issue because the expected increase and distribution of wildlife populations have not always occurred (Ohmart et al. 1988). Some wildlife managers suggest that water simply concentrates animals and may have little effect on reproductive success or survival (Gallizioli 1961). Others argue that wildlife water developments may disrupt native communities by altering competition or predation dynamics (Broyles 1995, Rosenstock et al. 1999).

Water catchments, also known as guzzlers, were developed by resource managers initially for Gambel's quail (*Callipepla gambelii*) in the southwestern US in the 1940s (Glading 1943, 1947). The guzzlers were expected to increase populations, expand distribution, and mitigate effects of drought conditions when water might be unavailable for this species first described by Colonel William Gambel in 1841 (Brown 1998). Water development for Gambel's quail is controversial because this species may not even need free water (Vorhies 1928, Leopold 1933, Gorsuch 1934, Krausman et al. 2006, Rosenstock et al. 1999, Krausman et al. 2006, O'Brien et al. 2006, Guillion 1960). Survey data suggest that Gambel's quail are associated with water sources during summer months, but few studies have addressed the effects of available water on populations (Bock 2015). Thus, quail might show a behavioral response, but water may not influence their survival (Tanner 2015).

The objective of my study was to determine the influence of water on space use and survival of Gambel's quail. I conducted an experiment by removing access to free water for radio-marked Gambel's quail. I hypothesized that "if" Gambel's quail required free water to live, then they would demonstrate lower survival when access to water was removed, or, they would alter space use patterns and move to another water source where access to this resource remained.

METHODS

Study Area

I conducted my research at the northern extent of the Gambel's quail range in the Mojave Desert of southwestern Utah (Johnsgaard 1973). The study area is approximately 50 km west of St. George, Washington County, Utah, USA and has characteristically low humidity and clear skies throughout the year (Figure 2). Temperature and precipitation data was obtained from the Federal Weather Service, Las Vegas, Nevada, which was collected from Brigham Young University's Lytle Ranch Nature Preserve weather station. The Lytle Ranch is located at the northwestern edge of my study area. The mean high temperature for the four summers, May through September 2010 – 2013, was 43.9 degrees C and the mean low was 4.4 degrees C. (Table 1). Precipitation, mainly from thunderstorms, averaged 60.5 mm for the 4 summers. The mean annual precipitation from 1989 until 2010 was 248.67 mm (xmacris.rcc-acis.org) and annual mean precipitation during my study years ranged from 153.9 mm to 425.2 mm (Table 2).

The topography in the study area consisted of descending ridges and washes originating at the 2042 m summit of the Beaver Dam Mountains and terminating at the lowest elevation (680 m) in Utah in the Beaver Dam wash along the Utah-Nevada border. These lands were administered by the Bureau of Land Management (BLM) and included the Woodbury Natural Study area (BLM 2014). The predominant native vegetation was creosote (*Larrea tridentata*) and shadscale (*Atriplex confertifolia)* intermingled with Joshua trees (*Yucca brevifolia*) along with a variety of desert shrubs including black brush (*Coleogyne ramosissima*), desert almond (*Prunus fasciculata*) and cholla cactus (*Cylindropuntia fulgida*). Invasive tamarisk (*Tamarix chinensis*) was an indicator of moist soils and springs. In 2005 and 2006, an estimated 50% of this area was burned by extensive wild fires that drastically altered the vegetative community. Burned areas were dominated by invasive grasses such as red brome (*Bromus rubens*) and cheatgrass (*Bromus tectorum*) and contained fewer shrubs—particularly blackbrush.

Capture and Radio-marking

I assessed space use and survival of Gambel's quail using radio telemetry, a resource not available to previous researchers because the transmitters were too large and have only recently been miniaturized such that the overall weight is suitable for Gambel's quail. My assessment occurred during the summer months from May through September, approximately 20 weeks, for four years (2010-2013), with the first 2 years as reference prior to implementation of a water removal treatment. To determine the influence of free water on Gambel's quail, I selected four upland game water catchments which were known to have historic use by populations of quail (Nish 1965).

I trapped quail beginning in mid-May and traps were checked at 10:00, 14:00, 18:00 and 21:00 hours. I constructed traps by using 2.5 cm poultry netting and structurally supportive 2.5 cm by 5.1 cm welded wire fence materials which enclosed a 4 to 5 m^2 area around the catchment. Funnel openings, 10 cm diameter at the small end, allowed easy entry into the trap and prevented quail from escaping. A side catchment cage facilitated easy removal of captured birds (Figure

1). Trapping ended by mid-July (sometimes earlier) of each year when the desired sample size of 30 birds was reached or repetitive captures made the effort no longer feasible.

According to accepted guidelines (Gaunt 1999), tracking devices should not exceed 5% of the animal's live weight so juvenile quail >80 g would meet those standards for the 4 gm transmitter. As I handled the juveniles, however, I chose to only collar birds > 110 grams. The sex of each bird was noted from their distinctive plumage and weight was measured in grams using a hand held Pesola spring scale with 300 gram capacity in two gram increments. I estimated weight to one gram. I placed each quail in a cloth bag and attached it to the clip on the scale for weighing.

Each captured quail was fitted with a permanent aluminum band on the right tarsus and a colored plastic band on the left tarsus. I attached an avian necklace transmitter to individuals over 110 grams, series A3900 from Advanced Telemetry Systems (ATS) with a 221 day battery capacity at 35 pulses per minute, 15 ms pulse width. I used a 52 mm wire cable with protective rubber tubing secured by metal clips and provided a proper fit around the bird's neck. When a transmitter remained motionless for eight hours, an increased pulse rate indicated "mortality mode". I used a telemetry receiver (Model R-1000 from Communications Specialists, Orange California, USA) and dual Yagi antenna to track and relocate marked quail by homing into radio signals. Quail locations were recorded using a global positioning system (GPS) Garmin Etrex series hand held device and coordinate readings set in Universal Traverse Mercator (UTM). Each bird was located three to four times per week randomly throughout daylight hours until the end of August, after which I located the birds biweekly until September 30.

For the water removal experiment, I selected a site where I collared 30 birds in 2010 and 36 birds in 2011. The water was removed at this guzzler when trapping ended in 2012 by using a hand held pump made by Valencia Pipe Company, VPC Pump-A-Way pump (available at Home Depot). To further prevent access to water from subsequent thunderstorms, I placed poultry netting over the catchment basin associated with this water development. Approval for capture, handling, and monitoring of Gambel's quail was provided by Brigham Young University's Institutional Animal Care and Use Committee (Protocol #100604) and the Utah Division of Wildlife Resources (COR #5BAND8464).

Space Use

Using ArcGIS and Spatial Analyst tools (ESRI, Environmental Systems Research Incorporated, Redlands California, USA), I calculated home range sizes in square meters as well as the spatial location of centroids for 95% fixed kernel density estimates (KDE) (Worton 1989). I limited this analysis to quail with ≥ 15 GPS locations because area of estimates of summer space use appeared to reach an asymptote at 15. I examined home ranges for each bird in each of the 4 years, and those birds before and after water removal. Kernel-based methods use a utilization distribution and have the potential to accurately estimate home range sizes of multiple shapes, given that the smoothing parameter is selected properly (Seaman and Powell 1996). In order to avoid under smoothing or over smoothing of the estimated home ranges, I selected the smoothing parameter (h) using an ad-hoc method (Kie 2013).

Once estimates of space use size were completed for each year, I made comparisons between years and in relation to removal of access to free water (Beyer, 2004) using an ANOVA analysis. In order to determine if the location of summer space use areas shifted in relation to removal of water, I measured the distance of the centroid of each KDE from the water source where access was removed in each year. I then compared those distances before and after water removal using a paired *t*-test. I used program R (R Version 2.14.0, http://cran.stat.ucla.edu, accessed 2012) for all statistical tests involving space use and set alpha (α) = 0.05 (R Development Core Team 2011).

