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Trapping, Survival, and Probable Causes of Mortality of Chukar Partridge

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TRAPPING, SURVIVAL, AND PROBABLE CAUSES OF MORTALITY OF CHUKAR PARTRIDGE

By

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GRADUATE COMMITTEE APPROVAL

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TRAPPING, SURVIVAL, AND PROBABLE CAUSES OF MORTALITY OF CHUKAR PARTRIDGE

ABSTRACTS

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CHAPTER 1

We present an efficient and effective method for trapping chukars (*Alectoris chukar*) on artificial water sources. We compared a B-trap, a prairie chicken (*Tympanuchus cupido*) walk-in trap, a modified quail recall trap, and a newly designed Utah walk-in-funnel trap. Our Utah funnel trap outperformed standard techniques by more than 65%, and exceeded previous published results by 35%. Use of this method allows researchers and managers the ability to capture large numbers of Chukars relatively efficiently. With appropriate modifications this design is applicable for capturing a variety of bird species using small water developments.

CHAPTER 2

Chukars (*Alectoris chukar*) have been introduced throughout the world. Limited information regarding seasonal survival, causes of mortality, and other basic life history characteristics such as movements, home range, nesting and brood ecology, are available throughout their historical and introduced range of distribution. Lack of information is surprising because chukars have been introduced throughout the world and are popular with sport hunters. Survival estimates are particularly important for understanding population fluctuations which allows for adequate management. We evaluated the relationship of fall raptor migration, peak migration, reproductive period, and year effects on survival of chukars at 5 sites in western Utah. We also evaluated the probable cause of death for chukars with transmitters attached by examining evidence at kill sites. We captured and fitted 128 chukars with two different sized radio transmitters (99 females, 21 males, 8 sexes undetermined). Survival differed among study years where survival estimates showed significant ($P< 0.01$) differences between estimates in 2005 ($\varphi = 0.03$, 95% CI = 0.01 - 0.09), compared to 2006 ($\varphi = 0.26$, 95% CI = 0.18 - 0.38). Estimates showed that chukars were less likely to survive ($P = 0.01$) during the fall peak of raptor migration in 2006 (bi-monthly $\varphi = 0.86$, 95% CI = 0.74 - 0.93) than (base survival) outside this migration period and during the chukar reproductive period (bi-monthly $\varphi = 0.97$, 95% CI = 0.95 - 0.98). We documented 95 deaths; with 45% of causes unknown, avian predation accounted for 30%, mammals killed 1%, and hunters accounted for 7.6%. Our research suggested that predation on chukars was substantial during the fall raptor migratory period.

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I especially thank Dr. Jerran Flinders for his knowledge, experience, and tutelage. I would also like to thank Randy Larsen for mentoring me throughout my experience.

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TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

CHAPTER 1

CHAPTER 2

CHAPTER 1. A MORE EFFECTIVE TRAPPING TECHNIQUE FOR CHUKARS ON SMALL WATER DEVELOPMENTS

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INTRODUCTION

Detailed studies of life history characteristics are often contingent on successful capture and subsequent banding and/or of placing radio transmitters on a sample of individuals from the population. Depending on the species, researchers can find themselves with limited or no information on trapping techniques. Such is the case with chukars (*Alectoris chukar).* Nevada Division of Wildlife successfully captured chukars for many years, yet there was no published methods available to researchers and managers. The limited body of literature indicated that capture rates were low regardless of methods (Harper et al.1958, Lindbloom 1998, Shaw 1971, Walter 2000). In response to this challenge we developed and tested a new trap design and methodology which researchers and managers can use to successfully capture chukars.

Capture of chukars is requisite because only limited information is available regarding basic life history characteristics such as movement, home range, survival, and etc. This lack of information is surprising since chukars were introduced throughout the world and are popular with sport hunters. Native to mountainous regions in parts of Asia, Western Europe, and the Middle East (Ali & Ripley 2001, Cramp & Simmons 1980, Dement'ev & Gladkov 1952), Chukars have purposely been established in Australia (Ryan 1906), Hawaii (Walker 1967), St. Helena Island (Atlantic Ocean) (Watson 1966), New Zealand (Williams 1950), South Africa (Winterbottom 1966), and North America (Long 1981). Chukars were first introduced into North America in 1893 (Lever 1987). Persistent, self-sustaining wild populations are found in the following states and province: Arizona, California, Colorado, Idaho, Montana, Nevada, Oregon, Utah, Washington, Wyoming, and British Columbia, Canada (Christensen 1996).

Management of chukars in the Western U.S.A. has generally been limited to water development with particular emphasis on the installation of rainwater catchments (guzzlers) to expand populations into new areas (Benolkin & Benolkin 1994). Nevada, for example, installed over 1500 guzzlers—many of which are designed to benefit chukars (Nevada Division of Wildlife 1999). Guzzlers come in many shapes and sizes, but a recent smaller design (Scott 1994) specifically targeted chukar populations collected water in an 1136 liter tank located directly beneath a precipitation collection area (apron) (Fig. 1). The tank is designed with a descending slope; as water recedes, smaller animals can walk into the tank and down the slope to drink. The apron overlaps the front of the tank by approximately 80 cm and the total surface area of the apron is 266 cm ×365 cm. The height from ground to apron varies from guzzler to guzzler depending on how each unit is installed, but is generally near 60 cm.

Our specific objective was to identify previously employed trapping techniques used to capture chukars and to develop and test a new design for use on small water developments.

STUDY AREA

Chukars were trapped in Utah during the summer of 2005 on five small guzzlers at the southern end of the Grouse Creek Mountains, Box Elder County (centered at 41° 24' 14" N 113° 54' 34" W) and four small guzzlers on the Fish Springs Range, Juab County (centered at 39° 51' 58" N 113° 26' 10" W) as part of an ongoing research project evaluating the benefits and impacts of wildlife water developments.

METHODS

Trapping was attempted with the following four designs: 1) B-shaped traps developed by biologists in Nevada, 2) Greater prairie chicken walk-in traps (Schroeder 1991) with reduced funnel dimensions, 3) a double sided funnel trap similar to quail traps (Delehanty, Eaton et al. 2004), and 4) our new design, hereafter referenced as Utah walk-in-funnel trap . The Nevada B-style trap, named after its shape, is placed so that chukars are funneled between the two lobes of the B while attempting to get into the guzzler tank. Prairie chicken walk-in traps were 92 cm (diameter) circular traps with one funnel entrance; two of these were placed in front of the guzzler tank—effectively blocking chukars from water. Both the Nevada B-trap and prairie chicken walk-in trap did not allow access to water in the guzzler tank while in the trap. These traps were baited with water in a bowl. The third trap design and our new Utah design allowed captured chukars access to the water within the tank. Initially developed to capture quail, the third design was a modular cage trap with two small walk-in funnels adjusted to the larger size of a chukar. The new Utah walk-in-funnel trap was developed for use on the Nevada style small game guzzlers with a similar principle of allowing access to water while in the trap.

