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 Reinking, Adele K., <u>Coupling Mortality Risk and Multi-Scale Resource Selection to Understand</u> <u>the Effects of Environmental and Anthropogenic Change on Pronghorn in the Red</u> <u>Desert, Wyoming</u>, MS, Department of Ecosystem Science and Management, 2017.

Pronghorn (Antilocapra americana) are an iconic, endemic wildlife species in sagebrush (Artemisia spp.) and grassland habitats of western North America. Over 50% of pronghorn are found in Wyoming; however, state-wide populations have declined by nearly 30% in less than 20 years. Over the same time, in the Red Desert region of south-central Wyoming, pronghorn herds have experienced declining population trends. These demographic changes have coincided with increasing oil and traditional and coalbed methane natural gas development and varied environmental conditions, including heavy snowfall and continuous drought. Our research was prompted by observed pronghorn population declines in this region and the potential for energy development, anthropogenic infrastructure like roads and fences, and changing environmental conditions to influence ungulate mortality risk and habitat selection. Our study objectives were thus designed to evaluate the potential impact of human-induced disturbance and environmental change on mortality risk (Chapter 2) and multi-scale seasonal resource use (Chapter 3) of adult female pronghorn between 2013 and 2016. In addition, during summer 2014 we monitored pronghorn behavior using focal observations (Appendix A) and recruitment using aerial surveys (Appendix B). In total, my thesis consists of 3 chapters: an introductory chapter, a mortality risk chapter, and a resource selection chapter; two appendices are also included that describe the results of our behavioral observations and recruitment surveys.

In Chapter 2, we evaluated mortality risk of adult female pronghorn relative to intrinsic, environmental, and anthropogenic factors. Adult female pronghorn, unlike other temperate

ungulates, are most likely to die in summer seasons, when nutritional condition is poorer due to energetic demands of reproduction that are higher than in all other ungulate species. We used Cox's proportional hazards regression to model summer mortality risk as a function of intrinsic, environmental, and anthropogenic conditions. We found that this demographic was influenced by both intrinsic and environmental factors; summer mortality risk was greatest for individuals in the poorest condition entering the previous winter and for individuals that experienced the greatest variation in average daily snow depth during the previous winter. Consistent with other research evaluating pronghorn mortality risk relative to oil and gas development, we did not detect an effect of this form of anthropogenic features (roads and fences) on summer mortality risk. During years of increased winter severity, mortality during the following summer may be higher, likely resulting from the high energetic expense associated with winter survival and spring reproduction for female pronghorn.

In Chapter 3, we evaluated seasonal resource selection across multiple scales within third-order selection, or selection of habitat components within the home range. We utilized a traditional resource selection function (RSF) to assess summer and winter home-range selection and a step-selection function (SSF) to evaluate finer-scale, patch-level seasonal selection within home ranges. We also evaluated resource use during daytime and nighttime hours with the SSF method, as ungulates may respond differently to anthropogenic activity levels that fluctuate on a diurnal basis. The results of our RSF indicated that in summer and winter at the seasonal homerange scale, pronghorn selected for areas with more sagebrush and areas closer to oil and gas wells. This selection likely resulted from the placement of oil and gas wells in quality pronghorn habitat with high proportions of sagebrush, rather than a predilection for development. Our SSF

indicated selection at the finer scale for sagebrush and avoidance of fence crossings in all seasons and at all times-of-day. We recommend minimizing anthropogenic disturbance in high quality seasonal pronghorn range, particularly during winter when risk-avoidance responses may be stronger due to increased energetic costs of foraging, locomotion, and potential fasting. Behavioral observations (Appendix A) and recruitment surveys (Appendix B) were conducted across study areas with varying levels of anthropogenic disturbance during summer 2014. We found that the proportion of time spent in a variety of behaviors was not different between areas. In addition, aerial surveys in which marked females were located may be a beneficial method for assessing individual recruitment, but is likely less effective for evaluating population-level fawn-to-female ratios for pronghorn than the line-transect survey methods currently employed by wildlife management agencies.

# COUPLING MORTALITY RISK AND MULTI-SCALE RESOURCE SELECTION TO UNDERSTAND THE EFFECTS OF ENVIRONMENTAL AND ANTHROPOGENIC CHANGE ON PRONGHORN IN THE RED DESERT, WYOMING

By

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in

# RANGELAND ECOLOGY AND WATERSHED MANAGEMENT

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# **CHAPTER 1. Introduction**

### **PRONGHORN AND THEIR HABITATS**

Pronghorn (Antilocapra americana) are the only extant species in their genus, where they are endemic to grassland and sagebrush (Artemisia spp.) habitats of western North America. Although pronghorn are found throughout the western expanse of North America,  $\geq$ 50% of the global population has occurred in Wyoming (Yoakum and O'Gara 2000). Pronghorn are often considered to be sagebrush obligates, relying heavily on sagebrush species as a primary food source year-round; diets of Wyoming pronghorn are composed of higher proportions of shrubs, including sagebrush, than those of pronghorn in other locations (Severson and May 1967, Taylor 1972, O'Gara and Yoakum 2004). Wyoming rangeland communities, like much of the sagebrush systems upon which pronghorn rely, experienced historic overstocking of cattle and domestic sheep in the late 1800s and early 1900s, which resulted in the degradation of native habitat and an expanded network of fencing across the landscape (Dennen 1976, O'Gara and Yoakum 2004). In addition to the 1908 closure of the Wyoming pronghorn hunting season because of greatly reduced populations from heavy overharvest (O'Gara and Yoakum 2004), pronghorn populations rebounded in part due to regulation of public land grazing; the Taylor Grazing Act of 1934, which called for a leasing system for grazing rights on public land and mandated the prevention of overgrazing and rangeland deterioration (Ross 1984), improved management of public lands used by pronghorn. Today, one of the largest habitat disturbances occurring in grassland and sagebrush ecosystems is increasing energy development (Allred et al. 2015). The habitats that pronghorn use are prime for oil and gas extraction because the probability of hydrocarbon deposits underlying these areas is high (Copeland et al. 2009). The state of Wyoming ranks fourth in the United States in production of natural gas and eighth in production of crude oil

(U.S. E.I.A. 2015, 2017). Given the high demand for extraction and production of oil and natural gas resources, there is concern that in time, large regions of the native sagebrush habitat in Wyoming may be impacted by energy development.

# PRONGHORN AND ANTHROPOGENIC DISTURBANCE

Oil and natural gas development and anthropogenic infrastructure including roads and fences can impact the demography and behavior of wildlife (Holloran 2005, Sheldon et al. 2005, Gavin and Komers 2006, Roever et al. 2010, Dzialak et al. 2011, Beckmann et al. 2012, Buchanan et al. 2014, Taylor et al. 2016, Sawyer et al. 2017, Yoo et al. 2017). For pronghorn specifically, such landscape disturbance has the potential to cause an increased risk of direct mortality. For example, the increased vehicular traffic associated with oil and natural gas development, which is particularly heightened during active drilling (Sawyer et al. 2009), could result in a greater risk of pronghorn-vehicle collisions (Finn and Knick 2011). Similarly, pronghorn can become entangled in fencing when trying to jump over or, as is more common, crawl under these obstacles, resulting in death due to injury or starvation (Harrington and Conover 2006, Gates et al. 2012). In addition to the direct mortality risk that they can present, energy development and linear anthropogenic features may also indirectly increase risk of death for pronghorn. It is hypothesized that the presence of anthropogenic disturbance on the landscape may be perceived as a source of risk akin to the threat posed by predators (Frid and Dill 2002). Pronghorn reduced foraging time in favor of risk-averse behaviors in response to vehicular traffic in Alberta (Gavin and Komers 2006). Predator avoidance responses such as these can cause increased mortality risk through a loss of feeding opportunities and subsequent degradation in nutritional condition (Lima 1998, Winnie and Creel 2007). In addition, an index of long-term pronghorn population

abundance in North Dakota was negatively impacted by density of oil and natural gas wells, suggesting an indirect population-level impact of energy development (Christie et al. 2015).

Altered pronghorn behavior may also result, in addition to the potential demographic effects of oil and natural gas development and anthropogenic infrastructure. Not only can these landscape features cause increased vigilance (Gavin and Komers et al. 2006), but they can also induce other avoidance behaviors and change movement patterns. In a western Wyoming natural gas field, pronghorn winter resource selection was altered, with animals avoiding areas with the greatest industrial footprint (Beckmann et al. 2012). Whereas alterations in habitat selection like these can result from the predator-avoidance response that anthropogenic infrastructure may evoke (Frid and Dill 2002), pronghorn movement patterns can also change due to the barrier effect imposed by these features, resulting in inhibited daily movements and seasonal migrations (Sheldon 2005, Gates et al. 2012, Sawyer et al. 2013, Seidler et al. 2015).

The negative effects of altered pronghorn habitat use caused by anthropogenic activity and infrastructure may be further exacerbated by extreme environmental conditions, such as continuous drought or severe winters. Avoidance behaviors, in combination with the barrier effect imposed by such features, may cause functional habitat loss, as animals may no longer be able to access high quality resources (Yoakum and O'Gara 2014). These resources become even more important during challenging environmental conditions. For example, in times of drought, access to forage with high succulence is crucial for pronghorn to avoid mortality (Beale and Smith 1970, Dunn and Byers 2008). During severe winters, changes in movement and loss of critical resources due to anthropogenic features may be more extreme because of the combined effect of these movement barriers and deep snow. In addition to reduced access to browse (Bruns 1977) and increased energetic costs of locomotion that are common for ungulate species (Parker

et al. 1984, Telfer and Kelsall 1984, Monteith et al. 2013), snow may increase the barrier effect of linear features for pronghorn. For example, the build-up of deep snow in the depressions underneath fences can make wildlife-friendly fencing impermeable (Bruns 1977, Sheldon 2005, Yoakum et al. 2014).

## **PRONGHORN AND ENVIRONMENTAL CONDITIONS**

Climate can influence population dynamics of ungulate species, particularly when environmental conditions are extreme (Gaillard et al. 2000). One of the main limiting factors for pronghorn populations is precipitation. In the southwestern portion of pronghorn range, forage quantity and quality is strongly controlled by precipitation levels; in severe drought years, pronghorn in these areas may experience extreme die-offs due to starvation (Bright and Hervert 2005, Brown et al. 2006, Yoakum et al. 2014). Not only can drought result in decreased survival, but it can also have negative impacts on pronghorn productivity (Hailey et al. 1966, Dunn and Byers 2008). Furthermore, precipitation is important for pronghorn in arid environments year-round, with October–May precipitation greater than 5 cm being required for herd maintenance (Brown et al. 2002), and heavy summer rainfall improving pronghorn habitat suitability indices (Duncan et al. 2016). Precipitation from gestation through weaning proved to be an important predictor of long-term population growth for southwestern pronghorn populations (Gedir et al. 2015).

Pronghorn in more northerly environments are similarly affected by drought compared with pronghorn farther south, but experience greater changes in demographic parameters as a result of snowfall. Moving through deep snow is energetically costly (Parker et al. 1984, Telfer and Kelsall 1984, Monteith et al. 2013), and can result in increased mortality risk for pronghorn, likely as a result of depleted fat reserves (Reinking et al., unpublished data). Deep snow presents an additional challenge for pronghorn in that it reduces access to forage, particularly when snow

depths reach 25–30 cm (Bruns 1977, Yoakum et al. 2014). Deep snow has resulted in major dieoffs across the northern portion of pronghorn range (Barrett 1982, O'Gara and Yoakum 2004). Low temperatures, particularly in combination with deep snow, can negatively impact pronghorn survival because of the high energetic expense required to increase metabolic rate and boost internal temperatures (Wesley et al. 1973).

### THE RED DESERT REGION

The Red Desert region of south-central Wyoming has experienced large increases in anthropogenic disturbance levels. In the last two decades, development of oil and traditional and coalbed methane natural gas has boomed, with roughly 80% of wells being drilled after 2000 and current well densities as high as 12.4 wells/km<sup>2</sup> (WOGCC 2017). As a result, road densities in the region have also increased, reaching 14.2 km/km<sup>2</sup> in some areas (O'Donnell et al. 2014). Fencing associated with oil and gas infrastructure and historic and current livestock production, can reach densities as high as 2.2 km/km<sup>2</sup> across the landscape (Wyoming Cooperative Fish and Wildlife Research Unit, unpublished data).

In addition to altered anthropogenic conditions, the region has experienced fluctuating environmental conditions. Between 1996 and 2015, 11 of 20 years (55%) were characterized as drought years, and 4 of 20 years (20%) were described as extreme drought years (NOAA 2017; Fig. 1.2). During this period, snowfall has varied across the region and across years, reaching depths greater than 1.5 m in extreme winters (USDA 2017). The Red Desert also includes a wide range in landscape characteristics with varied elevations (range: 1,850–3,287 m; USGS 2016), land ownership, and vegetative communities. Wyoming big sagebrush (*A. tridentata wyomingensis*) is a dominant species across the region, often associated with perennial grasses, such as bluebunch wheatgrass (*Psuedoroegneria spicata*), indian ricegrass (*Achnatherum* 

*hymenoides*), and Sandberg bluegrass (*Poa secunda*), and varied forb species. At higher elevations, aspen (*Populus tremuloides*) stands and various conifer species are present. The Red Desert has historically served as a stronghold for pronghorn populations, with numbers approaching nearly 40,000 animals during several of the last 20 years; however, population trends in the region are declining overall, with some herds decreasing in size by 20% in the last two decades (WGFD 1996–2016).

