

AN ABSTRACT OF THE THESIS OF

David Speten for the degree of Master of Science in Wildlife Science presented on November 25, 2014.

Title: Assessment of Mule Deer Fawn Survival and Birth Site Habitat Attributes in South-Central Oregon.

Abstract approved: _____

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Mule deer (*Odocoileus hemionus*) populations in south-central Oregon are near their lowest levels since census efforts began in 1961. I investigated fawn survival, cause-specific mortality, and factors contributing to mortality from 2010 – 2012 to identify potential causes for the decline. I also explored pre-parturition and parturition site characteristics.

I studied fawn survival among two different population segments in south-central Oregon. Adult females ($n = 126$; > 1 year old) were captured on winter ranges to collect biological samples and attach transmitters. Vaginal implant transmitters facilitated the capture of fawns ($n = 127$). Fawns (birth to < 1 year old) were radio-collared and mortalities investigated. Fawns died primarily as a result of predation, but other sources of mortality included vehicle collisions, fence entanglement, hunter harvest, drowning, disease, and unknown causes. Predation was primarily attributed to coyotes (*Canis latrans*) but bears (*Ursus americanus*), cougars (*Puma concolor*), and bobcats (*Lynx rufus*) also preyed on study animals. To investigate survival, I developed known-fate models within Program MARK using 9 individual covariates and 3 environmental

covariates. Estimated annual fawn survival was 34% and positively correlated with a linear time trend. Survival was not correlated with indicators of female body condition including rump fat, blood serum non-esterified fatty acids, blood serum triglycerides, and blood serum β -hydroxybutyrate. Survival did not differ by fawn sex, fawn weight, date of birth, wintering area, or whole blood selenium levels. Environmental covariates including precipitation, year, and temperature did not significantly explain fawn survival. I concluded that predation might be limiting mule deer population growth in south-central Oregon. However, I did not explore the full suite of factors that would indicate sources of population regulation.

I also investigated adult female habitat use prior to and during parturition from 2010 – 2013. I measured 10 habitat attributes at all parturition sites for comparison to randomly selected pre-parturition locations within each adult female's seasonal range. Birth sites that occurred in habitats characterized by juniper (*Juniperus occidentalis*), were closer to water and within greater vegetative cover compared to summer range sites in the same habitat type. Other birth sites were located in areas characterized by conifer spp. (*Abies concolor*, *Pinus spp.*, *Pseudotsuga menziesii*) and in these areas there were no differences in habitat attributes between birth sites and summer range sites. I concluded that within each habitat type birth sites might be chosen to maximize predator avoidance and within juniper habitats low water resources might contribute to site selection.

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Assessment of Mule Deer Fawn Survival and Birth Site Habitat Attributes in South-
Central Oregon

by
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APPROVED:

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

David Speten, Author

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CONTRIBUTION OF AUTHORS

Dr. Dana Sanchez contributed to study design and writing chapters 2 and 3. Dr. Julia Burco performed veterinary services, assisted with statistical analysis, interpreted blood results, and contributed to chapter 2. Dr. Katie Dugger contributed to my understanding of Program Mark, analysis of survival results, and writing chapter 2.

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DEDICATION

I dedicate this to my parents Jim and Donna Speten who took me on hunting, fishing, and camping expeditions and fostered my love for the outdoors.

CHAPTER1: GENERAL INTRODUCTION

Mule deer (*Odocoileus hemionus*), found throughout much of the western U.S., are important to recreation, the economy, and culture. For these reasons, mule deer have been studied extensively, accounting for >1,180 peer reviewed publications since 1960 (*Wildlife & Ecology Studies Worldwide*; accessed 10/5/2014). Despite these efforts to understand the needs of the species, populations within south-central Oregon remain below management target levels (The Klamath Tribes 2005).

Mule deer population abundance in south-central Oregon might be lower than in the 1960's (Figure 1.1). However, understanding current abundance compared to pre-1960's levels is complicated. Peter Ogden, a trapper hired by The Hudson Bay Company provided the first written account of mule deer in the region (Binns 1967). In 1826, wild animals were so scarce that he reduced the size of his party, reduced rations, culled horses for meat, and resorted to eating dogs provided by the Klamath Indians (Salwasser 1979). John Work and his party also trapped beaver in northern California during the fall of 1832 and resorted to consumption of horse meat due to a scarcity of game (Maloney 1945). Similarly, John Fremont found no big game during an expedition across the winter range in 1843 (Fremont 1847). These accounts attest to the historical scarcity of deer found in the area.

Following settlement and land use conversion in the late 1890's, citizen conservation began as a response to deer scarcity (Clements and Young 1997). In 1920, managers reduced livestock on the Modoc National Forest (winter range) and California game management regulated deer harvest (Salwasser 1979). Additionally, logging and

fire opened the forest canopy, releasing nutrients to the remaining vegetation and altering succession which contributed to the establishment of brush fields (Salwasser 1979).

Moreover, the introduction of cheatgrass (*Bromus tectorum*) was initially viewed as favorable as it provided a supply of green forage weeks before native grasses (Salwasser 1979), and a rabies outbreak in 1915 resulted in a mass coyote (*Canis latrans*) die-off, a major predator of mule deer fawns in southern Oregon (Trainer 1981). Deer populations appear to have responded by increasing as it was estimated 6,700 deer were on the Modoc National Forest in 1923 and 27,000 deer occupied the range in 1935 (Fischer et al. 1944). It was also estimated that 20,000 deer migrated from Oregon summer ranges in 1939 (Randle 1939).

The Oregon Department of Fish and Wildlife (ODFW) began to track deer abundance in the 1960's using track count transects (Salwasser 1979). Track counts consist of counting the number of deer tracks that cross a pre-established transect, the number of which can be compared between years to provide an index to the mule deer population. The index has not been validated to coincide with population abundance. However, if assumptions of constant environmental variation, animal behavior, and track detectability are upheld, the index might still provide a relative estimate of a changing population over time. The ODFW established 80 transects throughout the Fremont and Winema National Forests in 1964. A subset of these track counts indicated mule deer populations had declined substantially through the late 1960's and 1970's (Figure 1.1; David Speten, The Klamath Tribes, unpublished data). The decline was attributed to a lack of quality forage leading to poor female condition, poor fawn survival, and low recruitment of fawns into the adult population

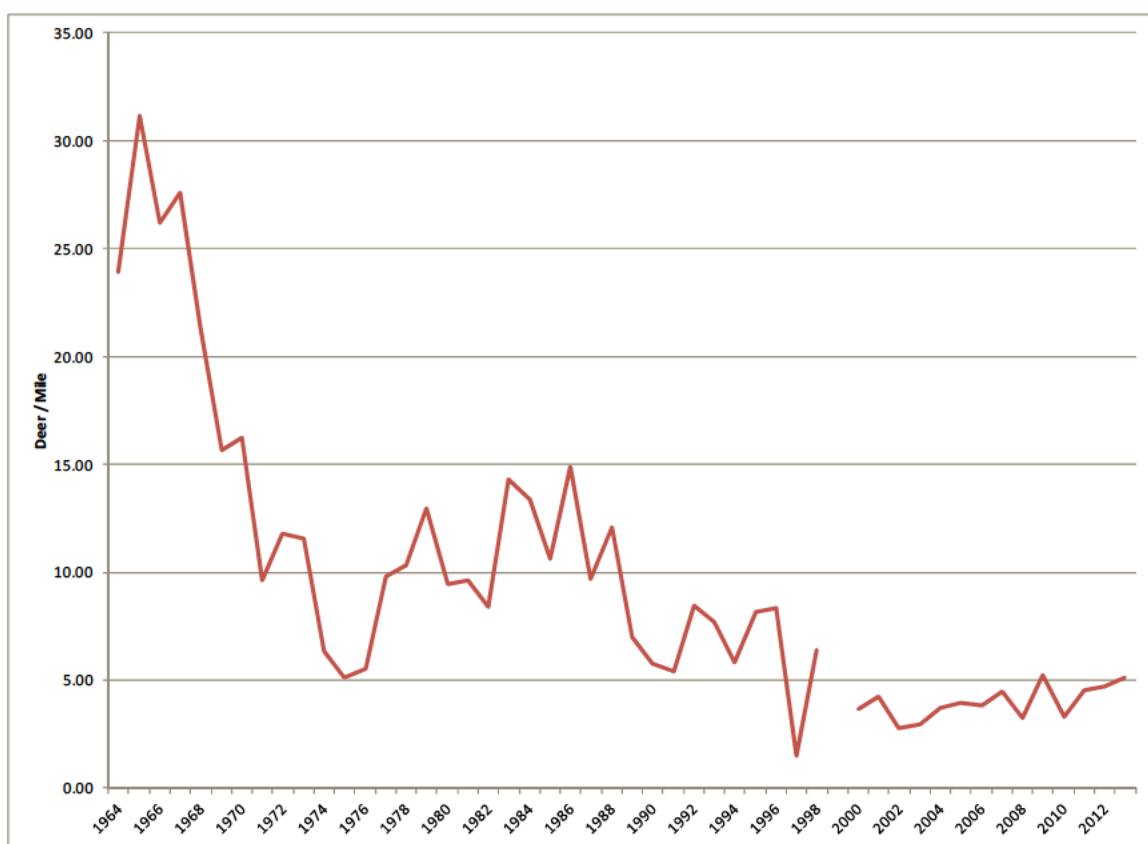


Figure 1.1: Index of adult mule deer (*Odocoileus hemionus*) abundance per square mile derived from 33 track count transects within the Sprague herd management unit, south-central Oregon, USA, 1964 – 2013.

(Salwasser 1979). Peek (2002) correlated population abundance with vegetation characteristics and attributed population declines to poor forage condition as a result of forest maturation, fire suppression and canopy closure. Mule deer populations continued their decline into the 1990's, but have stabilized at low levels since then (Figure 1.1).

Changes in mule deer population abundance are driven by reproduction (pregnancy rates and fetal counts) and annual survival of adults and fawns (White and Bartmann 1997). Reproduction can be high even when forage is limiting (Salwasser 1979), and adult survival can show little annual variation (Unsworth et al. 1999, Gaillard et al. 2000). However, annual fawn survival can be highly variable with many sources of mortality, and survival can be influenced by many factors (Lomas and Bender 2007).

Ecological theory also suggests wildlife populations can be regulated by top-down or bottom-up processes (Power 1992). Under both scenarios, rates of predation can be high but the relative relationship of the population to environmental carrying capacity (K) can determine whether predation results in additive or compensatory mortality (Pierce et al. 2012). Top-down regulation can result in a population far below K , predation would be an additive source of mortality, and populations would be characterized by good body condition and high rates of reproduction (Pierce et al. 2012). Conversely, predation can be compensatory when the population is near K and habitat conditions prevent population growth (bottom-up; Pierce et al. 2012). Due to intraspecific competition, the population would have poor body condition and low rates of reproduction (Hurley et al. 2011, Pierce et al. 2012). Efforts initiated by wildlife managers to affect population change can vary depending on the relative strength of the processes driving population abundance.