Trap construction involved 14 gauge vinyl coated 2.5 cm × 5 cm mesh welded wire. We cut this wire to the approximate dimensions of the area between the ground and front of the apron (266 cm wide and 60 cm tall). Lighter 24 gauge vinyl coated wire mesh was used on the back and sides of the trap, usually extending no more than

81-102 cm from the front of the apron to slightly behind the opening of the tank (Fig. 2). Rocks were used to secure the wire mesh to the ground, while plastic zip ties secured the mesh to the apron. Chukars enter the trap through a walk-in funnel built into the welded wire. The funnel was 56 cm long with an entrance opening of 30 cm in diameter and an inside opening diameter of 18 cm. The length of the funnel allowed placement of the inside opening directly at the tank entrance allowing yet uncaptured chukars a clear view of water in the tank (Fig. 3). The bottom of the funnel was lined with rocks to decrease funnel diameter, cover the wire mesh, and help guide birds into the trap. Although slightly variable, the area inside the trap was about 2.2 m^2 which is larger than the Nevada B-trap, prairie chicken walk-in trap, and the modified quail walk-in trap. Extraction of chukars from the Utah trap was done through two doors cut in the wire approximately 30 cm^2 located on both sides of the funnel. A small fishing net can be inserted through the doors to quickly capture trapped chukars.

During our initial summer trapping we used only the Nevada B-trap, prairie chicken walk-in trap, and modified quail trap, in the Grouse Creek Mountains. After assessing the ineffectiveness of the different trapping methods we developed the Utah walk-in-funnel trap. We tested the Utah design in the Fish Spring Mountains simultaneously with the other traps being used in the Grouse Creek range. Chukar abundance was considered to be higher in the Grouse Creek range than the Fish Spring range during the summer field season with more and larger coveys observed.

RESULTS

A total of 384 birds were captured in traps representing the four designs over 38 trap days in July-September. Results indicate a significant variation in the success of the four trap designs. Despite higher numbers of chukars in the Grouse Creek area, the new Utah design outperformed standard techniques by 65% (Table 1), and exceeded by 35% the highest previously published results for chukars in any trapping scenario (Harper et al. 1958; Shaw 1971). Over 50 chukars were captured with the Utah walk-in funnel trap on two occasions whereas the other techniques resulted in no more than a dozen birds captured at one time between all traps combined. In addition to chukars, we trapped the black-billed magpie (*Pica hudsonia*), mourning dove (Zenaida macroura), pinyon jay (*Gymnorhinus cyanocephalus*), sage thrasher (*Oreoscoptes montanus*), and western meadowlark (*Sturnella neglecta*).

DISCUSSION

Published capture rates of chukars are relatively low during winter and summer trapping. Lindbloom (1998) trapped 56 chukars using baited clover-leaf traps from January to May over two years with up to 54 trap stations. Walter (2000) trapped 47 chukars in approximately 18,000 trap days (0.0026 birds per trap day) during the winter of two different years in eastern Oregon. Summertime trapping over water can be more effective (Christensen 1970). In western Utah, Shaw (1971) captured 6.7 chukars per trap day in 1969 and 2.0 chukars per trap day in 1970. Harper et al. (1958) captured 13.4 chukars per trap day in California around springs in 1955 using several different trap designs. Our Utah walk-in funnel trap outperformed standard designs by nearly 65% (Table 1).

The success of the Utah design over the other traps was attributed to more area inside the trap and placement so that the funnel and associated rocks guide chukars directly into the tank. With appropriate modifications (i.e. smaller gauge mesh and/or smaller dimensions for the funnel), we believe this design is applicable for capturing a variety of wildlife species utilizing small water developments. Furthermore, combinations of one or more traps and appropriate modification show promise for trapping at natural springs, stock tanks, and other water sources used by chukars and other birds.

MANAGEMENT IMPLICATIONS

Chukars are the number one pursued game bird by sport hunters in Nevada and Oregon and have quickly become one of the most popular upland game species in the Western United States (Christensen 1996). Appropriate use of this new trap will allow researchers and managers to successfully capture large number of chukars for transplants, mark-recapture studies, or other research.

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Figure 1. Shown is a Nevada style small game guzzler.

Figure 2. Here are diagrams of our original Utah trap design, with associated dimensions, for trapping Chukars at small-game guzzlers. These diagrams are looking both from the front (top) and side (bottom) views. This design can be modified and applied to a host of situations and shows promise for other birds as well as Chukars.

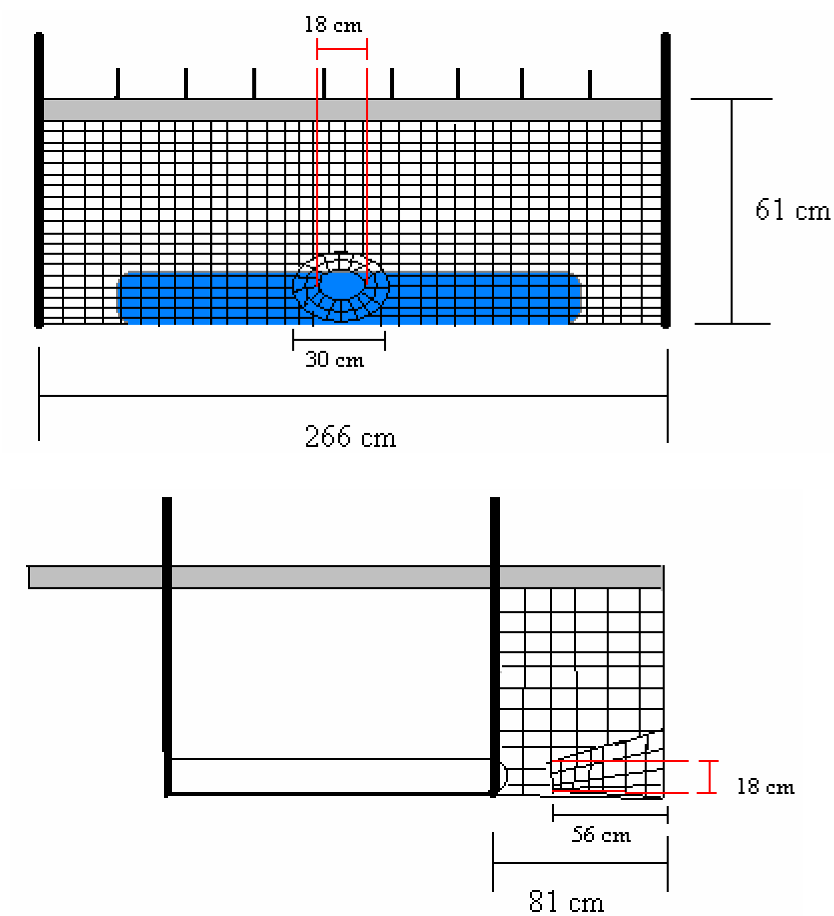

Figure 3. Note here that the funnel entrance allows a clear view of the water in the tank. As Chukars search for a way to the water the funnel and rocks direct them into the trap.

Table 1. Listed here is a summary of trapping success for Chukars across trap designs.

Trap Design	# Trap Days	# Birds Trapped	Birds/Trap Day
Utah Walk-in-funnel Trap	15	303	**20.2**
Modified Quail Walk-in Trap	3	21	**7.0**
B-Trap	5	10	**2.0**
Greater Prairie Chicken Trap	15	50	**3.3**

CHAPTER 2. SURVIVAL AND PROBABLE CAUSES OF MORTALITY IN CHUKAR PARTRIDGE

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INTRODUCTION

An understanding of survival and cause-specific mortality are important aspects of wildlife demography. For most vertebrate wildlife seasonal and annual survival estimates are particularly important for understanding population fluctuations which allows for responsive changes in management (White and Garrott 1990). Without these data, managers make decisions with limited or incomplete information. Such is the case with chukars *(Alectoris chukar*), where knowledge of seasonal survival, causes of mortality, and other basic life history characteristics such as movements, home range, nesting and brood ecology, are lacking. This lack of information is surprising because chukars have been introduced throughout the world and are popular with sport hunters.