Survival Analyses

I used known-fate models in Program MARK 6.1 (White and Burnham 1999, Franklin 2001) and model selection (Burnham and Anderson 2002) to evaluate hypotheses regarding survival of Gambel's quail in relation to removal of access to drinking water. I used the staggered entry method because of the small sample size and input of birds across up to 11 weeks of trapping. First, I formatted encounter histories into weekly intervals beginning 25 July 2010 through 22 July 2012. I formatted study site (water removal or reference area) as a grouping variable in the input file and included age, mass, and sex as individual covariates in my models (Bailey 1968). I followed standard model-selection protocol and first made a list of *a priori* candidate models incorporating year, site, and individual covariates. My list of *a priori* models included several models to capture a difference in survival related to removal of access to free water. These models included several with linear or quadratic trends in relation to the timing of removal of access to water.

I used Akaike's Information Criterion adjusted for small sample sizes (AICc) and AICc model weight (w_i) to rank models and evaluate relative support for candidate hypotheses (Akaike 1973, Lebreton et al. 1992, Buckland et al. 1997, Burnham and Anderson 2002). In the presence of model-selection uncertainty, I obtained model-averaged estimates of survival for the various time periods and influences (Burnham and Anderson 2002).

I categorized quail mortalities in the field as avian, mammal, or human/hunter caused. Possible avian predators, all of which were personally observed in my study area, included common raven (*Corvus corax*), cooper's hawk (*Accipiter cooperii*), great-horned owl (*Bubo virginianus*), northern goshawk (*Accipiter gentilis*), prairie falcon (*Falco mexicanus*), peregrine falcon (*Falco peregrinus*), red-tailed hawk (*Buteo jamaicensis*), and greater road runner (*Geococcyx californianus*). Mammalian predators photographed by remote cameras at the guzzlers where I trapped included American badger (*Taxidea taxus*), bobcat (*Lynx rufus*), coyote (*Canis latrans*), kit fox (*Vulpes macrotis*), spotted skunk (*Spilogale gracilis*), and striped skunk (*Mephitis mephitis*).

RESULTS

A total of 206 quail (74 adult males, 67 adult female, and 65 juvenile males and females) were collared across the four year study. Adult males averaged 168.5 gm (range 145 gm to 194 gm) and coincidentally adult females averaged 168.5 gm (range from 141 gm to 210 gm) (Table 3). Mean weight for the 65 juveniles was 110.7 gm (range 80 gm to 136 gm). I recorded 2,589 location points during the study of which 18% were <100 meters from a water source, 11% were 101 to 200 meters from water, 14% were 201 to 300 meters and 57% were > 300 meter from water. I had 29 non-treatment birds with ≥ 15 pts. Of which 5 birds had ≥ 15 points multiple years. A total of 54 birds from my treatment site had ≥ to 15 points.

For treatment, water was removed from the Eardley Brick wash guzzler July 11 in 2012 and on July 25 in 2013. Although the guzzler was visited by quail for several days after water removal each year as noted by GPS locations and trail camera photographs, the birds soon abandoned visiting the guzzler. I found that the distance from the center of the home range to the nearest water source did not differ by year ($F = 1.63$; $P = 0.19$) or treatment (removal of water) ($F = 0.89$; $P = 0.35$). The interaction term between these two factors was significant ($F = 6.50$; $P = 0.01$), but none of the individual comparisons were ($P>0.05$) (Table 6). For area of summer home ranges, however, I found strong effects for year ($F = 3.07$; $P = 0.03$), treatment ($F = 4.67$; $P = 0.03$), and their interaction ($F = 7.61$; $P = 0.01$) (Table 5). Mean home range size for quail was 3.05, 7.82, 6.10, and 1.63 km^2 in areas without water removal for 2010, 2011, 2012, and 2013, respectively. In the treatment area, size of summer home ranges was 5.07 and 8.99 km^2 in 2012 and 2013, respectively. Home range sizes were similar for birds without access to water in 2012, but nearly 4 times larger in 2013 (Figure 4).

Survival Analyses

I had 38 quail mortalities of which 19 were avian (50%), 11 mammal (29%), 5 hunter (%13), and 3 trapping related incidents (8%). Avian kills were noted by abundant feathers and lack of blood, tissue, or body parts. The transmitter cables were usually unbroken. One male collared as an adult on July 14, 2010 was killed July 24, 2013 by an avian predator, making it at least 4 years old, matching the longevity of a 4 ½ yr. old female in the Yucca Mountain, Nevada, Gambel's quail study (Sharp 1999). Seven quail were at three plus years old when the study ended. Mammal kills were determined by puncture/bite marks on the rubber tubing and transmitter, tissue, presence of blood, tracks and proximity at dens. I could not determine if badgers or coyotes preyed on quail, but kit foxes did, as determined from tracks and transmitters at or within their den sites. Hunters reported band number and location of five marked quail, two of which were harvested in December outside of the home range polygon created using summer locations.

I found little influence of water removal on survival as models with this effect received little to no support (Tables 4 and 5) and overlap in confidence intervals occurred between treatment and reference groups (Figure 4). My estimates of survival also showed very little annual variation (Figure 4). Most importantly, survival was not altered by the removal of water. My data suggested juvenile quail survived at a lower rate, although β estimates overlapped zero (Table 6).

DISCUSSION

Quail did not move to other sources of free water as a result of removing access to water from the trapping site and I found no influence of removal of access to water on survival rates. Regardless of water, sex, mass or age, throughout the entire study area, I concluded that free water had limited importance to survival of quail (Table 7). This is not to suggest that Gambel's quail do not need water of any kind but, rather their water needs can be met from their diets. Finding no evidence that water affected quail survival supports similar findings in Oklahoma at the extreme ranges where bobwhite quail (*Colinus virginianus*) and scaled quail (*Callipepla squamata*) overlap (Tanner 2015).

Quail did, however, expand their summer space use patterns following water removal suggesting increased demand for succulent forage and a need to range farther. Interestingly, however, quail did not leave established home ranges in search of other water sources as I originally hypothesized. This finding is supported by others who have suggested that Gambel's quail do not depend on free water (Vorhies 1928, Leopold 1933, Gorsuch 1934, Krausman et al. 2006) (Rosenstock et al. 1999, Krausman et al. 2006, O'Brien et al. 2006).

Gambel's quail, living near guzzlers, used water almost daily in early summer, May and

June, which coincides with nesting. The greatest influence artificial water may have on desert quail may be on breeding and survival of young (Campbell 1960). As juveniles neared adult size by the end of July and early August, visits to the "home" guzzler became more infrequent. Then, as a direct result of water removal at their home range's guzzler where quail were trapped, they did not move to other natural sources of free water. Instead, the treatment birds moved down the main wash of their home range to the same area used during the control years. (Figure 5).

My quail sample was small and notably biased because all my study birds were trapped at guzzlers, nevertheless, trail cameras and UTM locations confirmed not all of the quail visited guzzlers, even when in the vicinity. Gambel's quail in southern Arizona have relatively small home ranges <2 km (Greenwalt 1955, Gullion 1962), whereas in the neighboring State of Nevada quail have larger home ranges. Nevada coveys commonly travel up to 6.8 km from point of capture (Sharp 1999) and in one extreme example, a 4 ½ year old female, roamed 10.5 km (Gullion 1962). The southwestern Utah Gambel's quail population followed a similar large home range pattern sometimes traveling 5 km from point of capture. This finding suggests that larger home ranges are required to meet life sustaining sustenance of Gambel's quail in the Mojave Desert of southern Nevada and southwestern Utah.

Management Implications

My research suggests that Gambel's quail do not require free water to survive but, they favored it when available and that removal of access to water sources resulted in increased space-use patterns. This study determined that removal of free water had no effect on survival rates, but did influence size of home ranges in 2013. In 2013, the size of summer home ranges in the water removal area were 4 times those in the reference area suggesting quail had to move more and expand summer space use patterns to meet forage requirements in the absence of free water. This study adds to the historical knowledge of Gambel's quail populations 50 years after Nish's initial study in this area (Nish 1965) and wildlife managers should consider these results to make informed decisions about the future of quail and water management in southwestern Utah.