Current mule deer population abundance might be perceived to be low when compared to levels experienced in the 1960's (Figure 1.1). Because of the importance of mule deer to recreation, the economy and culture, managers wish to increase populations beyond their current abundance. The ability of the population to respond to land management actions, as evidenced through the grazing, logging, and fire history of the area (Salwasser 1979), also indicates that managers might be able to affect population change through similar management actions.

I captured mule deer fawns for three consecutive years (2010 – 2012). I explored fawn survival rates and causes of mortality. I incorporated factors that would indicate bottom-up processes (forage conditions as reflected in maternal body condition) and indications of top-down processes in my models to estimate monthly rates of survival from birth to 1 year of age (Chapter 2). During deer fawn capture attempts, I observed habitat use of adult females. I questioned whether parturition site characteristics differed from use of habitat prior to the parturition period. Therefore, I quantified habitat variables of birth sites and sites within an adult female's pre-parturition range to identify factors that influenced parturition site selection (Chapter 3).

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CHAPTER 2: SURVIVAL AND MORTALITY OF MULE DEER FAWNS, SOUTH-CENTRAL OREGON

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Mule deer (*Odocoileus hemionus*) populations throughout the western U.S. peaked in the 1960's (Julander and Low 1976) and experienced widespread declines into the 1970's (Unsworth et al. 1999), before remaining steady or slightly increasing thereafter (Kie and Czech 2000). However, an unvalidated population index indicates populations in south-central Oregon experienced an additional decline in the 1980's and 1990's and they have not yet recovered (Figure 1.1). Because mule deer are important for recreation, the economy and culture, land managers in south-central Oregon share a desire to increase mule deer abundance above current levels (The Klamath Tribes 2005).

Historical accounts indicate mule deer populations in south-central Oregon might have been low prior to European settlement. Journal entries illustrating the expeditions of Peter Ogden (1826; Binns 1967), John Work (1832; Maloney 1945), and John Fremont (1843; Fremont 1847) into south-central Oregon indicate deer were scarce and low wildlife populations necessitated consuming horse meat to feed their parties. Following European settlement and initiation of conservation measures in the 1890's, changes to the vegetation community in the early 1900's, which likely increased environmental carrying capacity, and a natural rabies outbreak in 1915 that reduced the coyote population (a primary predator of mule deer fawns), the mule deer population appears to have responded by increasing to an unsustainable level in the 1960's (Salwasser 1979).

Mule deer populations can decline for many reasons but annual population fluctuations can be the result of adult (> 1 year old) and fawn (birth to 1- year old) survival (White and Bartmann 1997). Annual adult survival often shows little variation compared to fawn survival which can be highly variable from year to year (Unsworth et

al. 1999, Gaillard et al. 2000). Fawn survival was implicated as the primary driver of population variability in Montana, Idaho, and Colorado (Gill et al. 1999) and in Arizona and California (Connolly 1981).

The majority of deer within south-central Oregon are migratory and occupy a similar summer range found within the Fremont and Winema National Forests (Salwasser 1979). However, they occupy different primary winter ranges near the towns of Silver Lake, Dairy, and Bly (T. Collom, Oregon Department of Fish and Wildlife, personal communication). In 1961, 80 track count transects were established on these summer ranges as a technique to create a mule deer population index (Eastman 1962). This index declined up to 90% between 1964 and 2013 (Figure 1.1). Declines throughout the 1960's and 1970's were primarily attributed to declining forage conditions (Salwasser 1979, Peek et al. 2002) and fawn survival, of which coyote predation was identified as the primary cause of mortality (Salwasser 1978). We hypothesized that if the population is currently below carrying capacity, and that poor fawn survival is precluding increases in this population.

Proximate causes of fawn mortality can include predation, accidents, starvation, disease and anthropogenic obstacles (Trainer et al. 1981, White et al. 1987, Pojar and Bowden 2004, Bleich et al. 2006, Lomas and Bender 2007). However, the ultimate cause of mortality can be related to resource stress, chronic disease, or nutritional status and can be influenced by a later birth date, lower birth weight and poor maternal body condition (Pojar and Bowden 2004, Bleich et al. 2006, Monteith et al. 2014). High nutritional condition in the female can lead to improved fawn survival by influencing birth mass, early immunity, rate of fawn growth, vigor at birth, and quantity and quality of milk

(Lomas and Bender 2007). Conversely, adult females in poor condition would be expected to exhibit low pregnancy rates (Monteith et al. 2014), non-synchronous parturition dates, and low fawn birth weights (Bowyer 1991), resulting in higher rates of fawn mortality.

Female body condition influences fawn survival (Stephenson et al. 2002). The depth of rump fat is a reliable indicator of total body fat stores (Stephenson et al. 2002), and measures of non-esterified fatty acids (NEFA; Seal et al. 1978), triglycerides (TRI; DelGiudice et al. 1990) and β -hydroxybutyrate (BHBR; Bowden 1971), can be used as indicators of maternal condition. Low NEFA values in white-tailed deer indicate a diet adequate in nutrition to maintain a positive energy balance, whereas increased NEFA values indicated nutritional stress and mobilization of fat reserves (Seal et al. 1978). Elevated TRI in white-tailed deer (*O. virginianus*) indicated lypolysis during periods of low nutrition (DelGiudice et al. 1990) and elevated BHBR indicated severe nutritional stress in domestic sheep (Bowden 1971). Measurements of rump fat and blood lipids are one line of evidence indicating whether deer in south-central Oregon are receiving adequate levels of nutrition to support maternal body condition and subsequent fawn survival, or whether food resources might be limiting.

Selenium level in maternal females is another nutritional measure that has been positively correlated with fawn survival (Flueck 1994). Selenium is a dietary mineral that plays a role in numerous important biological functions including antioxidant defense, creation of thyroid hormone, DNA synthesis, fertility and reproduction (Mehdi et al. 2013). Low selenium in cervids can produce unthriftiness, chronic diarrhea, decreased growth rate, impaired immune response, lower reproductive efficiency, higher

post-natal mortality, lower fecundity, and lower survival (Ullrey et al. 1981, Hein et al. 1994, Wolf et al. 2008). In the neighboring state of California, selenium supplementation increased survival of black tailed deer (*O. h. columbianus*; Flueck 1994). Historically the Pacific Northwest has had low selenium in vegetation, crops (Carter et al. 1968), and livestock (Oldfield 1988); however, selenium levels in Oregon deer have not been documented.

The diversity and interaction of factors influencing survival complicates identification of specific management actions that can produce population changes. Because local mule deer populations are low compared to historic accounts (Speten Chapter 1) and because deer populations in south-central Oregon had previously declined due to poor forage conditions (Salwasser 1979, Peek 2002), we expected to find low rates of fawn survival and we hypothesized that female body condition would explain significant amounts of variation in fawn survival. Additionally, because birth weight can influence survival (Lomas and Bender 2007) and male fawns tend to be larger than female fawns (Unsworth et al. 1999), we predicted males would survive at a higher rate than females.

Spatial separation between study areas also might be associated with differences in forage availability, weather patterns, predators, or migration obstacles. Consequently, we hypothesized that fawn survival would vary between capture areas and years. Finally, birth synchrony evolved as a predation avoidance technique (Bowyer 1991), therefore, we hypothesized that fawn survival would favor fawns born during the peak of parturition. Our objectives were to explore one potential cause of low mule deer population abundance in south-central Oregon by 1) determining overall annual fawn

survival, 2) identifying sources and contributing factors to mortality, and 3) assessing variability in survival between population segments that winter in three different locations.

STUDY AREA

Our study area was located in south-central Oregon, east of the Cascade Mountains, and comprised approximately 1.266 million hectares (Figure 2.1). Public lands were managed by the U.S. Forest Service (48%; Winema and Fremont National Forests), the Bureau of Land Management (8%), the US Fish and Wildlife Service (1%; The Klamath Wildlife Refuge), and a mixture of state agencies (1%). Privately owned lands (42%) were primarily managed for agriculture, commercial logging, and residential development.

Elevations ranged from 1,230 m to 2,550 m. Soil types varied greatly throughout the area due to the influence of pumice and ash created by the eruption of Mount Mazama approximately 8,000 years ago (Youngberg and Dyrness 1959). Annual precipitation averaged 31.5 cm from 2010 – 2012 at the nearest weather monitoring station in Klamath Falls, Oregon. Most of the precipitation occurred during the winter and fell as snow. Minimum temperatures ranged from -19° C to -28° C, while maximum temperatures ranged from 34° C to 37° C (National Oceanic and Atmospheric Administration 2014). Plant associations within the study area were described in detail by Hopkins (1979) and Volland (1985) and were verified through further vegetation sampling (Chapter 3; Speten and Sanchez).

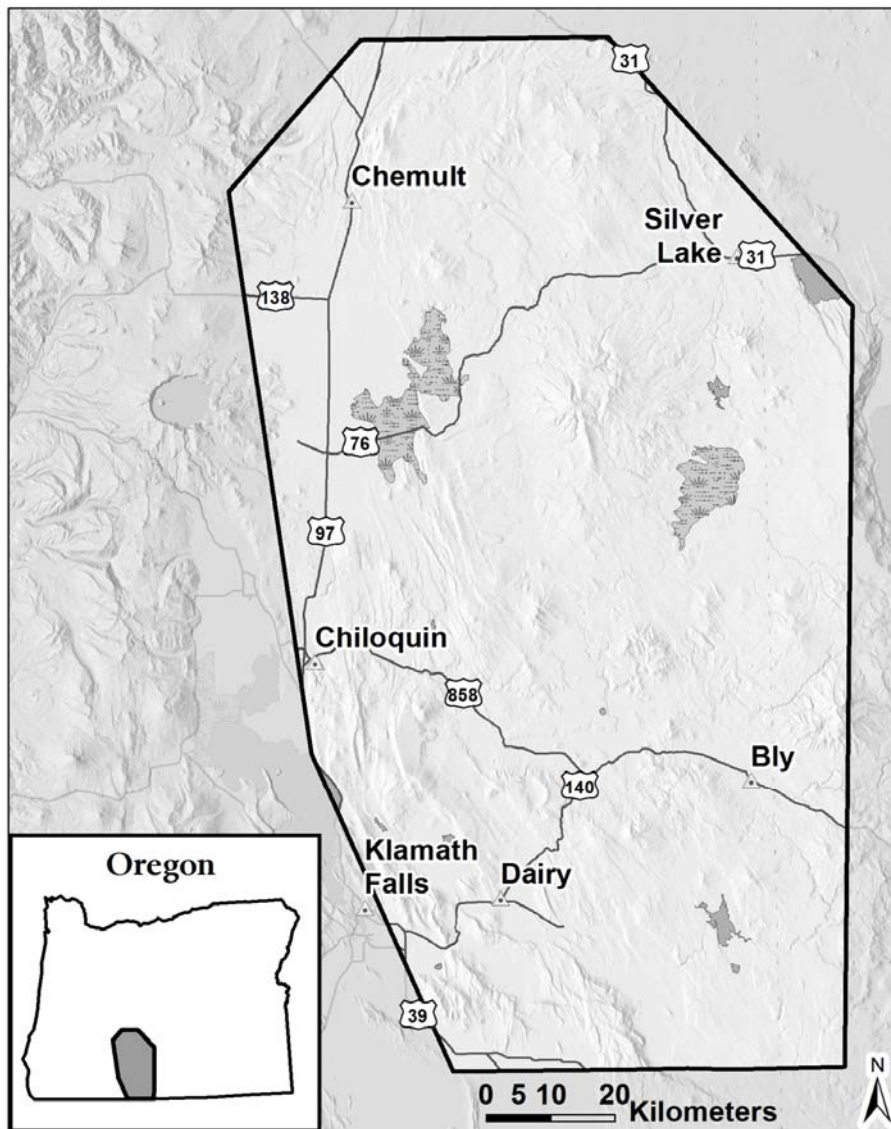


Figure 2.1: Study area encompassing the location of all mule deer (*Odocoileus hemionus*) fawn captures in south-central Oregon, USA, 2010 – 2012.