Native to mountainous regions in parts of Asia, Western Europe, and the Middle East (Dement'ev and Gladkov 1952, Cramp and Simmons *eds* 1980, Ali and Ripley 2001), chukars have purposely been established in many parts of the world including Australia (Ryan 1906), New Zealand (Williams 1950), St. Helena Island, Atlantic Ocean (Watson 1966), Hawaii (Walker 1967), South Africa (Winterbottom 1966), and North America (Long 1981). Chukars were first introduced into North America in 1893 (Lever 1987) and by 1954 state wildlife agencies in California, Idaho, Nevada, and Washington considered chukars as successfully established (Christensen 1954). By 1968 six additional western states (Arizona, Colorado, Montana, Oregon, Utah, and Wyoming) had sufficient populations to consider establishment successful and thus initiated hunting seasons (Christensen 1970). Currently, persistent self-sustaining wild populations in North America are found in the following states and province: Arizona, California, Colorado, Idaho, Montana, Nevada, Oregon, Utah, Washington, Wyoming, and British Columbia, Canada (1971, Christensen 1996).

Following widespread establishment of chukars in western North America during the middle of the 20th century, several state wildlife agencies produced documents referent to chukar survival (Galbreath and Moreland 1953, Bohl 1957, Christensen 1970), but did so without the benefit of technological advances such as radio telemetry. These early documents were followed by nearly a 30 year gap in chukar research addressing questions related to survival. Lindbloom (1998) studied chukar habitat utilization, reproduction, and seasonal survival in Idaho, Walter (2000) assessed the ecology of chukars—including survival—in Eastern Oregon, and Slaugh (1990) estimated survival of wild chukars vs. pen-reared birds. These studies employed radio telemetry, but suffered from relatively small sample sizes ($n < 29$ per year). They are the only studies that have quantitatively estimated survival using radio telemetry and known fate parameters for chukars in North America. Other earlier studies used qualitative observations to estimate survival. Christensen (1970) attributed mortality of chukars to predation, hunting, and weather. Galbreath and Moreland (1953) estimated survival at 25-35% during sever winter conditions in Washington. These and other qualitative reports suggested that chukars had a short life span offset by high reproduction (Christensen 1996). Statistically sound estimations of seasonal survival and the known probable causes of chukar mortality will: 1) show the function of chukars in seasonal food webs and chains; 2) identify habitats that seem to ensure increased survival of chukars; and 3) provide managers with better data upon which to make management decisions.

We conducted a two year field study to estimate survival of chukars in the western deserts of Utah. Specific objectives were to: 1) estimate seasonal and annual variations in survival, 2) identify probable causes of mortality, 3) examine survival during the crucial reproductive period and in relation to the known fall raptor migration, and 4) compare estimates of survival for chukars carrying transmitters weighing 9.5 grams or 14 grams.

STUDY AREA

Our study area included five different locations in western Utah located in Box Elder, Juab, Davis, and Tooele counties. Areas were: Chukar Knolls, and the south end of the Grouse Creek/Bovine Mountains, Box Elder County (centered at 41° 24' 14" N 113° 54' 34" W); the north end of the Fish Springs range, Juab County (centered at 39° 51' 58" N 113° 26' 10" W); the north end of the Deep Creek Mountain range, Tooele County (centered at 40° 06' 54" N 113° 51' 52" W); the north end of the Dugway Mountain range, Tooele County (centered at 40° 00' 22" N 113° 12' 32" W); and Antelope Island, Davis County (centered at 40° 57' 54" N 112° 13' 21" W). These locations were selected because of an ongoing investigation into the effects of artificial water developments (guzzlers) on chukar populations.

All five study areas are within the Great Basin physiographic region characterized by roughly north to south parallel mountain ranges separated by desert basins (Fenneman 1931), except for Antelope Island (AI) which is surrounded by the Great Salt Lake. Climate is described by hot summers and moderately cold winters (Dice 1943), with a deficiency of precipitation (Thornthwaite 1931). All areas had some history for having self-sustaining populations of wild chukars.

Abundant native trees include juniper (*Juniperus* sp.) and pinyon pine (*Pinus edulis).* Dominant native shrubs include sagebrush (*Artemisia* sp*.),* Mormon tea (*Ephedra* sp*.),* Mexican cliff rose (*Purshia stansburiana)*, curl leaf mountain mahogany (*Cercocarpos ledifolius)*, saltbush (*Atriplex sp.)*, and others. Grasses and forbs include several native species as well as many exotics. A partial list included: cheatgrass (*Bromus tectorum)*, bluebunch wheatgrass (*Elymus spicatum),* indian rice grass (*Stipa hymenoides*), needle and thread grass (*Stipa comata*), sandberg bluegrass (*Poa secunda*), halogeton (*Halogeton glomeratus),* Russian thistle (*Salsola iberica*), and redstem filaree (*Erodium cicutarium)*. Generalized vegetative communities in the study areas included: 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).

METHODS

Capture, Marking, and Monitoring

We trapped chukars from July to September of 2005 and June to September, 2006. In 2005 we trapped chukars using the following four trap designs: 1) B-shaped traps developed by biologists in Nevada, 2) greater prairie chicken walk-in traps (Schroeder 1991) with reduced funnel dimensions, 3) a double sided funnel trap similar to quail traps (Delehanty et al. 2004), and 4) a new funnel design developed in Utah. Named after its shape, the Nevada B-style trap is placed so chukars are funneled between the two lobes of the B while attempting to get into the guzzler tank to drink. Prairie chicken walk-in traps were 92 cm (diameter) circular traps with one funnel entrance. Two of these traps were placed in front of the guzzler tank—effectively blocking chukars from water. Traps were then baited with water in a bowl; both the Nevada B-trap and prairie chicken walk-in trap did not allow access to water in the guzzler tank. The third design was a cage trap with two small walk-in funnels. Chukars inside this trap had full access to water. The funnels were similar to quail walk-in funnels but adjusted to the larger size of a chukar. The new Utah design was developed for use on the Nevada style small game guzzlers with a similar principle of allowing access to water while in the trap (Fig. 1). During our initial 2005 summer trapping we used only the B-trap, prairie chicken walk-in trap, and modified quail trap, on the Grouse Creek Mountains. After assessing the ineffectiveness of the different trapping methods we developed the new funnel design. We used the new design on the Fish Spring Mountains simultaneously with the other traps being used on the Grouse Creek range. In 2006, we only used the new Utah design given superior results from 2005.

Traps were checked every few hours and captured chukars removed . Chukars were classified as male or female by measurement of the tarsus. Chukars with a tarsus ≥ 60 mm were classified as males (Woodard et al. 1986), and as juvenile (≤ 12 months) or adult (> 12 months) based on plumage characteristics (Smith 1961, Weaver and Haskell 1968, Alkon 1982). Body mass was measured with a Pesola spring scale accurate to 10 grams.