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Table 1. Mean, min, and max temperatures (°C) during the summer (May – September) months of 2010 – 2013 from Lytle Ranch, Washington County, Utah, USA where I evaluated response of Gambel's quail (Callipepla gambelii) to availability of free water. Official recording of temperature began in 1988

Year	May	Jun	Jul	Aug	Sep	Season
2010 (Mean)	18.44	25.89	29.89	27.61	25.00	25.39
Min	2.78	10.00	11.67	10.55	10.55	2.78
Max	33.89	41.11	43.33	40.00	40.00	43.33
2011 (Mean)	15.39	24.89	27.94	29.5	25.167	24.55
Min	4.44	8.33	15.00	15.00	11.11	4.44
Max	27.78	41.67	42.78	42.78	39.44	42.78
2012 (Mean)	22.94	26.28	28.89	28.78	25.22	26.44
Min	27.78	13.89	13.33	16.67	13.33	5.55
Max	37.78	40.00	45.00	41.11	37.78	45.00
2013 (Mean)	21.11	27.55	30.78	27.61	23.00	26.00
Min	6.11	12.78	19.44	13.55	5.00	5.00
Max	37.22	44.44	45.00	40.00	36.67	45.00
22-year (Mean)	20.11	24.11	27.83	26.61	22.83	24.30
Min	2.78	6.67	11.67	10.55	6.11	7.56
Max	43.33	43.89	43.11	45.00	41.67	43.4

Table 2. Precipitation (mm) during 2010 - 2013 from Lytle Ranch, Washington County, Utah, USA where I evaluated response of Gambel's quail (Callipepla gambelii) to availability of free water. Official recording of precipitation began in 1988.

Year	May	June	July	August	September	Season	Annual
2010	0.00	0.00	24.13	29.32	0.00	44.45	425.20
2011	0.00	0.00	11.94	0.00	4.064	16.00	153.92
2012	0.00	0.00	16.00	39.12	13.97	69.09	208.53
2013	4.06	0.00	21.59	15.24	70.87	111.76	214.38
22-year (mean)	8.32	6.35	15.49	16.26	13.97	57.15	248.67

Table 3. Summary of Gambel's quail (*Callipepla gambelii*) captured at water sources and radio-marked in southwestern Utah's Mojave Desert, Washington County, Utah, USA 2010 – 2013 study.

Year	No. Collared birds	Males	Females	Juveniles
2010	38	22	14	2
2011	42	12	16	14
2012	53	26	24	3
2013	73	14	13	46
Total	206	74	67	65

Table 4. Akaike's Information Criterion selected time models of survival (s) for Gambel's quail (*Callipepla gambelii*) in Washington County, Utah, USA, from May 2010 until September 2013. We report AIC, change in AIC (ΔAIC_c), AIC_c weight (w_i), number of parameters (K), and deviance for all time models (stage 1, top half of table) and time models with individual covariate models (stage 2, bottom half of table) with $w_i > 0.01$.

Model	AIC_c	ΔAIC_c	w_i	K	Dev
Model					
{S(month)}	286.90	0.00	0.78	5	276.87
{S(.)}	290.89	3.99	0.11	1	588.89
{S(20 week linear trend)}	291.90	5.00	0.06	2	287.90
{S(year)}	293.32	6.42	0.03	4	285.30
{S(20 week linear trend*year}	294.78	7.88	0.02	5	284.75
Time models with individual covariates					
{S(month + age)}	282.78	0.00	0.31	5	272.75
{S(month + age + mass)}	283.25	0.47	0.24	6	271.21
{S(month + sex + age)}	284.60	1.82	0.12	6	272.56
{S(month + sex+ age + mass)}	285.14	2.36	0.10	7	271.08
{S(month + mass)}	286.33	3.55	0.05	5	276.31
{S(month + sex)	286.57	3.79	0.05	5	276.55
{S(month)}	286.90	4.12	0.04	5	276.87
{S(month + sex + mass)}	288.07	5.29	0.02	6	276.03
{S(. + age)}	288.88	6.10	0.01	2	284.88
{S(. + age +mass)}	289.17	6.39	0.01	3	283.16

Table 5. Akaike's Information Criterion selected site models of survival (s) for Gambel's quail (*Callipepla gambelii*) in Washington County, Utah, USA, from May 2010 until September 2013. We report AIC, change in AIC (ΔAIC_c), AIC_c weight (w_i), number of parameters (K), and deviance for all site models with $w_i > 0.01$.

Model	AIC_c	ΔAIC_c	w_i	K	Dev
Model					
{S(month + age)}	282.78	0.00	0.23	5	272.75
{S(month + age + mass)}	283.25	0.47	0.18	6	271.21
{S(month + sex + age)}	284.60	1.82	0.09	6	272.56
{S(month + age + site)}	284.72	1.94	0.09	6	272.68
{S(month + sex+ age + mass)}	285.14	2.36	0.07	7	271.08
{S(month + age + mass + site)}	285.15	2.37	0.07	7	271.10
{S(month + mass)}	286.33	3.55	0.04	5	276.31
{S(month + sex)}	286.57	3.79	0.03	5	276.55
{S(month + site)}	286.65	3.87	0.03	5	276.62
{S(month)}	286.90	4.12	0.03	5	276.87
{S(month + sex + age + mass + site)}	287.04	4.26	0.03	8	270.97
{S(month + sex + mass)}	288.07	5.29	0.02	6	276.03
{S(month + mass + site)}	288.17	5.39	0.02	6	276.13
{S(month + sex + site)}	288.34	5.56	0.01	6	276.30
{S(. + age)}	288.88	6.10	0.01	2	284.88
{S(. + age + mass)}	289.17	6.39	0.01	3	283.16
{S(. + age + site)}	290.41	7.63	0.01	3	284.40

Table 6. Model estimates (β) from the top model of Gambel's quail (*Callipepla gambelii*) survival during summer months in southwestern Utah from 2010-2013.

Parameter	Beta	SE	95% Conf Lower	95% Conf Upper
Intercept	5.94	1.10	3.79	8.10
June	17.04	3501.90	-6846.69	6880.76
July	-0.62	0.60	-1.79	0.55
August	-0.50	0.59	-1.65	0.66
September	1.03	0.87	-0.67	2.74
Age	-1.61	1.02	-3.61	0.40

Figure 1. Trap used to capture Gambel's quail (*Callipepla gambelii)*. Note: remote camera (upper center) for monitoring wildlife use and the side cage (bottom right) to retrieve trapped birds.

Figure 2. Map showing study area (star) in western Washington County, Utah, USA.

Figure 3. Gambel's quail (*Callipepla gambelii*) watering at guzzler in the Eardley Brick wash, Washington County, Utah, USA. Note the transmitters and leg bands on marked birds.