## **STUDY AREAS**

Within the Red Desert region, we designated 4 study areas based on Wyoming Game and Fish Department pronghorn Hunt Areas 53, 55, 57, 60, and 61 (Fig. 1.1). Three areas (CDC, Baggs, and Bitter Creek) were considered to be impacted by energy development with moderate-to-high densities of oil and natural gas wells (range: 0.0–5.0 wells/km<sup>2</sup>), and 1 area (Red Desert) was used as a control because it was characterized by relatively low densities of oil and natural gas wells (range 0.0–0.6 wells km/km<sup>2</sup>). Study areas also varied in landscape characteristics, providing a unique opportunity to assess mortality risk and seasonal resource selection as a function of land cover and climate conditions.

### STUDY DESIGN AND GENERAL METHODS

Population declines in Red Desert pronghorn, which coincided with expanding energy development and continuous drought, were the impetus for our research. We sought to evaluate the potential role of environmental conditions (such as snow depth, temperature, distance to water, and vegetation quality) and anthropogenic disturbance (including roads, wells, and fences) on pronghorn within areas impacted by energy development relative to areas less impacted by development. To do this, we evaluated adult female mortality risk using Cox's proportional

hazards regression (Cox 1972; see Chapter 2) and assessed seasonal resource selection at two different scales within third-order selection (see Chapter 3, Johnson 1980). In Chapter 3 we employed a traditional resource selection function to evaluate resource use at the seasonal homerange scale, and a step-selection function to assess selection at the seasonal patch-level scale within the home range (Fortin et al. 2005). In addition to evaluating mortality risk and seasonal selection of adult female pronghorn in the Red Desert, we also monitored behavior (see Appendix A) and assessed recruitment (see Appendix B) in summer 2014.

In November 2013, February 2014, and November 2014, we captured 186 adult (≥1.5-yr) female pronghorn. Animals were equipped with very high frequency (VHF; model M2510B, Advanced Telemetry Systems, Inc., Isanti, MN 55040; 22 individuals) or global positioning system (GPS; model G2110D, Advanced Telemetry Systems, Inc., Isanti, MN 55040; 164 individuals) necklace transmitters to monitor movements and survival (GPS collars) and, during the summer 2014 field season, to assess behavior and recruitment (VHF and GPS collars). All animals were captured and processed in accordance with protocols approved by Wyoming Game and Fish Department (Chapter 33-923 Permit) and University of Wyoming Institutional Animal Care and Use Committee (protocol 20131028JB00037). Global Positioning System collars were programmed to record locations every 2 hours over a 2-year period, after which time a mechanical drop-off mechanism was triggered. Very High Frequency collars did not record locations, but transmitted a signal indicating a live (40 beats per minute) or dead (80 beats per minute) animal, and did not drop off, remaining on the animal until death.

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Figure 1.1. Red Desert, Continental Divide-Creston (CDC), Baggs, and Bitter Creek study areas used to evaluate summer mortality risk and multi-scale resource selection of adult female pronghorn in the Red Desert, south-central Wyoming, USA 2013–2016. Behavioral observations and aerial recruitment surveys were conducted in the Red Desert, Baggs, and Bitter Creek study areas during summer 2014, as the CDC study area was not added until November 2014. We mainly captured adult females in 5 Wyoming Game and Fish Department pronghorn Hunt Areas (53, 55, 57, 60, and 61). Captures in Hunt Area 61 largely occurred in an area constricted by the boundary of a Bureau of Land Management (BLM) Environmental Impact Statement (EIS) area. Study area boundaries were defined with a 100% minimum convex polygon around pronghorn locations recorded in each area for the mortality risk component of this research.



Figure 1.2. National Oceanic and Atmospheric Administration (NOAA) 1996–2015 Palmer Drought Severity Index (PDSI) for the NOAA's Wyoming Climate Division 10, which covers the majority of the Red Desert region in south-central Wyoming. Values of -2.0 or less indicate drought years, while values of -4.0 or less indicate severe drought years.

# CHAPTER 2. Do Intrinsic, Environmental, or Anthropogenic Factors Influence Pronghorn Summer Mortality in Wyoming?

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## ABSTRACT

Pronghorn (*Antilocapra americana*) are an iconic wildlife species of sagebrush (*Artemisia spp.*) and grassland habitats in western North America. Over 50% of pronghorn have historically

occurred in Wyoming; however, these populations have declined by nearly 30% in less than two decades, concurrent with expanding energy development and prolonged drought. Research suggests adult female pronghorn, unlike other temperate ungulates, are more likely to die in summer, when body condition is lower from extreme energetic demands of reproduction, which are higher for pronghorn than other ungulates. To evaluate the potential impact of intrinsic, environmental, and anthropogenic factors on summer mortality risk, we monitored 114 adult female pronghorn equipped with Global Positioning System transmitters in the Red Desert region of south-central Wyoming, USA between 2013–2015. We modeled mortality risk using Cox's proportional hazards regression. Summer mortality risk was influenced by both intrinsic and environmental factors; mortality risk increased when individuals were in poorer body condition at capture and when they experienced greater variation in average daily snow depth during the previous winter. We did not detect an effect of the distance to and density of roads, oil and gas wells, or fences on pronghorn mortality. During years of increased winter severity with deep and fluctuating snow depths, managers may observe not only higher winter mortality, but also higher mortality the following summer, likely as a consequence of the energetic expense associated with both winter survival and spring reproduction for female pronghorn.

### **KEY WORDS**

*Antilocapra americana*, body condition, climate variability, energy development, income survivalist, pronghorn, snow depth variability, summer mortality risk, Wyoming.

## **INTRODUCTION**

Most ungulate species in temperate ecosystems are considered capital breeders, with reproduction largely fueled by fat reserves (Jönsson 1997, Andersen et al. 2000, Stephens et al.

2009). Pronghorn (Antilocapra americana), however, may align more closely with income breeders along the income-capital breeder spectrum (Clancey et al. 2012), suggesting that their reproduction is fueled not only by fat reserves, but also by energy as it is acquired (Stephens et al. 2009). Other income-breeding ungulates, such as roe deer (*Capreolus capreolus*), time their reproduction to coincide with periods of spring green-up, whereas energy reserves stored by capital-breeding ungulates serve as insurance against inconsistent nutritional availability across the landscape (Parker et al. 2009). While this distinction in breeding strategy mainly serves as an economic metaphor for the balancing act between acquired energy and the costs of reproduction (Stephens et al. 2009), it is closely tied to the strategies employed to ensure survival (Parker et al. 2009). For example, Arctic reindeer (Rangifer tarandus tarandus) finance both their survival and reproduction using fat reserves, thus employing a capital strategy in both instances (Barboza and Parker 2008). If pronghorn do rely more heavily on the immediate acquisition of energy relative to other ungulates, the link between adult survival and reproduction and surrounding environmental conditions may be even stronger for pronghorn compared with other species. While pronghorn may align more closely with ungulates employing an income strategy, fat reserves still play an important role in their seasonal survival.

Pronghorn in the northern portions of the species' range face increased thermoregulatory and locomotive costs during winter (Parker 1984, Byers 1997), equating to net energy loss and declining body condition (Bear 1971, Byers 1997). Therefore, after experiencing the depletion of fat reserves common to temperate ungulates during winter (Mautz 1978, Monteith et al. 2013), pronghorn are often in poor condition prior to parturition. Pronghorn invest more highly in reproduction than all other ungulate species, expending substantial energetic reserves during both prenatal and postnatal phases of offspring development (Robbins and Robbins 1979, Byers 1997,
O'Gara and Yoakum 2004). For example, the length of pronghorn gestation is roughly 8 months, which is longer than other ungulates of a similar body size (O'Gara and Yoakum 2004), and the weight of pronghorn offspring at birth constitutes 15.5% of maternal weight, making the ratio of offspring to adult female weight higher for this species than all other ungulates (Robbins and Robbins 1979). Prior research found fat levels in adult female pronghorn to be at their lowest in June (Bear 1971), largely due to the high energetic costs associated with late gestation and lactation (Smyser et al. 2005, Dunn and Byers 2008, Clancey et al. 2012). Female pronghorn were the only sex and species to experience higher mortality rates in summer than winter compared to 87 other species of wild ruminants kept in zoos (Carisch 2016). Furthermore, Bender et al. (2013) found that 73% of adult female pronghorn mortality in New Mexico occurred in summer months between parturition and weaning. While ungulate demographic trends can be influenced by juvenile survival (Raithel et al. 2007), adult survival also has the potential to be a strong driver of population growth (Gaillard et al. 2000). Given the potential increase for mortality rates in adult female pronghorn during summer and the important role that adult survival can play in population dynamics, it is crucial to understand what factors contribute to female pronghorn mortality risk during that season.

Although the high energetic cost of reproduction can contribute to body degradation in pronghorn, other external factors may play a role as well. Environmental disturbances provoke risk-averse behaviors in many ungulate species, potentially depleting energy reserves due to lost foraging opportunities (Lima 1998, Winnie and Creel 2007). It has been hypothesized that animals perceive anthropogenic activities on landscapes as a source of risk (Frid and Dill 2002), a subject that has been increasingly studied in light of the worldwide growth in energy resource demand (e.g., Buchanan et al. 2014). Not only can such development cause increased stress for

wildlife, but associated infrastructure may directly inhibit their ability to move to areas of improved resource quality, as is frequently demonstrated by the barrier effect of roads and fences (Sheldon 2005, Sawyer et al. 2013). In many areas, flat, sagebrush (*Artemisia spp.*) habitats preferred by pronghorn are ideal locations for energy development, and these environments are projected to continue experiencing increased disturbance as a result of energy extraction efforts (Copeland et al. 2009).

Historically, Wyoming, USA has provided habitat to  $\geq$ 50% of all pronghorn worldwide (Yoakum and O'Gara 2000), where they are emblematic of state culture and are popular with big game hunters. State-wide pronghorn populations have declined by nearly 30% since reaching estimated population highs during the mid-2000s (Wyoming Game and Fish Department [WGFD] 1995–2015). At the same time, Wyoming has experienced an increase in severe droughts (NOAA 2017), which have the potential to negatively impact wildlife by limiting forage availability and body condition, potentially resulting in decreased productivity and survival (Beale and Smith 1970, Dunn and Byers 2008). Wyoming also has experienced some of the greatest increases in resource extraction in the United States and ranks as the leading producer of Federal onshore natural gas (BLM 2012). Impacts of such infrastructure may affect wildlife by altering movement patterns, habitat selection, behavior, and demography (e.g., Sawyer et al. 2005, Dzialak et al. 2011, Beckmann et al. 2012, Buchanan et al. 2014, Gregory and Beck 2014). Increasingly, energy development has become the focus of management and conservation efforts for an array of Wyoming's wildlife. To manage pronghorn populations and provide effective mitigation for risks to survival, practitioners need scientifically rigorous information regarding stressors for pronghorn. Understanding factors contributing to adult

female mortality, particularly during summer, improves our ability to understand key demographic drivers of pronghorn populations.

We evaluated mortality of adult females in the Red Desert of south-central Wyoming from 2013 to 2015. Pronghorn populations in the Red Desert region have experienced declines of 15–30% over the last 20 years, and show little to no recovery (WGFD 1995–2015). Congruent with these declines, the region also has experienced rapid increases in oil and conventional and coalbed methane natural gas extraction (WOGCC 2016) coupled with 11 of 20 years (55%) characterized as drought, and 5 of 20 years (25%) described as extreme drought between 1996 and 2015 (NOAA 2017). Our objectives were to identify the role of intrinsic, environmental, and anthropogenic stressors on summer mortality risk of adult female pronghorn. We predicted that intrinsic factors, environmental conditions, and anthropogenic features would influence pronghorn summer mortality in our study areas. First, given the role that individual characteristics can play in risk of death (Gaillard et al. 2000, Parker et al. 2009), we predicted that intrinsic factors including older age and poorer body condition would increase likelihood of death in summer for adult female pronghorn. Second, given the strong link between pronghorn survival and their environment, we predicted that poorer climate and land cover conditions, such as decreased summer precipitation or greater distance to water, would increase mortality risk (Yoakum et al. 2014). Third, we predicted that anthropogenic features like roads, wells, and fences would negatively influence survival, because disturbance associated with oil and natural gas extraction has been shown to negatively impact the physiology, behavior, and survival of pronghorn and other ungulate species (Sawyer et al. 2006, Dzialak et al. 2011, Wasser 2011, Beckmann et al. 2012, Northrup et al. 2015). Furthermore, anthropogenic features such as roads and fences have been shown to be a source of direct and indirect mortality for pronghorn

(O'Gara and Yoakum 2004, Harrington and Conover 2006, Kolar et al. 2012, Taylor et al. 2016), and can alter pronghorn movement and behavior (Sheldon 2005, Gavin and Komers 2006, Gates et al. 2012, Sawyer et al. 2013, Yoakum et al. 2014). To address these predictions, we relied on location and survival data from Global Positioning System (GPS)-collared adult female pronghorn.