We studied female mule deer and their fawns from three wintering herds, near the towns of Silver Lake (SL), Dairy (DA) and Bly, Oregon (Figure 2.1). The habitat of each wintering area was primarily comprised of widely spaced western juniper (*Juniperus occidentalis*), low sagebrush (*Artemisia arbuscula*), scab rock flats, and ponderosa pine (*Pinus ponderosa*) forests with a bitterbrush (*Purshia tridentata*) understory. All SL and Bly deer were migratory; DA deer comprised both migratory and non-migratory deer. Non-migratory study animals remained in the wintering habitat type. Study animals that migrated shared a single summer range comprising a mix of single or mixed conifer types interspersed with meadows and riparian areas. Dominant conifer species included ponderosa pine, white fir (*Abies concolor*), lodgepole pine (*Pinus contorta*), and Douglas fir (*Pseudotsuga menziesii*). Understory vegetation was dominated by bitterbrush at low to mid elevations, while snowbrush (*Ceanothus velutinus*) and greenleaf manzanita (*Arctostaphylos patula*) predominated at higher elevations.

METHODS

Capture and Handling

Adult.— We captured 40, 41, and 47 adult (>1 year old) females in 2010, 2011 and 2012; respectively. Capture occurred via helicopter net gunning (Krausman et al. 1985) in April on three distinct winter ranges near the towns of Silver Lake, Dairy, and Bly, Oregon (Figure 2.1). Monitoring deer near Bly proved difficult; therefore, we limited capture to Silver Lake and Dairy in subsequent years. We physically restrained does with hobbles to prevent movement and blindfolded them to reduce stress. We administered sedatives to further reduce stress and struggling from the procedures: azaperone (15 mg intramuscularly) and midazolam (7.5 – 15 mg intravenously). Drug effects lasted for 10

– 20 minutes and did not necessitate reversal. We determined pregnancy status through ultrasound analysis (Ibex pro, E.I. Medical Imaging, Loveland, CO; Bishop et al. 2007) or external abdominal palpation (J. D. Burco, Oregon Department of Fish and Wildlife, personal communication). Non-pregnant females were neither marked or collared and were immediately released. We fitted each pregnant female with a radiocollar (Followit, Lindesberg, Sweden; Advanced Telemetry Systems, Isanti, MN; Telonics, Mesa, Arizona) and an ear tag. We used a vaginoscope (Jorgensen Labs, Loveland, CO) and sterilized lubricating jelly to implant a vaginal-implant transmitter (VIT; Advanced Telemetry Systems, Isanti, MN) in the vaginal canal as a primary method to locate and capture fawns (Stephenson et al. 2002, Bishop et al. 2007). Between uses, the vaginoscope was cleansed and stored within a 2% Chlorhexidine solution (MWI, Meridian, ID).

Fawns.— Vaginal implant transmitters alerted us to birth events. Upon expulsion during birth, individual VITs registered a temperature change due to exposure to the outside environment. When the transmitter temperature dropped below 32° C, the transmitter pulse rate doubled from 40 pulses per minute (ppm) to 80 ppm, indicating that parturition had occurred (Bishop et al. 2007). Therefore, we monitored VIT radio frequencies daily to ensure detection of birth events within 24 hours. We searched VIT-ejection sites (birth sites) in an attempt to capture fawns, and expanded our search to grid the surrounding area if fawns were not located within the birth site (Bowman and Jacobson 1998). Alternatively, we would locate the doe and her location would become the center of the search area (Bishop et al. 2007). Because we suspected many fawns

died prior to capture and fawns quickly developed the ability to evade capture, we only made 3 attempts to capture fawns from a given female.

Upon locating a fawn, we used standard procedures to ensure the safety of fawns during capture and handling (Pojar and Bowden 2004, Lomas and Bender 2007, Carstensen et al. 2009). Each fawn was sexed, weighed, ear-tagged, and fitted with an expandable radio-telemetry collar equipped with a mortality sensor set to indicate inactivity when motionless for 4 hours or more (Telonics, Mesa, Arizona; Advanced Telemetry Systems, Isanti, MN).

During the course of daily female monitoring activities, we realized additional opportunities for fawn captures. Some females retained functional radio collars for more than one year, allowing us to locate them during the anticipated birth window in subsequent years and thus providing opportunities for fawn capture attempts. Similarly, we occasionally encountered unmarked females during fawning season. In both instances we began searching for fawns with the location of the female as the center of the search area, continuing our search in an expanding grid pattern (Bowman and Jacobson 1998). These opportunistic searches resulted in the capture of 10 and 2 additional fawns in 2011 and 2012, respectively. All activities were performed in accordance with Oregon Department of Fish and Wildlife (ODFW) and Oregon State University's Animal Care and Use Committee permit stipulations (ODFW permit #'s 017-09, 010-10, 03-11, 049-12; OSU ACUP #4035).

Maternal Covariates

Rump fat thickness.— We determined rump fat thickness via ultrasound by measuring to the nearest millimeter “at its thickest point immediately cranial to the cranial process

of the tuber ischium (pin bone)” (Stephenson et al. 2002:558). We used the program STATA (v. 13.1, StataCorp LP, College Station, Texas) to perform all statistical tests with significance determined at the $\alpha=0.05$ level. We used Kruskal-Wallis analysis of variance to determine if doe rump fat depth differed among years and the Wilcoxon rank-sum test to determine if doe rump fat depth differed between maternal wintering areas.

Blood parameters (NEFA, TRI, BHBR, and Whole Blood Selenium).— We collected up to 20 cc of blood via jugular venipuncture and placed it into anticoagulant tubes (EDTA) for whole blood Se analysis and serum separator tubes for ruminant fatty acid profiles, which included NEFAs, triglycerides, and β -hydroxybutyrate. Whole blood selenium was analyzed at the Diagnostic Center for Population and Animal Health at Michigan State University (Lansing, MI) and ruminant fatty acid profiles were analyzed at Oregon State University Veterinary Diagnostic Laboratory (Corvallis, OR). We used Kruskal-Wallis analysis of variance to determine if female whole blood selenium levels, NEFAs, TRIs and BHBR levels differed among years and the Wilcoxon rank-sum test to determine if levels differed between maternal wintering areas.

Maternal wintering area.— We included maternal wintering area as an individual categorical variable within our survival models. Fawns of unmarked does were retroactively assigned a migration status according to the subsequent fall and winter migration behavior, or in the event of death prior to migration, from the location of initial fawn capture. Locations obtained from GPS collared adults indicated that individuals summering in the north portion of the study area consistently wintered in Silver Lake while those that summered in the south wintered in Dairy. Therefore, fawns captured within the north portion of the study area were assigned to the SL wintering area; those in

the south were assigned to the DA wintering area. We used a two-sample t-test to determine if maternal or fawn covariates differed between maternal wintering areas.

Fawn Covariates

Birth date.— We documented and estimated fawn birth dates. For fawns not captured on the date of birth, birth date was determined by reading the VIT signal, which indicates time of birth to within a 30-minute interval. Occasionally the VIT code became unavailable because prolonged exposure to the sun could cause device reset. When necessary, we estimated the age of the fawn by using the doe's telemetry history aided by visual clues (e.g., wet/dry pelage and behavior) as sources of information. Wet pelage indicated that birth occurred within the previous few hours. Behavioral clues included fawn willingness to flee (younger fawns are more likely to lie down and stay motionless) and ability to walk or run (younger fawns are less stable on their legs and incapable of running).

Birth weight.— The birth weight of a fawn was determined by using an estimated daily growth rate of 0.195 kilograms per day (Lomas and Bender 2007), subtracted from the capture weight. We used analysis of variance to determine if fawn weight differed among capture years or between maternal wintering areas and a two-sample t-test to determine if weight differed by fawn sex. We also used Kruskal-Wallis analysis of variance to determine if mean fawn date of birth differed among years.

Environmental Covariates

Precipitation and temperature.— Migratory study animals from both winter capture areas used the same summer range. Therefore, we used winter range weather data to test for the effects of precipitation and temperature on fawn survival. Female and fawn

condition can be directly influenced by weather conditions or indirectly through precipitation effects on forage availability and quality (Smith and Lecomte 1979).

Because most precipitation in our study area falls during the winter, female condition in April can be influenced by precipitation that fell during the preceding winter.

Additionally, female and fawn condition can be influenced by the amount and kind of precipitation that falls during winter in the year of capture. Therefore, we tested for both the effects of precipitation from the year of capture and with a 1-year lag. For example, we tested the effects of both month-specific precipitation (November – April) recorded during 2010 and 2009 on month-specific survival in 2010. We predicted that higher amounts of winter precipitation would have resulted in more forage, positively affecting female condition, thereby increasing fawn survival. We also predicted that higher winter temperatures would require less energy expenditure for thermoregulation resulting in higher fawn survival. Therefore we tested for the effect of winter temperatures (November – April) on month-specific survival. We used weather data acquired at Klamath Falls, Oregon (National Oceanic and Atmospheric Administration 2014) to represent the DA study area and Remote Automatic Weather Stations (RAWS; Western Regional Climate Center, Reno, NV) data from the Fort Rock Oregon station to represent the SL study area.

Cause-Specific Mortality

We monitored for mortality signals while performing scheduled radiotelemetry tracking of fawns. We monitored fawns daily until they were 2 weeks old, 3-5 times weekly through the 4th week, and then a minimum of once weekly through the following May. When a mortality pulse was identified we conducted a site analysis within 24 hours.