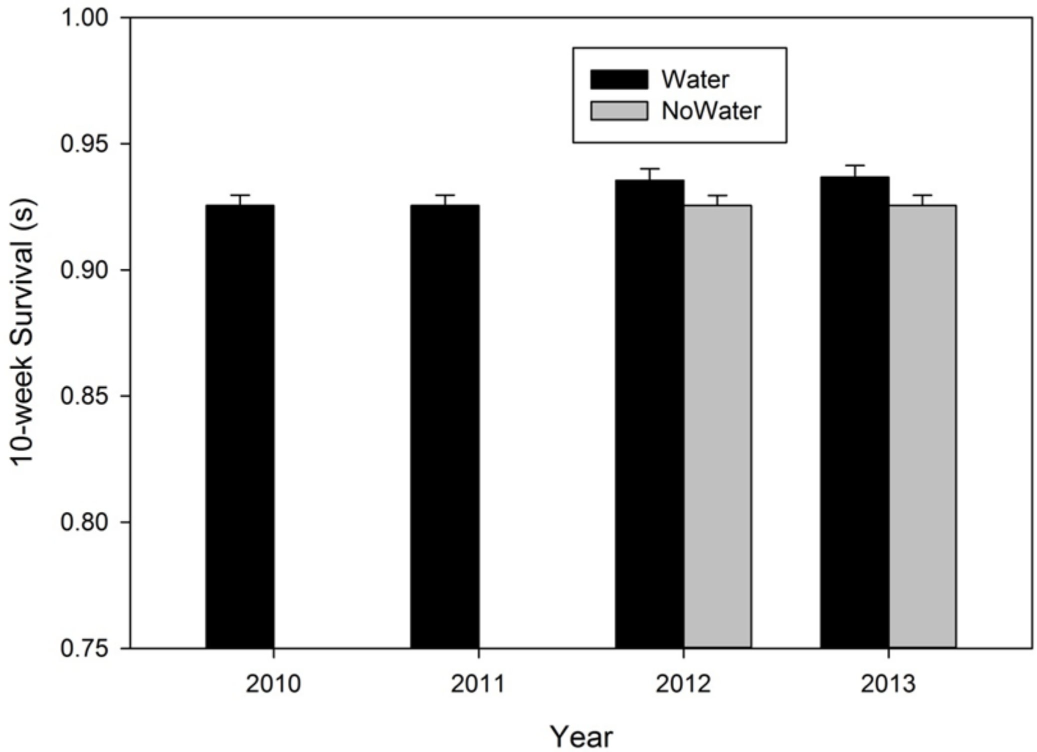

Figure 4. Gambel's quail (*Callipepla gambelii*) survival in relation to removal of access to water across 10-weeks during summer of 2010-2013 in southwestern Utah, USA.

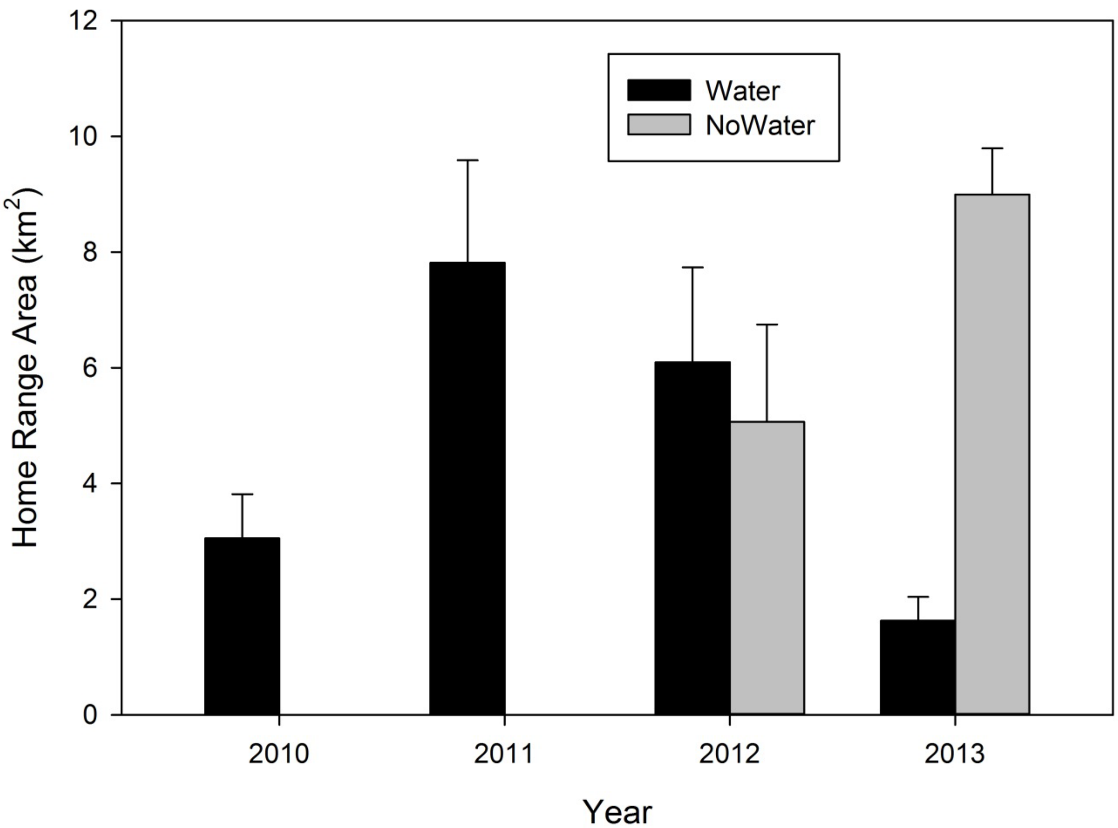

Figure 5. Size of Gambel's quail (*Callipepla gambelii*) home range during summer months in relation to removal of access to water (treatment) in southwestern, Utah, USA 2010-2013.

CHAPTER 2

HABITAT SELECTION BY GAMBEL'S QUAIL (*CALLIPEPLA GAMBELII*): INFLUENCE OF FIRE, TOPOGRAPHY, AND WATER

ABSTRACT

I evaluated Gambel's Quail (*Callipepla gambelii*) habitat selection in relation to fire, topography, and water in western Washington County, Utah, USA. I used radio telemetry, locating birds three to four times per week for a 20 week period, May to September, for four years 2010 – 2013 to generate 2,589 locations used in habitat selection analyses. I then used resource selection functions (RSF) to evaluate the influence of fire, topographic features, and water on habitat selection by this species. Topographic features were derived from a 10-m National Elevation Dataset (NED) and included aspect, distance to roads and power lines, elevation, habitat type, roughness, slope, and topographic position index (i.e., wash, ridge, or hillside terrain). Gambel's quail selected areas with decreased roughness that were closer to water and fire boundaries than random locations. I found that quail preferred moderate hillsides < 10 degree slope (28% of points). Wash bottom and valleys accounted for 49% of the points and ridges had 21% of the points. As the roughness of the terrain increased, the relative probability of use by quail decreased. Quail used the burned habitat within their home ranges in roughly equal proportion to the unburned areas. Of their telemetry point locations, 80% were <500 meters from an edge of the burn. The birds preferred the Sonora Mojave Creosote/White Bursage desert shrub vegetation having 70% of the location points. The Mohave Mid-Mixed desert shrub accounted for the remaining 30% of points. These data suggest preference for topographic features common to much of the Beaver Dam slope and that quail showed strong selection for water

sources in the summer months. The data also suggest that wildfires had limited influence on habitat selection by quail four to seven years after the 2005 and 2006 fires.

INTRODUCTION

Habitat loss and degradation threatens species across the globe (Pimm 2000, Dirzo R. 2003, Foley 2005). The quantity and quality of habitats available to wildlife, including the rangelands of western North America, continue to dwindle due to the multiple impacts of anthropogenic development, wildfires, climate change, and invasive species (Saab 1997, Wisdom et al. 2005, Bradley 2010). How individual species respond to these changes is a function of their life history and adaptive capacity. In general, habitat obligates are more sensitive to habitat alterations (Saab and Rich 1997, Dirzo R. 2003) compared to habitat generalists. Examining how species respond to habitat changes, whether through experimental or observational studies, is essential for effective conservation and management.

In the semi-arid Western United States, the invasion of two non-native plant species, red brome (*Bromus rubens*) and cheatgrass (*Bromus tectorum*), have drastically altered native landscapes (D'Antonio and Vitousek 1992). These grasses are native to the Mediterranean region and arrived in the United States sometime in the 1850's via contaminated soils and grains used as ballast in shipping vessels (Mack and Pyke 1983). Cheatgrass was believed to spread west by railways and roads in grain shipments contaminated with seed soon after arriving in the eastern United States. Early cheatgrass specimens were collected in parts of western North America as early as 1884. It is likely that red brome entered North America in a similar manner (although perhaps from the west coast) and early specimens were collected by 1926 (Reid et al. 2008). Both of these grasses influence fire frequency and intensity by providing a continuous cover of fine fuels (James 1995). Historically, fire intervals occurred anywhere from 60 – 100 years in many arid shrublands of the western United States. Today, some sites dominated by invasive grasses burn every 3 – 5 years (Whisenant 1990). Moreover, invasive grasses provide fuel over large tracts of land which leads to increased fire size compared to historical fires (Brooks 2006). Frequent and larger fires suppress the reestablishment of native forbs, shrubs, and trees which recover slowly when compared with invasive annual grasses (D'Antonio and Vitousek 1992).