## **STUDY AREA**

The Red Desert region in south-central Wyoming, USA extends from the Wyoming-Colorado border to north of Interstate 80 near Atlantic City, Wyoming, USA and the southern portion of the Wind River Mountain Range; and east to west from Rawlins to Rock Springs, Wyoming, USA (Fig. 2.1). We designated 4 study areas within the Red Desert encompassing 13,626 km<sup>2</sup>. Study area boundaries were defined using a 100% minimum convex polygon around locations of pronghorn captured primarily within 5 WGFD Antelope Hunt Areas. The Baggs area was based in Hunt Areas 53 and 55, Bitter Creek in Hunt Area 57, Red Desert in Hunt Area 60, and Continental Divide-Creston (CDC) in a portion of Hunt Area 61 constricted by the Bureau of Land Management's CDC Environmental Impact Statement (EIS) area (Fig. 2.1). Environmental characteristics, ownership, and levels of anthropogenic development varied across study areas, providing an opportunity to evaluate pronghorn mortality risk in response to a range of habitat conditions (Table 2.1). We used infrared traffic monitors (Model TM1550, TrailMaster, Lenexa, KS 66215) to evaluate annual road traffic in Baggs and Bitter Creek to better understand vehicle volumes on lower and higher traffic roads in study areas with low and high oil and gas development, respectively. On lower traffic roads, there was an average of 7.7 vehicles per day (range: 0.8–21.2) in Baggs and 25.2 (range: 15.5–36.8) in Bitter Creek. On higher traffic roads,

there was an average of 285.7 vehicles per day (range: 56.6–482.0) in Baggs and 490.2 (range: 43.4–1981.0) in Bitter Creek.

Study areas were dominated by Wyoming big sagebrush (*A. tridentata wyomingensis*) communities interspersed with an herbaceous understory of perennial grasses and forbs. Black greasewood (*Sarcobatus vermiculatus*) and Gardner's saltbush (*Atriplex gardneri*) dominated low-lying areas with alkaline or saline soils. Higher elevations were dominated by mountain big sagebrush (*A. t. vaseyana*), mixed shrub communities, and aspen (*Populus tremuloides*) stands. Oil and natural gas extraction, livestock grazing, and big game hunting were predominant land uses. Big game hunting license quotas for doe or fawn pronghorn remained low across study areas throughout the monitoring period, and did not have the potential to cause summer mortality given fall hunting season dates. In most Red Desert Hunt Areas, 25 or fewer doe/fawn licenses were allotted in the 2013 and 2014 hunting seasons, with quotas for some areas increasing to as many as 100 doe/fawn licenses in the 2015 hunting season (including private-lands-only hunts), after those areas experienced slight pronghorn population growth in 2014 (WGFD 1995–2015).

#### METHODS

## **Capture and Handling**

We contracted to capture pronghorn using helicopter net-gunning (Native Range Capture Services, Ventura, CA) in November 2013 and 2014. To reduce capture-related mortality rates, which can be high in pronghorn compared with other wild North American ungulates (Yoakum et al. 2014), we followed guidelines by Jacques et al. (2009*a*). Additionally, we administered a cold-water-enema to animals whose rectal temperature approached or exceeded 40° C (Jacques et al. 2009*a*). We weighed each female to the nearest 0.1 kg and collected biological samples for

lab analyses. Age of individuals was estimated based on tooth eruption and wear (Lubinski 2001). We also developed a correction factor for age (Corrected age = 0.786\*Estimated age + 2.009;  $r^2 = 0.69$ ) by regressing ages for 18 dead pronghorn determined via cementum annuli analysis (WGFD Forensic Laboratory, Laramie, WY) on estimated age at death based on estimated age at capture. Animals were fitted with store-on-board GPS (model G2110D, Advanced Telemetry Systems, Inc., Isanti, MN) necklace transmitters with a uniquely colored and numbered ear tag to facilitate field identification. Pronghorn locations were programmed to record every 2 hours over a period of 2 years. Mortality sensors on collars were triggered after 8 hours of inactivity, and aerial surveys to locate mortalities were conducted roughly every 2-3 months.

Given capture-related mortality periods used in other pronghorn research, we considered all deaths of released animals occurring within 3 weeks of capture date to be capture-related, barring evidence indicating another fate (Amstrup et al. 1980, Grogan and Lindzey 2007, Jacques et al. 2009*b*). Individual pronghorn were captured, handled, and monitored in accordance with protocols approved by WGFD (Chapter 33-923 Permit) and University of Wyoming Institutional Animal Care and Use Committee (protocol 20131028JB00037).

## **Mortality Risk Covariates**

We assessed pronghorn mortality risk with time-independent and time-dependent covariates representing intrinsic, environmental, and anthropogenic conditions (Table 2.2). Intrinsic covariates were time-independent and included age and body condition metrics. Environmental covariates were time-dependent and included variables related to climate and land cover. Anthropogenic covariates were time-dependent and included total distance to and density of surrounding anthropogenic features. Extraction of covariate values and all other analyses were

performed using RStudio and Program R (R Version 3.4.1, www.r-project.org, accessed 31 July 2017) and ArcMap version 10.4.1 (Environmental Systems Research Institute, Inc., Redlands, CA, USA). We evaluated environmental and anthropogenic covariates at each pronghorn location, and then averaged covariates for each individual during each day. Averaging accounted for differing location frequencies for each individual that occurred as a result of infrequent GPS error. Correlated covariates were not included in the same model.

Intrinsic covariates. - In studies assessing the nutritional condition of sample animals, individuals are often re-captured multiple times, as condition can change drastically across seasons and years (e.g., Cook et al. 2010, Monteith et al. 2013, Aikens et al. 2017). However, the high rates of capture-related mortality observed in pronghorn (Yoakum et al. 2014) increased the risk that our previously collared animals would die if re-captured, and the potential to collect longer-term movement and survival data would be lost. Therefore, body condition was only evaluated once, at each animal's single capture. For this reason, mortality risk analysis intervals spanned only the first year after capture. During November 2013 and November 2014 capture events, we assessed body condition with palpation and ultrasonography (Ibex ® Pro, E. I. Medical Imaging, Loveland, CO), following protocols developed and standardized for other ungulates (Stephenson et al. 2002, Cook et al. 2007, Cook et al. 2010). We measured maximum depth of subcutaneous fat directly cranial to the cranial process of the tuber ischium (Stephenson et al. 2002) and assigned a leanness score via manual palpation that was associated with depth of indentation between the sacrosciatic ligament and caudal vertebrae. Higher values of the leanness score reflect animals with lower somatic reserves and thus, poorer condition compared with lower scores. This score is comparable to validated body condition scores developed in cervids, but has not yet been validated to estimate percent body fat for pronghorn (Cook et al.

2007). Therefore, we included estimates of body mass, depth of rump fat, and a leanness score as 3 metrics of body condition in analyses.

*Environmental covariates.* –We obtained daily raster layers (250 m grid) using SnowModel to evaluate covariates related to climate (temperature, precipitation, and snow depth; Liston and Elder 2006*a*; InterWorks Consulting LLC, Loveland, CO). SnowModel simulates processes related to snow; including but not limited to snow precipitation, blowing snow, snowdensity evolution, and snow melt. The meteorological forcings required by SnowModel were provided by MicroMet (Liston and Elder 2006*b*) and included temperature, precipitation, and other meteorological variables.

We used Landfire Existing Vegetation Type raster data (LANDFIRE 2013) to assess the minimum distance to water from each location for individual pronghorn. To evaluate vegetative quality, we assessed the Normalized Difference Vegetation Index (NDVI) at each pronghorn location using MODIS terra satellite data products, collected once every 8 days. NDVI is often used as a proxy for forage quality, as it measures vegetative greenness across the landscape (Hamel et al. 2009).

*Anthropogenic covariates.* –We used fence data obtained from the Wyoming Cooperative Fish and Wildlife Research Unit and 2009 National Agricultural Imagery Program Imageryderived road data from the United States Geological Survey (O'Donnell et al. 2014). We obtained locations of producing oil and gas wells from the Wyoming Oil and Gas Conservation Commission (WOGCC 2016). Wells were filtered by spud date (the date when drilling activity began) to ensure wells were present during the time when individual pronghorn locations were recorded. If first spud date was not available, we used the completion date (the date of the first completion report filing).

We assessed the daily average of most land cover and all anthropogenic covariates over the previous week, month, and season (winter). Temperature and snow depth-related variables were evaluated over the previous season (winter) only, as these covariates were unlikely to influence summer mortality risk during other times of the year. Additionally, we evaluated the moving weekly average (average of the daily average during the previous week for each individual since entering the study), and cumulative weekly values (sum of daily average during the previous week for each individual since entering the study). All animals compared during a given time interval in mortality risk modeling had the same period of exposure since capture, and therefore, the use of cumulative variables was justified. We also assessed the potential influence of the density of fences, roads, and oil and gas wells across 4 spatial scales (0.5, 1, 3, and 5 km; Buchanan et al. 2014) for each of the 5 time periods (weekly, monthly, seasonally, moving weekly average, and cumulative weekly). We additionally evaluated the potential effect of the interaction between an environmental variable (total snow depth) and an anthropogenic variable (fence density) across these 4 spatial scales.

#### **Mortality Risk Modeling**

We used the Andersen-Gill formulation of the Cox's (1972) proportional hazards regression model with mixed effects to assess pronghorn mortality risk for the summer 2014 and 2015 seasons with the 'coxme' package in Program R (Therneau 2015, R package version 2.2.5, www.r-project.org, accessed 1 November 2014). This method models mortality as intervals of risk, and allows for multiple observations and staggered entry of individuals (Andersen and Gill 1982, Cox 1972). Seasons were defined based on population-averaged dates of individual seasonal movement using net squared displacement. Net squared displacement is a measure of the straight line distance between an animal's first location and each subsequent location, and

can be used to visually designate periods of migratory and non-migratory movement behavior (Bunnefeld et al. 2011). We defined summer as the period between when the individual arrived on summer range and traveled to winter range. Non-migratory individuals were not used to determine season dates, and their seasonal range use periods were defined by the mean dates of seasonal use periods of migratory individuals. Mean dates for individuals occupying summer range in 2014 and 2015 were 6 April–29 November and 22 March–24 October, respectively.

We assessed weekly mortality risk for the summer 2014 and 2015 seasons as a function of covariates related to intrinsic, environmental, and anthropogenic conditions experienced by marked adult female pronghorn (Table 2.2). We used locational data collected outside of the summer seasons to generate lag-time, moving average, and cumulative covariate values, but we did not include these data in our evaluation of weekly intervals of mortality risk. Pronghorn that were captured in November 2013 and survived the entire study period were right censored so that mortality risk was only evaluated during the first summer after capture. Any sample animals that died prior to the summer season after capture were not included in analyses.

We first determined whether study area, individual, or year, or two-variable combinations of these covariates would serve as the best random covariate(s) by ranking models with Akaike's Information Criterion (AIC). The most predictive random effects only model was considered the null model for subsequent model evaluation. We used the same technique to compare single covariate models containing each individual survivorship covariate and our best random effects only model. Covariates in models ranking better than the null model were retained, and only the most predictive spatial and temporal scale of each variable was assessed. We then created a global model containing all remaining covariates and the best random effect, and tested all possible combinations of non-correlated global model covariates to determine the predictive

value of all possible models ( $|r| \le 0.6$ ). We determined a top model with AIC rank, and considered models within 4  $\triangle$ AIC of the top model competitive (Arnold 2010); however covariates within competitive models were considered predictive of mortality risk if they were significant at the 85% confidence level.

Final model performance was evaluated using multiple techniques. We assessed Schoenfeld residuals to evaluate the assumption of proportional hazards (indicated by a trend line with a slope near zero and residuals that are randomly distributed; Schoenfeld 1982). We also evaluated a concordance (*c*) index for the top model to determine its predictive ability (Pencina and D'Agostino 2004). A maximum *c* index value of 1.0 indicates perfect concordance between observed and predictive responses, while *c* index values  $\geq 0.8$  indicate models with good predictive capabilities (Pencina and D'Agostino 2004). Variance inflation factors were calculated for coefficients in the top model. Variance inflation factor values  $\leq 5$  indicate a lack of inflation resulting from collinear variables being included in the same model (Heiberger and Holland 2004).

#### RESULTS

We used data from 151 adult female pronghorn captured and released during 2 events (113 adult female pronghorn in November 2013 and 38 in November 2014). Fourteen individuals were excluded due to cause of death (12 [7.9%] died as a result of capture and 2 were likely harvested illegally [1.3%]), and 6 (4.0%) were excluded because they died before the summer season. In addition, we did not relocate 5 (3.3%) individuals, and 11 (7.3%) transmitters were still deployed at the time of analysis. One (0.7%) individual was excluded due to collar malfunction. We thus evaluated mortality risk for 114 adult female pronghorn (38 from Baggs, 38 from Bitter Creek, 27 from Red Desert, and 11 from CDC) using 470,126 locations and 24 (21.1% of 114

pronghorn) mortality events. Naïve survival estimates for summer 2014 and 2015 were 80.0% (72 survived of 90) and 75.0% (18 survived of 24), respectively.

## **Mortality Risk Modeling**

We used year as a random effect in all models because it had the lowest AIC value compared to other combinations of random effects. Seven covariates ranked above the null model in single-covariate modeling, and of these, 4 were included in the global model to be tested in all combinations, because they were the best spatial or temporal scales for that covariate and were uncorrelated with other variables. Covariates included in the global model were leanness score at time of capture (leanness), cumulative total of each week's average daily distance to water (CumDistWater), standard deviation (SD) in daily snow depth during the previous winter (SDSnow\_Seas), and corrected age (AgeCorr).