Upon arrival at the site, we located the collar and any carcass remains. We classified mortalities as 1 of 6 types: anthropogenic, malnutrition, disease, predation (unknown predator), predation (predator known), and unknown. Anthropogenic deaths included fawns that were involved in vehicle collisions, were harvested by hunters, or were entangled in fencing. Malnutrition deaths included abandonments that occurred when the fawn was still reliant on maternal care. We classified mortalities as disease when clues of predation were absent, milk was present in the rumen confirming the animal was not abandoned, and/or upon evidence of diarrhea at the site of mortality. If a bloody and tooth -marked collar was found but carcass remains were absent, the cause of mortality was identified as an unknown predator (Steigers and Flinders 1980). When a carcass was present or the feeding site was located, we attempted to assign the mortality to a specific predator. We used the presence of tracks and scat as well as the feeding and burying behavior as predator-specific indicators (Pojar and Bowden 2004, Lomas and Bender 2007). Coyote (*Canis latrans*) kills were characterized by a clean feeding site and burial of the collar and carcass parts in a shallow hole (Pojar and Bowden 2004). Cougar (*Puma concolor*) or bobcat (*Lynx rufus*) predation was identified when the carcass remains were covered with forest debris, and the two species were distinguished by the length of the scratch marks used to drag debris over the carcass (Pojar and Bowden 2004). Feeding sites of black bears (*Ursus americanus*) were very disorderly and contained small pieces of prey remains including bone shards, hooves, and hide (Pojar and Bowden 2004).

Unfortunately, not all mortalities were associated with enough evidence to assign a cause of death. If clues for assigning cause of death were absent or signs for multiple

potential causes of mortality were present, we classified the mortality as being of unknown cause. We assumed the collar was shed or slipped in cases where no sign of mortality existed or the collar was located at the base of a barbed wire fence. We classified predator specific predation within 2-month intervals (June – July, August – September, October – November, December – January, February – March, and April – May).

Survival Analysis

We used known-fate models in Program MARK (White and Burnham 1999) to estimate monthly survival (S ; 12 month-specific estimates annually). To account for possible capture-related mortalities we did not include fawns that died within 4 days of capture. We also censored 4 stillborns discovered during capture attempts and any fawns for which we were unable to acquire all maternal blood values. Fawns ($n = 10$) captured from the Bly adults also were not included in the survival modeling effort.

We created our model set using a multi-step approach where we first investigated general group effects. We predicted survival would vary between sexes (sex) with males surviving at a higher rate than females. We also predicted that survival would vary among years (year) and between capture locations (loc) as forage availability might differ between the two study areas. Therefore, we tested survival probabilities of these three covariates independently, as single-factor models and also as multi-factor models where we investigated all combinations of additive (+) and interactive (x) effects among covariates. We retained the model with the lowest AICc value and any competing models that were ≤ 2 AICc from the best fitting model and used them for the next stage of the modeling effort where we investigated basic time effects, including general

variation in survival by month $[S(t)]$. Because predation is a primary cause of mortality (Forrester and Wittmer 2013), we expected that fawns would survive at higher rates as they aged, either in a general linear (T) pattern, as a pseudo-threshold effect (lnT) where survival increased to a certain age and then leveled off, or as a quadratic effect (TT) where survival increased into, or through fall, but then declined again over winter (December – February) likely due to nutritional stress. We investigated environmental effects, average monthly temperature (temp) and total monthly precipitation (precip), as time-specific covariates, replacing the general time effects (t) with temporal weather covariates (temp: average monthly temperature; precip: total monthly precipitation; precip – previous year: total monthly precipitation from the year prior to fawn capture) to see if they better explained the temporal variation in survival. Next, we examined the effect of individual fawn covariates including birth weight (Weight) and birth date (DOB). We predicted fawns with higher birth weight and those closest to the mean date of birth would survive at higher rates, therefore we tested for these effects independently (single-factor models) and as additive effects in addition to the covariates in our best models from the prior step. We also expected that increased maternal body condition and diet would positively contribute to fawn survival. Therefore, we next introduced individual covariates for each fawn that reflected maternal female body condition, including rump fat depth (rump), whole-blood selenium (se), non-esterified fatty acid (NEFA), triglyceride (TRI), and Beta-hydroxybutyrate (BHBR) levels and tested the resulting model against our best model from the previous modeling phase. Because rump, NEFA, TRI, and BHBR are all measurements of body condition, we conducted a Spearman rank correlation test to avoid redundancy that might occur by adding more than

one of these covariates in a single model. If the test results fell between -0.60 and 0.60, no correlation existed and all covariates were included.

We selected models at each stage of the modeling process using an information theoretic approach (Burnham and Anderson 2002). We used Akaike's Information Criterion corrected for small sample size (AICc), the difference between AICc values (ΔAICc), and AICc model weights to evaluate models. All models $\leq 2 \Delta\text{AICc}$ were considered competitive. The degree to which 95% confidence intervals for slope coefficients (betas) overlapped zero was also used to evaluate the strength of evidence for the importance of variables in competing models ($\leq 2 \Delta\text{AICc}$ values). During the modeling process, we generally selected the model with the lowest AICc value as our best model. However, when confidence intervals on slope coefficients suggested the additional covariate was uninformative (Arnold 2010), we chose to move forward in the process with the closely competing model (within one AICc unit of the best model) without that covariate.

Sibling fawns are subject to similar predation risks and utilize similar resources including maternal care (Bishop et al. 2008). Therefore, datasets that include a high proportion of twins might violate the assumption of independence between individuals (Bishop et al. 2008). Our dataset included 21 sets of twins and 26 individual fawns. Only a modest lack of independence (overdispersion) was found in similar studies of mule deer fawn survival in Colorado (Bishop et al. 2008; 1.25) and California (Monteith et al. 2014; 1.18). To account for potential overdispersion within our data, we set the variance inflation factor (\hat{c}) to 1.25 as recommended by Bishop et al. (2008).

RESULTS

In each year of capture, 98% of females were pregnant and all VITs were expelled during the expected birth period. We captured fawns from 80 individual females and among these females, litter counts averaged 1.8 fawns. We captured 26, 55, and 46 fawns in 2010, 2011, and 2012; respectively, including 4 stillborns which were located at birth sites (1 in 2010; 3 in 2012). Eight fawns died from malnourishment (7%) within 4 days of capture. Capture of these fawns might have induced abandonment and malnutrition, therefore we excluded these animals from survival estimates. Two fawns drowned while fleeing from researchers post capture and were excluded from analysis. In addition, 9 fawns slipped their collars (8%; 1 in 2010, 6 in 2011, 2 in 2012) which were snagged on barbed wire fences or vegetation with all expansion units separated. We lost contact with 6 collars (5%), all in the spring of 2012, most likely as a result of battery failure rather than emigration. These fawns were censored from the analysis once status could no longer be determined.

Maternal Covariates

Mean maternal rump fat depth, mean triglycerides, and mean NEFA did not differ among wintering areas ($P = 0.165$, $P = 0.720$, $P = 0.804$, respectively; Table 2.1) but all three differed in the same pattern among years (rump fat depth: $P = 0.036$; triglycerides: $P = 0.005$; NEFA: $P = 0.006$; Table 2.2) with greater values reported in 2010 compared to 2011 and 2012, which were similar. Conversely, mean BHBR did not differ between females from different wintering areas ($P = 0.166$; Table 2.1) but differed between years ($P = 0.035$; Table 2.2) with 2011 lower than 2010 and 2012, which were similar. Finally, mean maternal whole blood selenium differed between females from different wintering

Table 2.1: Birth weight (kg) and birth date (Julian) of mule deer (*Odocoileus hemionus*) fawns and rump fat (mm), whole blood selenium (ng/mL), NEFA (mEq/L), triglycerides (mg/dL), and BHBR (mg/dL) of adult mule deer females comparing capture areas, south-central Oregon, USA, 2010 – 2012. We used two sample t-test to determine significance of birth weight and Wilcoxon rank sum test to determine significance of all other variables. Values not sharing a letter differ ($P < 0.05$).

Year / Location	Mean / Standard Error	fawn <i>n</i>	doe <i>n</i>	Variable						
				Birth weight (kg)	Birth date (Julian)	Maternal rump fat (mm)	Whole blood selenium (ng/mL)	NEFA ^a (mEq/L)	Triglycerides (mg/dL)	BHBR ^b (mg/dL)
Dairy	\bar{X}	62	53	3.6A	161.00	2.05B	79.16	0.44C	64.65D	3.4E
	SE			0.07	1.06	0.10	8.94	0.02	2.76	0.09
Silver Lake	\bar{X}	50	39	3.43A	163.00	2.26B	141.12	0.44C	62.68D	3.6E
	SE			0.69	0.75	0.09	16.80	0.03	3.80	0.14

^aNEFA = non-esterified fatty acids; ^bBHBR = β -Hydroxybutyrate

Table 2.2: Birth weight (kg) and birth date (Julian) of mule deer (*Odocoileus hemionus*) fawns and rump fat (mm), whole blood selenium (ng/mL), NEFA (mEq/L), triglycerides (mg/dL), and BHBR (mg/dL) of adult mule deer females comparing years, south-central Oregon, USA, 2010 – 2012. We used analysis of variance (ANOVA) to determine the significance of birth weight and Kruskal Wallance ANOVA to determine significance of all other variables. Values not sharing a letter differ ($P < 0.05$).

Year / Location	Mean / Standard Error	fawn <i>n</i>	doe <i>n</i>	Variable						
				Birth weight (kg)	Birth date (Julian)	Maternal rump fat (mm)	Whole blood selenium (ng/mL)	NEFA ^a (mEq/L)	Triglycerides (mg/dL)	BHBR ^b (mg/dL)
2010	\bar{X}	25	22	3.54A	164.00B	2.50	62.60D	0.28	80.77	3.71F
	SE			0.13	1.30	0.14	16.65	0.39	6.06	0.20
2011	\bar{X}	52	40	3.62A	161.00	2.15C	62.50D	0.42D	65.00E	3.22
	SE			0.08	1.18	0.11	6.29	0.23	3.17	0.08
2012	\bar{X}	44	39	3.46A	163.00B	2.04C	151.38	0.48D	59.64E	3.63F
	SE			0.07	0.78	0.10	15.19	0.02	3.39	0.13

^aNEFA = non-esterified fatty acids; ^bBHBR = β -Hydroxybutyrate

areas ($P = 0.001$; Table 2.1) and among years ($P < 0.001$; Table 2.2). Selenium values were similar in 2010 and 2011, but lower than those recorded in 2012 (Table 2.2).

Fawn Covariates

The mean birth weight of males (3.62 kg, SE = 0.07; $n = 64$) was greater than females (3.47 kg, SE = 0.07; $n = 59$) although the difference was not significant ($P = 0.062$).

Additionally, mean fawn weight did not differ by capture year ($P = 0.406$; Table 2.2) and there was only a weak association with wintering area ($P = 0.055$; Table 2.1). The earliest birth occurred May 24th and the latest occurred July 7th. Fawn birth date varied by maternal wintering area ($P = 0.001$; Table 2.1) and year ($P = 0.002$; Table 2.2).

Fawns arrived earlier for females using the DA wintering area and arrived earlier across both areas (DA and SL) in 2011 compared to 2010 and 2012, which were similar (Table 2.1, Table 2.2). The mean and median date of parturition across all years was June 12th with the largest proportion of births occurring on June 9th.