Increased wildfire frequencies due to invasion by these two grasses are changing perennial desert shrublands into grasslands throughout much of the western United States (Brooks 2004). This condition impacts native animals which rely on desert shrubs for food and cover. In the Mojave Desert, wildfires have eliminated areas of Joshua trees (*Yucca brevifolia*) that were previously protected from range fires by the absence of connecting ground fuels (Rogers 1985, Miller et al. 1995). In the Mojave Desert portion of Washington County in southwestern Utah, recent fires have altered habitats across large tracts of land. These recently burned areas were found to have fewer small mammals compared to adjacent unburned sites (Horn 2012), but the response of other animals to these changes remains unclear.

Gambel's quail (*Callipepla gambelii*) are adapted to desert shrublands (Guthery 2001) and they are known to make use of the desert almond (*Prunus fasciculata*) and blackbrush (*Coleogyne ramossisma*) communities for protection, resting, and roosting cover (Behle 1932, Engel-Wilson 2002, Kuvlesky et al. 2002). Only trace amounts of invasive grasses have been reported in the diet of this species suggesting conversion to annual grasslands may have a negative impact on this species (Nish 1965). Recently, Gambel's quail water hole trend counts in southwestern Utah went from a high of 995 in 2004, before expansive fires in 2005 and 2006, to a low of 16 in 2007 following large fires that altered large tracts of desert shrubland (Bernales 2011-12). Water hole counts have improved slightly in recent years, but the influence of fire on this species remains unknown.

My specific objective was to investigate habitat selection by Gambel's quail in relation to topographic features, availability of water, and recent (< 10 years) wildfires. I hypothesized that quail would prefer specific topographic features near water sources in unburned habitats because of their preference for protective shrub cover (Kuvlesky et al. 2002). If quail avoided burned areas dominated by invasive grasses, I will conclude that wildfires have impacted habitat selection for this species.

METHODS

Study Area

My research was conducted at the northern extent of the Gambel's quail range in the Mojave Desert of southwestern Utah (Johnsgaard 1973). The study area was approximately 50 km west of St. George, Washington County, Utah, USA, and was characterized by low humidity and clear skies throughout the year. Mean high temperature for the four summers, May through September 2010 – 2013, was 43.9 degrees C and mean low temperature was 4.4 deg. C. (Table 7). Precipitation, mainly from thunderstorms, averaged 60.5 mm for the 4 summers. The mean annual precipitation from 1989 until 2010 was 248. 7 mm (xmacris.rcc-acis.org) and during my study years means were both above and below average (ranged from 425.2 to 153.9; Table 8).

Topographically, the study area consisted of descending ridges and washes originating at the 2042 m summit of the Beaver Dam Mountains and terminating at the lowest elevation (680 m) in Utah in the Beaver Dam wash along the Utah-Nevada border. These lands were administered by the Bureau of Land Management (BLM) and included the Woodbury Natural Study area (BLM 2014). The predominant native vegetation consisted of creosote (*Larrea tridentata*) and shadscale (*Atriplex confertifolia)* intermingled with Joshua trees (*Yucca brevifolia*) along with a variety of desert shrubs including black brush (*Coleogyne ramosissima*), desert almond (*Prunus fasciculata*) and cholla cactus (*Cylindropuntia fulgida*). Invasive tamarisk (*Tamarix chinensis*) was present and a visible indicator of moist soils and springs. In 2005 and 2006, approximately 50% of the study area burned during extensive range fires which altered the vegetative community to one dominated by invasive grasses, primarily red brome and cheat grass (Figure 6).

I assessed habitat selection of Gambel's quail using radio telemetry, a resource only recently made available for this species due to technological advances and miniaturization of transmitters. This assessment occurred during the summer months from May through September (20 weeks) over four years (2010-2013). I trapped quail at four upland gamebird water catchments which were known to have populations (Nish 1965). These four sites were in or near burn boundaries associated with fires in 2005 or 2006 (Figure 6). I constructed traps using 2.5 cm wire poultry netting and structurally supportive 2.5 cm by 5.1 cm welded fence wire material which enclosed a 4 to 5 m^2 area around the catchment. Funnel openings 10 cm diameter at the small end, allowed easy entry into the trap and prevented quail from escaping. A side catchment cage facilitated removal of captured birds (Figure 7). I used a canvas cover to calm and provide shade for the birds in the catchment cage. Trapping ended by mid-July (sometimes earlier) of each year when the desired sample size of 30 birds was reached or repetitive captures made the effort no longer feasible. According to accepted guidelines (Gaunt 1999), tracking devices should not exceed 5% of the animal's live weight so juvenile quail >80 g would meet those standards for the 4 gm transmitter. As I handled the juveniles, however, I chose to only collar birds > 110 grams. The sex of each bird was noted from their distinctive plumage and weight was measured in grams using a hand held Pesola spring scale with 300 gram capacity in two gram increments. I estimated weight to one gram. I placed each quail in a cloth bag and attached it to the clip on the scale for weighing.

Each captured quail was fitted with a permanent aluminum band on the right tarsus and a colored plastic band on the left tarsus. I attached an avian necklace transmitter to individuals over 110 grams, series A3900 from Advanced Telemetry Systems (ATS) with a 221 day battery capacity at 35 pulses per minute, 15 ms pulse width. I used a 52 mm wire cable with protective rubber tubing secured by metal clips and provided a proper fit around the bird's neck. When a transmitter remained motionless for eight hours, an increased pulse rate indicated "mortality mode". I used a telemetry receiver (Model R-1000 from Communications Specialists, Orange California, USA) and dual Yagi antenna to track and relocate marked quail by homing into radio signals. Quail locations were recorded using a global positioning system (GPS) Garmin Etrex series hand held device and coordinate readings set in Universal Traverse Mercator (UTM). Each bird was located three to four times per week randomly throughout daylight hours until the end of August, after which I located the birds biweekly until September 30. Approval for capture, handling, and monitoring of Gambel's quail was granted by Brigham Young University's Institutional Animal Care and Use Committee (Protocol #100604) and the Utah Division of Wildlife Resources (COR #5BAND8464).

Statistical Analyses

I evaluated habitat selection by Gambel's quail at the population level (Johnson 1980) using a resource selection function (RSF) within a used-available study design (Manly 2002). I used a mixed-effects, logistic regression model with a random intercept for individual and year, comparing descriptive variables at used versus available (i.e., random) locations. To capture availability, I generated one random location for every quail location (2589 used and 2,590 random). Because my study was based on a used-availability and not presence-absence design, my RSFs represented relative probabilities of use, given our data and the available resource units in our study area.

I extracted landscape-level variables potentially influencing Gambel's quail habitat selection using a geographic information system (GIS). I divided our analysis into two steps. First, I evaluated the relative influence of several topographic features and habitat type on selection. Topographic features were derived from a 10-m National Elevation Dataset (NED) and included aspect, distance to roads and powerlines, elevation, habitat type, roughness, slope, and topographic position index (i.e., wash, ridge, or hillside terrain), etc. I used the Vector Ruggedness Model (VRM) to create a layer of landscape roughness (Sappington 2007). Second, I included distance to fire edge and water features to assess their influence on habitat selection. To estimate distance to the edge of a feature (e.g., water feature or fire boundary), I used the Euclidean distance tool in the Spatial Analyst extension in ArcGIS 10.2, and then intersected used and available points with the layer. For all other variables, I simply intersected the locations with the layer. I standardized all variables prior to model development $[(x_i - \bar{x})/s]$ and then back transformed the coefficients for interpretation.