Results from testing all possible combinations of these 4 covariates indicated that all models were competitive (within 4  $\Delta$ AIC of top model), including the null model (Table 2.3). The top model contained covariates related to our intrinsic and environmental hypotheses, but none related to our anthropogenic hypothesis. The model best explaining summer mortality risk in adult female pronghorn in the Red Desert included leanness and SDSnow\_Seas. While a model containing all 4 covariates was competitive, only the leanness and SDSnow\_Seas covariates were significant at the 85% confidence level. Pronghorn summer mortality risk increased by 5% for every 1 mm increase in leanness and by 19% for every 1 cm increase in SDSnow\_Seas (Table 2.4; Fig. 2.2). Average leanness score (mm) at time of capture for pronghorn that died was 1.3-times greater (22.1; SE = 1.8) compared to pronghorn that survived (17.5, SE = 1.1). Pronghorn that died were exposed to an average SD in daily snow depth (cm)

during the previous winter (6.4, SE = 0.5) 1.1-times greater than that experienced by pronghorn that survived (5.7, SE = 0.2).

Analysis of Schoenfeld residuals revealed a trendline with a near-zero slope and randomly distributed residuals, indicating that the assumption of proportional hazards was met. The *c* index value for our best model was 0.74, indicating our model had moderate concordance between observed and predicted summer mortality risk of pronghorn. Variance inflation factor values for coefficients in the final model were  $\leq 5$ , indicating that no collinearity of coefficients in the model resulted in variance inflation.

## DISCUSSION

Risk of mortality for adult female pronghorn in the Red Desert of Wyoming in summers 2014 and 2015 was explained in part by a combination of intrinsic and environmental factors, but we did not detect an influence of anthropogenic features. Summer mortality risk was heightened by poorer early-winter body condition and by exposure to greater variation in snow depth during the previous winter. Naïve survival estimates for adult females in summers 2014 and 2015 (80% and 75%, respectively) were relatively high and consistent with survival estimates of adult female pronghorn in other areas of Wyoming (Beckmann et al. 2008).

While intrinsic and environmental factors were shown to influence summer mortality risk of adult female pronghorn in the Red Desert, energy development, a common land use in the region, is a growing concern for many species worldwide. Oil and natural gas fields, particularly, pose a potential threat to the fitness of many species that spend a substantial portion of time in sagebrush environments (Copeland et al. 2009). Such development and its associated infrastructure has, for example, caused reduced survival of adult females (Holloran 2005) and lek attendance by males (Gregory and Beck 2014) in greater sage-grouse (*Centrocercus* 

*urophasianus*) and increased avoidance of developed areas by mule deer (*Odocoileus hemionus*; Sawyer et al. 2006) and elk (*Cervus canadensis*; Buchanan et al. 2014). While natural gas development may have a demonstrated effect on habitat selection in pronghorn (Beckmann et al. 2012, Seidler et al. 2015), like other studies (Beckmann et al. 2008, 2016), we did not detect an influence of density of or proximity to oil and natural gas wells on mortality risk of adult female pronghorn. However, any negative influences of oil and natural gas development on pronghorn fitness may lag behind the observed behavioral changes in habitat selection and movement associated with this infrastructure (Beckmann et al. 2016), in which case such demographic effects would not be detected except over a longer monitoring period.

Similarly, we found no effect of density of and proximity to roads and fences on adult female pronghorn summer mortality risk in the Red Desert. In addition to the hypothesis that animals may perceive such linear features as a source of risk (Frid and Dill 2002, Gavin and Komers 2006), it is well-demonstrated that they can impose a strong barrier effect on pronghorn movement (Sheldon 2005, Gates et al. 2012, Sawyer et al. 2013). Fences and roads may prevent pronghorn from accessing high-quality resources, which become increasingly important during periods of high energetic demand or harsh environmental conditions (Yoakum et al. 2014). The ability to move to areas that offer better habitat, such as higher quality forage, may be even more important for pronghorn, as an animal potentially employing more of an income strategy (Clancey et al. 2012), than many other ungulates in western North America that may rely more heavily on previously accrued energy reserves. Though there have been demonstrated changes in pronghorn movement behavior in relation to roads and fences (Sheldon 2005, Gates et al. 2012, Sawyer et al. 2013, Yoakum et al. 2014), and direct mortality observed as a result of these features (O'Gara and Yoakum 2004, Gavin and Komers 2006, Harrington and Conover 2006, Kolar et al. 2012), we found no evidence of an indirect effect of roads and fences on pronghorn mortality risk.

While we found no impact of anthropogenic conditions, we found that energetic resources played an important role in risk of summer mortality for adult females in the Red Desert of Wyoming. Body condition upon entering winter may dictate not only an animal's ability to survive that winter season, but may also affect their ability to endure the costly period of reproduction that follows (Jönsson 1997, Monteith et al. 2013). Pronghorn inhabiting northern regions fare worse in snow than many other ungulate species, largely because of their small hoof area relative to body weight (Telfer and Kelsall 1984), and they struggle with snow depths greater than 25 cm (Bruns 1977, Yoakum et al. 2014). When animals experience increased variation in snow depth, and likely increased exposure to deep snow, they deplete energy reserves by incurring increased energetic costs associated with locomotion, foraging, and potentially fasting (Barrett 1982, Parker et al. 1984). These costs can be heightened when deep snow is coupled with fencing (Gates et al. 2012). Pronghorn usually elect to crawl under fences, rather than jump over them (O'Gara and Yoakum 2004), and deep snow filling the depression underneath fences can cause wildlife-friendly fencing to become an impermeable barrier (Bruns 1977, Sheldon 2005, Yoakum et al. 2014). Loss of energy reserves during winter seasons may be exacerbated by anthropogenic features like fences, and it is therefore possible for anthropogenic conditions to play a role in pronghorn mortality risk. However, we did not detect an effect of the interaction between total snow experienced and fence density during the previous winter on summer mortality risk at any spatial scale. The decreases in fat stores commonly seen in winter make it more difficult to fuel reproduction and survival the following summer, a pattern that is intensified by the extreme reproductive effort of pronghorn relative to other ungulates (Robbins

and Robbins 1979). Our results showed that body condition and exposure to increased variability in snow depth during the previous winter were important components of summer mortality risk for adult female pronghorn. Additionally, NDVI was not predictive of mortality risk, potentially suggesting that it is difficult for pronghorn to recover from the energetic losses associated with the winter season and poor body condition, even with exposure to high quality vegetation. Although pronghorn may display many characteristics consistent with ungulates using income to finance energetic expenditures (Clancey et al. 2012), they are still highly dependent on the maintenance of stored energy reserves for survival.

## MANAGEMENT IMPLICATIONS

Our results indicate that variability in snow depth, coupled with the high energetic demand pronghorn face during gestation and lactation, may impact their ability to fuel their own survival through the summer months. Thus, during harsh winters with fluctuating snow conditions, it is likely that managers in Wyoming will observe not only higher over-winter mortality in pronghorn (Barrett 1982, O'Gara and Yoakum 2004, Smyser et al. 2005, Taylor et al. 2016), but increased mortality during the following summer, as well. While we did not find evidence that anthropogenic conditions within the Red Desert were influencing summer mortality of adult female pronghorn, it is possible that these features can exacerbate the effects of intrinsic and environmental stressors. We did not detect an effect of the interaction between total snow depth and fence density experienced during the previous winter on summer mortality, but it is conceivable that fencing coupled with deep snow could result in an increased loss of energy reserves during winter seasons, as it can inhibit access to high quality resources and increase energy expenditure associated with locomotion (Yoakum et al. 2014). Therefore, pronghorn populations would presumably benefit from increased permeability in fencing, as well as fence

removal in areas where livestock fencing or wildlife exclusion fencing is unnecessary (Sheldon 2005, Gates et al. 2012, Yoakum et al. 2014).

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Associate Editor:

Table 2.1. Landscape characteristics of study areas where summer mortality risk for n = 114 adult female pronghorn was evaluated in the Red Desert, south-central Wyoming, USA, 2013–2015.

	Study Area				
Landscape characteristic	Baggs	Bitter Creek	CDC <sup>a</sup>	Red Desert	
Size (km <sup>2</sup> )	4,665	2,435	878	5,648	
Elevation (m)					
Mean	2,256	2,068	2,074	2,140	
Range	1,915-3,287	1,850-2,413	1,968-2,215	1,966–2,646	
30-yr precipitation (cm) <sup>b</sup>					
Mean	45.8	25.4	19.7	25.2	
Range	23.1–94.3	19.0-39.3	18.8-22.6	17.4–36.8	
Land ownership (%)					
Federal	56	70	51	83	
State	9	2	0	5	
Private	36	28	49	12	
Well density (no./km <sup>2</sup> ) <sup>c</sup>					
Mean	0.2	0.7	0.7	0.0	
Range	0.0-3.0	0.0-5.0	0.0–4.9	0.0-0.6	
Fence density (km/km <sup>2</sup> ) <sup>d</sup>					
Mean	0.4	0.3	0.3	0.1	
Range	0.0-2.1	0.0-1.7	0.0-1.9	0.0-2.0	

Road density (km/km<sup>2</sup>)<sup>e</sup>

Mean	0.4	0.9	1.1	0.3
Range	0.0–4.0	0.0-7.1	0.0–7.1	0.0–4.9

<sup>a</sup>Continental Divide-Creston (CDC).

<sup>b</sup>30-yr annual precipitation (1981–2010, Prism Climate Group 2017).

<sup>c</sup>Kernel density estimate of number of oil and natural gas wells/km<sup>2</sup> as of December 31,

2015 (Wyoming Oil and Gas Conservation Commission [WOGCC] 2016).

<sup>d</sup>Line density estimate of fences within 1-km search window (Wyoming Cooperative Fish and Wildlife Research Unit).

<sup>e</sup>Line density estimate of roads within 1-km search window (O'Donnell et al. 2014).

Table 2.2. Predictor covariates considered in pronghorn summer mortality risk modeling using Cox proportional hazards regression in the Red Desert, Wyoming, USA, 2013–2015.

Variable class	Covariate	Description
Intrinsic		
Age	AgeEst	Estimated age at mortality risk interval
	AgeCorr	Corrected age at mortality risk interval
Body condition	Mass <sup>a</sup>	Mass (kg)
	Leanness <sup>a</sup>	Leanness score associated with depth of indentation
		between sacrosciatic ligament and caudal vertebrae (mm)
	MaxFat <sup>a</sup>	Maximum rump fat thickness (mm)
Environmental		
Climate		
temp	Temp <sup>b,d</sup>	Average daily temperature (°C)
Precipitation	Prec <sup>c,e</sup>	Average daily precipitation (cm)
Snow depth	Snow <sup>b,e</sup>	Average daily snow depth (cm)
Snow days	SnowDays <sup>b</sup>	Number of days animal experienced snow depths $\geq$ 25 cm
Snow x fence	SnowFence <sup>b,g</sup>	Interaction between total snow depth and fence density
Land cover		
Distance to water	DistWater <sup>c,f</sup>	Minimum distance to water (km)
Vegetative quality	NDVI <sup>c,f</sup>	Normalized difference vegetation index (NDVI)
Anthropogenic		

Distance to

Roads	DistRd <sup>c,f</sup>	Minimum distance to road (km)		
Wells	DistWell <sup>c,f</sup>	Minimum distance to well (km)		
Fences	DistFence <sup>c,f</sup>	Minimum distance to fence (km)		
Density of				
Roads	DensRd <sup>c,f,g</sup>	Density of roads (km/km <sup>2</sup> )		
Wells	DensWell <sup>c,f,g</sup>	Density of wells (no./km <sup>2</sup> )		
Fences	DensFence <sup>ec,f,g</sup>	Density of fences (km/km <sup>2</sup> )		

<sup>a</sup>Estimated at time of capture.

<sup>b</sup>Assessed during previous season only.

<sup>c</sup>Assessed during previous week, month, and season.

<sup>d</sup>Estimated mean, minimum, maximum, and standard deviation.

<sup>e</sup>Estimated total, maximum, and standard deviation.

<sup>f</sup>Estimated moving weekly average and cumulative weekly average since entering the study.

<sup>g</sup>Assessed within 0.5, 1.0, 3.0, and 5.0 km analysis regions.

Table 2.3. Model fit statistics for models comprised of all possible combinations of noncorrelated global model covariates, used to evaluate pronghorn summer mortality in the Red Desert, south-central Wyoming, USA 2013–2015. Models shown include top three models and the null model. All models were competitive (within 4  $\Delta$ AIC of the top model; Arnold 2010). Number of parameters in each model (K), Akaike's Information Criterion (AIC), difference in AIC from the top model ( $\Delta$ AIC), AIC weights (w<sub>i</sub>), and log likelihood (LL) are also reported.

Hypothesis testing model	K	AIC	ΔΑΙϹ	Wi	LL
Leanness <sup>a</sup> + SDSnow_Seas <sup>b</sup>	2	190.3	0.0	0.1	-93.2
$Leanness^{a} + SDSnow\_Seas^{b} + CumAvgDistWater^{c}$	3	190.6	0.2	0.1	-92.3
$Leanness^{a} + SDSnow\_Seas^{b} + AgeCorr^{d}$	3	191.5	1.1	0.1	-92.7
Null	0	194.1	3.8	0.0	-97.1

<sup>a</sup>Leanness score associated with depth of indentation between sacrosciatic ligament and caudal vertebrae at time of capture (mm).

<sup>b</sup>Standard deviation in average daily snow depth during the previous winter season (cm).

<sup>c</sup>Cumulative total of each week's average daily distance to water (km).

<sup>d</sup>Corrected age (years; based on age at time of capture).

Table 2.4. Parameter estimates for the top model predictive of summer mortality risk for pronghorn in the Red Desert, south-central Wyoming, USA, 2013–2015.

			Hazard ratio	Hazard ratio 85% CI	
Variable	β	SE	[exp(coefficient)]	Lower	Upper
Leanness <sup>a</sup>	0.047	0.023	1.05	1.02	1.08
SDSnow_Seas <sup>b</sup>	0.172	0.085	1.19	1.07	1.31

<sup>a</sup>Leanness score associated with depth of indentation between sacrosciatic ligament and caudal vertebrae at time of capture (mm).