Captured chukars were marked with individual numbered aluminum leg bands and attached adults with backpack style radio transmitters (Slaugh 1989) randomly with either a 9.5 or 14 gram transmitter. Transmitters were manufactured by Advanced Telemetry Systems (ATS). The 9.5 gram transmitters (Model A1250) were a small coin shaped transmitter with dimensions 27mm x 35mm x 11mm and battery life capacity of 524 days. The 14 gram transmitters (Model A1320) were a larger rectangular shaped transmitter weighing 14 grams with dimensions 18mm x 49mm x 8mm and battery life capacity of 390 days. Both transmitters were programmed with a six-hour mortality switch. The 9.5 g transmitters were < 2% of total body mass ($\bar{x}$ = 477 *g*, SD= 52 *g*, range = 380-610 *g*, *n* = 55) and the 14 g transmitters were < 2.7% of total body mass ($\bar{x}$ = 525 *g*, SD= 49 *g*, range = 430-650 *g*, *n* = 36). Both transmitter weights were below the recommended 3% total body mass recommended for avian telemetry research (Withey et al. 2001).

Throughout each study year, chukars with transmitters were monitored weekly using a four-element Yagi antenna (Telonics Incorporated, Mesa, AZ) and an R -1000 digital radio receiver (Communication Specialists Incorporated, Orange, CA). Chukars were flushed as often as possible to obtain visual confirmation of survival. Chukars were listened for every 24 hrs during the summer field season (May- Aug) and once a week thereafter. Upon discovery of a mortality signal, attempts were made to recover the transmitter within 24 hrs. For each day of monitoring, signals were classified as alive, or mortality, or not heard. When chukars were not heard for several weeks, aerial surveys were conducted from fixed-wing aircraft to relocate missing transmitter signals. Upon discovery of a missing signal, attempts were made to locate the transmitters from the ground and classify each bird visually as alive or dead.

Probable Cause of Mortality

We investigated mortality signals and, depending on evidence at the radio location, classified the probable cause of chukar mortality as avian, mammalian, hunter, or unknown. It is difficult to be sure about causes of mortality and thus we adopted an approach similar to Hagen et al. (2007) by referring to cause specific mortalities as "probable cause of mortality". Efforts to assign probable causes were further hampered by woodrat (*Neotoma* sp.) and antelope squirrel (*Ammospermophilus leucurus*) scavenging of carcasses and hoarding of radio transmitters.

We classified mortalities as avian predation when circumstantial evidence around the kill site included carcasses with all the flesh stripped from the bones, the presence of feathers that had been plucked, and/or fecal remains. Potential avian predators included prairie falcon (*Falco mexicanus*), red-tailed hawk (*Buteo Jamaicensis*), northern harrier (*Circus cyaneus*), sharp-shinned hawk (*Accipiter striatus*), cooper's hawk (*Accipiter cooperii*), ferruginous hawk (*Buteo regalis*), swainson's hawk (*Buteo swainsoni*), and golden eagle (*Aquila chrysaetos*). Mortalities were classified as mammalian when evidence was found of bite marks on the transmitter, cached carcasses, and/or mammal scat or tracks around the kill site. Possible mammalian predators include badger (*Taxidea taxus*), bobcat (*Lynx rufus*), coyote (*Canis latrans*), kit fox (*Vulpes macrotis*), long-tailed weasel (*Mustela frenata*), mountain lion (*Puma concolor*), and skunks (*Mephitis mephitis* or *Spilogale gracilis*). Hunters were assigned as the probable cause of mortality when chukars with transmitters were reported by the public or apparent wounding losses were recovered during the regular Chukar season (Sep-Jan). Probable causes of mortality were classified as unknown when circumstantial evidence was not present or when the transmitter was retrieved from a woodrat nest. Given our objectives and the concurrent timing of the chukar hunt with known period of raptor migration (Smith and Neal 2005, Smith and Neal 2006) all chukars harvested by hunters were excluded from survival modeling.

Survival Modeling

Seasonal and annual survival estimates were calculated from telemetry data using known-fate models in Program MARK 4.1 (White and Burnham 1999). An encounter history was formatted into periods of two week intervals (bins) beginning from our first trapping date of 3 July, 2005 to 1 July, 2007, and coded each encounter as live, dead, or censored. Each chukar was located at least twice within each two-week interval, but chose to bin by this interval given our samples sizes (n = 49 and 79). Sex and weight were included as potential individual covariates and we used Pearson's correlation coefficient to determine if body weight and sex were correlated prior to analysis. After evaluating the Pearson's correlation statistic (r =.54, p =.001), body weight was excluded from our analysis. Sex is a biologically significant variable in relation to seasonal survival, and there was more complete data for sex due to missing weight values. Furthermore the ease of using a binary covariate to obtain model averaged estimates allowed us to exclude weight.

Survival of chukars could be related to fluctuations in predator abundance. To evaluate these ideas we included several models in our *a priori* candidate list that accounted for the fall raptor migration. Tabulations acquired from Hawk Watch

International were used to determine the timing and peak of fall raptor migration in each year (Smith and Neal 2005, Smith and Neal 2006). These data were collected from 15 August to 5 November in 2005 and 2006 with peak migration occurring between 11-24 September in 2005 and 8-21 October in 2006 (Fig. 2). Yearly surveys were collected on the Goshute Mountains in eastern Nevada approximately 40 kilometers south of Wendover and contribute to the long-term trends data for populations of raptors using the Intermountain Flyway. We accounted for the effect of reproduction on survival using a 26 March to 18 June interval based on timing from initial pair bonding through the nesting and brood rearing periods.

Analyse were conducted in two phases. First, we examined 19 *a priori* candidate models accounting for seasonal survival as a function of the raptor migration, raptor migration peak, chukar reproductive time period, and year. This initial list also included models allowing for differences in chukar survival by radio weight to test our hypothesis of lower survival for birds with 14g radios. Second, sex was added as an individual covariate to the top model structure and included this 20^{th} model in our list (Table 1) to assess the effect of sex. Models were constructed using the design matrix and a logit link function in Program MARK 4.1 (Cooch and White 2005). Model selection was based on the minimization of Akaike's Information Criterion corrected for small sample size (AIC_c), and AIC_c weights (w_i). Model-averaged estimates of survival were used to test significance using the Wald test (Agresti 2002).

Information was pooled from all chukars from each of the five study areas given small sample sizes from each study area. Trapping and handling of chukars was approved by the Utah Division of Wildlife Resources (permit #1COLL6160) and

Brigham Young Universities Institutional Animal Care and Use Committee (IACUC approval # 06-0205).

RESULTS

We captured and fitted 128 chukars with two different sized radio transmitters; including 49 chukars in 2005 and 79 chukars in 2006; the sexes included 99 females, 21 males, and 8 undetermined. As noted each chukar was randomly fitted with either a 14g transmitter or a 9.5g transmitter (Table 2) but eleven birds were excluded from analysis (4 in 2005, and 7 in 2006) due to death, loss of signal from emigration out of our study site, or loss of signal due to radio failure within the first month after initial marking. Two birds survive the entire study period (July 2005 to July 2007). One of these birds did not get recaptured in 2006 and was censored due to radio failure in November 2006 despite a recapture in July 2007. A total of 121 birds were used to estimate survival.

Survival

Results of model selection show that our top three competing models account for more than 99% of the total AIC weight (w_i) (Table 3). Raptor migration, peak raptor migration, chukar reproductive period, and year were all important effects contributing to chukar mortality and survival in each of these models. The top model (0.58 of the total weight) included sex as an effect. We hypothesized that radio weight would influence overall survival, but the only model allowing for group differences to reach the top three was third, and it was only given 12% of the AIC weight. Wald test results for a group effect were also not significant ($P = 0.92$).