Model Development and Assessment

I developed *a priori* models (hypotheses) within an information theoretic framework (Burnham 2002). I selected hypotheses based on ecology and life history of Gambel's quail

(Leopold 1933, Gorsuch 1934, Johnsgaard 1973, Brown 1998, Bishop 2008). I used a hierarchical approach in my analysis. First, I identified the best scale (30, 50, or 500 m) of selection for Gambel's quail and each topographic feature. For each stage, I developed a unique set of univariable and multivariable *a priori* models, avoiding correlated variables ($r \geq |0.7|$) in the same model. For each stage, I identified variables in competitive ($AIC_c \leq 2.0$) (Carpenter, 2010) models and advanced those variables to the next stage. In the final stage, I generated a new set of *a priori* hypotheses based on variables that advanced from earlier stages, this time adding distance to fire boundaries and water features. I reported all models from the final stage with ≥ 1% of total AIC_c weight.

Variables may be uninformative despite being in models with some measure of weight (Arnold 2010). I used AIC_c values and model composition to identify the most supported models and which variables were informative (Arnold 2010). For example, if a model with a lower AIC_c differed by only one variable and approximately 2.0 AIC_c from a model ranked above it, I considered that variable uninformative and instead advanced the top (more parsimonious) form. In the case of multiple models with support, I employed model averaging using the MuMin package (Barton 2013) in program R 3.1.3 (R Core Team, 2015). Following identification of the most-supported models, I applied the models to my study area. I used 5 equal-area bins (Fedy 2015) to categorize the relative probabilities of use for each pixel in my study area from low to high. Finally, I estimated marginal effects on non-standardized observations and then used the margins command in STATA 14 to graphically represent the relationship between probability of use and 1) roughness, 2) distance to fire boundary, and 3) distance to water feature.

To help assess final models, I used variance inflation factors (VIF) to test for multicollinearity among variables. I considered VIF > 10 to indicate evidence of multicollinearity (Aldridge 2007, O'Brien 2007, Colles 2009, Holloran 2015). To assess predictive ability of our final models, I performed a *k*-folds cross validation (Long et al. 2009) with *k*=5. I randomly sorted observations into 5 partitions, with an approximately equal number of locations in each partition. During each iteration of this procedure, I used four partitions (80% of the data) as the training set to estimate model coefficients and the remaining partition (20% of the data) as the test set. I repeated this procedure until all observations were used both as the test set and as part of the training set.

RESULTS

A total of 206 quail (74 adult males, 67 adult female, and 65 juvenile males and females) were collared across the four year study. Adult males averaged 168.5 gm (range 145 gm to 194 gm) and coincidentally adult females averaged 168.5 gm (range from 141 gm to 210 gm) (Table 9). Mean weight for the 65 juveniles was 110.7 gm (range 80 gm to 136 gm). I collected a total of 2589 locations from these 206 radio-marked quail over 4 years which ranged from1 to 49 locations per bird. My primary objective was to analyze quail locations in relation to fire and 50% of quail locations were inside fire boundaries with 13% <100 m from fire edges and 80% <500 m from burn edges. Incidentally, I found 18% of my quail locations were <100 m from water and 63% were <500 m.

The top model (all of the AICc weight) from step one included roughness at a 50 m scale and landform along with a random effect for year and bird ID. Models with other variables were not supported (Table 4). I found little support for distance to roads or power lines as influencing selection by Gambel's quail. In step 2, I incorporated distance to water and fire boundary into this model which dramatically improved AICc scores (Table 10, Table 11). All variables were significant discriminants between used and available locations ($P < 0.05$) with distance to water having the greatest influence on habitat selection, followed by roughness, landform, and then distance to fire boundary. Gambel's quail selected areas that were 1) closer to water, 2) less rough, 3) more likely to be in wash or canyon bottoms, and 4) closer to fire boundaries than random locations (Figure 8).

All variables in the top model (Table 10, Table 11) were judged as informative. Predictive ability of our top model from the five-fold cross validation was high (Spearman ρ = 0.90). I found no evidence for multicollinearity in any of my final models (VIF < 5). The vegetation classification described as Sonora-Mojave Creosote bush-White bursage Desert Scrub contained 70% of quail locations followed by Mojave Mid Mixed Desert Scrub which accounted for the remaining 30%. Application of the top model to my study area showed preference for areas near water that were located in canyon bottoms with less roughness than the surrounding area (Figure 9).

DISCUSSION

Range fires occurred in Gambel's quail habitat in southwestern Utah during 2005 and 2006 due to the encroachment of annual non-native grasses which provided fuel for larger and more intense wildfires. As early as the 1930's, research on the effects of prolific exotic grasses and increasing range fires were suggested for study of quail response (Gorsuch 1934). More study about increased range fires and water development on quail survival was suggested from research in the 1960's (Gallizioli, 1965). Although I hypothesized that quail would avoid burned areas, my results showed that Gambel's quail used burned and unburned habitat similarly four to seven years after wildfire. Quail were predominantly found in canyon or wash bottoms where shrubs were actively recovering. I found they selected the burn edges (Figure 8) and commonly observed them foraging on forbs and grasses within the burn area.

Quail avoided steep mountain sides. As roughness increased, the relative probability of use for quail decreased (Figure 9). Quail also favored wash or canyon bottoms and were often found in these areas loafing underneath shrubs. Although statistical models considered the presence of roads and power lines, these variables had no effect on habitat selection by quail during my study.

In chapter one, I found that Gambel's quail do not depend on free water (Vorhies 1928, Leopold 1933, Gorsuch 1934, Krausman et al. 2006, Rosenstock et al. 1999, Krausman et al. 2006, O'Brien et al. 2006) but they did favor it. In this chapter, water factored in as Gambel's quail showed significant selection for water (Figure 8). The probability of habitat use derived from our telemetry points showed similar patterns with respect to selection for burn edges, water, and decreased roughness (Figure 9).

My study is timely because advancements in the use of miniaturized radio-transmitters provide opportunities for careful examination of quail habitat use relative to wild fire and free water. I found Gambel's quail did not avoid burned areas in southwestern Utah.

MANAGEMENT IMPLICATIONS

My study adds to the historical knowledge of Gambel's quail populations 50 years after Darrell Nish's initial study in this area (Nish 1965). Wildlife managers should consider my results, with others, to make informed decisions about the future of quail management in southwestern Utah. I found quail selected for water and burn edges 4-7 years after expansive wildfire. Quail occupied washes, hillsides and moderate ridges in burned areas, enhanced by the eventual recovery of shrubs. They showed selection for water when it was available, but there was no influence on survival when it was removed (chapter 1).

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TABLES

Table 7 Mean, min, and max temperatures (°C) during the summer (May – September) months of 2010 – 2013 from Lytle Ranch, Washington County, Utah, USA where I evaluated habitat selection of Gambel's quail (*Callipepla gambelii*) in relation to fire, topographic features, and water. Official temperature records began in 1988.

Year	May	Jun	Jul	Aug	Sep	Season
2010 (Mean)	18.44	25.89	29.89	27.61	25.00	25.39
Min	2.78	10.00	11.67	10.55	10.55	2.78
Max	33.89	41.11	43.33	40.00	40.00	43.33
2011 (Mean)	15.39	24.89	27.94	29.5	25.167	24.55
Min	4.44	8.33	15.00	15.00	11.11	4.44
Max	27.78	41.67	42.78	42.78	39.44	42.78
2012 (Mean)	22.94	26.28	28.89	28.78	25.22	26.44
Min	27.78	13.89	13.33	16.67	13.33	5.55
Max	37.78	40.00	45.00	41.11	37.78	45.00
2013 (Mean)	21.11	27.55	30.78	27.61	23.00	26.00
Min	6.11	12.78	19.44	13.55	5.00	5.00
Max	37.22	44.44	45.00	40.00	36.67	45.00
22-year (Mean)	20.11	24.11	27.83	26.61	22.83	24.30
Min	2.78	6.67	11.67	10.55	6.11	7.56
Max	43.33	43.89	43.11	45.00	41.67	43.4

Table 8. Precipitation (mm) during 2010 - 2013 from Lytle Ranch, Washington County, Utah, USA where I evaluated habitat selection of Gambel's quail (*Callipepla gambelii*) in relation to fire, topography, and availability of free water. Official precipitation records began in 1988.