<sup>b</sup>Standard deviation in average daily snow depth during the previous winter season (cm).



Figure 2.1. Location of the Red Desert, Continental Divide-Creston (CDC), Baggs, and Bitter Creek study areas used to evaluate adult female pronghorn summer mortality risk in the Red Desert, south-central Wyoming, USA 2013–2015. Study areas were based on 5 Wyoming Game and Fish Department pronghorn Hunt Areas and 1 Bureau of Land Management (BLM) Environmental Impact Statement (EIS) area. Study area boundaries were delineated using a 100% minimum convex polygon encompassing the pronghorn locations recorded within each study area.



Figure 2.2. Hazard rates for mortality factors in the final model predicting adult female pronghorn summer mortality risk in the Red Desert, south-central Wyoming, USA, 2013–2015. Hazard rates are plotted with 85% confidence intervals. Variables include leanness (leanness score associated with depth of indentation between sacrosciatic ligament and caudal vertebrae [mm]) and SDSnow\_Seas (standard deviation in daily snow depth [cm] during the previous winter). Higher leanness values indicate animals in poorer condition at the time of capture, and higher SDSnow\_Seas values indicate animals that experienced greater variability in snow depth during the previous winter.



Figure 2.3. Variability in snow depth (as measured by the standard deviation in average daily snow depth during the previous winter; SDSnow\_Seas) and leanness score (a measurement of body condition associated with the depth of the indentation between the sacrosciatic ligament and the caudal vertebrae; leanness) for adult female pronghorn that lived and died. The SDSnow\_Seas and leanness covariates were the 2 predictive covariates in the top mortality risk model for adult female pronghorn summer mortality in the Red Desert, south-central Wyoming, USA, 2013–2015.

# CHAPTER 3. Multi-Scale Seasonal Resource Selection of Pronghorn Relative to Anthropogenic Disturbance

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## ABSTRACT

Pronghorn (*Antilocapra americana*) are endemic to western North America where they occupy expanses of grassland and sagebrush (*Artemisia spp.*) habitats. The Red Desert region in southcentral Wyoming, USA has historically served as a stronghold for pronghorn populations, but many herds in the region have experienced declining population trends over the last two decades, concurrent with oil and natural gas development. These demographic changes and the potential
for such energy development, its associated infrastructure, and other anthropogenic features including roads and fences to influence pronghorn habitat selection were the impetuses for our study. We sought to evaluate the potential effect of human-induced disturbance on multi-scale seasonal resource use of 142 adult female pronghorn between 2013 and 2016 using 442 unique animal-season-year datasets. We utilized a traditional resource selection function to evaluate seasonal home-range selection and a step-selection function to assess fine-scale, patch-level seasonal selection. We also evaluated resource use during daytime and nighttime hours with step-selection analyses. Across all seasons at the seasonal home-range scale, pronghorn selected for areas with more sagebrush and areas closer to oil and gas wells. This selection was likely a consequence of the placement of oil and gas wells in high quality pronghorn habitat with greater proportions of sagebrush, rather than an affinity for development. At the finer, patch-scale level, pronghorn selected for sagebrush and avoided crossing fences in all seasons and at all times-of-day. We recommend minimizing anthropogenic disturbance, in high quality seasonal pronghorn range, particularly during winter when risk-avoidance responses may be amplified.

## **KEY WORDS**

Anthropogenic infrastructure, *Antilocapra americana*, pronghorn, resource selection function, sagebrush, seasonal resource selection, step-selection function, Wyoming.

#### INTRODUCTION

The distribution of wildlife populations reflect ecological processes of resource selection and avoidance of areas with greater risk and competition (Johnson 1980). The risk-allocation hypothesis suggests that through behavioral decisions, animals balance energetic trade-offs associated with acquiring resources and avoiding potential threats to their survival (Lima and

Dill 1990), and for large mammalian herbivores, one of the greatest sources of mortality risk is predation (Gaillard et al. 2000). In one example, female boreal caribou (Rangifer tarandus) both avoided open areas and increased their movement speed and path directness when wolves (Canis lupus) were within 2.5 km (Basille et al. 2015), exemplifying the rapid behavioral responses central to minimizing risk and maximizing reward (Lima and Bednekoff 1999). In addition to predation as a traditional source of risk on the landscape, it is conceivable that animals may perceive other types of disturbance as a threat akin to that posed by predators. The riskdisturbance hypothesis of Frid and Dill (2002) proposes that avoidance behaviors resulting from predation risk are similar to behaviors resulting from human-induced disturbances. Congruently, Sawyer et al. (2006) observed an immediate avoidance of natural gas development by mule deer (Odocoileus hemionus) in western Wyoming, USA, and perpetual avoidance of infrastructure remained through 15 years of continued development (Sawyer et al. 2017). Anthropogenic features associated with such energy development, like roads, fences, and oil and gas wells, may indirectly cause habitat loss for ungulate species by inhibiting daily movements and seasonal migrations necessitated by varying climatic conditions and changes in plant phenology (Sheldon 2005, Beckmann et al. 2012, Lendrum et al. 2012, Sawyer et al. 2013, Seidler et al. 2015, Prokopenko 2016). Not only can such features serve as physical barriers to ungulate movement, but they may also invoke a stress response that can consequently illicit risk-avoidance behaviors (Frid and Dill 2002, Wasser et al. 2011, Northrup et al. 2013, Buchanan et al. 2014). As a result of increased vehicular traffic, for example, pronghorn in Alberta reduced the amount of time spent foraging and increased the amount of time spent in a vigilant state (Gavin and Komers 2006). When environmental conditions are particularly harsh, such as during winters with heavy snowfall, lost access to crucial resources due to anthropogenic infrastructure and activity can

have a combined effect that exacerbates the challenges environmental conditions may present on their own (Bruns 1977, Gates et al. 2012, Yoakum et al. 2014). Knowledge of behavioral changes such as increased vigilance or altered resource use is critical, as these changes may have severe impacts on individual and population-level fitness (Creel and Christianson 2008; Sawyer et al. 2017).

The Red Desert region in south-central Wyoming, USA has experienced a drastic increase in intensive energy extraction efforts. Of all active and producing oil and traditional and coalbed methane natural gas wells in the area, roughly 80% were drilled since 2000 (WOGCC 2017), and sagebrush-steppe habitats similar to those in the Red Desert are expected to experience increasing disturbance as a result of continued energy development (Copeland et al. 2009). This region has historically served as a stronghold for Wyoming pronghorn populations, and whereas some Red Desert herds have experienced population increases over the last two decades, others are still suffering declines of greater than 20% (WGFD 1996-2016), concurrent with expanding energy development in the area. Pronghorn behavior is altered by anthropogenic features including roads (Gavin and Komers 2006; Seidler et al. 2015), fences (Sheldon 2005), and natural gas wells (Beckmann et al. 2012), often resulting in the loss of high quality resources. Given declining trends in pronghorn populations and coinciding anthropogenic change in the region, we sought to evaluate the potential influence of natural gas extraction, its associated infrastructure, and other anthropogenic features on resource selection behavior of adult female pronghorn in the Red Desert.

We quantified the selection of habitat components within the home range (third-order resource selection; Johnson 1980) for pronghorn at both the seasonal home-range-level and seasonal patch-level between 2013 and 2016 with traditional resource selection (resource

selection function [RSF]), as well as step-selection (step-selection function [SSF]; Fortin et al. 2005) approaches. Step-selection functions are unique in that they allow the characterization of selection as the animal moves through the landscape by linking consecutive locations (Thurfjell et al. 2014), which is not captured with more coarse-scale RSF approaches. An RSF at the seasonal home-range level may fail to identify fine-scale, temporally-linked behavioral responses, while the seasonal patch-level SSF does not wholly characterize the selection process occurring at the seasonal home-range scale (Johnson 1980; Fortin et al. 2005). Therefore, we used multi-scale methods to identify third-order pronghorn resource use in response to anthropogenic activity within the Red Desert.

#### **STUDY AREA**

The Red Desert region in south-central Wyoming, USA (42.03°N, -108.31°W) roughly extends north to south from the southern end of the Wind River Mountain Range south to the Colorado state border; and east to west from Rawlins to Rock Springs, Wyoming, USA (Fig. 3.1). We designated a single study area within the Red Desert encompassing 19,558.1 km<sup>2</sup>. The study area boundary was defined using a 100% minimum convex polygon around locations of 142 pronghorn captured primarily within 5 Wyoming Game and Fish Department (WGFD) Antelope Hunt Areas (53, 55, 57, 60, and 61; Fig. 3.1).

The Red Desert region and our designated study area provided the unique opportunity to assess pronghorn habitat use in response to a wide range of conditions, as environmental characteristics, land ownership, and levels of anthropogenic development were highly varied throughout. Average elevation was 2,141 m (range: 1,850–3,287 m). Across the study area, the 30-year normal annual precipitation (1981–2010; Prism Climate Group 2017) averaged 29.3 cm (range: 16.0–124.5 cm), with higher elevation areas usually receiving greater levels of

precipitation. Our study area was mostly composed of federal land (66.3%), followed by private property (29.4%) and lands under state ownership (4.3%). At the initiation of our study in November 2013, density of active and producing oil and gas wells in the area averaged 0.2 wells/km<sup>2</sup> (range: 0.0–12.4 wells/km<sup>2</sup>; WOGCC 2016). Fence density averaged 0.1 km/km<sup>2</sup> (range: 0.0–2.5 km/km<sup>2</sup>), whereas road density was higher than fence density, averaging 0.3 km/km<sup>2</sup> (range: 0.0–14.2 km/km<sup>2</sup>; O'Donnell et al. 2014).

Vegetation in our study area mostly consisted of Wyoming big sagebrush (*A. tridentata wyomingensis*) communities with perennial grasses and forbs mainly forming the understory. In low-lying areas, black greasewood (*Sarcobatus vermiculatus*) and Gardner's saltbush (*Atriplex gardneri*) were the dominant species. In higher elevations, mountain big sagebrush (*A. t. vaseyana*), mixed shrub communities, and aspen (*Populus tremuloides*) stands were common. Major land uses included oil and natural gas extraction, livestock production, and big game hunting.

### METHODS

## **Capture, Processing, and Monitoring**

We used helicopter net-gunning (Native Range Capture Services, Ventura, CA 93003) to capture adult ( $\geq$ 1.5-yr) female pronghorn in November 2013, February 2014, and November 2014. To minimize capture-related mortality, we limited chase time and the distance between capture and processing locations, and administered a cold-water enema to animals whose rectal temperature approached or exceeded 40°C (Jacques et al. 2009). We weighed each female to the nearest 0.1 kg, collected biological samples for lab analyses including blood, hair, and feces, and estimated age of individuals based on tooth eruption and wear (Lubinski 2001). We fitted individuals with store-on-board GPS (model G2110D, Advanced Telemetry Systems, Inc., Isanti, MN 55040) necklace transmitters.

Pronghorn locations were set to be recorded every 2 hours over a 2-year period. We censored locations recorded within the first week of capture to avoid any influence of capture events on individual movement behavior (Northrup et al. 2014, 2015). We defined summer as May through August and winter as December through February of the following year, and retained data for animals with 500 or more locations for each individual season to ensure accurate characterization of seasonal ranges (e.g., Prokopenko 2016). Other techniques of seasonal designation, such as visual or net squared displacement methods, are not consistently accurate, particularly for animals that make frequent excursions or do not have clear, spatially clustered locations (Peters et al. 2017). Our seasonal definitions also ensured that all pronghorn had roughly the same number of locations and therefore the same weight in seasonal models. All pronghorn were captured, processed, and monitored in accordance with protocols approved by Wyoming Game and Fish Department (Chapter 33-923 Permit) and University of Wyoming Institutional Animal Care and Use Committee (protocol 20131028JB00037).

## **Habitat Selection Covariates**

We evaluated resource selection of adult female pronghorn using environmental and anthropogenic covariates (Table 3.1). Environmental covariates included climate and land cover variables, whereas a different suite of environmental covariates was used for assessing selection during summer and winter seasons across multiple scales. Anthropogenic covariates remained the same for summer and winter analyses, and included the distance to roads, wells, and fences. Two additional binary anthropogenic variables were included in the SSF modeling approach that evaluated whether pronghorn steps crossed road or fence features (i.e., 0 = no intersection, 1 =

intersection). All covariates were scaled and centered prior to analyses. We computed the Pearson correlation coefficients between all continuous covariates, and retained the most informative of any correlated ( $r \ge |0.7|$ ) variables. The extraction of covariate values and all subsequent analyses were performed using RStudio and Program R (R Version 3.4.1, www.rproject.org, accessed 31 July 2017) and ArcMap version 10.4.1 (Environmental Systems Research Institute, Inc., Redlands, CA, USA).