Survival differed among study years where estimates showed significant ($P <$ 0.01) differences between estimates in 2005 ($\varphi = 0.03$, 95% CI = 0.01 - 0.09), compared to 2006 ($\varphi = 0.26$, 95% CI = 0.18 - 0.38). Model-averaged estimates showed that chukars were less likely to survive ($P = 0.01$) during the fall peak of raptor migration in 2006 (bi-monthly $\varphi = 0.86$, 95% CI = 0.74 - 0.93) than (base survival) outside the migration and chukar reproductive periods (bi-monthly $\varphi = 0.97$, 95% CI = 0.95 - 0.98). In 2005 this difference in estimates (0.80 vs 0.85) was not significant ($P > 0.05$). Differences between base survival and reproductive periods in 2005 and 2006 were also not significant ($P > 0.05$). Comparisons of chukar survival between males and females showed males with higher survival in each time period (Fig. 3), but these differences were not significant ($P > 0.05$).

Probable Cause of Mortality

During the study period we documented 95 deaths (Table 4). The cause of death for many of the birds was unknown (45%). This large percent included transmitters retrieved from woodrat nests (n =28; 29%). The second most prevalent probable cause of mortality was avian predation accounting for (30%). In 2005 hunters killed seven birds (14%); only one bird was killed by hunters in 2006 (1.8%). Three of the seven hunter-killed birds in 2005 were found as intact carcasses shortly after the hunting season opened and we attributed these mortalities to hunter wounding loss. Over the course of our study, eight birds were killed by hunters resulting in 7.7% hunter caused mortality. Only two birds were classified as having been killed by mammalian predators throughout the entire study (Fig. 4).

DISCUSSION

Survival

Seasonal variation in estimated survival of chukars was evident with lower survival associated with the peak of the fall raptor migration (Fig. 3). In 2006 over 35% of all known chukar mortalities occurred between September and November with survival significantly lower during the peak of raptor migration. Raptor species that were most abundant during the migration, and in particular the peak, were red-tailed hawks accounting for 28% and 32% of all raptors observed from the Goshute Mountain surveys during 2005 and 2006, respectively. Sharp-shinned hawks made up 23% and 25% during 2005 and 2006 Goshute raptor counts, while cooper's hawks accounted for 18% and 23% during the same years respectively. These three species made up 69% and 80% of all migrating raptors counted during the fall Goshute Mountain surveys in 2005 and 2006 (Smith and Neal 2005, Smith and Neal 2006). Additionally, we observed golden eagles, northern harriers, and prairie falcons pursuing chukars.

Although we did not detect a difference between transmitter-weight groups, we do not discount an effect of transmitters. Chukars with transmitters would often hold tight and be the last bird to flush. This result is consistent with other research that commonly attributes high mortality to increased conspicuousness and impediment of flight mechanics due to transmitter package (Marcstrom et al. 1989, Reynolds et al. 1991, Slaugh et al. 1989, Ward and Flint 1995). In France for example, Bro et al. (1999) concluded that radio transmitters had negative effects on gray partridge (*Perdix perdix*) survival after accounting for covariates such as physical condition at initial capture and periods of inclement weather.

We found annual variations in estimates of chukar survival between study years (Fig. 5). Yearly estimates of survival from model averaging were significantly ($P < 0.01$) higher in 2006 (26%) than 2005 (3%). Higher estimates in 2006 could be influenced by adult to juvenile ratios; 94% of all birds with transmitters in 2006 were adults while only 75% in 2005 were adults with transmitters. Reproduction and recruitment was excellent in 2005 and we put transmitters on all chukars weighing at least 430 g. Some of these were young of the year from early hatches that met the weight threshold. Sample size was also smaller in 2005 (*n*=49) compared to 2006 (*n*=79) resulting in reduced precision for seasonal estimates that did not match reality since three birds (6.1%) survived the first year.

Previous studies addressing chukar survival have been qualitative with the logical assumption that over-winter survival is a major limiting factor (Christensen 1970). Walter (2000) and Lindbloom (1998) provided quantitative assessment of chukar survival during spring-fall periods but were hampered by relatively small sample sizes. These studies estimated survival at 0.48 in Idaho during a five month period (Lindbloom 2000) and 0.49 and 0.19 for two different study years through spring-fall in Oregon (Walter 2000).

Probable Cause of Mortality

Determining probable causes of mortality for chukars proved extremely difficult. Circumstantial evidence is risky based on presence of diagnostic tracks, feces, or marks on the carcass. These efforts were further hampered by scavenging woodrats and antelope ground squirrels who moved and cached the carcass and/or transmitter away from the initial kill site. Additionally, the rocky nature of chukar habitat reduces the amount and availability of diagnostic evidence such as mammalian tracks. Given these challenges, we classified 45% of mortalities (the largest category) as unknown. This high percent occurred despite retrieval of transmitters generally within 24 hours from the time mortality signal were detected. Our radio transmitters had a lack of motion switch set at six hours, but carcass consumption and/or scavenging activities can delay onset of a mortality signal. Furthermore, caching of transmitters by woodrats and subsequent jostling of them in middens can further prolong onset of a mortality signal. We were able to classify causes of mortality more frequently during the summer when monitoring occurred more frequently, but during the fall and winter field work decreased, resulting in longer periods between onset of mortality signal and examination of the kill or carcass location site.

Avian predators were the most prevalent identifiable estimated cause of mortality. Avian predation accounted for 77% of the of the total estimated predation events. Of these mortalities, nearly one-half occurred during the fall raptor migration period from September-November. These results are consistent with Lindbloom (1998) who estimated avian predators accounted for 60% of mortality, and Walter (2000) reported 59%. Others have documented from observational studies avian predation on chukars as a significant cause of mortality including Jonkel 65% (1927), Bohl 75% (1957), Messerli 50% (1970), and Zembal 100% (1977).

Our results suggest that chukars may be an important food resource for migrating raptors in the Great Basin. Chukars ranked fourth in dietary prevalence based on weight for nesting golden eagles on the California-Nevada border (Bloom & Hawks 1982) and were found in 15.8% of prairie falcon nests in California's Mojave Desert (Boyce 1985). Fielder (1982) discovered that chukars made up 46% of the total prey items of bald eagles around Rufus Woods Lake, Washington. These values may underestimate the annual importance of chukars to raptors because most dietary studies are conducted during the raptor nesting season when chukar populations are generally at the lowest point of the year (Alkon 1974). Moreover, some evidence from related taxa suggested that birds in general may be more prevalent in raptor diets outside of the breeding season; Manosa (1994) in his study of red-legged partridge (*Alectoris rufa*) ranked 1st in annual dietary frequency (18%) and relative weight (57%) for goshawks in Spain.

Mammal predation on chukars was not classified frequently during our study at only 1.8%. Evidence of mammalian predation at chukar carcass sites usually could not be distinguished between predation and scavenging behavior. Christensen (1970) reported that coyotes were the main mammalian predator in Nevada. In Idaho, Lindbloom (1998) reported 40% of mortalities were caused by mammals, and in Oregon mammals caused 41% of the total depredation on chukars (Walter 2000). These studies did not report the possibility of scavenging on chukar carcasses.