Year	May	June	July	August	September	Season	Annual
2010	0.00	0.00	24.13	29.32	0.00	44.45	425.20
2011	0.00	0.00	11.94	0.00	4.06	16.00	153.92
2012	0.00	0.00	16.00	39.12	13.97	69.09	208.53
2013	4.06	0.00	21.59	15.24	70.87	111.76	214.38
22-year (mean)	8.32	6.35	15.49	16.26	13.97	57.15	248.67

Table 9. Number of Gambel's quail (*Callipepla gambelii*) captured and radio-marked in western Washington County, Utah, USA, from 2010 – 2013 by sex and age.

Year	No. Collared birds	Ad Males	Ad. Females	Juvenile Male & Female
2010	38	22	14	2
2011	42	12	16	14
2012	53	26	24	3
2013	73	14	13	46
Total	206	74	67	65

Table 10 Ranking of models of habitat selection by Gambel's quail (*Callipepla gambellii*) from step one (variables other than distance to fire or water) showing number of parameters (*K*), corrected Akaike's Information Criterion (AIC_c), ΔAICc, model weight (ω_i), and log likelihood (LL).

Model	Structure	*K*	AIC_c	ΔAIC_c	ω_i	LL
m18	Used ~ Rough50 + Landform30 + (1|Year) + (1|BirdNo)	11	6873.94	0.00	1.00	-3425.94
m20	Used ~ Landcov30m + Rough50 + (1|Year) + (1|BirdNo)	10	6898.33	24.39	0.00	-3439.14
m13	Used ~ Rough50 + Road_Dist + (1|Year) + (1|BirdNo)	7	6909.87	35.94	0.00	-3447.93
m8	Used ~ Rough50 + DEM5m + (1|Year) + (1|BirdNo)	7	6920.35	46.41	0.00	-3453.16
m1	Used ~ Rough50 + (1|Year) + (1|BirdNo)	6	6921.36	47.43	0.00	-3454.67
m14	Used ~ Edge_DIST + Landform30 + (1|Year) + (1|BirdNo)	11	6959.61	85.67	0.00	-3468.78
m7	Used ~ Landform30 + Landcov30m	14	6989.85	115.91	0.00	-3480.88
m16	Used ~ Landcov30m + Aspect + Edge_DIST + (1|Year) + (1|BirdNo)	11	7028.62	154.68	0.00	-3503.28
m11	Used ~ Road_Dist + Edge_DIST + (1|Year) + (1|BirdNo)	7	7035.55	161.61	0.00	-3510.76
m17	Used ~ Aspect + Road_Dist + DEM5m + (1|Year) + (1|BirdNo)	8	7036.56	162.63	0.00	-3510.27
m2	Used ~ Landform30 + (1|Year) + (1|BirdNo)	10	7055.91	181.98	0.00	-3517.94
m19	Used ~ DEM5m + Edge_DIST + (1|Year) + (1|BirdNo)	7	7067.65	193.72	0.00	-3526.82
m9	Used ~ Landcov30m + Aspect + (1|Year) + (1|BirdNo)	10	7083.83	209.89	0.00	-3531.89
m12	Used ~ Edge_DIST + Aspect + (1|Year) + (1|BirdNo)	7	7084.08	210.14	0.00	-3535.03
m4	Used ~ Edge_DIST + (1|Year) + (1|BirdNo)	6	7086.76	212.82	0.00	-3537.37
m3	Used ~ Landcov30m + (1|Year) + (1|BirdNo)	9	7087.41	213.47	0.00	-3534.69
m15	Used ~ Aspect + DEM5m + (1|Year) + (1|BirdNo)	7	7126.99	253.06	0.00	-3556.49
m10	Used ~ Aspect + Road_Dist + (1|Year) + (1|BirdNo)	7	7149.72	275.78	0.00	-3567.85
m6	Used ~ Road_Dist + (1|Year) + (1|BirdNo)	6	7158.03	284.09	0.00	-3573.01
m5	Used ~ Aspect + (1|Year) + (1|BirdNo)	6	7181.38	307.45	0.00	-3584.68
m.null	Used ~ 1 + (1|Year) + (1|BirdNo)	5	7186.85	312.92	0.00	-3588.42

Table 11 AIC ranked models from step 2 of evaluation of habitat selection by Gambel's quail (*Callipepla gambelii*) in southern Utah, USA 2010-2013. Table shows number of parameters (*K*), corrected Akaike's Information Criterion (AIC_c), ΔAICc, model weight.

Model	Structure	*K*	AIC_c	ΔAIC_c	ω_i	LL
mFireWater	Used ~ Rough50 + Landform30 + Fire_DIST + Water_DIST + (1|Year) + (1|BirdNo)	11	6641.55	0.00	0.69	-3309.75
mWater	Used ~ Rough50 + Landform30 + Water_DIST + (1|Year) + (1|BirdNo)	10	6643.13	1.58	0.31	-3311.54
mFire	Used ~ Rough50 + Landform30 + Fire_DIST + (1|Year) + (1|BirdNo)	10	6868.29	226.74	0.00	-3424.13
m18	Used ~ Rough50 + Landform30 + (1|Year) + (1|BirdNo)	9	6876.88	235.33	0.00	-3429.42
m.null	Used ~ 1 + (1|Year) + (1|BirdNo)	3	7182.85	541.29	0.00	-3588.42

(ω_i), and log likelihood (LL).

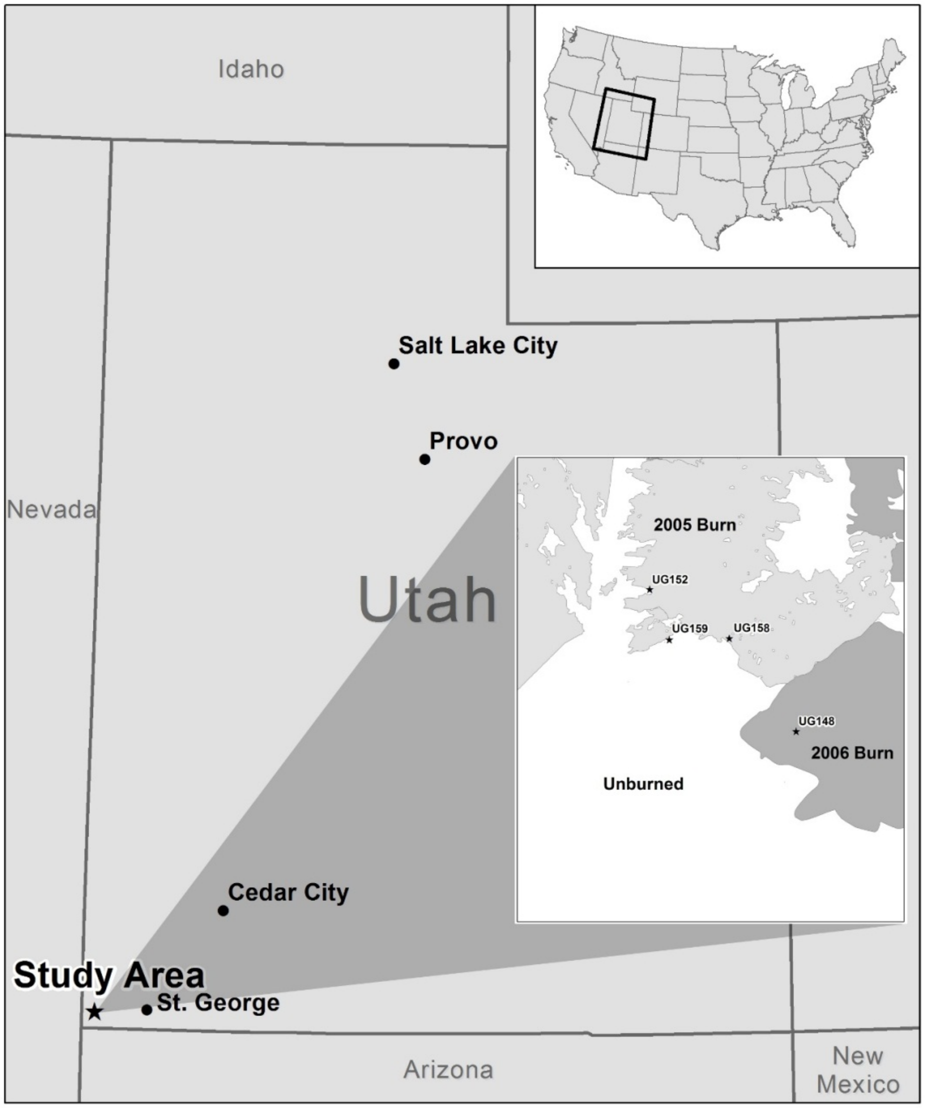

Figure 6. Map of study area (star) in western Washington County, Utah, USA where I evaluated habitat selection of Gambel's quail (Callipepla gambelii) in relation to fire, topography, and availability of free water during 2010-2013. Inset map shows location of water sources along burn scars from fires in 2005 or 2006 where I captured quail.