Survival Analysis

Estimated annual fawn survival (0.34, SE = 0.06, 95% CI: 0.23 – 0.48) was best modeled by an increasing linear time trend across monthly survival intervals within years [S(T); Table A1.1]. Thus, monthly rates of survival increased from birth through 12 months of age (Figure 2.2; $\beta = 0.20$, SE = 0.07, 95% CI: 0.06 – 0.34). Eight models were competitive (≤ 2 QAICc) and model weights were likely driven by the inclusion of the time trend (T; Table A1.1). The effect of other covariates (NEFA, Sex, DOB, Weight, loc) was weak (95% CIs overlap zero) so the inclusion of additional covariates was uninformative and did not add to model strength (Arnold 2010). Six competitive models included NEFA but the 95% CI on the coefficient overlapped zero ($\beta = 2.55$, SE = 1.50,

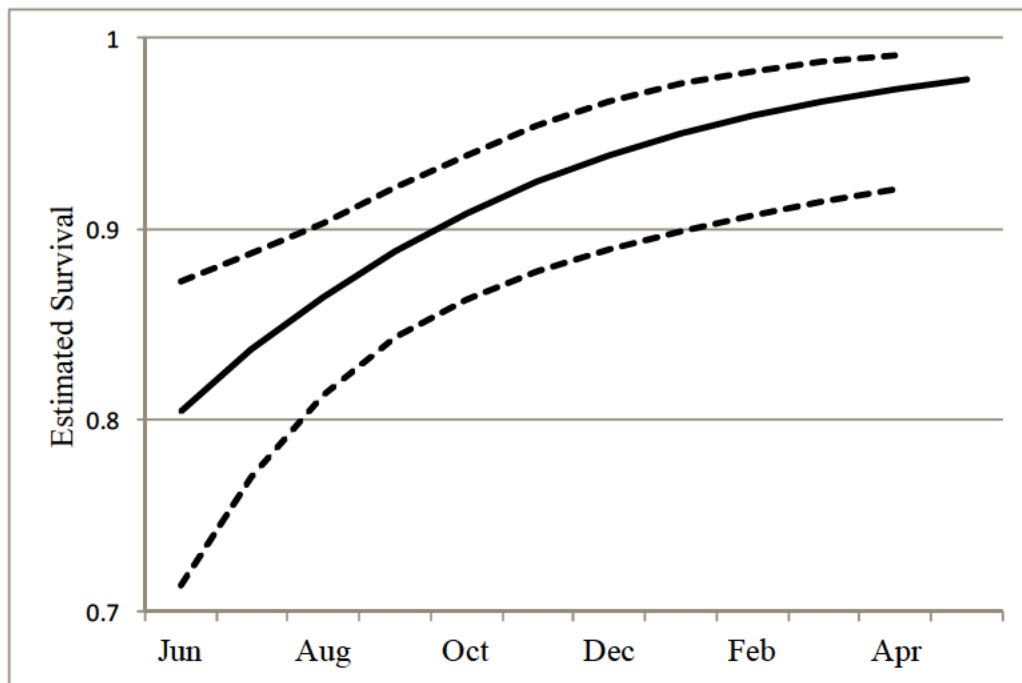


Figure 2.2: Estimated monthly survival rates and 95% confidence intervals of mule deer (*Odocoileus hemionus*) fawns in south-central Oregon, USA, 2010 – 2012. Estimates are derived from our best known fate survival model $\{S(T)\}$.

95% CI: -0.39 – 5.49). Additionally, four competitive models included fawn sex but the 95% CI on the coefficient also overlapped zero ($\beta = 0.42$, $SE = 0.39$, 95% CI : -0.35 – 1.19), supporting our conclusion that both the NEFA and sex effects were weak, and fawn age best explained monthly patterns in survival.

Cause-Specific Mortality

We were able to classify the cause of death for 61 of 113 fawns (54%) captured and collared during this project. The majority of these fawns died as a result of predation ($n = 52$; 85%). Of the mortalities assigned to a specific predator ($n = 34$), 71% were lost to coyotes ($n = 24$), 18% to bears ($n = 6$), 9% to bobcat ($n = 3$), and 3% to a cougar ($n = 1$). Anthropogenic mortalities (7% of total) included 1 fence entanglement, 2 hunter harvests, and 1 road kill. Five died as a result of disease or illness (8%) and we were unable to determine the cause of death for 13 fawns while 24 fawns survived through May of the year following capture (i.e., to yearling status).

We attributed the highest percentage of cause-specific mortality to predation during the months of June and July and then mortality in general declined greatly thereafter (Table 2.3). With the exception of cougars, predator-specific predation was also greatest in June and July and declined throughout the year. One mortality was attributed to cougar predation, which occurred in January (Table 2.3).

DISCUSSION

Survival Analysis

Monthly survival rates of fawns increased with fawn age (Figure 2.2). Our rate of annual fawn survival (0.34) is similar to 7 studies on mule deer and black-tailed deer populations throughout western North America from the 1960's through the 2000's as compiled by

Table 2.3: Percentage of mule deer (*Odocoileus hemionus*) fawn mortalities attributed to coyotes (*Canis latrans*), black bears (*Ursus americanus*), bobcats (*Lynx rufus*), cougars (*Puma concolor*), and unknown predators, south-central Oregon, USA, 2010 – 2012.

Predator	June-July	August- September	October- November	December- January	February- March	April-May	Annual Total ^a
Coyote	54	33	25	33	0	0	46
Bear	14	17	0	0	0	0	12
Bobcat	5	0	0	33	0	0	6
Cougar	0	0	0	33	0	0	2
Unknown	27	50	75	0	100	100	35

^aAnnual totals include the percentage of annual predator-specific predation. Totals not equaling 100 percent are a result of rounding.

Forrester and Wittmer (2013; 0.29, 95% CI: 0.19 – 0.39). Our capture of fawns was facilitated by the use of VITs and frequent monitoring of VIT frequencies. Although we attempted to capture fawns within 24 hours of detecting an expelled VIT, we likely overestimated survival because we likely did not locate all fawns prior to some deaths occurring (Gaillard et al. 2000). We caught fawns from 63% of adults despite documenting pregnancy status and the expulsion of all VITs. Bishop et al. (2008) could not account for the fate of 37% of fetuses, providing evidence that mortalities can occur prior to the capture of fawns despite the use of VITs. Moreover, we assumed all deaths prior to 4 days old were capture related and consequently removed them from analysis, further increasing survival estimates if some background mortality was naturally occurring.

We found no evidence to suggest the nutritional status of adult females contributed to survival rates, contrary to the findings of previous studies on this deer population (Salwasser 1979, Peek 2002). Indicators of female body condition (NEFA, TRI, BHBR, and rump fat) were not retained in our final models. However, our study animals exhibited high pregnancy rates (0.98) and litter counts (1.80) across all years of study and our fecundity estimates are higher than the mean estimate from other studies (1.70, SE = 0.12; Forrester and Wittmer 2013). Although mule deer typically exhibit high fetal rates (Forrester and Wittmer 2013), fecundity can be positively associated with female condition (Monteith et al. 2010), an indication our study animals might have been in similar or better condition than in some other studies. For example, fawn birth weight (Table 2.2) was greater than the mean weight of fawns as compiled by Anderson (1981; 3.4 kg) and in California (Monteith 2014; 2.8kg). This could reflect favorable female

condition (Parker et al. 2009). This evidence suggests that female condition was adequate to support high rates of reproduction, although female condition variables were not significant in our models of fawn survival.

Cause-Specific Mortality

Poor habitat quality, leading to poor maternal condition and subsequent fawn survival, is often indicated as an ultimate reason for mule deer population declines (Salwasser 1979, Peek et al. 2002). However, many proximate sources of fawn mortality are routinely documented (Trainer et al. 1981, White et al. 1987, Pojar and Bowden 2004, Bleich et al. 2006, Lomas and Bender 2007). In this study, predation was the primary source of known mortalities and coyotes were the primary predator. Our results were similar to 16 studies reviewed by Forrester and Wittmer (2013) that reported reported cause-specific mortality among mule deer fawns in western North America. In these cases, similar to ours, predation was the most common source of fawn mortality and predators included coyotes, cougars, bobcats, wolves (*C. lupus*), and black bears.

Selenium and Fatty Acid Profiles

Although selenium standards have not been developed for deer, a number of studies described levels observed in free-ranging cervids in multiple geographic areas throughout the northwest. Mean whole blood selenium values among deer in Washington were 0.081 (S.D. \pm 0.03 mg/L; Hein et al. 1994), and 0.089 mg/L for mule deer and black tailed deer in California where soils are considered selenium deficient (Oliver et al. 1990). Selenium supplementation increased whole blood selenium values from 37 ± 30 $\mu\text{g/kg}$ to 121 ± 90 $\mu\text{g/kg}$ and improved preweaning fawn survival from 0.32 fawns/doe to 0.83 fawns/doe in northern California (Flueck 1994). Significantly lower levels of

selenium were observed among migratory mule deer herds compared to resident herds in California (Oliver et al. 1990). Most of the animals in our study were migratory, with some wintering within 10 miles of the northern California border. Their whole blood selenium value was 0.125 mg/L. These results, along with litter counts of 1.8 fawns per female, might indicate adequate amounts of environmental selenium can be found within the study area. In addition, selenium values in 2012 were more than twice those recorded in 2010 or 2011 despite similar capture and processing procedures. While we lack an explanation for the inter-annual difference in selenium values, the lack of correlation between fawn survival and selenium values suggests that even the lower selenium values observed in 2010 and 2011 were adequate for fawn production.

Rump fat depth is a good predictor of total ingesta free body fat (IFBF; Stephenson et al. 2002). Using the Stephenson et al. (2002) regression equation, our deer had approximately 7% IFBF, ranging from 6% to 8%, which was similar to March IFBF values reported in studies across the western United States and compiled by Monteith et al. (2014; 2.0% – 9.9%). Deer can double fat reserves between April (the time of our measurements) and the fawning period in June (Salwasser 1979) resulting in estimated IFBF of 12% to 16% at the time of parturition. Several additional months of fat accrual are also available on high quality range, allowing mule deer to reach peak body condition during the breeding season (November; Anderson et al. 1970), developing body fat as high as 24% (Anderson 1981). While body condition thresholds for life processes have yet to be identified for mule deer, (Wakeling and Bender 2003) all VITs were expelled by our study animals, indicating they were in adequate condition to conceive and retain fetuses until parturition.

In summary, the fawns for which we could determine cause of death died primarily as a result of coyote predation but also experienced mortality from other predators, disease, vehicle collisions, fence entanglement, hunters and other unknown causes. We observed high pregnancy rates, litter sizes, and fawn birth weights in addition to a short birth pulse, an indication that female condition is adequate to maintain fawn production. We found no evidence to indicate that females were in poor condition and we found no support for environmental (temperature or precipitation) effects on fawn survival. Fawn survival increased with age and predation decreased greatly after the first two months of life.