Mortality of chukars resulting from sport hunters was low during 2005 and 2006. Only 7% hunter-caused mortality for both study years combined. In 2005 hunters shot seven birds compared to 2006 when a hunter shot one (Table 4). This difference could be due to higher chukar abundance in 2005 compared to 2006. Managers believe that chukar harvest correlate well with abundance since hunting efforts decrease when abundance is low and increase when abundance is high (Christensen 1958, 1970). These values are much lower than other estimates of hunter harvest in other states, Walter (2000) estimated a 25% harvest in 1997 and 14% in 1998 in eastern Oregon while Harper (1958) estimated 4% harvest in California, and Christensen (1970) estimated 25% in

Nevada. This provides evidence of variable harvest rates across the distribution of chukars in western North America. Harvest rates could be associated with accessibility, many hunters will only hunt areas close to roads and thus harvest rates may be higher in these areas.

MANAGEMENT IMPLICATIONS

Chukars are the number one pursued game bird by sport hunters in Nevada and Oregon and have quickly become one of the most popular upland game species in the Western United States (Christensen 1996). Despite this popularity, managers have largely been limited to management based on qualitative information published more than 30 years ago (Christenson 1970).

Understanding chukar survival and causes of mortality are vital to management. While predation is perhaps a limiting factor, predator control is not a viable option because chukar habitat encompasses vast amounts of land and thus predator control would not be cost effective. Furthermore a substantial amount of mortality events throughout the Western United States are identified to protected avian species.

This information may also help guide the timing of release and restocking efforts. Some states maintain captive breeding programs devoted to releasing pen-raised birds into the wild to supplement populations for hunting. Release times usually precede the fall hunting season and are often in the middle of the fall raptor migration. We recommend that if these practices are to be continued with a goal of maximizing hunter opportunity then releases coincide with estimated harvest dates as closely as possible. Sport hunting of chukar has occurred in all of our study areas except Antelope Island for several decades. Our data support Christensen's 1970 view that hunting pressure for chukars is self-regulating because hunting efforts decreases with low population size and that rough terrain and remoteness limits harvest. Our first study year (2005) was an excellent chukar hunting year and seven birds were harvested by hunters compared to only one in 2006. Increased research in the future is needed to supply quantitative biological data regarding basic life history characteristics of chukars throughout their range in order to implement prescriptive management plans that reflect the scientific basis.

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Figure 1. These diagrams show the dimensions for our original Utah trap that was designed for trapping chukars at small-game guzzlers. These diagrams are looking both from the front (top) and side (bottom) views. This design can be modified and applied to a host of situations and shows promise for other birds as well as chukars.

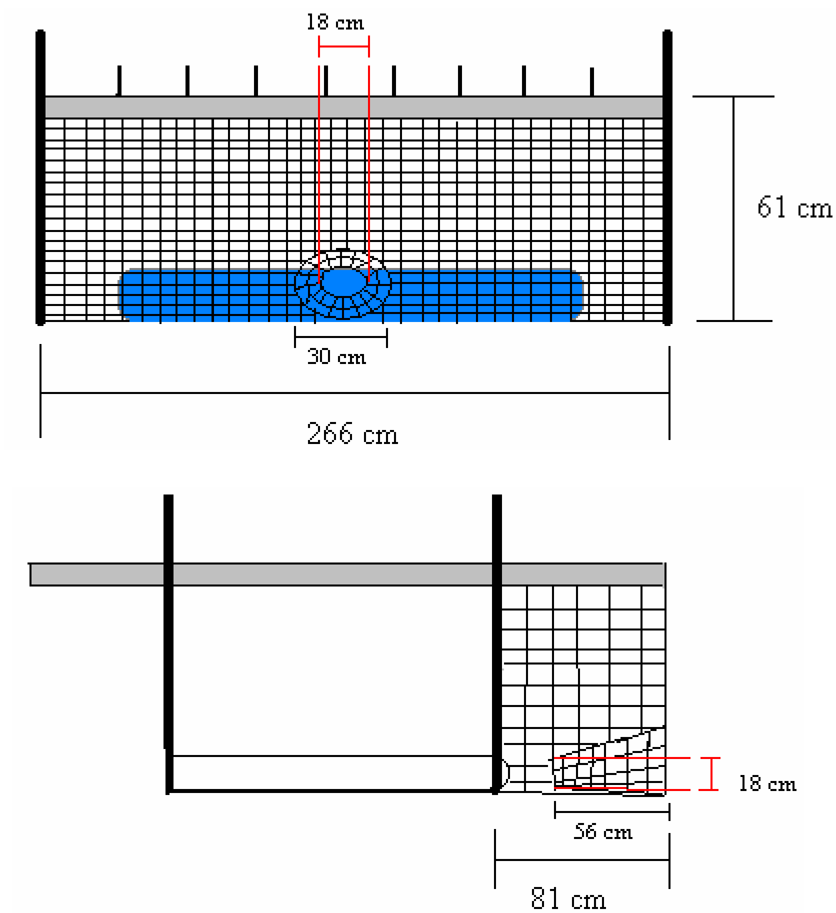

Figure 2. These data for raptor migration were collected by Hawk Watch International on the Goshute Mountains in Nevada (Smith and Neal 2005, Smith and Neal 2006).

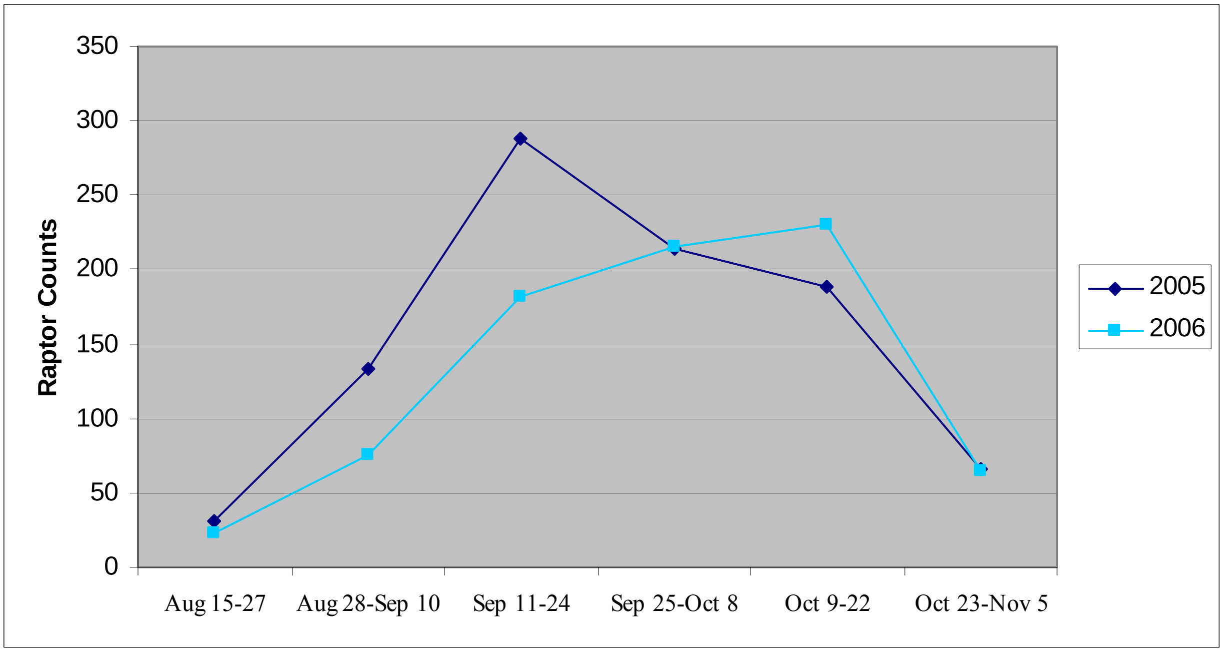

Figure 3. Note here the estimates of survival of male and female chukar representing model-averaged estimates of survival.