*Environmental covariates.* – Due to their small hoof area relative to body weight, pronghorn fare poorly in snow compared with other ungulate species (Telfer and Kelsall 1984); snow depths greater than 30 cm severely hinder movement and are usually avoided (O'Gara and Yoakum 2004). Additionally, pronghorn begin to reach their lower critical temperature at roughly 0°C (Wesley et al. 1973), resulting in increased metabolic rate as animals attempt to raise body temperature. The locomotive difficulty that deeper snow presents, combined with the energy required for self-maintenance in colder temperatures, ultimately increase the expense of winter survival in pronghorn, and in severe winters, die-offs can be extreme (Barrett 1982). Given that these climatic conditions can influence pronghorn mortality (Reinking et al., unpublished data) and therefore likely influence their resource use, we sought to identify the role that snow depth and temperature might play in pronghorn habitat selection during winter. We obtained daily snow depth (cm) and temperature data using SnowModel (Liston and Elder 2006a; InterWorks Consulting LLC, Loveland, CO 80538; 250 m resolution). SnowModel simulates processes related to snow; including but not limited to snow precipitation, blowing snow, snow-density evolution, and snow melt. The meteorological variables required by SnowModel were provided by MicroMet (Liston and Elder 2006b) and included temperature,

precipitation, and other meteorological factors. We calculated a heat load index (HLI), which incorporates slope, aspect, and latitude to identify the warmest slopes (McCune and Keon 2002).

We used Landfire Existing Vegetation Type raster data (LANDFIRE 2013) to assess vegetation type (sagebrush or non-sagebrush dominant pixels) and water. Pronghorn are often considered to be sagebrush obligates, relying heavily on this vegetation year-round as a source of dietary nutrition and cover (O'Gara and Yoakum 2004, Taylor et al. 2016). We classified a pixel as sagebrush dominant when it was classified as Great Basin xeric mixed sagebrush shrublands, Intermountain basins big sagebrush shrublands, Columbia Plateau low sagebrush steppe, Intermountain basins big sagebrush steppe, or Intermountain basins montane sagebrush steppe (sensu Donnelly et al. 2017). We then evaluated the proportion of sagebrush dominant pixels within 0.5 km of each pronghorn location for use in RSF modeling, and assessed the potential role of sagebrush in SSF analyses with a binary covariate representing whether an area was sagebrush dominant (Fig. 3.2). These two different sagebrush variables were used in RSF and SSF analyses because the distance between temporally linked locations used in SSF analyses was less than 0.5 km regardless of time of day or season. In addition to their reliance on sagebrush habitats, Poor (2010) found that habitat suitability for pronghorn increased closer to water. We estimated Euclidean distance to water from all water sources identified within LANDFIRE (2013). To evaluate vegetative quality, we assessed integrated Normalized Difference Vegetation Index (INDVI; 250 m resolution) for each year of our study; INDVI is related to growing season plant production and nutritional quality (Pettorelli et al. 2005, 2011).

*Anthropogenic covariates.* – Pronghorn movement and resource selection may be severely altered by impermeable and permeable anthropogenic infrastructure, such as roads and fences (Sheldon 2005, Sawyer et al. 2013, Seidler 2015), and natural gas wells (Beckmann et al. 2012).

We wanted to assess the potential impact of such features on multi-scale habitat selection by pronghorn in the Red Desert. We used fence data obtained from the Wyoming Cooperative Fish and Wildlife Research Unit and 2009 National Agricultural Imagery Program Imagery-derived road data from the United States Geological Survey (O'Donnell et al. 2014). We obtained locations of producing oil and gas wells from the Wyoming Oil and Gas Conservation Commission (WOGCC 2017). Wells were filtered by spud date (the date when drilling activity began) to ensure they were present during the time when individual pronghorn locations were recorded. If spud date was not available, we used the completion date (the date of the first completion report filing).

## **Resource Selection Function**

We used a two-stage approach to evaluate selection within summer and winter seasonal ranges by estimating an RSF for each pronghorn during each season and year (hereafter referred to as an animal-season-year [ASY]) and then estimating population level habitat selection (Fieberg et al. 2010). For each ASY, we assessed environmental and anthropogenic covariate values at used and 12,820 randomly generated available locations (10 times the average number of locations for each ASY) for each animal within a 90% utilization distribution representing their seasonal home-range (type 3 design; Thomas and Taylor 2006). We used generalized linear models to maximize the use-availability likelihoods with an exponential link function for each ASY (McDonald 2013). We bootstrapped model coefficients to generate population-level coefficient means and confidence intervals with package 'boot' in R (Cantry 2016). The RSF took the following form:

$$w(x) = exp[\beta_1 h_1(x) + \beta_2 h_2(x) + ... + \beta_n h_n(x)]$$

where w(x) was proportional to the probability of pronghorn occurrence, and representative of the strength of selection for covariates ( $h_n$ ), at location x in environmental space, and  $B_n$ 's were coefficients estimated for each covariate.

# **Step-Selection Function**

We employed a step-selection function (Fortin et al. 2005) to evaluate patch-scale resource selection during summer and winter. We also assessed potential differences in selection between day and night because ungulates exposed to anthropogenic development may behave differently during daylight hours, when human activity is often greater than during nighttime hours (Lendrum et al. 2012, Buchanan 2015). We categorized locations as occurring either during daylight or darkness based on daylight hours for Wamsutter, Wyoming, USA, near the centroid of our study area. For each ASY, we randomly selected one daytime and one nighttime (acknowledging that one nighttime period spans two days) location on each date for which an individual had movement data. We paired each used location with 10 random available locations, generated from the distribution of step length and absolute and relative turning angles of used locations observed in all sample animals (Fortin et al. 2005, Thurfjell et al. 2014). For each used and available endpoint of a given step, we determined values of environmental and anthropogenic covariates (Table 3.1). Additionally, we evaluated whether paths along used or available steps intersected roads and fences.

We used the 'survival' package in Program R (Therneau 2015) to apply a conditional logistic regression to compare covariate values at used and available locations. This allowed us to estimate an SSF of the following form:

$$w(x) = exp(\beta_1 x_1 + \beta_2 x_2 + \dots + \beta_n x_n)$$

where  $\beta_1$  represents the estimated coefficient describing the strength of selection for variable  $x_1$ .

## RESULTS

We used data from 164 adult female pronghorn captured and released during 3 events (113 adult female pronghorn in November 2013, 13 in February 2014, and 38 in November 2014). Eighteen individuals (11.0%) were excluded from analyses because they had fewer than 500 total locations (and therefore had fewer than 500 locations in a given season) and 4 transmitters (2.4%) were never recovered. We thus evaluated resource selection for n = 142 adult female pronghorn from 882,169 recorded locations. We filtered location data by summer and winter seasons, using 306,023 summer locations and 242,405 winter locations, constituting 479 unique ASY combinations (229 summer animal-year and 250 winter animal-year combinations) and capturing 62.2% of all recorded locations. For each ASY, we censored individuals with fewer than 500 locations, resulting in 442 unique ASY datasets (215 summer animal-year and 227 winter animal-year datasets) from 2013 to 2016.

# **Resource Selection Function**

Congruent with Sheldon's (2005) research evaluating pronghorn habitat selection in Wyoming, we found that summer home-ranges were roughly half the size of winter home-ranges. Across all animal-year datasets, the average summer home-range size was 73.4 km<sup>2</sup> (range: 3.0–1,851.6 km<sup>2</sup>), whereas the average winter home-range size was 156.7 km<sup>2</sup> (range: 11.0–1,582.7 km<sup>2</sup>). After the removal of ASY combinations for which models failed to converge, we utilized 164 summer animal-year models and 199 winter animal-year models to evaluate seasonal selection. Pearson's correlation coefficients for covariates did not exceed 0.68 in any season, and thus we retained all covariates in analyses. The 95% confidence intervals generated by bootstrapping individual selection coefficients indicated that at the population level, during both summer and

winter, pronghorn on average selected for areas closer to oil and gas wells and areas with higher proportions of sagebrush; during winter, pronghorn selected for areas farther from roads (Table 3.2). In the summer and winter season, there was negative selection for distance to wells in 64.0% and 52.8% of the individual animal-year models, respectively, indicating greater resource use of areas closer to wells than would be expected given availability by the majority of animals during both seasons. Pronghorn selected for areas with a greater proportion of sagebrush, displaying positive selection for sagebrush in all but 9.6% of animal-year models for winter, and 29.9% of summer models. During winter there was also positive selection for distance to roads in 54.8% of the individual animal-year models, indicating a preference for areas farther from roads during that season. At the 95% confidence level, no selection was evident in either season for other environmental (snow depth, HLI, distance to water, and INDVI) or anthropogenic (distance to fence) covariates (Table 3.2).

#### **Step-Selection Function**

We utilized 1,009,140 used and available steps (283,756 summer daytime, 280,115 summer nighttime, 221,353 winter daytime, and 223,916 winter nighttime steps) in our step-selection analyses. All variables were retained, as no Pearson correlation coefficients of continuous variables were  $\geq$ |0.7| for covariates during any season, daytime or nighttime. Across seasons and all times-of-day, the results of the conditional logistic regression indicated that at the 95% confidence level, pronghorn selected for sagebrush dominant areas and avoided crossing fences (Tables 3.3 and 3.4). During daylight hours in both summer and winter, animals showed selection for paths that intersected road features, while during nighttime hours, they showed avoidance of such paths. Avoidance of linear anthropogenic features was also evident during winter daylight hours, when pronghorn selected for areas farther from roads, and during summer

daylight hours, when pronghorn selected for areas farther from fences (Tables 3.3 and 3.4). While linear anthropogenic features were avoided, pronghorn selected for areas closer to wells during summer daylight hours, but avoided these features during the daytime in winter. During winter nights, pronghorn selected for areas with colder temperatures (Table 3.4).

#### DISCUSSION

Between 2013 and 2016, we sought to identify resource selection of adult female pronghorn in the Red Desert of south-central, Wyoming, USA, particularly as it related to the recent expansion of anthropogenic infrastructure in the region. To accurately capture the scope of pronghorn selection relative to both environmental and anthropogenic variables, we used 2 analysis techniques, each addressing different scales of selection within third-order resource use (Johnson 1980): a traditional resource selection function to evaluate selection at the seasonal home-range scale, and a step-selection function to assess selection at the seasonal patch-scale within home ranges. Our results indicated that at the seasonal home-range scale, pronghorn selected for greater proportions of sagebrush and areas closer to oil and gas wells in summer and winter. Pronghorn in Wyoming rely heavily on sagebrush habitats for cover and nutrition year-round; in the Red Desert, their diets can be composed of 62–97% shrub species, including sagebrush, with percent composition of shrubs being highest in winter (Taylor 1972, O'Gara and Yoakum 2004). Sagebrush shrublands are predicted to experience the greatest impacts of oil and gas development of all vegetative communities in the Intermountain West, as they have the highest potential for discovery of hydrocarbon deposits (Copeland et al. 2009). Because oil and gas development often occurs in high quality sagebrush habitats (Copeland et al. 2009, Smith et al. 2014, Kirol et al. 2015), pronghorn selection for areas closer to wells at the seasonal home-range scale is likely an indication of pronghorn selection for quality seasonal habitat with high

proportions of sagebrush, rather than a preference for oil and gas development. On average, the habitat within 0.5 km of oil and gas wells located in our study area was 65% sagebrush dominant. This conclusion is further supported by the results of our finer-scale, seasonal patchlevel SSF, which demonstrated that pronghorn selected for sagebrush dominant areas year-round, but did not consistently select for areas closer to wells, doing so only during the daytime hours of summer and avoiding areas close to these features during the daylight hours of winter, consistent with other research evaluating pronghorn use of an oil and gas field in winter (Beckmann et al. 2012). During winter, when pronghorn are faced with increased thermoregulatory and locomotive costs (Wesley et al. 1973; Barrett 1982; Telfer and Kelsall 1984; Reinking et al., unpublished data) they may be more risk-averse in an effort to avoid the loss of crucial energy reserves. Indeed, we observed selection away from development during winter at the seasonal home-range scale, as pronghorn showed positive selection for areas farther from roads. Our modeling also revealed avoidance of areas close to roads at the finer, seasonal patch-scale during winter daylight hours. Road activity in oil and gas fields is typically higher during daytime than nighttime (Buchanan 2015), and pronghorn may be displaying increased risk-avoidance towards this feature during daylight hours in the winter season. Interestingly, at the seasonal patch-level, pronghorn appeared to select for crossing roads during daylight hours, but selected against crossing roads during the nighttime. It is possible that pronghorn may be avoiding crossing roads at night, when there is an increased risk for wildlife-vehicle collision (Mastro et al. 2010, Diaz-Varela et al. 2011, Hothorn et al. 2016). This result may also be reflective of decreased pronghorn movement during nighttime hours in summer and winter. During summer daytime, pronghorn moved an average of 220.4 m/hr (95% CI: 219.3-221.5), while at night they moved an average of 146.7 m/hr (95% CI: 145.4-147.9). In winter daytime, pronghorn moved an

average of 245.6 m/hr (95% CI: 244.1–247.2), but moved an average of 93.1 m/hr (95% CI: 92.3–93.9) at night. Pronghorn selection against linear anthropogenic features is further emphasized at the patch-level scale where we found year-round avoidance of crossing fences during all hours of the day, and selection for areas farther from fences during the daytime in summer seasons. Fences can serve as a source of direct mortality for pronghorn (O'Gara and Yoakum 2004, Harrington and Conover 2006, Kolar et al. 2012), and indirectly alter habitat use through their effect as permeable or impermeable barriers to movement and through their potential to be perceived as a source of risk (Frid and Dill 2002, Sheldon 2005, Sawyer et al. 2013). Fences may represent an even greater source of risk during winter, when depressions under fences fill with snow, often causing wildlife-friendly fencing to become impassable (Bruns 1977, Sheldon 2005, Yoakum et al. 2014). It is unclear why pronghorn selected colder areas during winter nights; this result may be spurious, or further research may be required to determine a biological motivation for this behavior.