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CHAPTER 3: MULE DEER BIRTH SITE HABITAT ATTRIBUTES

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Female ungulates and their offspring can experience high levels of predation risk at or near the birth site (Bowyer et al. 1998b). Moreover, mule deer (*Odocoileus hemionus*) females in better nutritional condition can have a higher rate of fawn survival (Pojar and Bowden 2004). Therefore, to successfully raise offspring, a mule deer female must select a parturition site that balances the needs for food resources and predator avoidance. An area of high quality forage might not supply the cover requirements necessary to decrease predation risk to the fawn. Likewise, areas that provide security from predators might not provide adequate forage for lactation. Locations that supply both food and security resources should provide the best opportunity to wean a fawn.

Physiological requirements, predator avoidance strategies, predation risk, and anthropogenic disturbances influence birth site selection in many species (e.g., Bowyer et al. 1999, Fisher et al. 2002, Barbknecht et al. 2011, Leclerc et al. 2012). Moose (*Alces alces*) chose birth sites at low elevations with high forage quality and selected micro-habitats as a predator avoidance strategy (Bowyer et al. 1999). Caribou (*Rangifer tarandus*) chose birth sites at higher elevations to avoid predation despite decreased forage quality (Leclerc et al. 2012). Pronghorn antelope (*Antilocapra americana*) displayed birth site fidelity after experiencing reproductive success, but only when forage availability was adequate (Wiseman et al. 2006), whereas bighorn sheep (*Ovis canadensis*) did not display birth site fidelity (Hass 1989). Mule deer chose sites higher in elevation and on steeper slopes compared to white-tailed deer (*O. virginianus*) where the two species were sympatric (Butler et al. 2009). Black-tailed deer (*O. h. columbianus*) chose sites that were thermally advantageous (Bowyer et al. 1998a) and elk (*Cervus elaphus nelsoni*) chose sites that were advantageous at the study site scale but not

necessarily at the parturition site scale (Barbknecht et al. 2011). These studies demonstrate the diversity of selection criteria for birth sites in North American ungulates, indicating a need to better describe birth site habitat characteristics for mule deer.

Two predator avoidance strategies are observed in juvenile ungulates. Offspring are described as either followers or hiders (Fisher et al. 2002). Followers become mobile shortly after parturition, following the mother during foraging attempts (Fisher et al. 2002). The follower strategy is common among ungulates that occupy habitats with sparse vegetation (Fisher et al. 2002). Follower offspring benefit from maternal or group protection as a predator avoidance strategy rather than depending upon concealment (Fisher et al. 2002). Hiders primarily stay hidden within vegetation at or near the parturition site, while the dam returns several times throughout the day to allow nursing (Fisher et al. 2002). Mule deer fawns exhibit the traits of a hider for the first 3-4 weeks postpartum (Haskell et al. 2010). The hider strategy requires more cover at the birth site because predators are free to search for prey without maternal interruption (Fisher et al. 2002). Additionally, the strategy allows offspring to allocate energy resources to growth and development rather than locomotion and leads to accelerated attainment of independence (Fisher et al. 2002).

Birth sites can be compared to random sites within the maternal home range to determine differences between summer range and birth site habitat characteristics, thereby indicating birth site selection preferences (Bowyer et al. 1998a, 1999). Compared to summer range locations, we expected birth site characteristics to reflect doe selection for concealment cover during the high-vulnerability portion of the juvenile's first few days. Furthermore, we expected that contrast between these birth sites relative

to the summer range might vary among habitat types due to differences in understory and overstory vegetation density. We analyzed birth sites and pre-parturition sites within maternal summer ranges to describe 1) birth site habitat attributes and 2) birth site habitat preferences related to summer range sites.

STUDY AREA

The study area (1.27 million hectares) was located in south-central Oregon with the Cascade Mountains, the towns of Chemult and Bly and the state of California approximating the west, north, east, and southern boundaries, respectively. Privately owned lands (46%) were primarily managed for timber, livestock, or other agricultural uses. Public lands (54%) were managed by the U.S. Forest Service, U.S. Fish and Wildlife Service, Bureau of Land Management and Oregon Department of Forestry.

Precipitation was primarily snow, and in Klamath Falls, Oregon (located within the study area) averaged 31.5 cm. Elevations ranged from 2,550 m in the east to 1,230 m in the south. Soil types varied greatly but were primarily composed of pumice (Youngberg and Dyrness 1959). Minimum temperatures ranged from -19° C to -28° C, while maximum temperatures ranged from 34° C to 37° C (National Oceanic and Atmospheric Administration 2014).

Plant associations were described in detail by Hopkins (1979) and Volland (1985). Approximately 80% of mule deer within the study area were migratory and wintered within two low elevation winter ranges near the towns of Silver Lake and Dairy, Oregon (D. A. Speten, Klamath Tribes, unpublished data). Winter habitats were primarily comprised of widely spaced western juniper (*Juniperus occidentalis*), low sagebrush (*Artemisia arbuscula*), scab rock flats, and ponderosa pine (*Pinus ponderosa*)

forests with a bitterbrush (*Purshia tridentata*) understory. Non-migratory deer used these same juniper-dominated habitats as both summer and winter range. Migratory deer from both wintering herds used a common summer range on the Fremont/Winema National Forest and private timberlands. Conifer species dominated the summer range overstory and consisted of ponderosa pine, white fir (*Abies concolor*), lodgepole pine (*Pinus contorta*), and Douglas fir (*Pseudotsuga menziesii*). The understory included meadows and riparian areas along with uplands dominated by bitterbrush at low to mid elevations, with snowbrush (*Ceanothus velutinus*) and greenleaf manzanita (*Arctostaphylos patula*) dominating at higher elevations.

METHODS

We captured adult mule deer does on winter range via helicopter net gunning (Krausman et al. 1985) in March – April of 2010 – 2012. We blindfolded and hobbled deer to prevent escape and injury before sedatives Azaperone (15 mg intramuscularly) and Midazolam (7.5 – 15 mg intravenously) were administered to further reduce stress and struggling. We radio collared (Followit, Lindesberg, Sweden; Advanced Telemetry Systems, Isanti, MN) and ear tagged individual deer for tracking and identification.

We performed ultrasound analysis (Ibex pro, E.I. Medical Imaging, Loveland, CO; Bishop et al. 2007) or external abdominal hand palpation (J. D. Burco, Oregon Department of Fish and Wildlife, personal communication) to determine pregnancy status. We ear-tagged and released non-pregnant does ($n = 3$). To assist in locating birth sites, we implanted pregnant does with vaginal implant transmitters (VIT; Advanced Telemetry Systems, Isanti, MN) using a vaginoscope (Jorgensen Labs, Loveland, CO; Stephenson et al. 2002) and sterilized lubricating jelly. A 2% chlorhexidine solution was

used to maintain tool sterility. Vaginal implant transmitters were expelled during birth and subsequently located via radio telemetry. After locating the transmitter we identified birth sites by the presence of a ground depression, scrapes within the depression, presence of smashed feces, and the presence of birth fluids (Butler et al. 2009). There was no evidence of VITs being expelled prematurely and the coordinates of all birth sites were recorded.

All field methods were conducted in accordance with the Guidelines for the Capture, Handling, and Care of Mammals as Approved by the American Society of Mammalogists (Animal Care and Use Committee 1998). The Oregon Department of Fish and Wildlife (ODFW) and the Oregon State University Animal Care and Use Committee also reviewed and approved protocols prior to handling (ODFW #'s 017-09, 010-10, 03-11, 049-12; ACUP #4035).

Within one month of the estimated fawning date, we returned to birth sites to complete habitat measurements. At each site, we noted overstory and understory vegetation species, measured the slope with an inclinometer, aspect with a compass, elevation with a GPS, canopy cover with a densitometer, and distance to the nearest shrub. To determine the minimum height of complete vegetation coverage, one researcher held a pole demarcated in 5 cm increments, while a second researcher, observing from the center of the birth site, indicated the lowest visible portion of the pole. We repeated these observations as the pole was held at 5, 10, and 20 meters in each of the four cardinal directions. We included pole coverage resulting from dense vegetation, rocks, logs, or other terrain features. We measured canopy cover in five locations: one at the center of the birth site and one at the 20 m mark in each of the four cardinal

directions. We calculated a site-specific mean for both vegetation height (12 measured) and canopy cover (5 measured). We used these means to calculate summer range and birth site means within each habitat type across all years combined.

Our experience collecting birth site habitat data resulted in *a posteriori* observations of potential patterns of scale-specific selection. We deduced habitat use might differ during the pre-parturition and parturition periods. Therefore, for comparison to birth sites, we conducted the same set of measurements on 50 pre-parturition (summer range) locations of individual does in 2013. Radio telemetry data indicated does completed their migrations prior to parturition. Therefore, we defined potential pre-parturition sites as those locations used from the day the female arrived on the summer range to the day prior to the estimated date of birth. For non-migratory females, the pre-parturition period was defined as the five days immediately preceding the estimated date of birth. We used global information system (GIS; ArcMap, v.9.0; ESRI, Redlands, CA) to randomly select 50 individual females for which we had acquired GPS collar location data at a fine temporal and spatial scale. Only females that completed parturition on public lands were considered, due to private land access concerns. We randomly selected two potential sites, a primary or secondary, from among sites used by the deer prior to parturition (Hawths Analysis Tools for ArcGIS v.3.27). The primary site was used for analysis when habitat conditions were suitable for parturition. Secondary sites were used when the primary site was located on a road, on railroad tracks, or among other features unsuitable for parturition.

Using GIS and 30 cm resolution aerial imagery we measured the distance to riparian habitats, nearest road, and nearest primary road (World Imagery, ArcMap,

v.10.0, ESRI, Redlands, CA). Riparian habitats were identified by the presence of riparian vegetation or surface water. The nearest road was considered any road open for public use during the window of potential parturition dates, including roads only accessible via a four wheel drive vehicle. A primary road was defined as only roads maintained sufficiently for two wheel drive access. We completed a viewshed analysis (ArcMap, v.10.0) to determine the amount of visible area from within the birth or pre-parturition site out to a distance of 300 meters (Bowyer et al. 1999). We adjusted the height of view to 1 meter to represent the height of a deer while bedded.

Two primary habitat types occurred on our study area, a juniper dominated overstory or an overstory that included all other conifers (ponderosa pine, lodgepole pine, white fir). Differences between these habitat types confounded results when trying to compare birth sites and pre-parturition sites, therefore, we stratified our analysis by comparing birth vs. pre-parturition sites within each habitat type.

We used the program STATA (v. 13.1, StataCorp LP, College Station, Texas) to perform all statistical tests. We used Watson's U^2 test to determine if aspect differed and the Wilcoxon rank sum test to determine if all other habitat variables differed between birth sites and pre-parturition sites. Significance was determined at the $\alpha=0.05$ level.