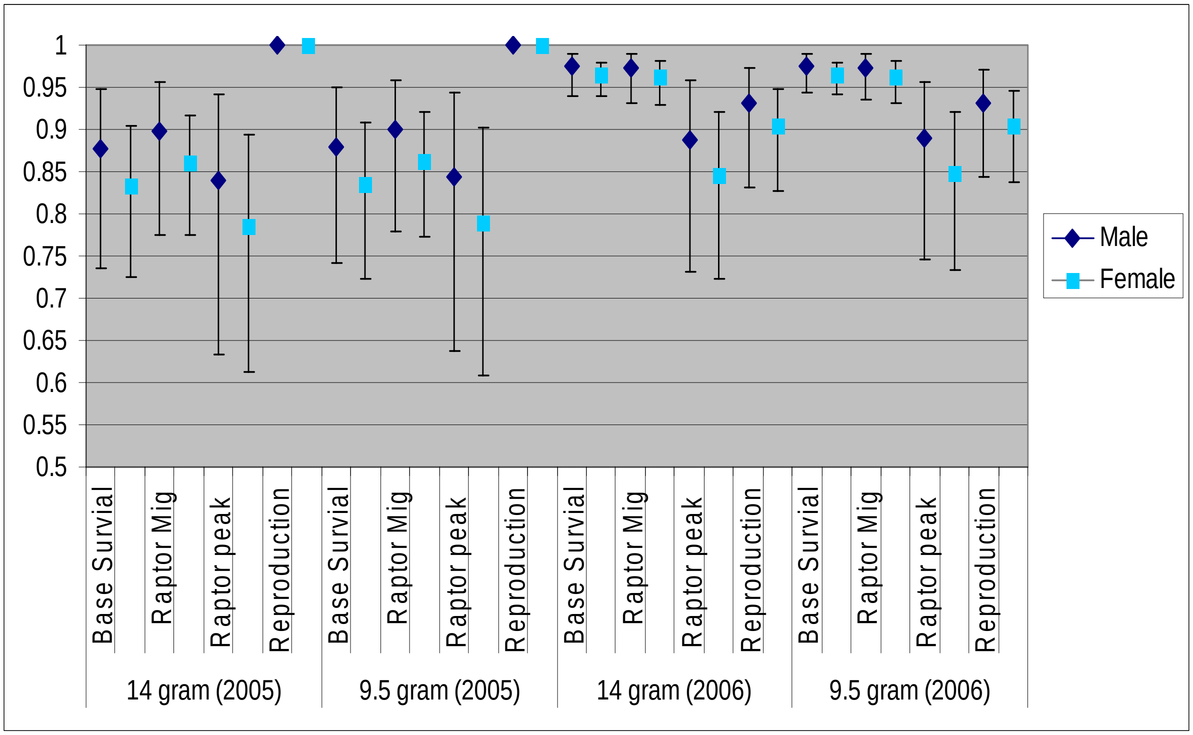

Figure 4. Listed here are the probable causes of mortality for chukars during 2005 and 2006 in Western Utah.

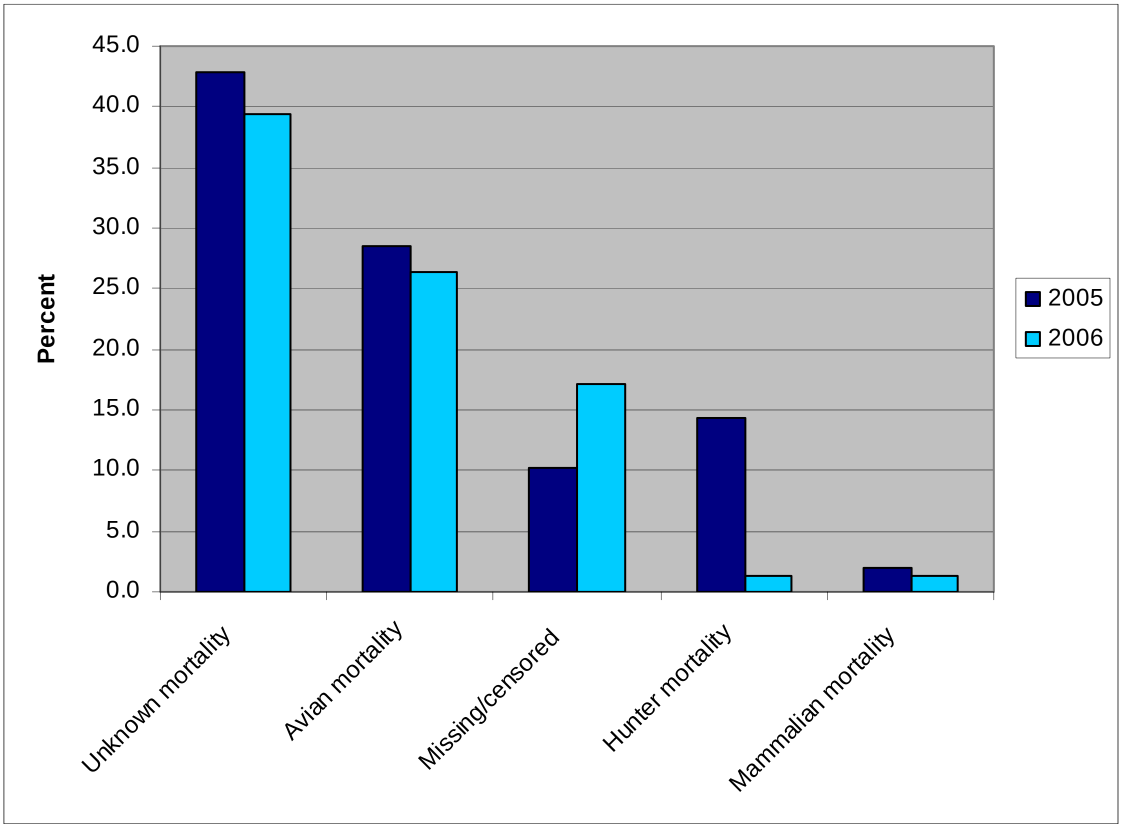

Figure 5. These data plot the yearly survival of adult chukars from June 2005 to July 2007.