# MANAGEMENT IMPLICATIONS

Our results indicate that high proportions of sagebrush are crucial for pronghorn, regardless of season and scale. Pronghorn displayed selection for areas closer to oil and gas wells year-round at the seasonal home-range scale, but this was likely a consequence of the placement of these features in high quality sagebrush habitat. Pronghorn would therefore benefit from the conservation of areas with large proportions of sagebrush, and given the potential for oil and gas development and its associated infrastructure to alter pronghorn resource selection (Beckmann et al. 2012, 2016; Seidler et al. 2015), we recommend that such development be limited in important summer and winter range dominated by sagebrush. We also found that at the patch-level, pronghorn avoid crossing fences during all seasons and all hours of the day, and prefer

areas farther from fences during winter daylight hours. Increased permeability in fencing, as well as fence removal in areas where livestock fencing or wildlife exclusion fencing is unnecessary, would presumably reduce the risk of altered resource selection and subsequent loss of high quality habitat, as well as minimizing the likelihood of direct mortality (Sheldon 2005; Gates et al. 2012; Yoakum et al. 2014). Finally, we found that during winter, pronghorn avoided areas closer to roads at the seasonal home-range scale and during daytime hours at the seasonal patchlevel scale. It is possible that during winter, risk-avoidance behavior is elevated given the potential in ungulate species to lose crucial energy reserves (Parker 1984, Monteith et al. 2013). We thus recommend limiting human activity during the winter season and minimizing anthropogenic disturbance in pronghorn crucial winter range.

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Associate Editor:

Table 3.1. Predictor covariates considered in multi-scale pronghorn seasonal resource selection modeling using both traditional resource selection function (RSF) and step-selection function (SSF) methods with data collected in the Red Desert, Wyoming, USA, 2013–2016.

Variable class	Covariate	Description				
Environmental						
Climate						
Heat Load Index	HLI <sup>d</sup>	Heat Load Index, derived from digital elevation model				
		(USGS 2016)				
Temperature	Temp <sup>b</sup>	Average daily air temperature (°C)				
Snow depth	Snow <sup>b,d</sup>	Average daily snow depth (cm)				
Land cover						
Distance to water	DistWater <sup>a,c</sup>	Minimum distance to water (km)				
Proportion Sagebrush	Sage <sup>a,b,c,d</sup>	For RSF modeling, proportion of sagebrush dominated				
		pixels within 0.5 km. For SSF modeling, binary variable				
		representing whether pixel was sagebrush dominant.				
Vegetation quality	INDVI <sup>a,c</sup>	Integrated Normalized Difference Vegetation Index				
		(https://phenology.cr.usgs.gov/methods_metrics.php)				
Anthropogenic						
Distance to <sup>a,b,c,d</sup>						
Roads	DistRoad	Minimum distance to road (km)				
Wells	DistWell	Minimum distance to oil and gas well (km)				
Fences	DistFence	Minimum distance to fence (km)				
Path overlap <sup>a,b</sup>						

*Road intersection* RoadInt Whether path along a step intersects road

*Fence intersection* FenceInt Whether path along a step intersects fence

<sup>a</sup>Used in SSF modeling for summer seasons

<sup>b</sup>Used in SSF modeling for winter seasons

<sup>c</sup>Used in RSF modeling for summer seasons

<sup>d</sup>Used in RSF modeling for winter seasons

Table 3.2. Coefficient estimates ( $\beta$ ), 95% confidence interval lower limits (LL), and 95% confidence interval upper limits (UL) for environmental and anthropogenic variables used in modeling seasonal home-range scale resource selection by pronghorn in the Red Desert, Wyoming, USA, 2013–2016. Covariates that were significant at the 95% confidence level are denoted by an asterisk (\*), and if a covariate was not evaluated for a given season, the value is N/A.

	Summer			Winter			
Covariate -	$\beta$ LL		UL	UL β		UL	
Environmental							
Distance to water	-0.08	-0.28	0.03	N/A	N/A	N/A	
Vegetation quality	0.07	-0.05	0.14	N/A	N/A	N/A	
HLI	N/A	N/A	N/A	-0.01	-0.02	0.01	
Snow depth	N/A	N/A	N/A	0.13	-0.26	0.44	
Proportion sagebrush	0.24*	0.12	0.29	0.37*	0.31	0.39	
Anthropogenic							
Distance to roads	-0.02	-0.12	0.16	0.15*	0.07	0.19	
Distance to wells	-1.35*	-2.03	-0.93	-0.16*	-0.37	-0.04	
Distance to fences	0.01	-0.16	0.45	0.14	-0.04	0.22	

Table 3.3. Coefficient ( $\beta$ ) estimates, robust standard errors (SE), 95% confidence interval lower limits (LL), and 95% confidence interval upper limits (UL) for environmental and anthropogenic variables used in modeling of summer patch-level resource selection by pronghorn in the Red Desert, Wyoming, USA, 2013–2016. Covariates that were significant at the 95% confidence level are denoted by an asterisk (\*).

	Summer Daytime			Summer Nighttime				
Covariate	β	SE	LL	UL	β	SE	LL	UL
Environmental								
Distance to water	-0.06	0.08	-0.22	0.09	-0.06	0.08	-0.22	0.10
Vegetation quality	-0.02	0.03	-0.07	0.04	-0.04	0.03	-0.10	0.02
Proportion sagebrush	0.04*	0.01	0.02	0.06	0.03*	0.01	0.01	0.05
Anthropogenic								
Distance to roads	0.01	0.04	-0.07	0.09	-0.08	0.05	-0.17	0.01
Distance to wells	-0.43*	0.16	-0.74	-0.11	0.22	0.16	-0.09	0.54
Distance to fences	0.44*	0.13	0.20	0.69	0.06	0.12	-0.18	0.30
Road intersection	0.25*	0.03	0.19	0.31	-0.23*	0.03	-0.30	-0.17
Fence intersection	-0.44*	0.07	-0.58	-0.31	-0.71*	0.07	-0.86	-0.57

Table 3.4. Coefficient ( $\beta$ ) estimates, robust standard errors (SE), 95% confidence interval lower limits (LL), and 95% confidence interval upper limits (UL) for environmental and anthropogenic variables used in modeling of winter patch-level resource selection by pronghorn in the Red Desert, Wyoming, USA, 2013–2016. Covariates that were significant at the 95% confidence level are denoted by an asterisk (\*).

	Winter Daytime			Winter Nighttime				
Covariate	β	SE	LL	UL	β	SE	LL	UL
Environmental								
Temp	0.32	0.92	-1.49	2.13	-7.63*	0.80	-9.19	-6.07
Snow depth	-0.21	0.16	-0.53	0.12	-0.21	0.13	-0.47	0.05
Proportion sagebrush	0.09*	0.01	0.07	0.11	0.08*	0.01	0.06	0.10
Anthropogenic								
Distance to roads	0.16*	0.04	0.09	0.23	-0.03	0.03	-0.09	0.03
Distance to wells	0.56*	0.16	0.24	0.87	-0.13	0.13	-0.39	0.12
Distance to fences	-0.02	0.11	-0.24	0.20	0.15	0.10	-0.04	0.35
Road intersection	0.37*	0.03	0.31	0.42	-0.86*	0.03	-0.93	-0.80
Fence intersection	-0.70*	0.07	-0.83	-0.57	-1.30*	0.09	-1.48	-1.13



Figure 3.1. Map of the Red Desert study area where adult female pronghorn seasonal resource selection was evaluated across multiple scales in south-central Wyoming, USA 2013–2016. Animals were primarily captured in Wyoming Game and Fish Department pronghorn Hunt Areas 53, 55, 57, 60, and 61. The study area boundary was delineated using a 100% minimum convex polygon encompassing locations recorded by 142 pronghorn.



Figure 3.2. Maps of sagebrush covariates in the Red Desert study area where third-order seasonal resource use of adult female pronghorn was evaluated across multiple scales in south-central Wyoming, USA 2013–2016. To assess the potential role of sagebrush in resource selection at the seasonal-home-range scale with a resource selection function, we used the proportion of sagebrush dominant pixels within 0.5 km of pronghorn locations (A). To assess the potential role of sagebrush in resource use at the seasonal patch-level scale using a step-selection function, we used a binary variable representing whether a pixel was sagebrush dominant (B).

# APPENDIX A. Pronghorn Behavior Relative to Anthropogenic Activity in the Red Desert of South-Central Wyoming, USA

# **INTRODUCTION**

Over the past two decades (1996–2016), pronghorn (Antilocapra americana) in the Red Desert region of south-central Wyoming, USA have experienced increasing exposure to human-induced disturbance in the form of energy development (mainly oil and natural gas development), roads, and fences (WOGCC 2017, O'Donnell et al. 2014). Such anthropogenic infrastructure can cause direct habitat loss through surface disturbance and disruption of primary plant productivity (Allred et al. 2015). It has also been hypothesized that animals may respond to such infrastructure with antipredator behaviors (Frid and Dill 2002), like increased vigilance (Liley and Creel 2007) and altered movement trajectories (Basille et al. 2015). Risk-averse behaviors like these can indirectly result in the loss of high quality resources by causing lost feeding opportunities (Lima 1998). In Alberta, for example, pronghorn showed increased vigilance relative to vehicular traffic and consequently spent less time foraging (Gavin and Komers 2006). Behavioral changes like these are important to recognize as they can have severe impacts on individual and, over time, population-level fitness (Creel and Christianson 2008). Given the human-induced changes that have recently occurred in the Red Desert, our goal was to evaluate whether behavioral responses were evident in pronghorn within the region.

# **STUDY AREA AND METHODS**

We sought to evaluate behavioral differences between pronghorn in two impacted treatment areas (Baggs and Bitter Creek; see Fig. A.1), which had relatively moderate-to-high levels of

traditional and coalbed methane natural gas development (mean: 0.2 and 0.7 wells/km2, respectively, range: 0.0-5.0 wells/km<sup>2</sup>), compared with animals in one minimally-impacted control area (Red Desert; see Fig. A.1), which had relatively low levels of natural gas development (mean 0.0 wells/km<sup>2</sup>, range: 0.0–0.6 wells/km<sup>2</sup>). We did not assess behavior of pronghorn in the CDC study area because pronghorn were equipped with Global Positioning System (GPS) transmitters in that area in November 2014, after we conducted behavioral sampling of the other study areas in summer 2014. Behavioral monitoring was conducted on pronghorn that were equipped with Very High Frequency (VHF; model M2510B, Advanced Telemetry Systems, Inc., Isanti, MN 55040) or GPS (model G2110D, Advanced Telemetry Systems, Inc., Isanti, MN 55040) necklace transmitters at capture. Our monitoring protocol was based on methods outlined by Gavin and Komers (2006). Each behavioral observation event consisted of 3, 5-minute observation bouts during which focal individuals were observed through high-powered spotting scopes (Vortex Razor HD Straight 16-48x65, Vortex Optics, Middleton, VA 53562) or binoculars (Vortex Viper HD 15x50, Vortex Optics, Middleton, VA 53562). We recorded the time at which each observation was initiated, and we subsequently classified observations as occurring in the morning (8:00-10:59), mid-day (11:00-13:59), afternoon (14:00-17:59), or evening (18:00-21:00) based on start time. The duration of individual behaviors was recorded as they occurred. Behaviors were classified as foraging/non-costly, vigilant, bedded, moving, or other. Foraging/non-costly behaviors consisted of behaviors related to feeding or those that were less energetically costly, such as standing. Vigilant behaviors included risk-averse and alert behaviors. Bedded behaviors consisted of bedding or reclining. Moving behaviors included gaits such as walking and running. Other behaviors mainly consisted of interaction with fawns (nuzzling, grooming, nursing, etc.) and self-grooming. During each

behavioral observation, we also estimated proximity to disturbance, and noted the presence of other hoofstock and whether the focal female was accompanied by one or more fawns.

### **RESULTS AND DISCUSSION**

Between 6 June and 14 August 2014, we conducted 117 unique focal behavioral observations evaluating behavior of n = 88 adult female pronghorn across 3 study areas located within the Red Desert region of south-central Wyoming, USA. Behavioral observations occurred between 20 June and 6 August 2014 in the Baggs area, 6 June and 5 August 2014 in the Bitter Creek area, and 21 July and 14 August 2014 in the Red Desert area (Fig A.2). We conducted 40 observations of 31 females in the Baggs study area, 60 observations of 40 females in the Bitter Creek study area, and 17 observations of 17 females in the Red Desert study area. Most of the observations in the Baggs study area were conducted in the morning and mid-day (11 morning, 13 mid-day, 9 afternoon, and 6 evening observations). In the Bitter Creek study area, observations were conducted relatively evenly across all times of day (15 morning, 15 mid-day, 17 afternoon, and 14 evening observations). The majority of behavioral observations in the Red Desert study area occurred in the afternoon and evening (1 morning, 1 mid-day, 7 afternoon, and 8 evening observations). Across our 3 study areas, when comparing the average proportion of observation time spent in each of the 5 behavior categories (foraging/non-costly, vigilant, bedded, moving, or other), foraging/non-costly behavior was the dominant behavior (Table A.1). For the Baggs and Bitter Creek study areas, bedded behaviors constituted the second highest proportion of time during behavioral observations, while for the Red Desert, it was vigilant behaviors. A comparison of the estimated proportion of time spent within a given behavior across study areas shows that for all behavioral categories, 95% confidence intervals around the mean proportion of time spent in that behavior were overlapping, indicating no differences between study areas

(Table A.1). We did observe an increase in the average proportion of time spent in a vigilant state when fawns were present (Fig. A.3), which is consistent with other observations of maternal care for neonates by pronghorn (Byers et al. 1997). However, the 95% confidence intervals around the mean proportion of time spent in a vigilant state for each study area and each level of fawn presence (present or absent) were overlapping, indicating no differences.