RESULTS

We measured 35, 31, and 36 birth sites in 2010, 2011 and 2012 respectively and 50 summer range sites in 2013. Birth sites in juniper habitats ($n = 20$) were further from the nearest shrub ($P = 0.05$), nearest road ($P < 0.01$), and nearest primary road ($P < 0.01$) than birth sites within conifer habitats ($n = 82$). Conversely, birth sites within conifer habitats were higher in elevation ($P < 0.01$), had higher canopy cover ($P = 0.04$), and had

a greater viewshed ($P = 0.01$) than birth sites within juniper habitats (Table 3.1).

Differences between juniper and conifer sites, however, were likely tied to the characteristics of those habitat types rather than indicating a preference for a particular habitat characteristic. Within conifer habitat, there were no differences between birth ($n = 82$) and summer range sites ($n = 42$; Table 3.1). Within juniper habitats, birth sites ($n = 20$) had greater vegetative cover ($P = 0.035$) and were closer to water ($P = 0.010$) than summer range sites ($n = 8$; Table 3.1).

DISCUSSION

Birth site selection can be driven by many factors (Bowyer et al. 1999, Fisher et al. 2002, Barbknecht et al. 2011, Leclerc et al. 2012). In pursuit of a quality birth site, up to 20% of moose completed long distance movements immediately prior to parturition (Bowyer et al. 1999), similar to some deer in this study (D. A. Speten, unpublished data).

However, within conifer habitats we did not detect any differences between birth and summer range sites. Deer might have selected birth sites based upon a habitat feature we did not measure such as wind speed (Bowyer et al. 1998a) forage abundance (Bowyer et al. 1998a), or percent of herbaceous vegetation (Bowyer et al. 1998a, Barbknecht et al. 2010). Birth sites might also have been selected as a result of anthropogenic disturbances (Singh et al. 2010, Leclerc et al. 2012), distance from known predator locations (Bowyer et al. 1999), or other selection criteria not investigated. Alternatively, we hypothesized that habitat at sites within the summer range scale was sufficient for parturition. Within juniper habitats, we determined that birth sites had greater vegetation coverage and were closer to water sources than summer range sites. In addition, juniper habitats occurred at lower elevations, which are subject to higher average temperatures while also receiving

Table 3.1: Elevation (m), slope (%), aspect (degrees), canopy cover (%), minimum vegetation height (cm), nearest shrub (m), distance to water (m), nearest road (m) and primary road (m), and viewshed (ha) of mule deer (*Odocoileus hemionus*) birth sites and pre-parturition sites within habitats dominated by western juniper (*Juniperus occidentalis*) and conifers in south-central Oregon 2010 – 2013. Watson's U² test was used to determine P-values of the variable aspect. Wilcoxon rank sum test determined P-values of all other variables. Values sharing a letter differ ($P < 0.05$).

Habitat type	Site	n	Mean / standard error	Variable									
				Elevation (m)	Slope (%)	Aspect (degrees)	Canopy cover (%)	Minimum vegetation height (cm)	Nearest shrub (m)	Distance to water (m)	Distance to nearest road (m)	Distance to primary road (m)	Viewshed ^a (ha)
Juniper	Birth	20	\bar{x}	1,388A	9	165	21B	39C	1.94D	704E	969F	1,711G	10.40H
			SE	20	2	25	4	5	0.369	96	179	148	1.28
Conifer	Pre-parturition	8	\bar{x}	1,429	14	127	9	28C	2.25	1,352E	1,416	1,669	12.40
			SE	18	4	29	5	8	0.41	234	319	318	0.99
Conifer	Birth	82	\bar{x}	1,561A	6	190	32B	47	1.34D	1,054	345F	840G	13.76H
			SE	19	0	11	3	3	0.1	105	46	103	0.59
Conifer	Pre-parturition	42	\bar{x}	1,522	6	166	25	43	1.95D	1,022	295	705	14.99
			SE	25	1	14	3	4	0.29	174	50	79	1.02

^aAmount of visible area to a distance of 300 meters at a view height of 1 meter

less rainfall (National Oceanic and Atmospheric Administration 2014). Accordingly, the proximity of birth sites to riparian areas might indicate the importance of water for lactating does, a thermal refuge, or higher quality nutrition than was necessary during the pre-parturition period. Juniper habitats also had less vegetation coverage and less area was visible from the birth site than from within conifer habitats. Deer might have reached a visibility threshold in which they felt susceptible to predation causing them to choose birth sites with more concealment cover, contrary to our hypothesis within conifer habitats.

Our results suggest that female selection of birth sites might be driven by predator avoidance behavior. Predation was the highest source of mortality on this area, accounting for a minimum of 51% of adult mortality and 85% of fawn mortality (Speten, Chapter 2). In juniper habitats, sparse vegetation concealment cover at the summer range scale might necessitate locating birth sites within thicker vegetation patches as an anti-predator strategy, where the female would use fawn concealment to avoid predation. Conversely, within conifer habitats, concealment by vegetation coverage might be sufficient at the summer range scale for parturition. Alternatively, site selection might be based upon the ability of the doe to detect potential predators, rather than selection for greater concealment in denser patches of vegetation for fawn concealment (Bowyer et al. 1999).

Our viewshed analysis was unable to detect a difference in viewable area between birth sites and summer range sites within each habitat type. However, this can be expected in areas where the ability to see determines habitat use at both scales. The four most common local predators were: coyote (*Canis latrans*) black bear (*Ursus*

americanus), cougar (*Puma concolor*), and bobcat (*Lynx rufus*) and these large predators might be detected under most scenarios within these habitat types. Data availability limited analysis of birth site elevations compared to the immediate surroundings.

However, we subjectively concluded that birth sites were primarily located in terrain that was elevated compared to their immediate surroundings, within both study area habitat types, allowing for greater sight distances. Moose (Bowyer et al. 1999), caribou (Leclerc et al. 2012), and mule deer (Butler et al. 2009) select for an elevated birth site presumably to assist in the detection of predators. We observed only one birth site within a riparian area with limited sight distance.

We expected females to select birth sites on southern aspects because they provide conditions advantageous to both adults and neonates. Females will select sites for bedding, and a fawn can then choose a nearby micro-site, fulfilling the needs of both the doe and fawn (Butler et al. 2009). South aspects also have a more variable tree canopy assisting in neonate thermoregulation and providing areas of light and dark contrast, causing a camouflage effect, helping to conceal the neonate among the vegetation (Bowyer et al. 1999, Rearden et al. 2011). It is also possible that sparse vegetation coverage on southerly aspects might facilitate a higher rate of predator detection. However, aspects did not differ significantly between summer range and birth sites in either habitat type.

In summary, mule deer did not display any differences in habitat use prior to and during parturition within conifer habitats. In juniper habitats mule deer selected for birth sites that were closer to riparian areas and which contained greater concealment cover. These patterns suggest that predator avoidance might influence site selection at both the

summer range and birth site scale and within both habitat types. Additionally, water availability is important during parturition especially within the drier environment within juniper habitats.

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CHAPTER 4: GENERAL CONCLUSION

Mule deer (*Odocoileus hemionus*) population indices in south-central Oregon suggest populations are near their lowest recorded levels since indexing (1960's) began (Figure 1.1). Earlier accounts in the area suggest however, that the population was very low prior to European settlement. Poor fawn survival and low recruitment into the adult population is often identified as a driving factor of deer population performance (Salwasser 1979). In chapter 2, I analyzed factors influencing fawn survival and sources of mortality from 2010–2012. Fawn (birth to 1 year) survival was estimated as 34% (SE = 0.06, 95% CI: 0.23 – 0.48), and was similar among years, between maternal winter ranges, and between sexes. Predation accounted for 85% of known mortalities, with coyotes (*Canis latrans*) the primary predator. Models indicated that fawn survival was positively correlated with fawn age. Management efforts that improve fawn survival early in life should result in higher fawn recruitment into the adult segment of the population and a subsequent increase in deer population over the long term, unless the population is at carrying capacity. Fawn survival was not correlated with maternal condition, contradicting the conclusions of 2 prior studies that identified poor forage conditions and female condition as population limiters (Salwasser 1979, Peek 2002).

Habitat management (logging, burning, mastication) projects are routinely conducted by the U. S. Forest Service within the summer range of the study population and are designed to maintain a historic vegetation species composition, age structure, and spacing while reducing the threat of wildfires among other goals. However, some land managers have expressed concern that the implementation of these projects will disturb mule deer and reduce birth-site availability. Chapter 3 compared habitat use of adult

females prior to parturition and during parturition to identify micro-site selection preferences for birth. In juniper habitats, females displayed a preference for birth sites that were closer to water and contained more vegetative cover than sites used prior to parturition. I hypothesized that site selection was to ensure water was available for lactation. Additionally, parturition sites might have been chosen for their ability to conceal a fawn, thereby reducing predation risk. To avoid reducing parturition site availability in juniper habitats, managers should ensure vegetation projects retain some denser patches of vegetation near riparian areas or other water sources. In conifer habitats I detected no differences in site use prior to parturition and during parturition. I hypothesized that habitat at the summer range scale was sufficient for parturition and a birth site might be chosen for the ability to detect an approaching predator rather than for concealment of a fawn. In conifer habitats, parturition site availability might be less vulnerable to changes brought on by vegetation management if the entire summer range habitat of an individual female is not treated simultaneously.

Management actions should focus on improving fawn survival early in life while maintaining security cover near potential fawning sites. It is unknown if this population is at carrying capacity (K) but observed rates of reproduction, high fawn weights, and a lack of winter related mortalities might indicate the population remains below K . Management of this population should also consider additional sources of information. It is unknown what affect tribal hunting and illegal harvest has on population performance. Additionally, new research has indicated that road mortalities are a major source of adult mortality along northern sections of the study area (Coe et al., in review). These

additional sources of information can better inform managers of the appropriate actions necessary to successfully increase mule deer populations in south-central Oregon.

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APPENDIX

Table A1.1: Model results predicting mule deer (*Odocoileus hemionus*) fawn survival as a result of grouping variables, time trend analyses, environmental, individual fawn, and adult female covariates in south-central Oregon, USA, 2010 - 2012.