Figure 7. Trap at water catchment used to capture Gambel's quail (Callipepla gambelii) prior to attaching radio transmitters to evaluate habitat selection in relation to fire, topography, and water in southwestern Utah, USA, 2010-2013. Note: remote camera (upper center) for monitoring wildlife use and the side cage (bottom right) to retrieve trapped birds.

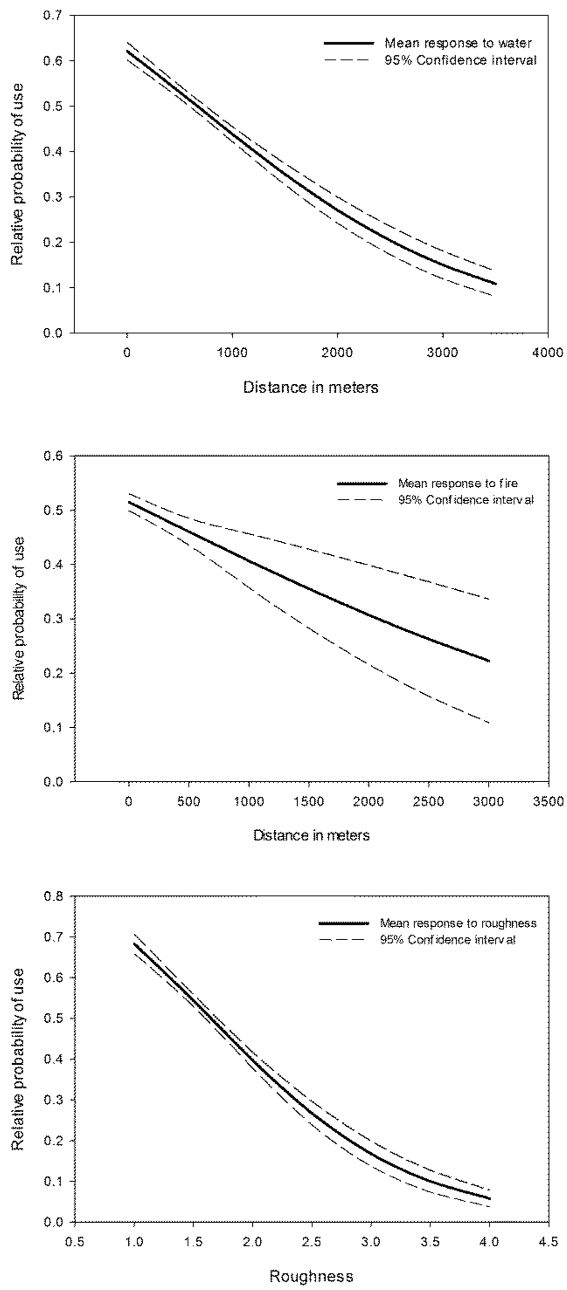

Figure 8. Partial regression plots showing relationship between relative probablity of use (predicted and 95% confidence intervals) by Gambel's quail (*Calipepla gambellii*) and the following three habitat features: 1) distance to water (top), 2) distance to fire boundary (middle), and 3) landscape roughness (bottom) from radio-marked birds in southwestern Utah, USA, 2010-2013.

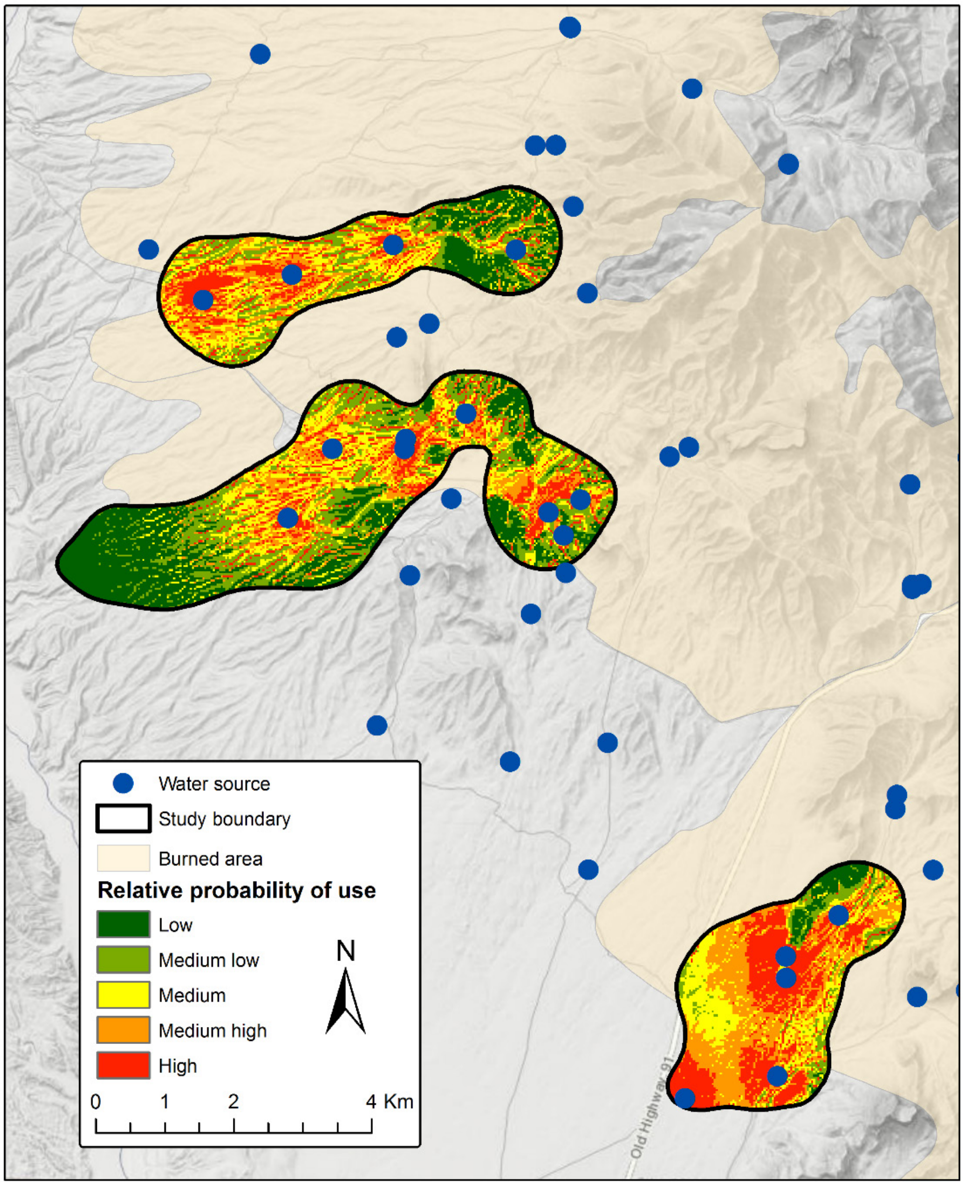

Figure 9. Relative probablity of use (predicted) in our study area polygons derived from locations of radio-marked Gambel's quail (*Calipepla Gambelii*) in southwestern Utah, USA, 2010-2013.