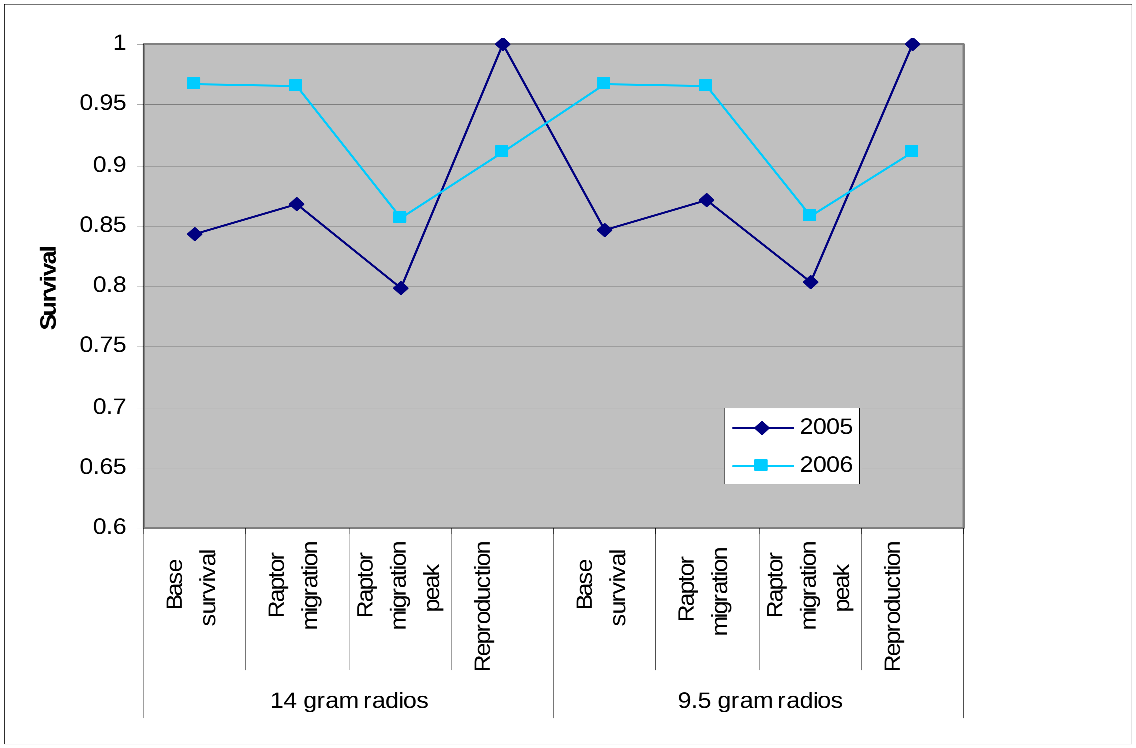

Table 1. These *a priori* models relate raptor migration, migration peak, reproduction, time, and sex on survival of adult chukars in Western Utah, USA, June 2005-July 2007.

Model	Hypothesis description	Model structure
1	Survival constant by year and two-week time intervals	(.)
2	Survival varied by time	t
3	Survival varied by year	Year
4	Survival varied by radio weight (group)	Group
5	Survival varied from base during raptor migration	Base[b]+raptor
6	Survival varied by group and time	Group×t
7	Survival varied by group and year	Group×year
8	Survival varied by group multiplicatively with base and raptor migration	Group(base+raptor)
9	Survival varied by group and year multiplicatively with base and raptor migration	Group×year(base+raptor)
10	Survival varied by group multiplicatively with base, raptor migration, and raptor peak	Group(base+raptor+peak)
11	Survival varied by group and year multiplicatively with base, raptor migration, and peak	Group×year(base+raptor+peak)
12	Survival varied by group and year multiplicatively with season	Group×year(season[a])
13	Survival varied by group and season	Group×season
14	Survival varied by year multiplicatively with base and raptor migration	Year(base+raptor)
15	Survival varied by base, raptor migration, and raptor peak	Base+raptor+peak
16	Survival varied by year multiplicatively with base, raptor migration, and raptor peak	Year(base+raptor+peak)
17	Survival varied by season	Season
18	Survival varied by year and season	Year×season
19	Survival varied by year and season with an additive group effect	Year(season) + group
20	Survival varied by year and season with sex as an additive effect	Year(season) + sex

[a] Season includes base, raptor migration, raptor migration peak, chukar reproductive time period, and base survival.
[b] Base survival is time intervals outside of the raptor migration, raptor migration peak, and chukar reproductive time period when these periods are in respective models

Table 2. This tabulation shows the number of male and female chukars captured and radiomarked at five study sites in Western Utah, USA, 2005-2006.

2005

Area	Male 14g	Female 14g	Male 9.5g	Female 9.5g	Sex undetermined 14 g radio	Total	
BX[b]		2		1	3	6	
DW[d]	1	13		5		19	
FS[e]	2	13		4	5	24	
Total	3	28		10	8	39/10	Sub total 14g/9.5g radios
						49	Total

2006

Area	Male 14g	Female 14g	Male 9.5g	Female 9.5g	Sex undetermined 14g radio	Total	
AI[a]	1	1	3	19		24	
BX[b]	3	3		6		12	
DM[c]	3	5	1	5		14	
FS[e]	4	5	3	17		29	
Total	11	14	7	47		25/54	Sub total 14g/9.5g radios
						79	Total

[a] Antelope Island State Park
[b] Box Elder County
[c] Deep Creek Mountains range
[d] Dugway Mountain range
[e] Fish Springs Mountain range

Table 3. Shown are the rankings of *a priori* models evaluating raptor migration, migration peak, reproduction, time, and sex on survival of adult chukars.

Model structure	Model	AICc	Δ AICc	w_i	K	Dev
$S_{year(season^{a})+sex}$	20	548.72	0.00	0.58	9	530.57
$S_{year(season)}$	18	550.12	1.40	0.29	8	534.00
$S_{group+year(season)}$	19	551.89	3.18	0.12	9	533.74
$S_{group\times year(season)}$	12	557.13	8.41	0.001	16	524.68
$S_{group\times year}$	7	568.42	19.70	0	4	560.39
$S_{year(base^{b}+raptor+peak)}$	16	569.02	20.30	0	6	556.95
$S_{group\times year(base+raptor+peak)}$	11	571.34	22.62	0	12	547.08
$S_{group\times season}$	13	571.54	22.83	0	8	555.43
$S_{group\times year(base+raptor)}$	9	574.64	25.92	0	8	558.52
S_{year}	3	574.83	26.12	0	2	570.82
$S_{year(base+raptor)}$	14	575.26	26.54	0	4	567.23
$S_{base+raptor+peak}$	15	577.97	29.25	0	3	571.95
$S_{group(base+raptor+peak)}$	10	577.99	29.27	0	6	565.92
S_{season}	17	579.71	30.99	0	4	571.68
S_{time}	2	582.35	33.63	0	53	471.45
$S_{group(base+raptor)}$	8	583.08	34.36	0	4	575.04
S_{group}	4	583.33	34.61	0	2	579.32
$S_{base+raptor}$	5	585.49	36.77	0	2	581.48
$S_{(.)}$	1	587.65	38.93	0	1	585.64
$S_{group\times time}$	6	676.62	127.90	0	106	444.29

[a] Season includes base, raptor migration, raptor migration peak, chukar reproductive time period, and base survival.

[b] Base survival is time intervals outside of the raptor migration, raptor migration peak, and chukar reproductive time period when these periods are in respective models.

Table 4. Shown are the number and percent of chukar mortality attributed to probable causes in Western Utah.

	No. of mortalities					
Probable Cause	2005 9.5 g	2005 14 g	2006 9.5 g	2006 14 g	Subtotal	%
Predator						
Avian	1	13	15	5	34	30.1
Mammal	1	0	0	1	2	1.8
Hunter[a]	2	5	1	0	8	7.4
Missing/censored	2	3	4	9	18	15.9
Unknown	4	17	22	8	51	45.1
Total	10	38	42	23	113	100

[a] Hunter percentage was calculated as the percent of birds killed by hunters that were available to harvest (i.e. exclude AI in 2006)