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Table A.1. Mean, standard error (SE), and 95% confidence interval (95% CI) of the proportion of observation time in which pronghorn displayed behavior categorized as Foraging/Non-Costly (ForNon), Vigilant (Vig), Bedded (Bed), Moving (Move), or Other (Oth) based on n = 117observations of 88 adult female pronghorn across the Baggs, Bitter Creek, and Red Desert study areas within the Red Desert region of south-central Wyoming, USA during summer 2014. Baggs and Bitter Creek study areas were impacted by relatively moderate-to-high levels of traditional and coalbed methane natural gas development, whereas Red Desert was minimally-impacted by energy development and served as a control study area.

		StudyArea		
Behavior	Value	Baggs $(n = 40)$	Bitter Creek ( $n = 60$ )	Red Desert $(n = 17)$
ForNon	Mean	0.52	0.46	0.65
	SE	0.06	0.04	0.06
	95% CI	0.41-0.63	0.38-0.55	0.52-0.77
Vig	Mean	0.12	0.14	0.13
	SE	0.02	0.02	0.04
	95% CI	0.07-0.16	0.10-0.18	0.06-0.21
Bed	Mean	0.31	0.25	0.12
	SE	0.06	0.05	0.06
	95% CI	0.19-0.42	0.16-0.35	-0.01-0.24
Move	Mean	0.05	0.11	0.09
	SE	0.01	0.02	0.03
	95% CI	0.03-0.07	0.07-0.15	0.05-0.14
Other	Mean	0.01	0.03	0.01

SE	0.01	0.01	$0.02 e^{-1}$
95% CI	$-0.02 e^{-1} - 0.02$	-0.19-0.25	$0.02 e^{-1} - 0.01$



Figure A.1. Red Desert, Continental Divide-Creston (CDC), Baggs, and Bitter Creek study areas used to assess summer mortality risk of adult female pronghorn in the Red Desert, south-central Wyoming, USA 2013–2015. Behavioral observations were conducted in the Red Desert, Baggs, and Bitter Creek study areas during summer 2014; the CDC study area was added after behavioral observations were completed. Pronghorn were primarily captured in 5 Wyoming Game and Fish Department pronghorn Hunt Areas (53, 55, 57, 60, and 61); within Hunt Area 61, animals were captured in an area constricted by the boundary of a Bureau of Land Management (BLM) Environmental Impact Statement (EIS) area. Study area boundaries were defined with a 100% minimum convex polygon around pronghorn locations recorded in each area.



Figure A.2. Number of focal behavioral observations conducted on each date of the field season within the Baggs, Bitter Creek, and Red Desert study areas in the Red Desert region of south-central Wyoming, USA during summer 2014. Baggs and Bitter Creek study areas were impacted by relatively moderate-tohigh levels of traditional and coalbed methane natural gas development, whereas Red Desert was minimally-impacted by energy development and served as a control study area.



Figure A.3. Mean and 95% confidence interval (95% CI) of the proportion of 117, 15-minute observations from 88 individual adult female pronghorn spent in a vigilant state (risk-averse and alert behaviors) when fawns were present compared with when fawns were absent for the Baggs, Bitter Creek, and Red Desert study areas within the Red Desert region of south-central Wyoming, USA during summer 2014. Baggs and Bitter Creek study areas were impacted by relatively moderate-to-high levels of traditional and coalbed methane natural gas development, whereas Red Desert was minimally-impacted by energy development and served as a control study area.

# APPENDIX B. Aerial Surveys to Evaluate Pronghorn Productivity in the Red Desert of South-Central Wyoming, USA

## **INTRODUCTION**

The energetic costs of pregnancy have implications for survival of adult female ungulates (Parker et al. 2009), and these expenses are higher for pronghorn than all other ungulate species (Robbins and Robbins 1979). Pronghorn gestation length is long relative to body size, and pronghorn almost always birth twins (O'Gara and Yoakum 2004). Also, offspring weight at parturition is nearly 16% of maternal weight (Robbins and Robbins 1979), and pronghorn fawns grow rapidly relative to fawns of other ungulate species (O'Gara and Yoakum 2004).

In our study evaluating mortality risk of adult female pronghorn in the Red Desert of south-central Wyoming, USA between 2013 and 2015 (Reinking et al., unpublished data; see Chapter 2), we hoped to assess the role that productivity might play in pronghorn survival. However, evaluating reproductive status of pronghorn is challenging. The increased handling time (up to 20 additional minutes; Canon et al. 1997) required to perform ultrasonography can increase the likelihood of capture-related mortality, to which pronghorn are highly susceptible compared to other North American ungulates (Yoakum et al. 2014). For example, helicopter net gun capture, transport to processing locations, and collection of biological data averaged 8.1 minutes per individual pronghorn (range: 3–14 minutes), which may have contributed to the 7.5% capture-related mortality rate of the 186 adult female pronghorn captured for our research. Delayed methods of assessing pregnancy, such as evaluating reproductive status using blood serum samples, are also challenging for pronghorn, as they do not produce pregnancy specific protein B (S. K. Wasser, University of Washington, personal communication), a hormone often used to assess pregnancy status in ungulates (e.g. Haigh et al. 1993). Moreover, pronghorn

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progesterone levels apparently do not differ between pregnant and non-pregnant females in the early stages of gestation (S. K. Wasser, University of Washington, personal communication). Fawn-to-female ratios, a measure of pronghorn population productivity, are often assessed using on-the-ground surveys (Woolley and Lindzey 1997) in August (WGFD 2015). At the end of each summer, the Wyoming Game and Fish Department (WGFD) identifies fawn-to-female ratios for pronghorn herds across the state to evaluate recruitment. Because we wanted to find a rapid, yet efficient method to assess productivity for pronghorn included in our mortality risk study, we implemented aerial surveys to locate collared females and determine numbers of their offspring from June–August 2014, when we were also conducting on-the-ground behavioral observations of marked individuals (see Appendix A). We compared notes related to fawn presence from these observations to aerial determinations of fawn status as a means to validate aerial surveys.

## **STUDY AREA AND METHODS**

We sought to evaluate pronghorn productivity by determining fawn status (whether an individual had fawns and how many she had) for each Very High Frequency (model M2510B, Advanced Telemetry Systems, Inc., Isanti, MN 55040)- or Global Positioning System (model G2110D, Advanced Telemetry Systems, Inc., Isanti, MN 55040)-collared adult female pronghorn in the Baggs, Bitter Creek, and Red Desert study areas (based on WGFD pronghorn Hunt Areas 53 and 55, 57, and 60, respectively) within the Red Desert of south-central, Wyoming, USA in summer 2014 (Fig. B.1). Aerial surveys were flown at roughly 305 m (1000 ft) above ground-level, and were conducted by one pilot (J. P. Romero, Owyhee Air Research, Inc., Nampa, ID, USA 83687) and one observer using standard or image-stabilizing binoculars. Flights were conducted throughout the day as we did not anticipate time of day would influence fawn detectability. Once a collared individual was located, the observer would assess the female's fawn status, and would

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rate their confidence in that assessment with a value of 1 (high), 2 (moderate), or 3 (low). During on-the-ground behavioral observations, which were conducted 6 June–14 August 2014, we noted fawn presence and how many fawn(s) likely belonged to the focal female. Certain behaviors helped us to identify fawns that were likely hers, such as nursing, following her closely, or touching noses in greeting (Byers 1997). On-the-ground estimates of fawn status were compared to aerial estimates. From our aerial surveys, we calculated fawn-to-female ratios for each study area and estimated 95% confidence intervals based on the standard error between all estimated fawn counts for each surveyed study area. We obtained WGFD fawn-to-female estimates (and their associated 95% confidence intervals) for pronghorn herds within our study areas for comparison. The WGFD evaluates pronghorn fawn-to-female ratios in August of each year through on-the-ground surveys (WGFD 2015).

## **RESULTS AND DISCUSSION**

Aerial surveys focused on locating n = 119 (15 VHF and 104 GPS) adult ( $\geq 1.5$  yr) female pronghorn (40 in the Baggs, 44 in the Bitter Creek, and 35 in the Red Desert study areas), and were successful in assessing fawn status for 76 of these individuals. The 64% (76/119) rate of assessment was due to inability to locate some animals from the air, difficulty in observing collared females and fawns separately from other females with females in the same area, and mortalities prior to aerial flights. Aerial surveys were conducted between 5–8 August 2014 over about 35 hours, costing roughly \$335 USD/hour. Survey cost per animal was roughly \$154 USD/animal for the 119 adult female pronghorn we surveyed.

#### **Baggs**

We located 39 of the 40 (98%) marked females in the Baggs study area. One female was never found, and 1 mortality was discovered. The flight crew evaluated fawn status for 35 of the 38 (92%) females located. Of these, status for 5 (14%) females was evaluated with high confidence, 10 (29%) with moderate confidence, and 20 (57%) with low confidence (Fig. B.2). Twenty-seven fawns were counted for the 35 females evaluated, equating to roughly 0.8 fawns for every 1 female (Fig. B.3). On the ground, we were able to locate and assess fawn status for 8 of the 35 females that the flight crew evaluated. For 3 females, aerial and on-the-ground estimates were congruent, whereas for 5 females, they did not match.

# **Bitter Creek**

The flight crew located 28 of the 44 (64%) marked females in this study area (1 female was never found, and for 15 females, location success was not recorded). One confirmed mortality and 1 suspected mortality were also discovered. The flight crew evaluated fawn status for 23 of the 26 (89%) females located. Of these, status for 3 (13%) females was evaluated with high confidence, 8 (35%) with moderate confidence, and 12 (52%) with low confidence (Fig. B.2). Twenty-seven fawns were counted for the 23 females evaluated, equating to roughly 1.2 fawns for every 1 female (Fig. B.3). On the ground, we located and assessed fawn status for 8 of the 23 females that the flight crew assessed. For 5 females, aerial and on-the-ground estimates were congruent, whereas for 3 females, they did not match.

# **Red Desert**

The flight crew was able to locate 30 of the 35 (86%) marked females in this study area. Five females were never found, and 4 potential mortalities were discovered. The flight crew evaluated

fawn status for 18 of the 26 (69%) females located. Of these, status for 1 (6%) female was evaluated with high confidence, 5 (28%) with moderate confidence, and 12 (67%) with low confidence (Fig. B.2). Eleven fawns were counted for the 18 females evaluated, equating to roughly 0.6 fawns for every 1 female (Fig. B.3). On the ground, we located and assessed fawn status for 5 of the 18 females that the flight crew assessed. For 3 females, aerial and on-the-ground estimates were congruent, whereas for 2 females, they did not match.

#### Summary

As suggested by overlapping confidence intervals, fawn-to-female ratios calculated from our sample of collared pronghorn were not different than fawn-to-female ratios computed by the WGFD from on-the-ground surveys in the Baggs (0.8 fawns for every 1 female) and Red Desert (0.6 fawns for every 1 female) study areas, however non-overlapping confidence intervals indicate our ratio was higher than the WGFD ratio calculated for the Bitter Creek study area at 1.2 fawns for every 1 female (Fig. B.3). Previously validated techniques currently employed by the WGFD for estimating population-level recruitment and other demographic rates (Woolley and Lindzey 1997) are more appropriate for these applications than use of aerial surveys to obtain fawn-to-female ratios from marked individuals.

Observers had low confidence in the majority of observations (57.9%). Given the low observer confidence in assessments of recruitment status, the aerial survey technique we employed may not be the most effective method for evaluating fawn status of marked females. However, the aerial survey method to obtain fawn status was arguably more efficient than ground surveys as it only took 27.7 minutes to locate and assess each of 76 female pronghorn for fawn status. In comparison, ground surveys routinely took approximately 2.5 hours to locate and obtain fawn status for each female pronghorn. Fawn deaths after ground surveys and before

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aerial surveys may have led to incongruences between both methods. Moreover, while confidence intervals between our fawn-to-female ratio estimates and WGFD estimates overlapped in 2 of the 3 study areas, identifying fawn status for individual, marked females for research purposes is reasonable via aerial assessment given the relative greater efficiency than ground surveys. An advantage of ground surveys for marked pronghorn is the ability to simultaneously assess behavior in an undisturbed setting, which is not possible from the air.

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Figure B.1. Red Desert, Baggs, and Bitter Creek study areas used to evaluate fawn-to-female ratios for adult ( $\geq$ 1.5 yr) female pronghorn in the Red Desert of south-central Wyoming, USA 2013–2015. Aerial recruitment surveys were only conducted in the Red Desert (Wyoming Game and Fish Department Hunt Area 60), Baggs (Hunt Areas 53 and 55), and Bitter Creek (Hunt Area 57) study areas during summer 2014, because the Continental Divide-Creston (CDC) study area (Hunt Area 61) was added after recruitment surveys were completed. Study area boundaries were defined based on a 100% minimum convex polygon around pronghorn locations recorded in each study area.



Figure B.2. Number of aerial pronghorn recruitment surveys in which observers had high, moderate, or low confidence in their assessments of reproductive status in the Baggs, Bitter Creek, and Red Desert study areas within the Red Desert region of south-central Wyoming, USA during summer 2014.



Figure B.3. Fawn-to-female ratio estimates ( $\pm$  95% CI) from University of Wyoming (UW) compared to Wyoming Game and Fish Department (WGFD) using aerial survey techniques for Very High Frequency- or Global Positioning System-marked adult ( $\geq$  1.5-yr) female pronghorn within the Baggs, Bitter Creek, and Red Desert study areas within the Red Desert, south-central Wyoming, USA, summer 2014.