Model	QAICc	Δ QAICc	w	Likelihood	K	QDeviance
{S(NEFA+T)}	188.809	0.000	0.076	1.000	3	182.742
{S(sex+NEFA+T)}	189.708	0.898	0.048	0.638	4	181.595
{S(T)}	189.861	1.052	0.045	0.591	2	185.827
{S(DOB+NEFA+T)}	190.065	1.256	0.040	0.534	4	181.952
{S(sex*T+NEFA)}	190.247	1.437	0.037	0.488	5	180.077
{S(Weight+NEFA+T)}	190.313	1.504	0.036	0.472	4	182.200
{S(loc+NEFA+T)}	190.349	1.540	0.035	0.463	4	182.236
{S(sex+T)}	190.606	1.796	0.031	0.407	3	184.538
{S(sex*T)}	190.616	1.807	0.031	0.405	4	182.503
{S(sex+DOB+NEFA+T)}	190.830	2.020	0.028	0.364	5	180.660
{S(DOB+T)}	191.109	2.300	0.024	0.317	3	185.042
{S(sex+loc+NEFA+T)}	191.140	2.331	0.024	0.312	5	180.970
{S(loc+T)}	191.309	2.500	0.022	0.287	3	185.242
{S(sex*T+DOB+NEFA)}	191.423	2.613	0.020	0.271	6	179.184
{S(Weight+T)}	191.513	2.704	0.020	0.259	3	185.445
{S(sex+DOB+T)}	191.690	2.881	0.018	0.237	4	183.577
{S(sex*T+DOB)}	191.775	2.965	0.017	0.227	5	181.605
{S(temp+T)}	191.817	3.007	0.017	0.222	3	185.749
{S(sex+loc+T)}	191.834	3.024	0.017	0.221	4	183.721
{S(precip - previous yr+T)}	191.861	3.051	0.016	0.217	3	185.793
{S(TT)}	191.875	3.065	0.016	0.216	3	185.807
{S(precip+T)}	191.892	3.083	0.016	0.214	3	185.824
{S(lnT)}	192.106	3.297	0.015	0.192	2	188.072
{S(sex*T+weight+NEFA)}	192.138	3.328	0.014	0.189	6	179.899
{S(sex*T+temp+NEFA)}	192.189	3.380	0.014	0.185	6	179.951
{S(loc*T)}	192.283	3.474	0.013	0.176	4	184.170
{S(sex+Weight+T)}	192.507	3.698	0.012	0.158	4	184.394
{S(sex*T+weight)}	192.567	3.758	0.012	0.153	5	182.397
{S(sex+temp+T)}	192.579	3.769	0.012	0.152	4	184.466
{S(sex*T+temp)}	192.581	3.772	0.011	0.152	5	182.411
{S(sex+precip - previous yr+T)}	192.605	3.796	0.011	0.150	4	184.492
{S(sex+TT)}	192.620	3.811	0.011	0.149	4	184.507
{S(loc+Weight+T)}	192.625	3.816	0.011	0.148	4	184.512
{S(sex+T+precip)}	192.646	3.837	0.011	0.147	4	184.533
{S(sex*T+precip - previous yr)}	192.647	3.837	0.011	0.147	5	182.477
{S(sex*T+precip)}	192.668	3.859	0.011	0.145	5	182.498

Table A1.1 (continued)

Model	QAICc	Δ QAICc	w	Likelihood	K	QDeviance
{S(temp)}	192.671	3.862	0.011	0.145	2	188.637
{S(loc+T+DOB)}	192.755	3.946	0.011	0.139	4	184.642
{S(sex+lnT)}	192.886	4.076	0.010	0.130	3	186.818
{S(sex*lnT)}	192.935	4.126	0.010	0.127	4	184.822
{S(sex+loc+T+DOB)}	193.142	4.333	0.009	0.115	5	182.972
{S(loc+T+temp)}	193.262	4.453	0.008	0.108	4	185.149
{S(sex+loc*T)}	193.272	4.463	0.008	0.107	6	181.034
{S(loc+TT)}	193.336	4.526	0.008	0.104	4	185.223
{S(loc+precip - previous yr+T)}	193.352	4.543	0.008	0.103	4	185.240
{S(loc+precip+T)}	193.354	4.545	0.008	0.103	4	185.241
{S(loc*TT)}	193.397	4.587	0.008	0.101	6	181.158
{S(loc*lnT)}	193.443	4.633	0.007	0.099	4	185.330
{S(sex+loc+Weight+T)}	193.477	4.668	0.007	0.097	5	183.307
{S(loc+lnT)}	193.493	4.684	0.007	0.096	3	187.426
{S(sex*T+temp+DOB)}	193.743	4.934	0.006	0.085	6	181.504
{S(sex+loc+temp+T)}	193.805	4.996	0.006	0.082	5	183.635
{S(sex+loc+TT)}	193.861	5.051	0.006	0.080	5	183.691
{S(sex+loc+precip - previous yr+T)}	193.887	5.078	0.006	0.079	5	183.717
{S(sex+loc+precip+T)}	193.890	5.081	0.006	0.079	5	183.720
{S(sex*TT)}	193.942	5.133	0.006	0.077	6	181.704
{S(sex+loc+lnT)}	194.029	5.220	0.006	0.074	4	185.916
{S(sex*T+temp+Weight)}	194.544	5.734	0.004	0.057	6	182.305
{S(temp+precip)}	194.545	5.735	0.004	0.057	3	188.477
{S(temp+precip-previous yr)}	194.608	5.799	0.004	0.055	3	188.540
{S(sex+loc*lnT)}	194.647	5.837	0.004	0.054	6	182.408
{S(NEFA+BHBR)}	195.822	7.013	0.002	0.030	3	189.755
{S(sex+loc*TT)}	196.340	7.531	0.002	0.023	9	177.824
{S(precip - previous yr)}	196.629	7.819	0.002	0.020	2	192.595
{S(NEFA)}	196.823	8.014	0.001	0.018	2	192.790
{S(precip)}	197.216	8.407	0.001	0.015	2	193.183
{S(NEFA+BHBR+Selenium)}	197.456	8.646	0.001	0.013	4	189.343
{S(NEFA+BHBR+TRI)}	197.633	8.823	0.001	0.012	4	189.520
{S(NEFA+BHBR+Rump)}	197.698	8.888	0.001	0.012	4	189.585
{S(NEFA+Selenium)}	198.603	9.794	0.001	0.008	3	192.536
{S(NEFA+TRI)}	198.678	9.869	0.001	0.007	3	192.611
{S(NEFA+Rump)}	198.726	9.917	0.001	0.007	3	192.659
{S(BHBR)}	198.736	9.926	0.001	0.007	2	194.702
{S(BHBR+TRI)}	198.926	10.117	0.000	0.006	3	192.859

Table A1.1 (continued)

Model	QAICc	Δ QAICc	w	Likelihood	K	QDeviance
{S(NEFA+BHBR+TRI+Selenium)}	199.224	10.414	0.000	0.005	5	189.054
{S(NEFA+BHBR+TRI+Rump)}	199.372	10.563	0.000	0.005	5	189.202
{S(NEFA+BHBR+Rump+Selenium)}	199.420	10.610	0.000	0.005	5	189.250
{S(sex)}	199.725	10.916	0.000	0.004	2	195.691
{S(TRI)}	200.044	11.235	0.000	0.004	2	196.011
{S(NEFA+TRI+Selenium)}	200.428	11.618	0.000	0.003	4	192.315
{S(NEFA+TRI+Rump)}	200.472	11.663	0.000	0.003	4	192.359
{S(sex+loc)}	200.490	11.681	0.000	0.003	3	194.423
{S(loc)}	200.534	11.724	0.000	0.003	2	196.500
{S(NEFA+Rump+Selenium)}	200.560	11.750	0.000	0.003	4	192.446
{S(BHBR+Selenium)}	200.592	11.783	0.000	0.003	3	194.525
{S(BHBR+TRI+Selenium)}	200.621	11.811	0.000	0.003	4	192.508
{S(weight)}	200.699	11.890	0.000	0.003	2	196.666
{S(dob)}	200.768	11.959	0.000	0.003	2	196.734
{S(BHBR+Rump)}	200.769	11.960	0.000	0.003	3	194.702
{S(BHBR+TRI+Rump)}	200.810	12.001	0.000	0.003	4	192.697
{S(NEFA+BHBR+TRI+Rump+Selenium)}	201.079	12.270	0.000	0.002	6	188.841
{S(t)}	201.317	12.507	0.000	0.002	12	176.415
{S(Selenium)}	201.328	12.518	0.000	0.002	2	197.294
{S(Rump)}	201.408	12.599	0.000	0.002	2	197.374
{S(sex+t)}	201.662	12.852	0.000	0.002	13	174.607
{S(TRI+Rump)}	201.841	13.031	0.000	0.002	3	195.773
{S(TRI+Selenium)}	201.872	13.062	0.000	0.002	3	195.804
{S(sex*loc)}	201.954	13.145	0.000	0.002	4	193.841
{S(NEFA+TRI+Rump+Selenium)}	202.286	13.477	0.000	0.001	5	192.116
{S(BHBR+TRI+Rump+Selenium)}	202.569	13.760	0.000	0.001	5	192.399
{S(BHBR+Rump+Selenium)}	202.631	13.821	0.000	0.001	4	194.518
{S(year)}	202.934	14.124	0.000	0.001	3	196.866
{S(loc+t)}	203.125	14.316	0.000	0.001	13	176.070
{S(sex+loc+t)}	203.329	14.520	0.000	0.001	14	174.108
{S(Rump+Selenium)}	203.349	14.540	0.000	0.001	3	197.281
{S(sex+year+loc)}	203.382	14.572	0.000	0.001	5	193.212
{S(sex+year)}	203.407	14.598	0.000	0.001	4	195.294
{S(year+loc)}	203.501	14.691	0.000	0.001	4	195.388
{S(TRI+Rump+Selenium)}	203.707	14.898	0.000	0.001	4	195.594
{S(sex*loc+yr)}	204.709	15.900	0.000	0.000	6	192.471
{S(year*loc)}	205.979	17.169	0.000	0.000	6	193.740
{S(sex*year)}	207.152	18.342	0.000	0.000	6	194.913

Table A1.1 (continued)

Model	QAICc	Δ QAICc	w	Likelihood	K	QDeviance
{S(sex*year+loc)}	207.278	18.469	0.000	0.000	7	192.959
{S(sex*year*loc)}	208.868	20.059	0.000	0.000	8	192.457
{S(sex*t)}	210.285	21.475	0.000	0.000	24	158.692
{S(sex*year*loc)}	212.323	23.513	0.000	0.000	10	191.690
{S(loc*t)}	216.548	27.738	0.000	0.000	24	164.955
{S(sex+loc*t)}	229.037	40.228	0.000	0.000	36	148.764
{S(g*t)}	378.538	189.728	0.000	0.000	97	111.695

^aModels were developed using known-fate data within Program Mark. Models were ranked according to Akaike's information criterion adjusted for overdispersion and small sample size (QAICc). The model deviance, number of parameters (K), model weights (w), model likelihoods, and Δ QAICc are given for all models. Additive (+) and multiplicative (*) effects are indicated. Shown are the covariates non-esterified fatty acids (NEFA), triglycerides (TRI), β -hydroxybutyrate (BHBR), rump fat (rump), whole blood selenium (selenium), fawn sex (sex), Julian date of birth (DOB), birth weight (Weight), maternal wintering location (loc), year of capture (year), winter precipitation during year of capture (precip), winter precipitation year prior to capture (precip – previous yr.), winter temperature during year of capture (temp), group effects (g), general time effects (t), a linear time trend (T), a quadratic time trend (TT), and a pseudothreshold time trend (lnT).

[†]Lowest Δ QAICc = 189.73

